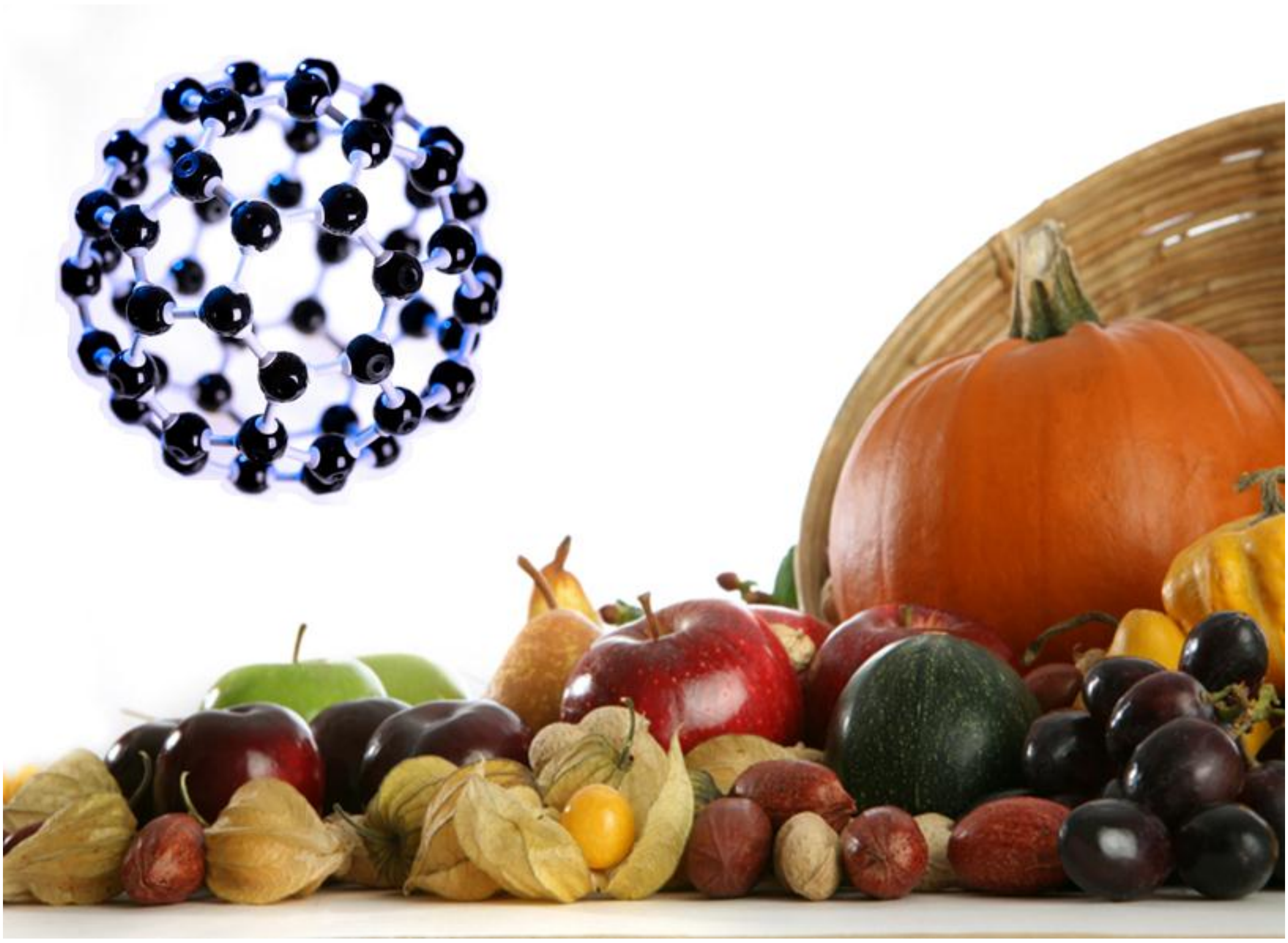
Nanotechnology in the Agri-Food industry on the island of Ireland: applications, opportunities and challenges



be safe be healthy be well

Nanotechnology in the Agri-Food industry on the island of Ireland: applications, opportunities and challenges

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Foreword and acknowledgements

This report is published as part of the project *Nanotechnology in the Agri-Food industry on the island of Ireland: applications, opportunities and challenges*. The study was conducted jointly by the Institute for Global Food Security at Queen's University, Belfast, and the Teagasc Ashtown Food Research Centre, Dublin. The project was funded by ***safe*food**.

Executive summary

Nanoscience and nanotechnology involve the manipulation and modification of material on the nanoscale level (up to 100 µm) resulting in unique physicochemical properties. It has the potential to transform the entire agri-food sector by increasing agricultural productivity, enhancing food and nutritional security and facilitating economic growth. Nanotechnology has a wide range of potential applications across the food chain including in precision-farming techniques, novel functional ingredients and nutrient delivery systems, safety testing, innovative and improved packaging, authenticity and traceability. Many of the proposed applications of nanotechnology will enhance the range, quality and quantity of food products, enabling new international marketing opportunities and improved profit margins. They also offer great potential for improvements to food and water safety and nutrition in developing countries.

However, as with all new sciences/technologies, rigorous safety testing and risk/benefit analyses will need to be undertaken to ensure that public and environmental concerns are addressed and any regulatory, ethical and policy challenges met. These include an assessment of the potential toxicity of nanotechnology applications in advance of any permission to market. Problems arise if safety assessments lag behind nanoparticle development: this can lead to damaged consumer confidence and the creation of long-lasting mistrust similar to that experienced in the case of genetic modification technology. Furthermore, there are ongoing issues relating to product labelling and a lack of unifying regulations and guidelines on nanotechnology governance. These gaps in knowledge are an impediment to the implementation of effective legislation which is essential to allow the successful adoption of nanotechnology by the agri-food industry. It is widely recognised that the technology will bring significant benefits, and research in this area is attracting large-scale investments by industry (eg. Heinz, Nestlé, Unilever, Kraft), academia and government which also provides conceptual backing.

A systematic literature review into the industrial ramifications of nanotechnology has identified the main applications, opportunities and challenges for the agri-food industry on the island of Ireland (IoI) and formed the basis of a qualitative survey conducted through face-to-face and telephone interviews, and subsequently an online survey as well. The review also highlighted the implications for consumer health, choice and confidence. The qualitative survey investigated the current level of industrial awareness and perceptions of nanotechnology in relation to food and food-related applications. It was conducted on twelve agri-food companies, ranging from multinationals to small and medium-sized enterprises (SMEs) across all food and feed sectors throughout the IoI. The online survey was conducted on micro enterprises, small to medium sized enterprises (SMEs) and large organisations involved in agriculture/primary production, manufacturing/processing/packaging, wholesale and distribution, retail/marketing, regulatory/monitoring and research and development (R&D). Communications options/strategies that would foment trust and thereby underscore consumer confidence in the technology and the regulatory regime were also considered.

The qualitative survey highlighted the current level of awareness of nanotechnology for food and food-related applications which was low amongst industry personnel on the IoI. Practical examples of agricultural applications of nanotechnology were not known; however those mainly involved in primary production identified potential uses in improving crop productivity, disease resistance in animals and plants, and enhancing the nutritional quality of animal feed. Industry personnel had a greater level of awareness of the use of nanotechnology in food packaging, which is at present the most active area of nanotechnology in the food industry. Those involved in food processing identified possible uses of nanotechnology in reducing the fat or salt content in food products and enhancing the nutritional properties of food and beverages. Practical examples of the application of nanotechnology in food manufacturing were few, with Cheesestrings and Denny deli ham being the only two such products identified on the current market.

Participants acknowledged that multinational companies have made some use of nanotechnology in the food ingredients sector. However, due to limited awareness and understanding, as well as the absence of a regulatory definition, they also noted that nanotechnology could already be applied without their being aware of it. Participants had a positive attitude towards the use of nanotechnology in food packaging, especially in the dairy, meat and prepared food sectors. The main benefits were identified as the extension of product shelf life, reduced food and packaging waste, and cost savings. They expressed some concern about negative comparisons with the genetic modification of foods (GM) which could lead to consumer rejection. The qualitative survey also highlighted concerns relating to the unknown effects on human health associated from consuming food products produced using nanotechnology. There was a general consensus that the development of a risk assessment framework is needed for adequate regulation in order to control and monitor potential risks, avoid misuse, and foment consumer trust in the technology. All of the participants specified a need to increase the knowledge base of nanotechnology amongst agri-food industry personnel if they are going to exploit same. In particular, the interviewees expressed the need for effective communication between scientific organisations, government bodies and industry personnel, through the provision of information on what nanotechnology is, the benefits and risks associated with each application, and how to implement the technology effectively in a clear and easy-to-understand format. The findings of the online survey corroborated those from the qualitative survey and attitudes toward the use of nanoparticles in food safety and food packaging were mostly positive, while moderately negative attitudes were shown towards the genetic manipulation of crops.

Therefore, despite the presence of nano-foods on the market, the future development of nano-foods, and the extent to which the technology might reach its potential in the food sector, is still uncertain. This is largely due to two “unknowns”. The first relates to uncertainty that persists from a scientific perspective regarding potential risks. The second arises from the uncertainty that exists regarding likely consumer acceptance. How consumers will react to applications of this technology is still difficult to accurately predict due to low levels of consumer awareness about nano-foods, and therefore high levels of uncertainty and largely unformed attitudes regarding the technology. Both of these issues indicate an important role to be played by organisations such as ***safe*food**, both individually and in collaboration with other actors, such as universities/research institutions, industry, NGOs etc., in influencing consumer perspectives through the provision of accurate, unbiased and reliable information.

Key project recommendations

In order for nanotechnologies to be widely adopted by the agri-food industry, a number of recommendations should be considered:

1. Clear descriptive definitions of nanotechnologies and associated terminology in relation to food and agri-food products for awareness and for legislative purposes should be provided.

2. Mechanistic toxicological assessments are needed in order to establish potential acute and chronic health and environmental effects associated with the use of nanoparticles in agriculture, animal feed, food and food-related products.

3. Adequate safety assessment should be conducted on a case-by-case basis where the application of nanotechnology alters existing products or processes prior to implementation on a commercial scale.

4. Analytical tools and methodologies for the determination and measurement of nanoparticles in food and the environment for quality control, risk assessment and the implementation of legislation should be developed where required.

5. A clear, transparent and comprehensive regulatory framework should be effectively implemented for the use of nanotechnology in agri-food products, encompassing nano-inside (eg. novel foods, food additives and flavourings), and nano-outside (eg. food contact materials). Ideally, the governance of nanomaterials should be globally harmonised through international bodies such as the Codex Alimentarius Commission (CODEX), but implementing regulations at local government and EU levels is the most feasible option. The legislation should also incorporate a risk assessment framework.

6. Industry personnel need to be informed and educated more about what nanotechnology is, how it can be used, and what the benefits and risks are in relation to its use for food and food-related applications. This should be done through the provision of informative guidelines from scientific organisations and government agencies, in addition to training events by nanotechnology experts. Practical examples of the successful application of nanotechnology may promote its uptake.

7. Those at the forefront of nanotechnological developments need to communicate more effectively with all stakeholders, including the media, so that they have an enhanced awareness and understanding of the technology. This will help avoid misperceptions or negative comparisons, as exemplified by the GM debate, and possible outright rejection by consumers.

8. The industry should, in turn, engage with consumers on product design, safety and efficacy, either through primary marketing or through the media, as an important means in the recognition of the use of nanotechnology. This should be done clearly and concisely and should highlight the associated benefits for food production.

Abbreviations

ADI	Acceptable Daily Intake
CCAN	Collaborative Centre for Applied Nanotechnology
CODEX	Codex Alimentarius Commission
DAFM	Department of Agriculture, Food and the Marine
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FSA	Food Standards Agency
FSAI	Food Safety Authority of Ireland
GI	Gastrointestinal
GM	Genetically Modified
IEA	Food and Drink Export Ireland
IGFS	Institute for Global Food Security
IoI	Island of Ireland
NFT	Novel Food Technology
NIFDA	Northern Ireland Food and Drink Association
NIGTA	Northern Ireland Grain Trade Association
NM	Nanomaterial
NP	Nanoparticle
NT	Nanotechnology
R&D	Research and Development
SMEs	Small and Medium-Sized Enterprises
SPSS	Statistical Package for Social Sciences
US	United States
USA	United States of America
WHO	World Health Organization

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1 Introduction and project background

Scientific research and the potential for use of nanotechnology in the agri-food industry has increased substantially in the last decade and it is predicted to grow rapidly over the next few years. Its potential for providing safer and more nutritious foods is important in an era when food security and sustainability are highly topical for a global population predicted to be greater than nine billion by 2050. The island of Ireland has the potential through its strong agri-food background to be a global player in the provision of high-quality, safe and nutritious food. However, to date there is no collated information on the current or potential use of nanotechnology on the island of Ireland within the agri-food sector.

The technology offers scientifically enhanced capabilities for product development through the provision of novel functional ingredients and nutrient delivery systems, safety testing, packaging and authentication. However, there are still many uncertainties about the technology and its potential applications, as well as doubts about its efficacy and safety in the long term. As with all new sciences and technologies, rigorous safety testing and risk-to-benefit analyses will need to be undertaken in order to ensure that public and environmental concerns are addressed and any regulatory, ethical and policy challenges met. These include an assessment of the potential toxicity of nanotechnology applications in advance of any permission to market them. Problems arise if safety assessments lag behind nanoparticle development: this has the potential to damage consumer confidence and create a long-lasting mistrust similar to what has been experienced with genetic modification technology.

This review was funded by *safe*food and set out:

1. To investigate the agri-food industry's awareness and perception of nanotechnology
2. To undertake a review of the scientific and technical literature to ascertain the industrial ramifications of nanotechnology
3. To conduct a review of the literature concerning consumer perceptions and the factors that influence acceptance of nanotechnology

A thorough introduction is included within each section of the report.

2 Project aims and objectives

The project aims and objectives are divided into three key sections:

2.1 To investigate the agri-food industry's awareness and perception of nanotechnology

The different aspects investigated set out to address the following questions:

- Based on the current definition, how widespread is the application of nanotechnology at the levels of processor and primary producer? Are there sectoral differences?
- What is the level of awareness among personnel at the levels of processor and primary producer that nanotechnology is being implemented?
- What are the prevailing attitudes toward nanotechnology and what are the factors that underpin such attitudes (e.g., industry scale, scope, nature of the manufacturing/production, endogenous or foreign, etc.)?
- What are the key considerations for industry with regard to the implementation of nanotech? What opportunities are identified?
- Where a desire for nanotechnology solutions is evident, what are the impediments to their implementation?
- How can the information and knowledge deficits that underpin industry concerns regarding nanotechnology be identified?
- What are the primary sources of information that industry personnel access for information on nanotechnology? Who do they trust?

2.2 To undertake a review of the scientific and technical literature to ascertain the industrial ramifications of nanotechnology

To meet this objective, the current and potential applications of nanotechnology at the primary producer and processing levels in the worldwide agri-food industry are examined. The different aspects investigated included different sectors across the agri-food sector:

- Primary production (e.g., targeted genetic engineering of crops; agrochemical delivery)
- Processing (e.g., nanoencapsulation; gelation and viscosifying agents; nanoemulsions; sanitisation of equipment)
- Products (e.g., antimicrobials; intelligent packaging; food contact materials)
- Nutrition and feed (e.g., nutraceuticals; nutrient delivery; fortification of vitamins and minerals)
- Safety (e.g., sensory diagnostics; security/anti-counterfeiting devices)
- EU legislation (e.g., what does it cover? How is it defined? What are its potential effects on industry and trade?)

2.3. To conduct a review of the literature concerning consumer perceptions and the factors that influence the acceptance of nanotechnology

This objective is to ascertain the current IoI consumer perspectives on nanotechnology and, where possible, relate how these compare internationally. The aspects investigated set out to include:

- The extent of IoI consumer knowledge/awareness of nanotech
- Current IoI consumer concerns regarding (1) nanotechnology per se, and (2) nanotechnology in the context of novel food technologies
- Knowledge gained from the experiences of implementing other novel food technologies for addressing consumer concerns
- The uncertainties about nanotechnology at the regulatory/industrial/academic levels and how these might impact on consumer confidence and acceptance
- The factors that influence the acceptance of the use of nanotechnology in agri-food (e.g., demographic, economic, specific applications, etc.)

3 Industrial awareness and perceptions of nanotechnology

3.1 Introduction

Technological advances such as nanotechnology are an important means of helping the agri-food industry to successfully deal with the challenges of a globalised food system in order to meet increased food production needs and ensure sustainability. This can be done through addressing long-term issues, including global population growth, climate change, changing consumer consumption patterns and increasing competition in the global food market (Godfray et al., 2010; Sastry et al., 2013).

Nanotechnology has been shown to have a wide range of current and potentially beneficial applications in the agri-food industry. These include precision-farming techniques, novel functional ingredients and nutrient delivery systems, safety testing, innovative packaging, and authenticity and traceability (Chen and Yada, 2011; Momin et al., 2013). The use of nanotechnology has undoubted economic benefits for food companies, giving them a competitive advantage over competitors, which in turn can facilitate longevity of companies. However, given the level of investment required to implement this technology, there are many factors that can greatly impede the agri-food industry's willingness to adopt such technologies, including existing uncertainties regarding nanotechnology's associated risks, such as potential implications for human health and the environment. Moreover, while multinational food companies have the knowledge, skills and finances to invest in novel technologies, for small and medium-sized enterprises (SMEs), innovation may be constrained by limited resources and difficulties in accessing research and know how to implement such technologies. The traditional challenges facing SMEs are further exacerbated by existing global economic conditions. Across the island of Ireland (IoI), the vast majority of food companies are SMEs which make an enormous contribution to the economy in both jurisdictions. Government efforts are, therefore, focussing on funding research institutes to support these food companies in implementing innovative technologies to expand on their capabilities.

This research was interested in examining the agri-food industry's current level of awareness of nanotechnology and the attitudes towards it on the IoI. Furthermore, the factors supporting and impeding the uptake of such technologies for food and food-related applications were explored and documented. These data should assist in informing and guiding the agri-food industry and government strategies. If nanotechnology is presented in a positive way, and is acknowledged over conventional products, this may increase the uptake of such technologies by even the most cautious agricultural producers and food companies.

3.2 Objectives

The research objectives were to:

- Determine the industry's awareness, understanding and perceptions of nanotechnology
- Examine industry's awareness and attitudes towards applying nanotechnology for agri-food applications
- Ascertain industry's awareness and understanding of nanotechnology issues relating to food and food-related applications

- Explore sources of information regarding emerging technologies, specifically nanotechnology
- Determine attitudes and confidence regarding regulators of science and technology and providers of information
- Evaluate differences in awareness, understanding and attitudes towards food nanotechnology and the factors underpinning these, including sector differences, industry scale and scope, and nature of the manufacturing/production

3.3 Materials and Methods

The key objective of the review was to provide an analysis of the awareness of the use of nanotechnology in the agri-food sector on the island of Ireland and the risk and opportunity perceptions of nanotechnology for the industry. This was performed by horizon scanning the key issues through consultation and discussions with industry. This was achieved by issuing invitations for one-to-one interviews as part of ongoing collaborative projects at Queen's University, Belfast (QUB), e.g., through the ***safe*****food** Knowledge Networks and other stakeholder databases to which the university has access. To achieve these objectives a number of sub tasks were created.

a) To expand the existing QUB database for agri-food stakeholders on the IOI
b) To distribute an expression of interest in the study to all industry-based stakeholders
c) To prepare an interview questionnaire based on the findings of the literature review
d) To perform a thematic analysis of the one-to-one interviews for the key findings
e) To prepare an online quantitative survey based on both the findings of the literature review and the one-to-one interviews with industry
f) To conduct an analysis of the data returned from the online questionnaire via SPSS

Enhancement of stakeholder database

Following a search of various internet sites, including Bord Bia (the Irish Food Board), the Northern Ireland Food and Drink Association (NIFDA), Invest Northern Ireland, Food and Drink Export Ireland (FDEI), the Food Standards Agency (FSA), the Food Safety Authority of Ireland (FSAI), the Top 1000 Food and Beverage Companies site, the Yellow Pages and the Golden Pages, the existing stakeholder database held within the Institute for Global Food Security for the IoI agri-food stakeholders was expanded.

Preparation and distribution of an expression of interest

A one-page document (Appendix 4) requesting stakeholders for an expression of interest in the project was prepared and distributed initially through Teagasc and QUB contacts, An Bord Bia, NIFDA, Invest NI and FDEI. Following the addition of further stakeholders to the database, the expression of interest was distributed.

Respondent selection

Those companies in the agri-food industry that expressed an interest in the study through contact were approached for an in-depth qualitative study conducted through open-ended questions derived from the information obtained from the literature search to ascertain and understand their perceptions. A thematic analysis of these interviews was performed to select the relevant information. The food companies ranged from multinationals to small and medium-sized enterprises

(SMEs) involved in primary production, manufacturing/processing/packaging, wholesale and distribution, or retail/marketing across the nine main food sectors, including beef and lamb, pork, poultry, dairy, bakeries, fruit and vegetables, beverages, fish and eggs. Due to the project having commenced in the summer months, participant uptake in the study was extremely slow, although this improved latterly. Due to project time constraints, a sample of 12 agri-food companies across the IoI participated in the interviewing. Further interviews will be conducted at a later stage to enable more in-depth comparative thematic analysis to be carried out. The outcomes of additional studies as part of ongoing PhD research will be provided to ***safe*****food** for publication on its website.

Qualitative interview protocol

A semi-structured interview guide (Appendix B) was designed after conducting a systematic review of the literature to ascertain the applications, opportunities and challenges in the use of nanotechnology in the agri-food sector. The main areas of application of nanotechnology identified include primary production, food processing, food packaging, nutrition and feed, and food safety. The projected benefits and risks arising from the use of nanotechnology for food and food-related applications were also established. Furthermore, regulatory aspects relating to food nanotechnology were explored. The survey was designed to consist of six parts and information was collected on:

- Demographic information: the respondent's name, gender and position within each company was recorded. Specific information on the company, i.e., the nature and age of the company, was also documented.
- Awareness and understanding of nanotechnology and its applications: respondents were asked about their knowledge of nanotechnology in general and specifically in relation to agriculture and the food industry. A definition of nanotechnology was then provided, as it was expected that some respondents would know very little or nothing at all about this technology. Next, the participants were asked if they were aware of any industries that had utilised nanotechnology; examples were provided for respondents with very little or no knowledge of this. The latter part of this section focussed on the respondents' awareness of nanotechnology in relation to agriculture and the food industry, and they were asked if they knew of any food or beverage products that are currently available on the global market.
- Benefits and risks of nanotechnology in relation to food: respondents were asked what they considered to be the benefits and relative risks of nanotechnology regarding food and food-related applications. Respondents were also asked what they thought could be done to reduce the risks, and whether they had any views on the regulation of nanotechnology, i.e., how it should be regulated for food and food-related products, and if this should be done at local industry level, European Union (EU) level or globally harmonised.
- Company's current usage of nanotechnology: respondents were asked if their company had used nanotechnology for any of their products, and if so, how/why it was used and for what products. For users of nanotechnology, further information was requested in relation to whether the company followed any guidelines relating to the technology's use, and if risk assessments were conducted for nanotechnology processes/products. For non-users of nanotechnology, examples of nano-inside (i.e., food production) and nano-outside (i.e., food packaging) products that are currently available on the market were presented. Finally, respondents were asked if they would label products accordingly if nanotechnology was used, and how they would promote these products to consumers.
- Nanotechnology opportunities: this section asked respondents if they would consider nanotechnology to be potentially useful in any areas of their company, and if so, what would they need to implement it.
- Obstacles to the adoption of nanotechnologies: respondents were asked if they expected to see

the application of nanotechnology increase in the future. Respondents were also asked if they had any general concerns about introducing new technologies, and specifically, what they considered to be the impediments regarding the implementation of nanotechnology in their company. Finally, the respondents were asked about their company's absorptive capacity, and how nanotechnology could be made less complicated for industry.

For the purpose of the interview, a standard introduction was used, which included a request for participation and assurance of confidentiality. The interviews were conducted by one researcher and lasted approximately 30 minutes. Handwritten notes were taken during all interviews, 10 interviews were recorded and partially transcribed, and the remaining two interviews could not be recorded due to company policy.

Analysis of qualitative data

The interviewees fell under three main groups as follows:

Agri-food sector	Primary production	Food processing	Food packaging
Number interviewed	5	4	3

The interview transcripts were examined numerous times to identify emerging themes and concepts within the data. The findings of the interviews that related to the specific research aims were grouped under three headings:

1. Awareness and knowledge of nanotechnology applications
2. Influences on nanotechnology application
3. Considerations for implementation of nanotechnology

The findings relating to each of these headings are discussed in detail with applicable quotes as illustrations. The quotes are illustrative and represent comparable comments made in the groups.

Quantitative survey

The systematic literature review and results from the qualitative phase of the current study informed a quantitative questionnaire, requiring between five and 10 minutes for completion (Appendix 6). This has been designed and will be distributed to food companies (n=100) across the IoI using the online tool (i.e., Survey Monkey). Agri-food industry contacts will also be invited to participate using the IGFS enhanced database and ***safe*****food** networks. The survey sample will be confirmed to be representative of all the major agri-food sectors, and the industry scale/scope and geographic spread of agri-food companies across the IoI. The results from the questionnaire will be analysed using the statistical package for the social sciences (SPSS). The findings from the online questionnaire will be presented as a supplementary report and submitted to ***safe*****food** thereafter. This will allow for the most detailed information on this topic to be collated and a thorough evaluation conducted.

3.4 Results

Awareness and knowledge of nanotechnology applications

The Primary Production Group that was interviewed included people involved in small-scale farming, a multinational meat producer, veterinary drugs testing personnel, and animal feed supply operatives. Awareness of nanotechnology varied greatly amongst the participants, from just knowing about this technology to having some knowledge about it and its applications. For this group, the predominant sources of information on nanotechnology included universities, the internet (i.e., agricultural websites), scientific literature, conferences, EU literature and EU projects. While one participant was unable to say what nanotechnology was, others were able to provide a good understanding of it, describing it as precise, small-scale and accurate technology, and that which could be used for the analysis of products or contaminants.

The main industrial applications of nanotechnology identified by the respondents were in pharmaceuticals, medicine, agriculture and the food industry. Other applications were in engineering, aeronautics, computers, plastics, microchips, household products, the military, sun creams and packaging. Some of the uses of nanotechnology provided by the respondents were:

- Resistance to drugs, viruses and bacteria
- Delivery of chemicals (e.g., fertilisers)
- Better performance in animals
- Targeting tumours
- Disease research
- Prevention of food spoilage

While knowledge of agricultural applications was limited, participants recognised potential uses in crop production, soil testing, delivery of chemicals and genetic modification (GM), while animal production, improved nutrition of animal feed and disease resistance were the main uses cited. Potential food industry applications of nanotechnology were mainly in relation to food packaging, in detecting spoilage and increasing product shelf life. Utilising nanotechnology for surface cleaning and in the analysis of different contaminants in food were other possible uses suggested.

Members of the Primary Production Group were not aware of any food or beverage products on the current global market that have been produced using nanotechnology. However, one participant indicated that it might have been applied in the manufacture of some sports or energy drinks. Participants were also unaware of any present use of nanotechnology within their company, but some thought that it could have been used unknowingly, due to a lack of awareness and understanding of the technology amongst industry personnel. For example, a possible use in animal feed was indicated for improved weight gain and live weight, and for more efficient animals. Nanotechnology could have also been utilised by suppliers to develop products which the primary producers are using.

The Food Processing Group comprised people from the dairy, meat, beverages and food ingredients sectors. All interviewees in this group had heard of nanotechnology but knew little about it, with one participant only knowing the term. Awareness of nanotechnology was gained predominantly through scientific journals, the internet, universities and the media (e.g., television). This group linked the term "nanotechnology" to functionality at a molecular level, using compound chemicals in the nanoscale range, creating unique properties, and targeting different areas of production. The participants' awareness of industries that are researching or using nanotechnology was diverse, from one participant demonstrating no knowledge of any industries to others giving a variety of uses in medicine, food packaging, clothing, plastics, metals, pharmaceuticals, medicine, agriculture, computers, household products and the military. Knowledge on applications specific to agriculture was limited, but the interviewees saw potential uses in pesticide application, increased crop yields, resistance to disease in plants and animals, and improvements to the nutrition of animal feed.

A number of uses of nanotechnology for food and food-related applications were identified, including improvements to infant nutrition, food preservation, increased product shelf life through packaging, food ingredients, and in increasing the nutritional properties of food products. Some participants were aware that nanotechnology has been applied in the manufacture of some sports drinks, processed deli meats and dairy products (i.e., milk and cheese) that are currently available on the global market. For this group, the current application of nanotechnology within their respective companies is low, but it has had some application in the food ingredients sector. Some interviewees also indicated that nanotechnology could be used unknowingly within their particular company.

The Food Packaging Group was comprised of members from the chilled foods sector, the poultry sector and the fruit and vegetables and fine foods sector. Awareness of nanotechnology and its applications ranged from participants knowing nothing at all to having some knowledge about this technology. The main sources of information on nanotechnology included packaging consultants, suppliers of packaging, newspaper articles, scientific publications, trade journals, food journals and the Technology Strategy Board (TSB). Nanotechnology was understood to involve the manipulation of atoms or molecules for different processes.

Industries identified as potentially researching or using nanotechnology included the food industry for waste reduction, mechanics (e.g., cars and aircraft), and engineering, pharmaceuticals for the manufacture of drugs, electronics, hospitals, hand dryers, public phones, weapons, and paint protection with self-healing properties on cars. The majority of these applications were identified by the participant demonstrating the greatest level of knowledge regarding nanotechnology.

Similar to other groups, this group identified the potential applications of nanotechnology in relation to increased crop yields and crop strengths, GM and improved diets of animals and meat quality. For this group, food industry applications were predominantly focussed around the potential use in food packaging to delay food spoilage and increase product shelf life through using barrier films or trays, active packaging with oxygen-scavenging properties, smart packaging incorporating a nanosensor for detecting spoilage and improved packaging with different gas mixes. One participant was aware of nanotechnology being utilised for this application in the carbonated drinks and alcoholic drinks industry, but could not name any products that are currently available on the market.

Another participant had some awareness of nanotechnology application for the manufacture of food products. This participant also suggested that nanotechnology might have been used in fruit production to overcome seasonality issues, and , thus, increase the availability of fruit throughout the year. Some participants were not aware of any current use of nanotechnology within their company. The participant from a multinational poultry company indicated that trial work had previously been conducted in the food processing end of their business using cold plasma technology, but was unaware as to how or why this was used. This participant also indicated that nanotechnology could have been used in the packaging materials that they buy from their supplier, but again was uncertain of this.

Influences on nanotechnology application

Interviewees from the Primary Production Group had a positive attitude on the application of nanotechnology in the agri-food sector and saw a vast range of potential benefits to both industry and consumers. The main benefits of applying nanotechnology in the agri-food industry that were provided included efficient farming techniques, the manufacture of safer food, lower costs for industry, the production of cheaper food, reduced food wastage, as well as positive impacts on the environment. Though the participants raised some concerns in relation to the existing uncertainties about the risks associated with the use of nanotechnology for food and food-related products, with indications of possible side effects to consumer health, as well as environmental impacts. Some considered the public's perception of nanotechnology to be the main risk. Others felt that the benefits of nanotechnology outweighed these risks due to the solutions it can provide to existing problems, whilst others stated that further research is needed to remove the risks before the technology will be widely adopted by the agri-food industry. Other concerns related to the high costs of implementing the technology, resistance to change, availability of expertise, time and long-term value of the technology.

At one end of the food processing group spectrum, there was no awareness of the potential benefits associated with applying nanotechnology in the agri-food sector, while at the other end, the potential benefits were seen to be so vast that the question was too general to answer. For the remainder, a range of benefits were suggested, including cost savings for the food industry (i.e., through reductions in packaging materials) the production of better and healthier products for the consumer, reduced wastage, safer food and an extended shelf life of products. Some interviewees saw the main risks of nanotechnology to be in relation to negative consumer perceptions due to ineffective communication from experts, misinformation and bad press from comparisons to GM foods. Existing uncertainties regarding the implications to human health and the environment are also viewed as important risks. Some participants, however, felt that the benefits were greater than the risks and so had no concerns about introducing the technology as long as the benefits outweighed the costs.

A lack of knowledge and inadequate technical expertise within their company were considered to be the main impediments to the implementation of nanotechnology. Others viewed the benefits and risks to be very much dependent upon the application, and so identified a need to prove the effectiveness and safety of nanotechnology for all uses in the agri-food industry before they would consider implementing the technology.

For the food packaging group, the main benefits of applying nanotechnology to the agri-food industry were in relation to extended shelf life, reduced food wastage, improved food safety, improved distribution and sales, and a positive impact on the environment due to reduced packaging waste. Some people felt that the benefits associated with applying nanotechnology in the agri-food sector were so vast that they would outweigh the potential risks. Others suggested that further investigation is needed into the unknowns, such as the long-term health effects of applying nanoparticles (NP) to animals or feed, as well the harmful effects to humans of migration from food packaging.

A lack of public understanding and the potential for consumers to be misled about what nanotechnology is are also seen as potential risks. It was argued that scientific organisations should inform consumers about nanotechnology with a clear and positive message; communicating the benefits of using this technology would be a key step in promoting its use. It is also very risky for companies not to declare the use of nanotechnology on their product labelling as consumers have the right to choose what they eat and should be informed if they are eating food products that have been manufactured using this technology. Participants felt that misinformation could result in mistrust by the consumers, which, in turn, could have serious implications for the food industry, as in the recent example of the horsemeat scare.

Other important considerations for companies when investing in new technologies are the cost of implementation and whether this is commercially viable, and, if so, what the commercial benefits would be on a long-term scale. On the one hand, it was argued that it would take longer for nanotechnology to be put into operation in a multinational company due to the sheer size of it, while on the other, it was suggested that smaller companies would find it much more difficult to apply this technology due to their limited resources.

Considerations for implementation of nanotechnology

Primary Production Group

Members of the Primary Production Group anticipated that the use of nanotechnology in the agri-food sector would increase in the future due to the immense pressures that this industry is faced with in terms of costs being so high per crop and increased demands for meat, in addition to the further problems associated with the world's growing population. Therefore, any technology that could help alleviate these pressures would be of benefit.

Due to the diversity of this group, nanotechnology has been shown to be used in a number of different areas, including farming techniques, animal feed, animal health, encapsulation technologies, food packaging and lab assays. However, the participants felt that a greater knowledge base would be needed through meetings or training days in order for nanotechnology to be implemented effectively. Other needs for the industry included additional resources, new facilities and technical expert advice in relation to what equipment to buy and how to use it properly. Further scientific research trials should also be conducted in order to reduce the risks associated with the technology before it is rolled out commercially within the industry. There are also fears that a lack of public understanding will lead to outright rejection. Therefore, effective communication from government bodies and the provision of vast amounts of information promoting the benefits of nanotechnology were seen as a necessary means of gaining consumer acceptance.

The regulation of nanotechnology for food and food-related products is also seen as an important means of helping the food industry to provide consumers with some degree of confidence, as well as controlling and monitoring potential risks, and avoiding misuse of the technology. Due to the globalisation of the food supply chain, participants saw the benefit of globally harmonised legislation, with guidelines provided for testing products/processes.

Food Processing Group

Members of the Food Processing Group also predicted an increase in the use of nanotechnology in the agri-food sector in the future. Some felt that there was no need for nanotechnology in their company at the present time, and stated that they would need a lot more information on the technology to acquire a greater understanding of it before they would even consider implementing it. Others saw the potential benefits of using it in food processing, and also in other areas, such as food packaging. Interviewees seeing nanotechnology as potentially useful stated that they would need further research conducted on it to ensure that its use is safe, as well as expertise on how to use it. Informing and educating industry personnel about what nanotechnology is, as well as the benefits and risks associated with its application to food and food-related products, is also seen as important. This could be done through networking with universities, training workshops and seminars. There is also a benefit of seeing the practical application of nanotechnology so that people gain a better understanding of it.

Food Packaging Group

The agreed that the application of nanotechnology is going to increase in the agri-food sector in the future. Two of the participants saw vast potential for its use in their company, particularly within food packaging, with additional possible uses in processing equipment and food safety, while one of the participants did not see any current need for it in their company.

Participants in this group did indicate that in order for nanotechnology to be implemented, they would need more resources, i.e., funding from external bodies such as Invest NI, as well as better communication from experts in this area who can provide food companies with a lot more information in a clear and positive way so that they have a clearer understanding of it. More research and analysis is also needed in order to reduce the risks associated with the application in agri-food. The implementation of legislation is also an important means of risk reduction. There was conflicting views as to how this should be regulated; at one end of the spectrum, it was suggested that the industry could regulate itself through the FSA and other government bodies, whilst at the other end, globally harmonised regulations were seen as the best form of regulation, although it was agreed that this can be difficult and is not always feasible. This group also felt that there was a need to increase the knowledge base about nanotechnology amongst industry personnel to encourage the uptake of such technologies by food companies. Better communication from scientific organisations and training from nanotechnology experts were seen as essential so that nanotechnology would be clear and easy for people to understand.

3.5 Discussion

Nanotechnology is still a relatively new concept for the agri-food industry. The present level of awareness on the island of Ireland of nanotechnology applications for food and food-related products is generally low and comparable with findings in other areas (multinational food companies are the exception to this) (Chaudhry and Castle, 2011). Many of the potential applications are still at the R&D stage and may take years before commercialisation. In the course of our research, industry personnel, particularly those involved in primary production, identified a number of potential uses in precision-farming techniques, improving crop productivity, enhancing the nutrition of animal feed, and in disease resistance in animals and plants. Some respondents highlighted the potential impact of nanotechnology on the genetic modification of foods. There was no knowledge demonstrated of any practical examples of nanotechnology agricultural applications.

There are commercial examples of the application of nanotechnology to food products and food packaging, although the number of products is still somewhat low (Frewer et al., 2011). Food packaging is currently the most active area for nanotechnology in the food industry (Lyons et al., 2011; Duncan 2011a). Industry personnel have recognised the potential for nanopackaging to extend the shelf life of products and reduce food and packaging waste leading to economic and environmental benefits. The packaging applications identified from the interviews conducted as part of this study include the inclusion of oxygen scavengers, enhancing barrier properties by, for instance, incorporating different gas mixes, and smart packaging using nanosensors to detect spoilage. This is in line with the open literature (Momin et al., 2013). It must be noted that these specific applications were predominantly discussed by a packaging innovations manager in a multinational poultry company.

Those involved in food processing recognise the potential for applying nanotechnology to the creation of food products with added health and/or nutritional benefits for consumers and the knock-on competitive advantage this will bring. This includes a reduction in the salt/fat content of food whilst retaining the palatability, enhancing the nutritional quality of infant products, and improving the nutritional quality of foods/beverages through incorporation of vitamins and minerals. For example, Momin et al. (2013) indicate that the milk protein α-lactalbumin has been integrated into nanotubes to improve the protein quality of infant formula so that it is more comparable to breast milk. Practical examples from the IoI of nanotechnology-based food products are limited to Cheesestrings and Denny deli ham. These examples were provided by a food technologist from a global leader of food ingredients, dairy and meat products. Other participants proffered potential uses of nanotechnology in high-end sports and energy drinks and in dairy products, but they were unable to cite specific examples. To date, a research initiative (http://www.nanotechproject.org/) lists nano-described products on the market linked to food and beverages, but the majority of these products originate in the USA or Korea, with the most common nanomaterial incorporation being the additive, titanium dioxide. The food items include Mentos, Trident and Dentyne gum, M&Ms, Betty Crocker Whipped Cream Frosting, Jello Banana Cream Pudding, Vanilla Milkshake Pop Tarts and Nestlé Original Coffee Creamer. These examples suggest that while certain additives are used by the food industry, they may not be recognised or acknowledged as nanomaterials.

Companies involved in meat, dairy and prepared foods appear to have more of a positive attitude towards the use of food nanotechnology, especially in relation to food packaging. For example, Kraft is currently working with Rutgers University (USA) to develop an intelligent packaging with engineered nanosensors to detect food spoilage (Momin et al., 2013). Multinationals view technological advances as an important means of providing solutions to problems arising from the vagaries of a globalised food supply system. However, even in these companies, the general lack of knowledge about nanotechnology is an impediment to its exploitation. To redress this deficit, respondents highlighted the need for better communication and information from nanotechnology experts to inform and educate industry personnel how nanotechnology can be applied and what the associated benefits and risks are.

The perceived risks of nanotechnologies are varied and relate to customer/consumer acceptance, negative media perceptions, and implications for human health and the environment. Communication challenges remain (Duncan 2011b) particularly to arrest inappropriate comparisons between nanotechnology and GM foods. Frewer et al. (2011) indicated that some of the negative public perceptions of GM foods might be associated with nanotechnology in terms of it being perceived as relatively high risk, as well as views relating to its unnaturalness and ethical concerns. The unknown long-term effect of consuming nanotechnology food products was believed to aggravate these uncertainties and fears. The development and implementation of a risk assessment framework for adequate regulation is fundamental to controlling and monitoring any potential risks particularly where knowledge and individual control is seemingly lacking. This is in line with the literature findings, which indicate that existing laws are insufficient to assess risks posed by nanotechnology food products and packaging. Support from academia through continuous research into the potential risks was considered to be important amongst agri-food industry personnel. There are conflicting views as to how nanotechnology should be regulated; most suggest that global harmonisation is the best form of regulation due to the globalisation of the food supply system, although regulation at the EU level might be the most feasible option. A robust regulatory framework is also seen as an important means of giving consumers trust in the technology and increasing their acceptance of it. Further to increasing consumer trust is the need to provide clear and unbiased information, for example, functionality labelling, as consumers have the right to make an informed choice about products that they are consuming.

Cost versus benefit analysis is an important consideration for companies interested in implementing nanotechnology. They will need to estimate the potential impact for the new technology and the level of return on investment. Other considerations will be dependent on the scale and scope of the company, and the form in which nanotechnology will be used. While multinational companies might have the resources and technical expertise to implement nanotechnology, their size can prolong the processes of adoption and commercialisation. There is also a greater degree of risk involved with a multinational company implementing a new technology in case it is not widely received by the public or food safety is jeopardised, as this will take place on a far grander scale and could be detrimental to the company in terms of costs and reputation. Therefore, collaboration with universities and research institutes is necessary to prove the effectiveness and safety of the technology, and to give the assurance that the benefits vastly outweigh the risks. For SMEs, on the other hand, which are limited in their size, resources and access to information, as well as their capacity to evaluate the environmental or health impacts associated with nanotechnology applications, collaboration with universities and funding from external bodies (e.g. Invest NI or TSB) may be required to facilitate implementation. Nevertheless, the first step towards encouraging the use of nanotechnology in the entire agri-food industry is through increasing the awareness and understanding of the technology and its application for food and food-related products.

3.6 Recommendations

In order for nanotechnologies to be widely adopted by the agri-food industry, a number of recommendations are made, including:

1. Further research to establish the long-term health effects associated with the use of nanoparticles in food and food-related products needs to be undertaken;
2. A clear, transparent and comprehensive regulatory framework should be effectively implemented for the use of nanotechnology in food and food-related products, covering novel foods, food additives, flavourings and food contact materials. Ideally this should be globally harmonised through international bodies such as the Codex Alimentarius Commission (CODEX), but implementing regulations at the EU level is the most feasible option. Legislation should also incorporate a risk assessment framework;
3. Adequate safety assessments should be conducted on a case-by-case basis where nanotechnology alters existing products or processes prior to its commercialisation;
4. Industry personnel need to be informed and educated more about nanotechnology, its use, and the associated benefits/risks. This should be done in a clear and easy-to-understand form through the provision of information from scientific organisations and governmental agencies, as well as training events by nanotechnology experts. Practical examples of the successful application of nanotechnology may promote its uptake;
5. Those at the forefront of nanotechnological developments need to communicate more effectively with the media so that they have an enhanced awareness and understanding of nanotechnology. This will help avoid misperceptions or negative comparisons, as exemplified by the GM debate, and possible outright rejection by consumers.
6. Effective communication to consumers is an important for assuaging any unfounded fears or concerns. This should be done through the provision of accurate and concise information.

4 Industrial ramifications of nanotechnology

4.1 Introduction

Nanotechnology is a multidisciplinary field that covers a vast range of processes, materials and applications, encompassing physical, chemical, biological, engineering and electronic sciences. It focuses on the characterisation, fabrication and manipulation of substances at sizes in the nanoscale range, approximately between 1 and 100 nanometres. The smaller particle size, in combination with an increased surface area, exhibits unique and novel properties, thus creating a big potential for applications (European Food Safety Authority (EFSA), 2009; Rashidi et al., 2011; Weiss et al., 2006). A nanomaterial (NM) is defined as any material that has one or more dimensions in the nanoscale range, while an NP is a discrete entity that has all three dimensions in the nanoscale (Food and Agricultural Organization of the United Nations (FAO)/ World Health Organization (WHO), 2010). NMs and NPs can encompass any of the following nanoforms, which derive their names from their individual shapes and dimensions: NPs, nanotubes, nanofibres, nanorods, nanofilms, nanolayers, nanocoatings, nanosheets and so forth (Cushen et al., 2012). This review refers to a range of these nanoforms which best exemplify the recent developments in the agri-food sector.

Nanotechnology has already been used in construction materials – in floors, walls and machines –new devices and techniques in electronics, cosmetics, sporting equipment, wastewater treatment, medicine and, more recently, in agriculture and the food industry (Doyle, 2006). NMs are naturally occurring in many plant and animal products, including the major constituents of milk (i.e., casein micelles, whey proteins, fat globules and lactose), as well as the fibrous structures in fish and meat, the crystalline structures in innate starches, and the molecular structure of cellulose fibrils in plant cells (Magnuson et al., 2011; Morris, 2011). Engineered NMs are also being developed for a variety of food and food-related applications, such as food additives, flavourings, novel foods, food packaging, feed additives and pesticides. For food applications, nanotechnology can be applied using two different approaches, either from the "top down" or from the "bottom up" (Ravichandran, 2010). The top-down approach involves a physical or chemical process of breaking down larger particles of food matter into smaller particles of nanometres in dimension (Cushen et al., 2012). Grinding or milling are examples of mechanisms used to produce such NMs. Dry milling has been used for making high water-binding capacity wheat flour and has also been successfully applied to green tea powder to enhance its antioxidant activity (Ravichandran, 2010). For green tea powder, this technique is used to reduce the powder size to 1000 nanometres, and so the high ratio of nutrient digestion and absorption leads to an increase in the activity of an oxygen-eliminating enzyme (Ravichandran, 2010). Homogenisation is an alternative top-down, size-reduction process, where pressure is applied to reduce the size of fat globules. This mechanism is used in the dairy industry worldwide (Cushen et al., 2012). By comparison, the bottom-up approach involves manipulating individual atoms and molecules into nanostructures (Joseph and Morrison, 2006). Nanostructures are comprised of discrete functional parts, either inside or on the surface, of which one or more are in the nanoscale range (FAO/WHO, 2010). The bottom-up approach can create more complex molecular structures by design, based on the self-organisation of biological compounds. Methods applied in the bottom-up approach include crystallisation, layer-by-layer deposition, self-assembly and so forth (Cushen et al., 2012). For instance, the organisation of casein micelles or starch and the folding of globular proteins and protein aggregates are self-assembly structures which form stable entities (Ravichandran, 2010).

Nanotechnology has emerged as the technological advancement to develop and transform the entire agri-food sector, with the potential to increase global food production, in addition to the nutritional value, quality and safety of food (Joseph and Morrison, 2006; Mousavi and Rezaei, 2011). Applications may be classified as nano-inside (e.g., primary production, food processing) and nano-outside (e.g., food packaging). Nanosensors and nano-based smart delivery systems are some of the applications of nanotechnology that are currently employed in the agricultural industry to assist in combatting viruses and other crop pathogens, as well as to increase the efficiency of pesticides at lower dosage rates (Mousavi and Rezaei, 2011). Nanotechnology offers several perspectives for food applications due to the greater surface area of NPs per mass unit, making them more biologically active than larger-sized particles. For instance, NPs can be used as bioactive compounds in functional foods. Bioactive compounds are health-promoting ingredients that can be found naturally in foods, such as polyphenols, phytosterols, phytoestrogens, vitamins, minerals, omega 3, omega 6, probiotics and prebiotics (Chen et al., 2006). These compounds exert physiological effects that might cause a risk reduction for certain chronic diseases linked to oxidative stress, such as cardiovascular disease and various forms of cancer. Nanosizing can greatly improve the properties of bioactive compounds such as delivery properties, solubility, targetability, efficient absorption through cells, and prolonged compound residence times in the gastrointestinal (GI) tract (Chen et al., 2006). With regard to food packaging, nanotechnology can increase product shelf life by using packaging with antimicrobial properties to protect food against pathogens (Durán and Marcato, 2013). Within the food industry, nanotechnology has been shown to have a wide range of novel applications, including the use of nanoemulsions, nanocomposites, nanocarriers (nanocapsules) and nanofiltration, in addition to the development of nanosensors and nanobiosensors for quality control and food safety (Rashidi et al., 2011).

The application of nanotechnology in the agri-food sector is still a relatively new concept; the main reasons for its late incorporation are mainly due to issues relating to product labelling, consumer health risks and a lack of unifying regulations and guidelines on nanotechnology governance. Nevertheless, it is widely recognised by many countries worldwide that nanotechnology will bring significant benefits, and research in this area is attracting large-scale investments by leading food companies (including Heinz, Nestlé, Unilever and Kraft), support from academic science and increasing governmental financial investment and conceptual backing (Food Safety Authority of Ireland, 2008; Momin et al., 2013; Scrinis and Lyons, 2007). According to the US Department of Agriculture, nanotechnology's international market size is forecast to be $1 trillion per year by 2015. The value of nanotechnology in the global food market is indicated to reach up to $3.2 billion by 2015 (Durán and Marcato, 2013).

4.2 Objectives

The focus of this article is to systematically review existing articles to ascertain the current and potential applications of nanotechnology in the global agri-food sector, identifying a number of key opportunities for innovation in the food sector in addition to consideration of the challenges ahead, including the potential risks of NMs to human health and the environment, as well as regulatory issues.

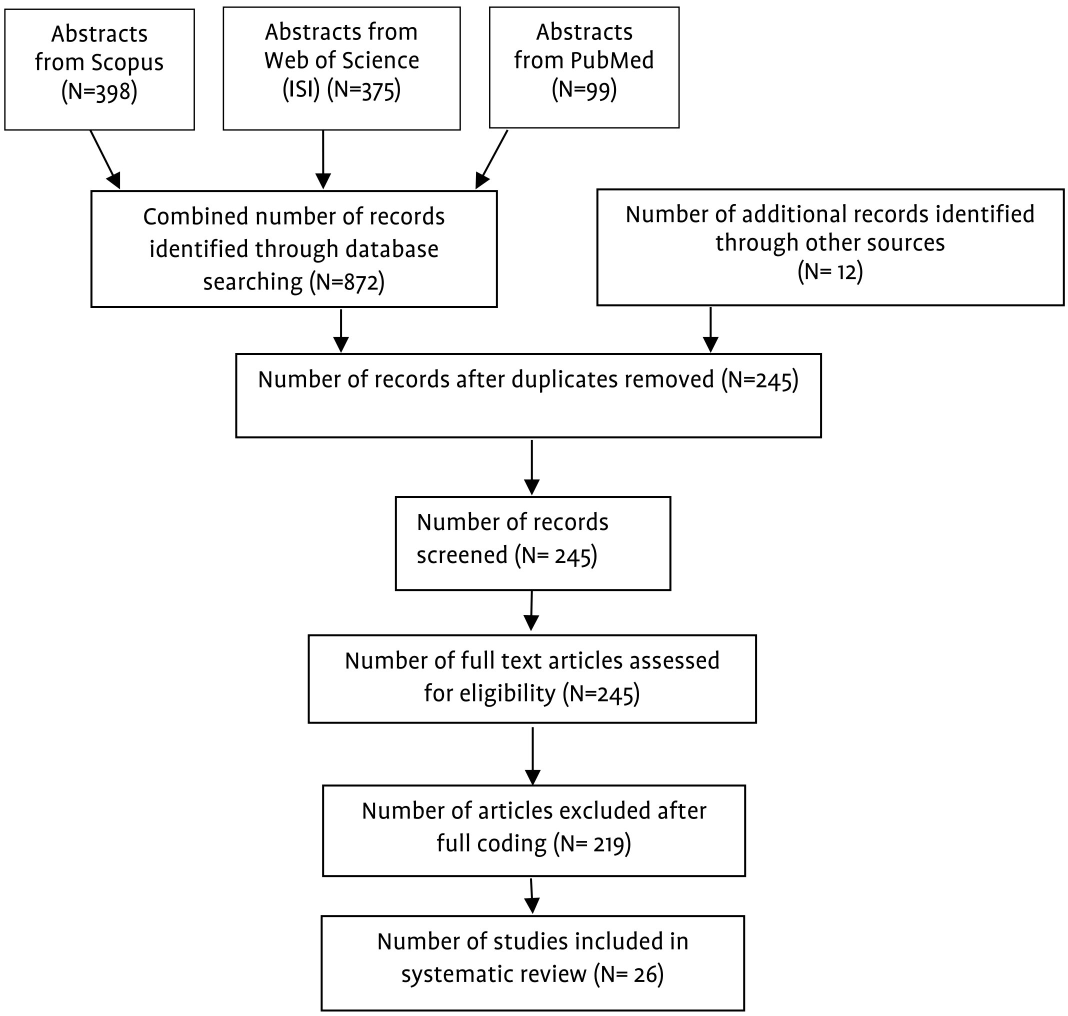
4.3 Materials and methods

Data sources and search strategy

A search of the commercially available electronic databases, PubMed, Scopus and Web of Science (ISI), was conducted for articles in the English language published between January 2008 and August 2013.

Specific key themes (“nanotechnology” and “food” and “application” or “opportunity” or “risk”) were selected from the research aim. The following search terms were used: “nanotechnology”, “application”, “food”, “agriculture”, “food packaging”, “food products”, “food production”, “food processing”, “food safety”, “nutrition”, “opportunity”, “legislation”, “regulation” and “risk”. Combinations of search terms were used to identify relevant articles. In addition, reference lists from selected reviews were searched for key articles. A flow diagram of the search strategy is shown in Figure 4.1. The fundamental foundation information for the production of the report was collated from peer-reviewed scientific publications. Moreover, a wide range of authentic sources of information was analysed and critiqued, for example, scientific committees, governmental, non-governmental, industrial and consumer organisation reviews and information on websites (e.g., WHO, FAO, USDA, DEFRA, FSA, NIFDA and CORDIS).

Figure 4.1: Flow diagram of search strategy



Inclusion and exclusion criteria

Many of the articles located were reviews; these were evaluated and formed the basis of this review. Traditional or narrative reviews and systematic reviews which evaluated the applications and opportunities of nanotechnology in the global agri-food sector were included. Furthermore, studies that addressed the challenges associated with the use of food nanotechnology, such as potential health risks and regulatory issues, were included. Articles not meeting the pre-defined methodology criteria (i.e., those that were not narrative or systematic reviews) were excluded. Studies which predominantly focussed on public awareness and perceptions of nanotechnology in the global agri-food sector were excluded.

Number of publications per year

A second search of the electronic database, Scopus, was conducted in October 2013 to obtain the total number of publications per year for specific search terms. The search terms used were "nanotechnology", "nanotechnology and food", "nanotechnology and food and agriculture", nanotechnology and agriculture", "nanotechnology and food and production", "nanotechnology and food and processing", "nanotechnology and nutrition", "nanotechnology and feed", "nanotechnology and food and packaging", "nanotechnology and food and safety" and "nanotechnology and food and legislation" (Figures 4.2 and 4.3). These searches were performed to determine when research into nanotechnology was first initiated, and to ascertain if interest in this field, and particularly in relation to food-related applications, had increased in recent years.

4.4 Results and discussion

The concepts that started nanotechnology were first discussed in 1959 by the renowned physicist, Richard Feynman, in his talk, "There's Plenty of Room at the Bottom", in which he described the possibility of synthesis via direct manipulation of atoms. The term "nanotechnology" was first used by Norio Taniguchi in 1974, although it did not become widely known for some time. Nanotechnology emerged as a field in the 1980s and since then, there has been an increase in scientific publications and awareness in the area, with an intensification of research in the 2000s (Figure 4.2) due to amplified scientific, political and commercial attention that led to both controversy and progress. Similarly, the commercialisation of products based on advancements in nanoscale technologies began emerging.

Nanotechnology research in relation to food and animal feed commenced in the late 1990s, but as it comprises less than 2% of research publications, it is considered to be a relatively small sector of the nanotechnology field (Figure 4.3).

The initial search of review articles generated a total of 872 citations, of which 245 titles met the inclusion criteria and were reviewed (Figure 4.1). Appendices D to F provide the number of citations per search term for each database utilised. An additional 12 review articles were identified through reference lists. One author independently assessed and retrieved titles and abstracts for relevance to the research question. Relevant review articles were obtained in full text, and assessed according to the inclusion and study quality criteria; 27 studies met the full inclusion criteria and were included. Selected articles included 25 traditional or narrative reviews and two systematic reviews. The characteristics of the included reviews are summarised in Appendix 10; these were sub-divided as applications, opportunities and risks. Most of the articles selected for review discussed one or more of these themes and so were included in more than one category if applicable.

Figure 4.2: Number of nanotechnology publications per annum

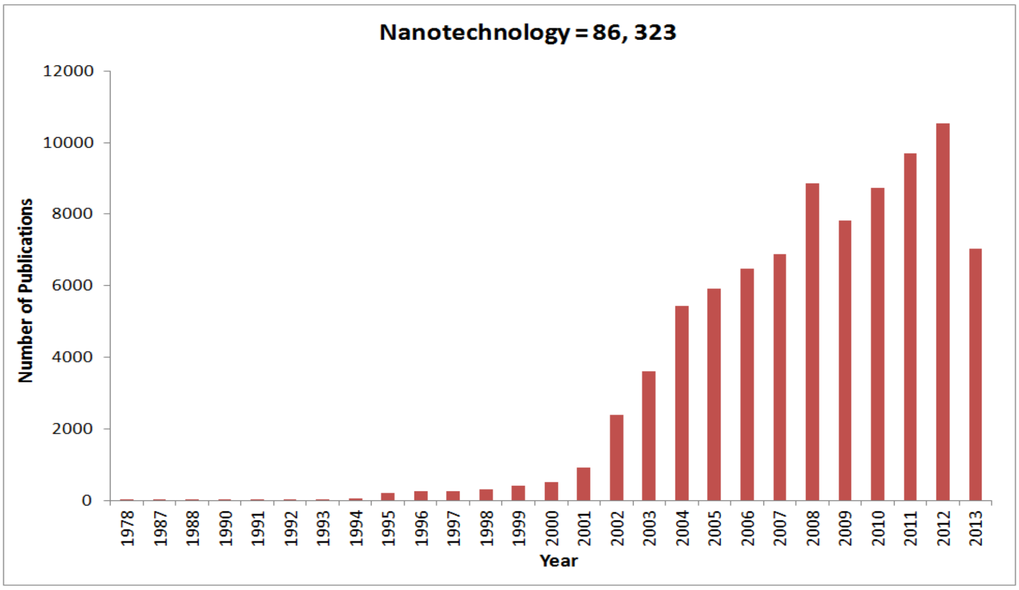
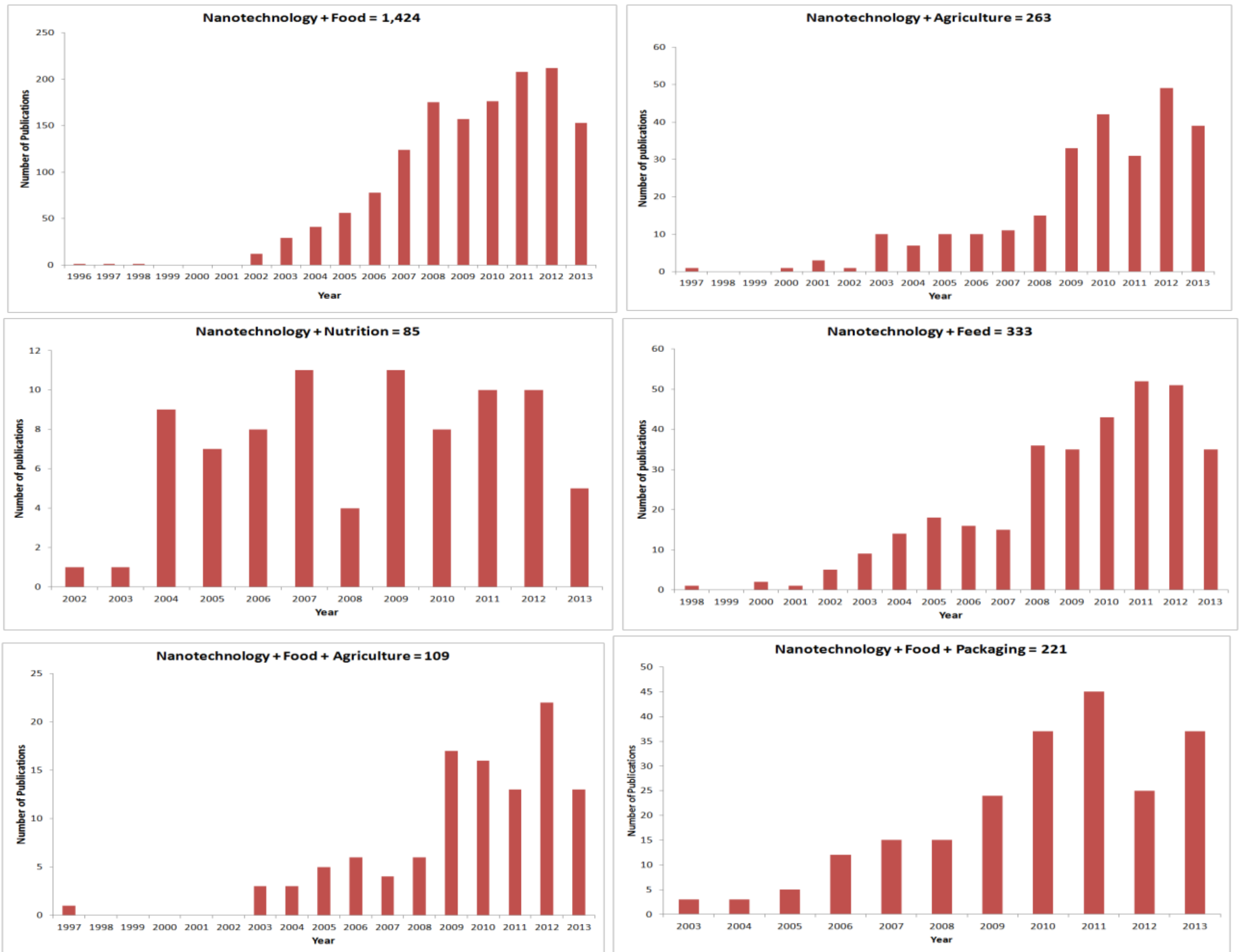
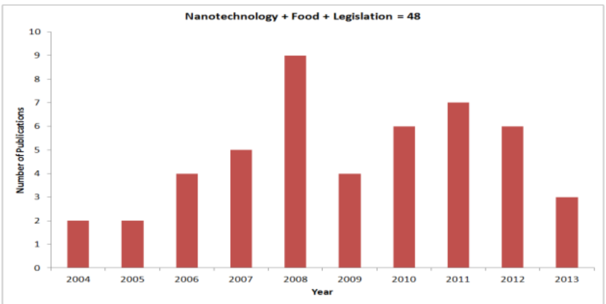
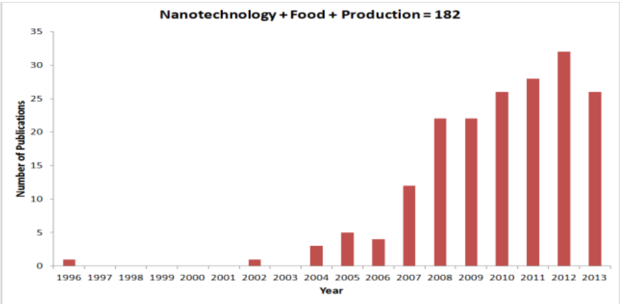
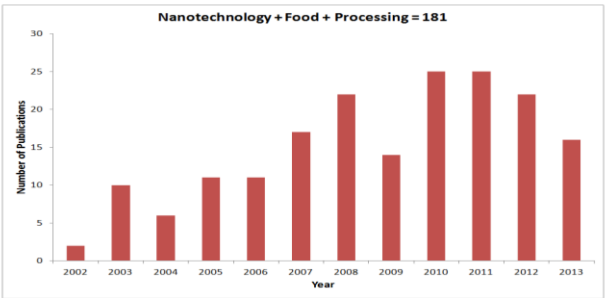


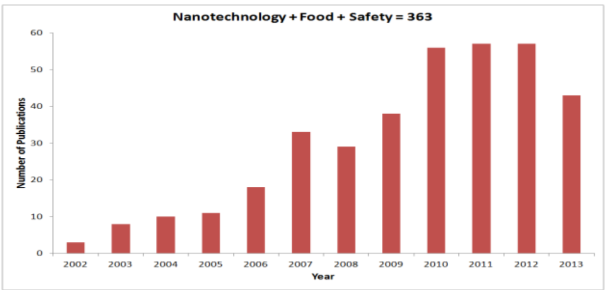
Figure 4.3: Number of nanotechnology publications per year in the Scopus database




Nanotechnology + Food + Legislation = 48
Number of Publications
Year
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013


Nanotechnology + Food + Production = 182
Number of Publications
Year
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

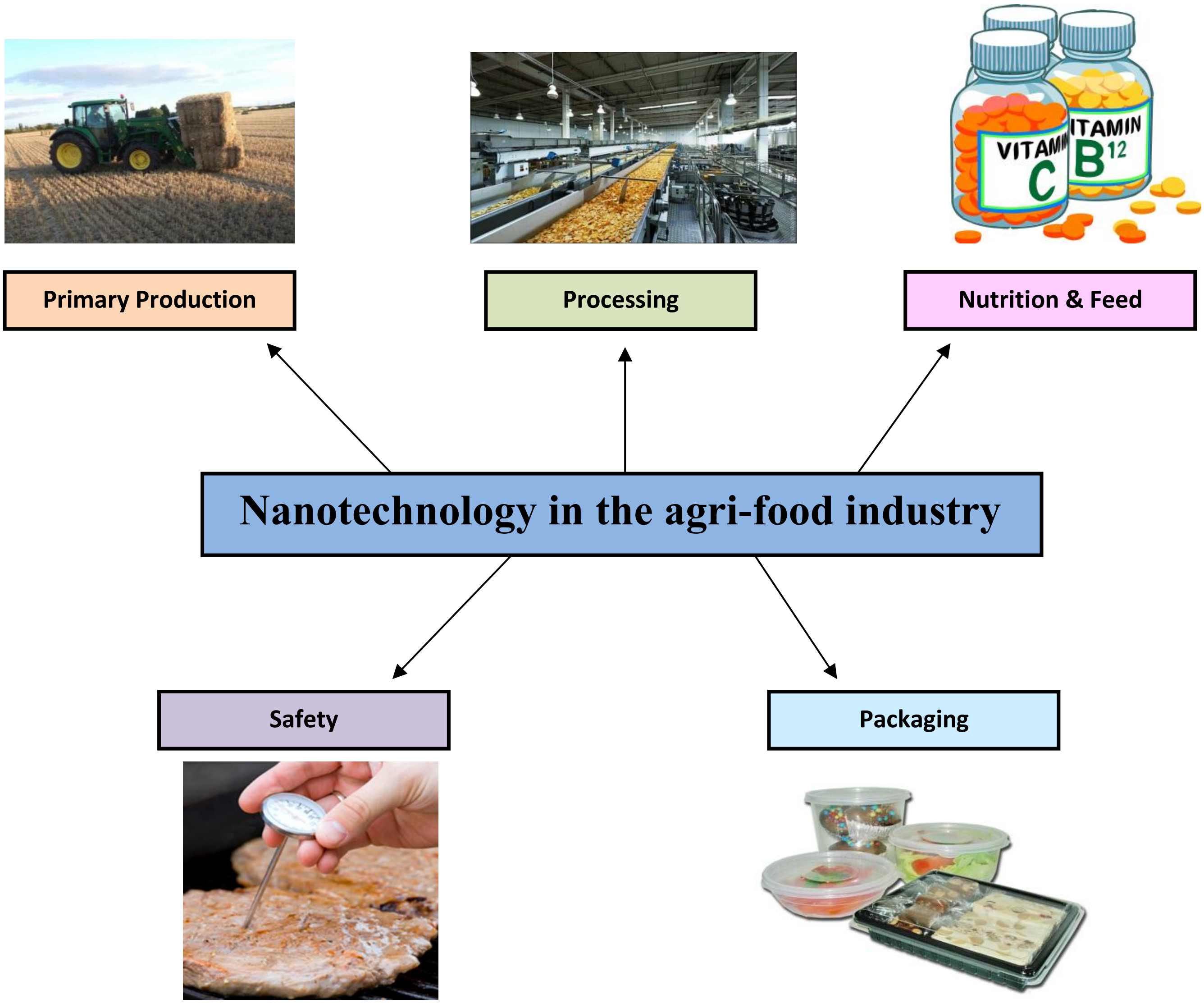

Nanotechnology + Food + Processing = 181
Number of Publications
Year
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013


Nanotechnology + Food + Safety = 363
Number of Publications
Year
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013

Applications of nanotechnology in the agri-food sector

The identification of emerging themes derived from the literature review and coding are summarised in Figure 4.4.

Figure 4.4: Identification of emerging themes through the coding of the papers; applications of nanotechnology in the agri-food sector



PRIMARY PRODUCTION

A number of reviews (Chaudhry and Castle, 2011; Chen and Yada, 2011; Ditta, 2012; Duncan 2011a; Durán and Marcato, 2013; Garcia et al., 2010; Grobe and Rissanen, 2012; Khot et al., 2012) have discussed the emerging applications of nanotechnology for agricultural production. Nanotechnology is expected to facilitate the next development stage of GM crops, animal production inputs, chemical pesticides and precision-farming techniques. Precision farming is one of the most important techniques utilised for increasing crop productivity by monitoring environmental variables and applying targeted action (Chen and Yada, 2011).

Applications of nanotechnology in agriculture are currently at the R&D stage and so may take many years before being commercialised worldwide. Such techniques are mostly intended to address some of the challenges and limitations facing large-scale, capital and chemical-intensive farming operations. The potential applications of nanotechnology in animal production include improved efficacy and nutrition of animal feeds (e.g., fortified with nanosupplements, antimicrobial additives and detoxifying NMs) and nanobiosensors for animal disease diagnostics. At present, there are very few examples of commercially available products where a nano-sized additive has been explicitly designed for animal feed. An example of a feed additive is one that contains a natural biopolymer from yeast cell walls that is intended to bind mycotoxins to protect animals against mycotoxicosis. The potential use of an aflatoxin-binding nano-additive for animal feed, which is derived from modified nanoclay, has also been suggested. Scientists have also developed an NP that adheres to E. coli, comprising a polystyrene base, polyethylene glycol linker and mannose-targeting biomolecule. These NPs are designed to be administered through feed to remove food-borne pathogens in the GI tracts of livestock (FAO/WHO, 2010). In plant-based agriculture, emerging applications include nano-formulated agrichemicals (e.g., fertilisers, pesticides, biocides and veterinary medicines) for improved efficiency, reduced use of farm chemicals, new toxin formulations for pest management and better control of applications (e.g., the slow release of pesticides). Nanosensors can be used, for example, for the detection of pathogens, pesticides and other chemicals. Nanosensors have been applied to pesticide residue detection such as organophosphates in fruit, plants and water (Durán and Marcato, 2013). Khot et al. (2012) have proposed that nanosensors offer high sensitivity, low detection limits, super selectivity, fast responses and small sizes. However, some issues have also been identified regarding this application, such as the accessibility of NMs sensitive to common pesticide residues, the simplicity of sensor fabrication techniques and instrumentation, the desired reliability and repeatability in trace level detection, the cost, and, finally, concerns relating to NM exposure and the environment. The outcome of this narrative review has pointed towards the need for further research in order to ensure complete success for these types of nanotechnology application (Khot et al., 2012).

Smart field sensing systems are another important application for the real-time monitoring of crop growth and field conditions, including nutritional status, light, temperature, moisture level, soil fertility, insects, weeds and plant diseases, etc. Chen and Yada (2011) have reported that networks of wireless nanosensors placed across cultivated fields provide detailed information on crop and soil conditions, enabling the best agronomic decisions to be made, with the aim of maximising agricultural yields while minimising resource inputs. This includes information on the optimal times for planting and harvesting crops, as well as the times for applying water, fertilisers, pesticides and other treatments – and their amounts – given the precise plant physiology and pathology and environmental conditions (Chen and Yada, 2011). Wireless nanosensors have already been used in certain parts of the US and Australia. For instance, a Californian vineyard, Pickberry, in Sonoma County has installed Wi-Fi systems with the aid of the information technology (IT) company, Accenture. The cost of installing this system has been rationalised by the fact that it facilitates the best grapes to be grown which, in turn, results in better-quality wines being produced. These then command a premium price (Joseph and Morrison, 2006).

Another emerging plant-based application is nanoscale carriers (i.e., encapsulation and entrapment, polymers, dendrimers, etc.) for the efficient delivery of agrichemicals (i.e., pesticides, herbicides, fertilisers, plant growth regulators, etc.). Nanoscale delivery vehicles appear to be useful in agronomic applications by improving stability against degradation in the environment and, in doing so, improving its effectiveness while decreasing the amount to be applied. This reduces agricultural chemical runoff and alleviates environmental problems (Ditta, 2012). These carriers can be designed in such a way that the plant roots or the surrounding soil structures and organic matter are anchored, provided that the molecular or conformational affinity between the delivery nanoscale structure and targeted structures and matters in soil are used. These mechanisms enable the slow uptake of active ingredients, thus reducing the amount of agricultural chemicals to be used, in addition to minimising inputs and the waste produced (Ditta, 2012).

The nanoencapsulation of pesticides involves manipulating the outer shell properties of a capsule, allowing slow and controlled release of the active ingredient, and, therefore, delivering more effective control over certain pests at lower dosage rates and over a prolonged period of time. Nanopesticides can increase the dispersion and wettability of agricultural formulations (i.e., decreased chemical runoff) and unwanted pesticide movement. Other potential benefits of nanoencapsulated pesticides include increased solubility and decreased contact of active ingredients with farm workers (Khot, et al., 2012). Globally, pesticides containing nanoscale-active ingredients are commercially available, with many of the world's leading agrochemical firms recognising their potential usefulness and conducting research into the development of novel nanoencapsulated pesticides. For example, Syngenta has incorporated nanoemulsions into its pesticide products. Primo MAXX® is one of its successful growth-regulating products, which, if applied before the onset of stress, such as heat, drought, disease or traffic, can strengthen the physical structure of turf grass, thus enabling it to withstand ongoing stresses throughout the growing seasons (Joseph and Morrison, 2006).

To summarise, while most agricultural applications are still at the R&D stage, they have the potential for adoption at a very large scale by the agricultural sector worldwide due to their ability to improve precision farming practices. Potential applications include nano-formulated agrichemicals, smart field sensing systems to monitor crop growth and field conditions, nanobiosensors for animal disease diagnostics and nanosensors for pathogen and pesticide detection. However, at present, research on methodology, identification and characterisation of NMs, testing priorities and the regulatory guidance on NP safety are still in their initial stages.

Opportunities: NMs are being developed that offer opportunities for agricultural chemicals (i.e., fertilisers and pesticides) to be administered more efficiently and safely.

Benefits: Nanotechnology offers beneficial effects, such as a reduced use of agrichemicals (i.e., fertilisers and pesticides), and the enhanced ability of plants to absorb nutrients, fight diseases and withstand environmental stresses.

Risks: There are concerns that when NPs are released into the soil or water directly through nano-based agricultural chemicals, a carry-over to crops is possible through accidental release or indirectly through contamination; this might affect plant health/and or be bio-accumulated through the food chain, thus resulting in consumer exposure.

FOOD PROCESSING: NUTRITION AND FEED

Nano-food implies that food has been cultivated, produced, processed or packaged using nanotechnology tools or techniques or to which NMs have been added (Sekhon, 2010). The intentions of nano-food technology are to improve the quality, safety and nutritional value of food, as well as to reduce costs. Consumers can benefit from this application in terms of meeting individual dietary and health requirements or taste preferences, while benefits to food companies include product differentiation, new market opportunities and economic gains.

Several reviews (Alfadul and Elneshwy, 2010; Chaudhry and Castle, 2011; Chaudhry et al., 2008; Durán and Marcato, 2013; Garcia et al., 2010; Grobe and Rissanen, 2012; Ileš et al., 2011; Momin et al., 2013; Rashidi and Khosravi-Darani, 2011; Sekhon, 2010) have identified that the emerging applications of nanotechnology in food processing are focussed on the development of nano-sized food ingredients and additives, and delivery systems for nutrients and supplements in the form of nutraceuticals. A diverse range of processes are being utilised to aid with this, such as nanoemulsions, surfactant micelles, emulsion layers, reverse micelles and functionally-designed nanocapsules.

Sekhon (2010) has indicated that a key application of nanotechnology in food processing involves the development of nano-structured food ingredients, which offers improvements to consistency, taste and texture. Nanoemulsion technology is frequently used to create low-fat mayonnaise, spreads and ice cream, where they are claimed to be as creamy as the full-fat alternatives, thus offering consumers healthier options (Cushen et al., 2012; Sekhon, 2010). For example, mayonnaise can be nano-textured using oil in water emulsion containing nanodroplets of water inside oil droplets. The mayonnaise offers taste and texture attributes that are similar to the full-fat equivalent but with significant reductions in the fat content. Unilever is another example, producing an ice cream with reductions in fat from 8-16% to 1% while not compromising on the flavour. Consumers can also benefit from more rapid and simpler thawing of frozen foods in the microwave, as developed by Nestlé using nanoemulsion technology. It has patented water-in-oil emulsions (10-500nm), and through the addition of polysorbates and other micelle-forming substances, aims to contribute to a uniform thawing of frozen foods (Alfadul and Elneshwy, 2010).

Food companies can greatly benefit from adding NPs to their food and beverage products in terms of making improvements to flavour, colour, flow properties and stability during processing or extending their shelf life. For instance, aluminosilicate materials are commonly used as anti-caking agents in granular or powdered processed foods, while titanium dioxide is a food whitening and brightening additive that is commonly used in confectionary, and in some cheeses and sauces (Alfadul and Elneshwy, 2010). According to the Project on Emerging Nanotechnologies, titanium dioxide is widely used in commercially available food and beverages, including chocolate (Hershey's, Kraft, Lindt, Mars Inc.), cheese (Albertsons, Kraft), ready prepared mashed potato (Betty Crocker), coffee creamer (Nestlé), yoghurts (Dannon Oikos), pop tarts (Kellogg's), mints (Mentos, Tic Tac), sports drinks (Coca-Cola), salad dressing (Unilever), sports drinks (Coca-Cola) (The Pew Charitable Trusts and Wilson Centre, 2013). Titanium dioxide was classified by the International Agency for Research on Cancer (IARC) as an IARC Group 2B carcinogen that is "possibly carcinogen to humans", and has been suggested as a possible cause of inflammatory bowel disease. However, the EFSA opinion on titanium dioxide safety, albeit for use in cosmetics, is inconclusive and further toxicological assessments are required for acute or long-term exposure.

Nanotechnology also offers opportunities to alter and manipulate food and beverage products to allow for more effective delivery of nutrients such as protein, vitamins and minerals, in addition to antioxidants, to specifically target the nutritional and health benefits to consumers. This application also enables food companies to gain a competitive advantage by satisfying individual dietary requirements and consumers' varied demands for foods. An important area of current nanotechnology application is nanoencapsulation of food ingredients and additives. Nanocarrier systems, including emulsions, micelles, liposomes, biopolymer matrices and association colloids, have been developed for use in food and beverage products. Nanoencapsulation can control the release of certain active ingredients (i.e., proteins, vitamins, minerals, enzymes and preservatives), mask undesirable odours and flavours such as fish oils, enhance the shelf life and stability of the ingredient and the finished food product, and improve the uptake of encapsulated nutrients and supplements (Chaudhry and Castle, 2011; Sastry et al., 2013). The modified characteristics of nanocarriers enable their use in a vast array of food and beverage products. For example, Alfadul and Elneshwy (2010) have reported that George Weston Foods, one of the leading bakeries in Western Australia, has successfully incorporated nanocapsules containing tuna fish oil into their "Tip Top" UP bread for additional health benefits. The nanocapsules are designed to be secreted once they enter the stomach, thereby avoiding the unpleasant taste of the fish oil. Another example is Shemen Industries, which has used minute compressed micelles, called nanodrops, in the development of canola active oil. The micelles work as a liquid carrier, enabling the penetration of vitamins, minerals and phenolic compounds that are insoluble in water or fats. The micelles are added to food products, and so pass through the digestive system efficiently, without breaking up, to the absorption site (The Pew Charitable Trusts and Wilson Centre, 2013).

Nutritional additives are an increasing source of the addition of NPs to food. The European Commission (EC) Concerted Action on Functional Food Science in Europe has defined a functional food as "a food that beneficially affects one or more target functions in the body beyond adequate nutritional effects in a way that is relevant to either an improved state of health and well-being and/or reduction of risk of disease" (EC, 2010). Nanoencapsulation technologies are being employed to protect bioactive compounds, including vitamins, minerals, proteins, lipids, carbohydrates and antioxidants, for the manufacture of foods with improved functionality and stability, thus offering huge potential for improvements to public health and nutrition (Sekhon, 2010). The Nutralease Ltd Company has developed novel carriers for nutraceuticals to be incorporated into food systems, thereby enhancing the bioavailability of the product. Lycopene, beta-carotenes and phytosterols are some of the nutraceuticals incorporated in the carriers, and are used in the production of healthy foods, especially to prevent the accumulation of cholesterol (Alfadul and Elneshwy, 2010). The added health benefits arising from this application are, therefore, particularly beneficial for consumers with health concerns. Food companies can also benefit from product differentiation and new market opportunities.

Rashidi et al. (2011) have proposed that micelles are capable of encapsulating nonpolar molecules, including flavourants, lipids, antimicrobials, vitamins and antioxidants. Various nano-micelle based carrier systems have been developed for nutraceuticals and nutritional supplements and are available on the market. For example, LivOn Laboratories has developed Lypo-Spheric™ vitamin C, using liposomes as the supplement delivery system. Lypo-Spheric™ vitamin C is able to produce serum levels of vitamin C that are nearly twice the level of any other oral form of vitamin C. Health Plus International® Inc. have also developed an innovative nutritional product line, known as Spray For Life. The technology offers benefits of introducing nutrients into the body in a way that enables more rapid, uniform and complete absorption than pills, capsules or other liquids (The Pew Charitable Trusts and Wilson Centre, 2013). Dairy products, cereals, breads and beverages are now fortified with vitamins, minerals, antioxidants, plant sterols, probiotics and bioactive peptides (Alfadul and Elneshwy, 2010). BioDelivery Sciences International has introduced its Bioral™ nanocochleate nutrient delivery system for micronutrients and antioxidants. The nanocochleates (~50 nanometres in size) are based on a phosphatidylserine carrier derived from soya beans, and are generally recognized as safe (GRAS). The nanocochleate system appears to prevent degradation of micronutrients and antioxidants during manufacture and storage (Chaudhry et al., 2008). Four reviews (Alfadul and Elneshwy, 2010; Chaudhry et al., 2008; Rashidi and Khosravi-Darani, 2011; Sekhon, 2010) discuss the German company, Aquanova, which has developed a nanocarrier system using 30 nanometre micelles to encapsulate two active substances for fat reduction and satiety; this is a novel innovation for intelligent weight management for consumers. Marketed as NovaSOL, it uses CoQ10 to target fat reduction and alpha-lipoic acid for satiety, thus enabling consumers to feel fuller for longer and assisting in weight loss. This technology has also been used to add antioxidants into food and beverage products through the introduction of nutrients such as vitamin A, C and E, thereby targeting the health and dietary requirements of consumers. NovaSOL also offers substantial advantages to food companies, such as cheaper ingredients, faster production process, enhanced shelf life, higher colour stability, improved uptake and bioavailability, and ready-to-use liquid form, thus resulting in overall reductions in energy usage, wastage and costs. Other examples of these include nano calcium/magnesium from Magi-I-Cal.com USA, and the nano-selenium-enriched Nanotea from Shenzhen Become Industry & Trade Co Ltd (Chaudhry et al., 2008).

A recent trend reported by Alfadul and Elneshwy, (2010) is the nanoencapsulation of live probiotic microbes for the promotion of GI health. They can be incorporated into various food and drink products, including fermented milk, yoghurts, cheese, puddings and fruit-based drinks. Nanoencapsulation technology is applied to aid in the development of designer probiotic bacterial preparations which can be transited to the GI tract where they interact with specific receptors and can improve intestinal microflora and , thus, support good consumer health (Sherwood and Gorbach, 2000).

Many of the large food companies worldwide (e.g., Heinz, Kraft Foods and Nestlé) are investing in nanotechnology and are on their way to commercialising food and beverage products. For instance, the development of interactive foods, which can be modified in terms of their colour, flavour or nutritional properties according to an individual's dietary requirements, allergies or taste preferences, are another function discussed by Alfadul and Elneshwy (2010). Numerous products based on nanocluster delivery systems are available commercially worldwide. For example, RBC Life Sciences® Inc. has developed a nutritional supplements line called NanoCeuticals™. This technology has been used to create a slimming product based on cocoa nanoclusters, which are coated on the surface of engineered NMs to enhance the chocolate flavour through the increase in surface area that targets the taste buds. This product offers consumers an effective solution to weight loss while appealing to their taste preferences.

A nanotube is a discrete hollow fibre entity, which has two dimensions in the nanoscale (FAO/WHO, 2010). The self-assembly of hydrolysed calcium binding milk protein α-lactalbumin into nanotubes is another recent development (Momin et al., 2013). These food protein-derived nanotubes show good stability and offer potential applications in food, nutrients and pharmaceuticals. α-lactalbumin has an important role in lactose formation, which is essential for milk production; it is already used as a food ingredient in infant formula. Human breast milk provides all the essential nutrients for an infant's growth and development in balanced proportions. Infant formula feeding is the most appropriate alternative if the mother is unable or chooses not to breastfeed her infant. Infant formula is designed to bear a close resemblance to human breast milk, and so extensive research has been dedicated to improving the protein quality of infant formula so that it is more like human milk (Lien, 2003). Due to the relatively high content of essential amino acids in α-lactalbumin, it is desirable for improved infant formula protein systems, by offering similar protein content to that of human milk, and , thus, helping to meet the nutritional needs of infants (Lien, 2003).

Food processing: equipment

The food processing system is faced with a number of challenges relating to the control of chemical contaminants, microbiological hazards and pathogens in order to promote food safety. A number of research initiatives are in the process of investigating the use of NPs as antibacterials for improving food safety. Silver NPs are being incorporated into food processing systems to kill food pathogens and bacteria (Alfadul and Elneshwy, 2010). Silver's effective antimicrobial properties are due to its intense antimicrobial activity and low toxicity to mammalian cells and tissues (Araujo et al., 2013). Therefore, silver NPs are being considered as an important means of overcoming the growing problem of antibacterial resistance. At present, these are being used as antimicrobial agents in foods, with the aim of developing food-related applications, such as microbe-resistant fabrics or non-biofouling surfaces (Alfadul and Elneshwy, 2010).

In food manufacturing, the greatest energy requirements are from the process heating and cooling systems, which are an essential part of the maintenance of food safety. Nanotechnology-based equipment insulation coatings have been developed to enable manufacturers to reduce heat loss and lower their energy costs. Nansulate has developed thermal insulation coatings using award-winning, patented technology, which integrates a safe, nano-sized internal structure into a low-volatile, organic compound, water-based, acrylic latex coating. Nansulate offers manufacturers an easy method of coating a number of difficult-to-insulate food and beverage processing equipment (i.e., heat exchangers, ovens, dryers and cookers), as well as protecting equipment from corrosion and mould growth. Furthermore, the clear coatings allow for easy visual inspection of the substrate surface. The overall benefits to food manufacturers include significant cost savings and improved profit margins (author unknown, 2010).

Another nanotechnology-based coating system is Bioni, which was also developed to satisfy the requirements of the food industry. The patented solution uses a two-layer system that can be applied directly to mould-affected substrates and other surfaces. The system also provides a permanent protection against the growth of new mould, mildew or bacteria on the coating film, thereby providing cost-saving benefits. A further advantage to Bioni is that it is eco-friendly as it does not require any other chemicals for disinfectant and pre-treatment of affected surfaces (Bioni-USA, 2013).

In summary, nanotechnology has promising applications for the sanitisation of food processing equipment (i.e., silver NPs), which can offer effective solutions to food safety issues and reduce resource costs. Moreover, many companies have already demonstrated successful nanotechnology applications in the development of nano-foods and beverage products, due to the various potential benefits they offer in terms of improvements to flavour, texture, consistency and nutritional value.. Some of the processes being utilised for the production of nano-food include nanoencapsulation, nanoemulsions, surfactant micelles, emulsion layers and functionally-designed nanocapsules.

Opportunities: Nanotechnology-based equipment coatings can be utilised to achieve more hygienic food/feed processing to kill pathogens and bacteria, thus improving food safety and reducing the risk of food-borne illness. There are opportunities for food companies to create innovative and novel food and beverage products with improved sensory attributes and/or nutritional properties to meet consumers' desires or health requirements.

Benefits: Nanotechnology has the potential to offer significant improvements to food safety and public nutrition, especially in developing countries.

Risks: Nano-sizing food ingredients and artificial additives may affect how these ingredients behave when broken down in the gut, and, subsequently, how they are treated in the GI tract. Furthermore, enhanced uptake of colouring or flavouring agents, or preservatives, may lead to the application exceeding the acceptable daily intake (ADI) value established for the additive (Chaudhry and Castle, 2011).

Food packaging

Nanopackaging applications as food contact materials are growing rapidly; this is now considered to be the most active area of nanotechnology in the food sector. At present, approximately 400 to 500 nanopackaging products are available on the global market, with predictions that nanopackaging will account for 25% of all food packaging within the next 10 years (Lyons et al., 2011). Manufacturers claim that nanopackaging can extend product shelf life, as well as assist in the maintaining, improving or monitoring of the quality and safety of foods. For instance, the use of NPs in food packaging can improve the mechanical and heat resistance properties, thereby affecting gas or water vapour permeability, and , thus, increasing shelf life. Several reviews (Chaudhry and Castle, 2011; Durán and Marcato, 2013; Garcia, 2010; Han et al., 2011; Momin et al., 2013; Rashidi and Khosravi-Darani, 2011; Restuccia et al., 2010; Silvestre et al., 2011; Sozer and Kokini, 2009) have reported three main categories of nanopackaging: improved packaging, active and intelligent packaging, and biodegradable nanocomposites food packaging. Improved packaging has been described by Silvestre et al. (2011) as incorporating NPs in the polymer matrix materials, with improved packaging properties in terms of temperature/moisture stability, flexibility, durability and gas barrier properties (e.g., nanocomposites, silicate NPs and nanosilver). Han et al. (2011) have also suggested that the application of NPs in food packaging has additional functions. such as antibacterial properties. Elgin, IL Multifilm Packaging has developed an ultra-thin coating known as N-Coat®, which is applied to a 48-gauge polyester film, resulting in a clear laminate with an excellent gas barrier that can compete with most metallised structures. N- Coat® has been primarily developed for nuts, coffee and dry foods (The Pew Charitable Trusts and Wilson Centre, 2013).

Active and intelligent food packaging are novel concepts of packaging compared with traditional materials. Polymer nanocomposites, integrating metal or metal oxide NPs, have been developed for active packaging. These include silver, gold, zinc oxide, silica, titanium dioxide and iron oxides (Chaudhry et al., 2008). Han et al. (2011) have indicated that active packaging has the ability to remove undesirable tastes and flavours, and improve the colour or odour of the packed food. For example, carbon black NPs incorporated into polymer packaging can absorb odours released from the food or packaging. An emerging active packaging application integrates NPs with antimicrobial or oxygen scavenging properties; this packaging is designed to stop microbial growth once the package is opened by the consumer and rewrapped with an active-film portion of the package (Momin et al., 2013). A number of food contact materials have been developed using nanosilver, which, it is claimed, preserves the food for longer and inhibits the growth of microorganisms. For example, BlueMoonGoods LLC has introduced new silver NP fresh box super airtight food storage containers that can reduce bacteria by up to 99.9%. Foods can easily be stored for up to four times the length of time than traditional food containers, thus offering consumers the benefits of fresher, higher quality food for a longer period of time, and, subsequently, reduced food wastage. Other examples include “FresherLonger™ Miracle Food Storage Containers” and “FresherLonger™ Plastic Storage Bags” from Sharper Image® USA, “Nano Silver Food Containers” from A-DO Global and “Nano Silver Baby Mug Cup” from Baby Dream® Co Ltd (The Pew Charitable Trusts and Wilson Centre, 2013). Nanosilver has also been used to provide an antibacterial coating on kitchenware and tableware (Changmin Chemicals, Nano Care Technology Ltd, Pro-Idee GmbH & Co KG) to kill attached bacteria and maintain permanently clean and hygienic surfaces, thus benefiting consumers in terms of reduced risks of foodborne illnesses (The Pew Charitable Trusts and Wilson Centre, 2013). Furthermore, nanosilver has been integrated into the interior coating of domestic refrigerators (LG, Samsung and Daewoo) for effective disinfection, deodorisation and anti-bacterial effects (The Pew Charitable Trusts and Wilson Centre, 2013). Intelligent or smart-food packaging incorporates a nanobiosensor for sensing and signalling microbial and biochemical changes, and releasing antimicrobials, antioxidants, enzymes, flavours and nutraceuticals to extend shelf life. A diverse range of devices has been developed to detect food spoilage organisms in food packaging (e.g., nanowires and antibodies), thus enabling versatility and much cheaper production (Durán and Marcato, 2013). Examples of some of the companies developing intelligent packaging for their food and beverage products include the nanotechnology company, pSiNutria, which is developing nano-based tracking technologies, including an edible BioSilicon, which can be placed in foods for monitoring purposes and pathogen detection. Another example is Kraft, which is working with Rutgers University (US) to develop engineered nanosensors in food packaging, which change colour to warn the consumer of food spoilage or, if the food has been contaminated by pathogens. These nanosensors use electronic ‘noses’ and ‘tongues’ to ‘taste’ or ‘smell’ scents and flavours (Momin et al., 2013). AgroMicron has developed the NanoBioluminescence Detection Spray, which encompasses a luminous protein that is intended to bind to the surface of bacteria such as salmonella and E.coli (Durán and Marcato, 2013).

Biodegradable nanocomposites food packaging has been described by Momin et al. (2013) as incorporating inorganic particles, such as clay, into the biopolymeric matrix, which can improve the delivery of micronutrients. The nano-layered structure also restricts the access of gases, and offers considerable improvements in terms of the gas barrier properties of nanocomposites. Biodegradable materials have potential use in a wide range of food packaging applications, including processed meats, cheese, confectionary, cereals and boil-in-the-bag foods, as well as extrusion-coating applications for fruit juices and dairy products or co-extrusion processes for the production of bottles for beer and carbonated drinks (Chaudhry et al., 2008). For example, Voridan has developed a nanocomposite containing clay NPs, called Imperm. This is ideal for beer, as the resultant bottle is lighter and stronger than glass and is less likely to shatter. Furthermore, the nanocomposite structure minimises loss of carbon dioxide from the beer and keeps oxygen out of the bottle, thereby retaining the freshness of the beer and extending its shelf life. This technology has been adopted by various companies, including the Miller Brewing Co (Joseph and Morrison, 2006). Aegix® OX (Honeywell Speciality Polymers) has also successfully engineered plastic beer bottles that integrate nanocomposites to enhance the barrier properties and extend shelf life by up to 26 weeks. This technology has been used in the Hite Pitcher beer bottle from Hite Brewery Co in South Korea (Joseph and Morrison, 2006). Durethan KU2-2601 (Bayer AG) is another example. This a hybrid plastic that is enriched with numerous silicate NPs. The plastic incorporates Nanocor’s clay to produce a film that is lighter, stronger and more heat resistant than traditional packaging materials. The film is intended to prevent the entrance of oxygen and other gases, and the exit of moisture, thus preventing food spoilage (Chaudhry et al., 2008).Conversely, Durán and Marcato (2013) have suggested that biodegradable materials demonstrate poor barrier and mechanical properties and require substantial improvements before replacing traditional packaging materials.

Nanopackaging has the potential to provide manufacturers with a vast range of benefits, including the ability to keep packaged food fresher for longer (Lyons et al., 2011). This may enable food to travel further and remain in storage for an extended period of time, thus resulting in a more reliable food supply. By increasing the shelf life of food products, manufacturers will also be able to sell food that would have otherwise been discarded due to spoilage, and hence contribute to reductions in food waste. Innovative and novel packaging that is lightweight, stronger and functional can also significantly reduce transportation costs and packaging materials in the environment. Smart labels on food packaging are likely to appeal to manufacturers due to the ability to effectively monitor the safety, quality and security of food and beverage products during transportation and storage, reducing the risks of food-borne illnesses. Consumers may also benefit from attractive new products on the market, which are safer and of better quality.

In summary, improved packaging, active and intelligent packaging, and biodegradable nanocomposites food packaging are the three main types of innovative packaging identified. The application of NPs to food packaging can extend shelf life and improve product quality and safety. However, for complete success, certain materials require further improvements before replacing traditional plastics.

Opportunities: Nanotechnology offers opportunities for novel, lightweight and functional packaging, with consequent extensions to the shelf life of products and improvements to the safety of food.

Benefits: Improved packaging can reduce transportation costs and packaging materials in the environment. Extensions to product shelf life can reduce food wastage, create a more reliable food supply and increase profits.

Risks: There is a potential risk for consumers from exposure from food packaging through possible migration of NPs into food and beverages.

Opportunities and anticipated benefits

A number of reviews (Bradley et al., 2011; Chaudhry and Castle, 2011; Kuan et al., 2013; Cushen et al., 2012; Meetoo, 2011; Momin et al., 2013; Rashidi and Khosravi-Darani, 2011; Ravichandran, 2010; Sekhon, 2010; Sonkaria et al., 2012) have recognised the vast opportunities for applying nanotechnology to agriculture and to all aspects of the food industry, providing preservation, processing, packaging and monitoring functions (Figure 4.5).

Discussion within these reviews has indicated that there are numerous potential benefits arising from the application of nanotechnology to food, which make it of real relevance for developing countries, as well as for developed nations (Figure 4.6). Nanotechnology enables more effective agricultural production methods with lower use of agrichemicals (e.g., pesticides, fertilisers and veterinary medicines), which can alleviate environmental pollution and lessen chemical run-offs. A range of benefits are available to farmers, including reductions in agricultural losses, enhanced production efficiency, lower resource costs and improvements to profit margins. The extended shelf life of food products is also possible through innovative packaging that incorporates antimicrobial properties. This application offers huge potential to the food industry by contributing to reductions in food waste, as well as a better quality and safer food supply. In addition, the use of nanosensors in food packaging for detection of food spoilage is important for combating pathogenic microorganisms, and consequently, reducing foodborne illnesses in consumers.

Figure 4.5: Identification of the main opportunities for nanotechnology in the agri-food sector

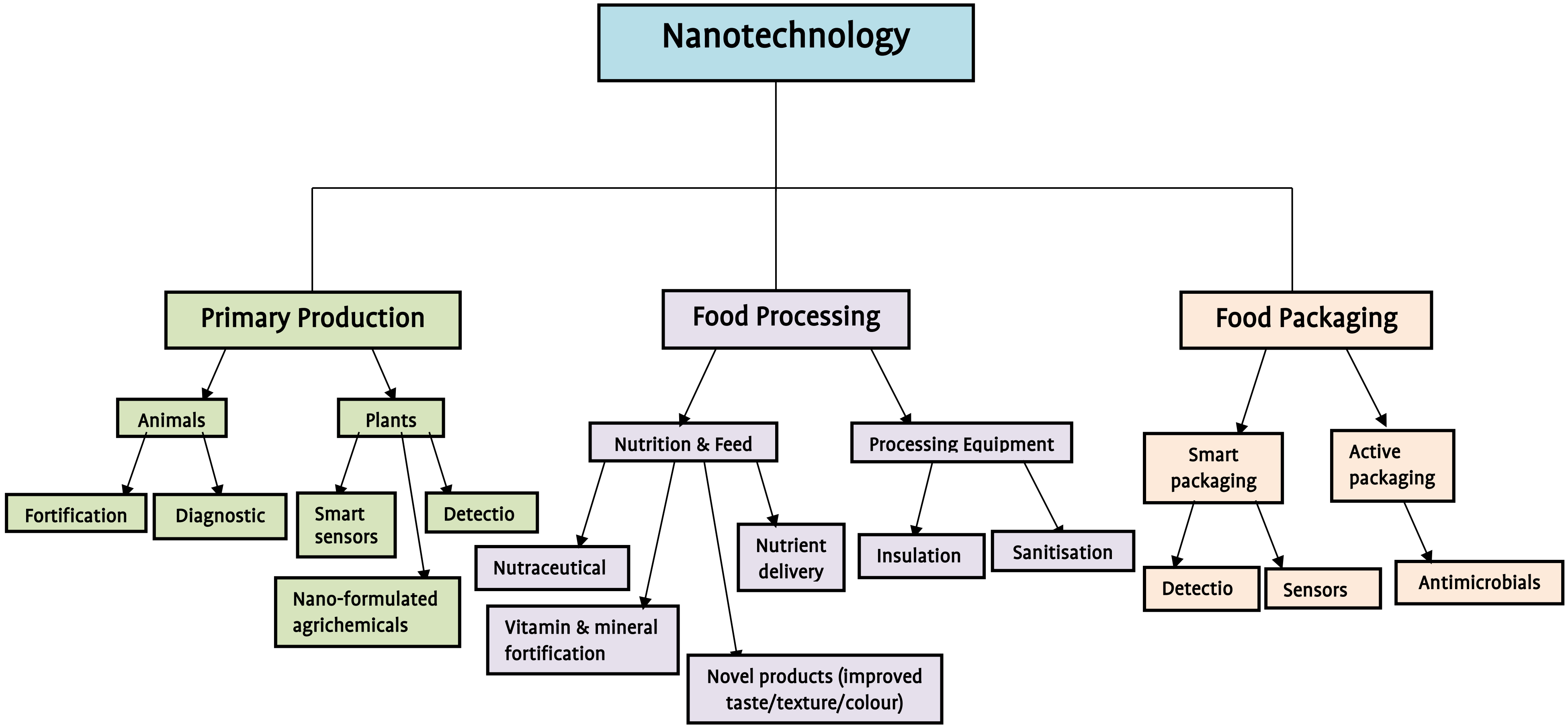
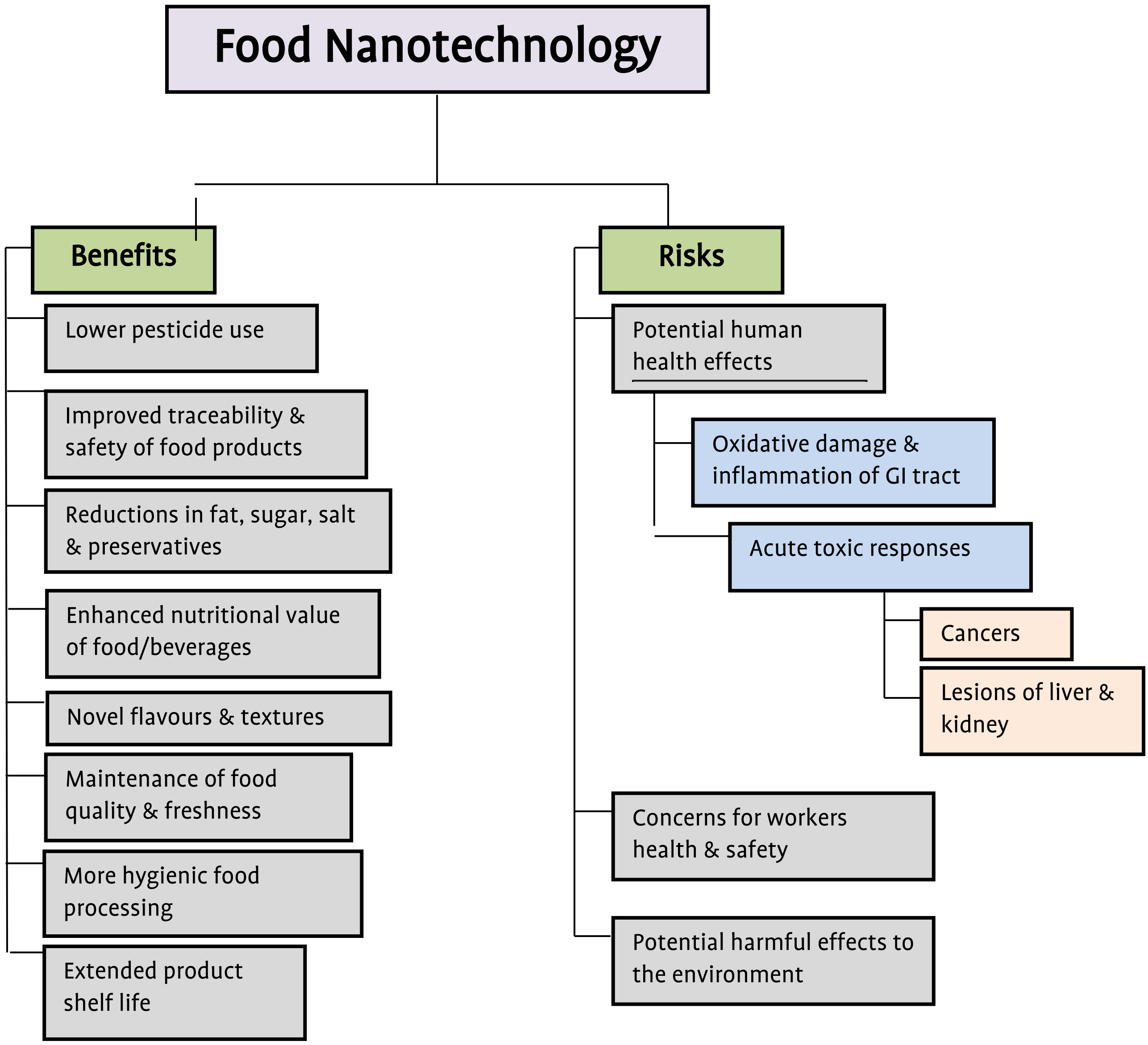


Figure 4.6: The main projected benefits and risks of nanotechnology applications in food and related products



Smart labels on food packaging can also help manufacturers to ensure the authenticity, traceability and safety of their food products. There are also opportunities for novel food and beverage products, with improved colour, flavour, texture or nutritional value to meet consumers' desires or dietary and health requirements. For example, nanotechnology can be used to enrich foods with fruit and vegetables, delivering a higher nutrient density in such foods (Ravichandran, 2010). Nanotechnology can be utilised to dissolve additives, such as antioxidants, phenolic compounds, vitamins and minerals. Furthermore, through nanoencapsulation technologies, additional nutrients can be added to food and beverage products without altering flavour or quality. The delivery of certain ingredients and additives to a specific target site within the body is also possible, thereby providing consumers with additional health benefits. The benefits of nanoencapsulation technologies are extended to manufacturers through the protection of food ingredients during processing and the extension of product shelf life, which can reduce food waste and improve revenues.

In view of the expected benefits (Figure 4.6), two reviews (Bradley et al., 2011; Chaudhry and Castle, 2011) have recognised the vast potential for improvements to food and water safety and public nutrition in developing counties. Moreover, nanotechnology offers huge potential for producers in terms of exporting, through increasing the local processing of basic commodities such as tea, coffee, spices, sugar, bananas and rice. This offers the potential to increase volumes of exports and, subsequently, profit margins. Further details on the opportunities of nanotechnology in the food sector for developing countries can be found in Bradley et al. (2011).

To summarise, nanotechnology offers vast opportunities across the whole agri-food sector, from improved precision-farming practices to novel food and beverage products with enhanced colours, flavours, textures and nutritional properties, in addition to improved food packaging and storage, which can increase the quality and safety of foods. Therefore, these opportunities offer enormous benefits to both the consumer and the producer.

Potential risks

Safety

Despite nanotechnology's vast opportunities and potential applications in the agri-food sector, there are increasing concerns relating to safety and health (Figure 4.6). Increasing scientific evidence has demonstrated that exposure to NPs (e.g., carbon black, silicates, titanium dioxide and iron oxide) may lead to oxidative damage and inflammatory reactions of the GI tract. Furthermore, long-term exposure to NPs has been linked to acute toxic response, including lesions of the kidney and liver, as well as numerous forms of cancer (Borm et al., 2006; Momin et al., 2013; Silvestre et al., 2011). Several reviews investigating the toxicology and safety aspects of NPs have indicated that the incorporation of NMs into food presents an entire new array of risks for consumers (Bouwmeester et al., 2009; Bradley et al., 2011; Chaudhry and Castle, 2011; Chaudhry et al., 2008; Cockburn et al., 2012; Cushen et al., 2012; Grobe and Rissanen, 2012; Han et al., 2011; Ileš et al., 2011; Kuan et al., 2013; Kuzma et al., 2008; Magnuson et al., 2011; Momin et al., 2013; and Silvestre et al., 2011). The most likely route of entry of NPs to the gut is through the consumption of food and drinks. The main concerns around NPs in relation to human health include their increased toxicological effects at smaller concentrations due to the much larger surface area, enhanced toxicity owing to improved bioavailability, greater access to the human body, compromised immune system response and possible longer pathological effects (Momin et al., 2013).

Discussion in the reviews suggests that scientific knowledge gaps exist in our understanding of the properties, behaviour and effects of NMs, which can cause great difficulties for risk assessors and risk managers and severely hinder risk assessment. Moreover, there is limited knowledge on current usage levels and exposure from applications of NPs to food and food-related products. A systematic approach was adopted by Cockburn et al. (2012) for the safety assessment of engineered NMs for food application, proportionate to their physiochemical characteristics and, therefore, their potential for toxicological concern. A decision tree is utilised for toxicological testing of engineered NMs and a tiered approach for subsequent hazard identification and characterisation. The safety testing strategy is considered appropriate to variations in engineered NM size. Furthermore, Magnuson et al. (2011) appraised the literature to determine the current state of knowledge regarding the safety of naturally occurring and engineered NMs for food and food-related applications. A systematic approach to assessing the reliability of toxicology studies of NMs was developed, which has been previously published by Card et al. (2011). The review identified a lack of studies conducted thus far to assess the toxicity of NMs following oral exposure, and much of the published research comes from in vitro studies or from in vivo studies using dermal or inhalation exposure routes (Magnuson et al., 2011). The possible effects of NPs through the GI route are mostly unknown. In the food sector, toxicology research is almost non-existent, and few studies have proved to be useful in terms of assessing toxicity. As a result, any individual risk assessment is likely to be subject to a high degree of uncertainty. The outcome of this review has pointed towards the need for additional toxicology studies of adequate design and duration on different types of NMs to provide more conclusive evidence regarding their toxicity in food. Existing toxicity methodologies applied to conventional materials may require modification to consider the unique characteristics of NPs. In relation to risk assessment, it is also important to note that toxicity is likely to vary among specific NPs. Thus, a risk assessment must be performed on a case-by-case basis.

There are a number of ongoing EU research projects aimed at addressing all aspects of nanosafety, including toxicology, ecotoxicology, exposure assessment, risk assessment, mechanisms of interaction and standardisation. Examples of ongoing EU projects include the NanoLyse project, which is dedicated to the development of analytical tools for the detection and characterisation of engineered NPs in food, and the NanoReTox project, which seeks to address the human health and environmental implications of exposure to engineered NPs (EU Nanosafety Cluster, 2013).

In summary, the addition of NMs to food offers an entirely new set of risks for consumers. There are existing uncertainties regarding the toxicity, behaviour and properties of NMs, and, thus, potential health risks following exposure to NPs in food and related products. These existing gaps in knowledge present enormous difficulties for risk assessors and risk managers.

Food packaging concerns

Several reviews (Chaudhry and Castle, 2011; Han et al., 2011; Kuzma et al., 2008; Silvestre et al., 2011) have reported uncertainties regarding the potential adverse effects of nanopackaging materials on human health. Discussion in these studies indicates that the main risk of consumer exposure to NPs from food packaging materials is indirectly through the possible migration into foodstuffs, or ingestion of edible coatings. A narrative review by Kuzma et al. (2008) demonstrates a need for consideration of the toxicity of clay NPs and their ability to move out of the film into food under different conditions for risk assessment. Clay in macro form is known to be nontoxic; however, the toxicity of NPs is not well established. NPs of clay are known to be highly reactive due to their much greater surface area, and so concerns have been raised that this reactivity could lead to more toxic forms of clay particles occurring during production or use. Migration studies are currently limited, despite the fact that a number of food packaging materials containing NPs are already commercially available in some countries. The few migration experimental and modelling studies that have been conducted thus far suggest that the likelihood of NP migration from polymer packaging to be either very low or nil, and, therefore, it does not pose any significant risk to the consumer (Chaudhry and Castle, 2011). Nevertheless, discussion in the reviews points towards the need for further research and investigation to provide more conclusive evidence (Chaudhry and Castle, 2011; Han et al., 2011; Kuzma et al., 2008; Silvestre et al., 2011). The risk assessment of NMs after ingestion has been studied for only a few of the NPs used in food packaging. Silvestre et al. (2011) have proposed that there is a lack of understanding on how NMs will act once they enter the human body. Questions like "how and if NPs will be absorbed by different organs?", "how will the body metabolise them?" and "how and in which way will the body eliminate them?" are still subject to uncertainty. There is a particular concern regarding the possible migration of NPs into the brain and into unborn foetuses. This narrative review recommends research be carried out urgently in both of these areas to either confirm or discard the theory of NPs' association with several brain diseases. The health implications of other NPs used in food packaging are under investigation.

To summarise, exposure to NPs from food packaging materials is possible via ingestion of edible coatings or indirectly through migration, and has potential human health implications. The literature assessment points to the need for further migration studies for substantiation.

Regulatory aspects

The success of the advancements of nanotechnology in the agri-food industry will depend on the consideration of regulatory issues. Legislation is essential to manage potential adverse effects, mitigate risks and protect consumers. Various government agencies worldwide are becoming increasingly interested in the use of nanotechnology in the food sector.

Numerous studies have reviewed recent developments in regulations for the application of NMs to food and food-related products (Chaudhry and Castle, 2011; Chaudhry et al., 2008; Cushen et al., 2012; Grobe and Rissanen, 2012; Ileš et al., 2011; Kuan et al., 2013; Momin et al., 2013; Silvestre et al., 2011). Problems arising from nano-food applications are shown in the practically non-existent laws to regulate this use. There are currently no international regulations of nanotechnologies or nano products (Momin et al., 2013). Chaudhry and Castle (2011) have suggested that current regulatory frameworks for food and food packaging materials in different jurisdictions, including the EU, the US and Australia, are extensive enough to encompass nanotechnology applications in the food sector. These include regulations regarding general food safety, food additives, novel foods, specific health claims, chemical safety, food contact materials, water quality and general product safety, as well as other specific regulations on the certain use of chemicals in food production (e.g., fertilisers, pesticides, etc.) In contrast, a more recent narrative review by Momin et al. (2013) indicates that existing laws are inadequate to assess risks posed by nano-foods and nanopackaging due to current uncertainties arising from the difficulty to detect and measure NMs in food, meaning that there is presently limited information available concerning aspects of toxicology and toxicokinetics. In addition, NMs are not assessed as new chemicals, according to many regulations. Current exposure and safety methods are unsuitable for them and many safety assessments use confidential industry studies. Nevertheless, the ongoing EU SmartNano project aims to develop an innovative, cost-effective technology platform that is based on ready-to-use, application-specific cartridges for the detection, identification and measurement of engineered NPs in food matrices. The primary purpose of developing a technology platform for the measurement of engineered NPs is to assess the fate and potential safety risks of engineered NPs in food and food-related products (EU Nanosafety Cluster, 2013).

A further issue relates to a lack of clear, uniform international definitions of NMs and nanotechnologies, which can lead to misinformation and inconsistencies when communicating risks (Cushen et al., 2012; Grobe and Rissanen, 2012; Kuan et al., 2013). There are many existing definitions of nanotechnology, which consider the specific properties of NMs (derived from their nanoscale range, shape and potentially reactive surfaces, etc.) and their nano features. Working definitions for various terms related to nanotechnologies have been developed for the purpose of the FAO, WHO and CODEX meetings; these include NPs, NMs, engineered NMs, nanostructures, nanocomposites, nanotubes and nanorods, amongst others (FAO/WHO, 2010). However, in 2011 the European Commission (EC) recommended a definition of NMs which is intended to be used by member states, EU agencies and companies. The EC defines an NM as "a natural, incidental or manufactured material containing particles, in an unbound state or as an aggregate or as an agglomerate and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1-100 nanometres. In specific cases and where warranted by concerns for the environment, health, safety or competitiveness the number size distribution threshold of 50 % may be replaced by a threshold between 1 and 50%" (European Commission, 2012). Efforts to establish a more comprehensive international definition for NMs are in progress (Cushen et al., 2012).

The EU is the global leader in the development and implementation of laws for nano-food applications (Ileš et al., 2011). Cushen et al. (2012) are a good source for a comprehensive list of current EU regulations and directives relating to NMs. Ileš et al. (2011) reported that the EC has acknowledged which scientific knowledge gaps (i.e., health and the environment) must be addressed in order to provide support for the legal framework. Moreover, the EU regulations for food and food packaging have recommended that there is a requirement for the introduction of new nanotechnology-specific safety standards and testing procedures (Momin et al., 2013). In the immediate future, it is anticipated that a succession of new EU laws will be adopted to enable more effective regulation of the nano-foods market and to protect consumers. Chaudhry and Castle (2011) have also proposed the establishment of a globally harmonised regulatory system to ensure pre-market evaluation of nano-foods and nano products, as well as to set liabilities and specify clear limits for any nano additives in food and food-related applications. International harmonisation of legislation is beneficial to food companies to facilitate in international trade. Effective regulation of nanotechnology in the agri-food sector will also enable products to be launched with trust and confidence, in addition to protecting consumers from potential safety risks. On the other hand, it is also possible that regulation of nanotechnologies and NMs could increase consumer concerns regarding its use in food, raising questions regarding its safety. It is important to appreciate consumer concerns and incorporate public opinions regarding nanotechnology's use in food at an early stage of its development to avoid a repeat of the controversy around GM materials, which have been rejected by the European market.

In summary, existing legislation for NMs are inadequate due to existing uncertainties emerging from the difficulty to detect, measure and characterise NMs in food, which are severely hindering risk assessment and exposure assessment. Nevertheless, regulatory considerations will ultimately dictate the success of nanotechnology in food applications.

4.5 Nanotechnology for a sustainable food system

The globalisation of the food system means that supply and demand is mostly dictated by global market driving forces. Increased food demands are driven by a rapidly growing global population, with the current population of approximately seven billion people projected to reach 9.3 billion by 2050 and 10.1 billion by 2100 (United Nations, Department of Economic and Social Affairs, Population Division, 2011). Global food production will have to increase by 50% by the year 2030 and double by 2050 to meet the anticipated demands (Parry and Hawkesford, 2010). Changing consumption patterns have also placed further pressure on the global food supply system, with an increase in the demand for meat and cereal products worldwide. Total meat production needs are projected to reach 455 million tonnes by 2050, while cereal production is expected to be three billion tonnes by 2050, with the greatest demand coming from developing countries, which now account for 61% of global cereal consumption (Parry and Hawkesford, 2010; Tilman et al., 2011).

International trade in foodstuffs has grown rapidly and changed profoundly in recent decades in response to global population growth and changing diets. This is a key driver of globalisation. The modern consumer-driven food industry is continuously seeking new ways to develop innovative and novel products that will not only offer new tastes and textures, but are also healthful, more nutritious, of improved quality and cost effective, thus facilitating a more sustainable, safe and nutritious food supply.

At present, the worldwide agricultural system is faced with a number of long-term challenges, including climate change, increasing competition for energy, land and water, and urbanisation, and environmental problems such as chemical run-offs (i.e., pesticides and fertilisers). In addition, increased food production needs are arising from global population growth (Chen and Yada, 2012; Godfray et al., 2010). Nanotechnology can play a fundamental role in contributing to a more efficient and sustainable agricultural and food production system, with opportunities to increase farm productivity, alleviate environmental issues and reduce resource costs. These include techniques that will preserve land and water by increasing crop yield while using lower resource inputs, as well as techniques aimed at protecting the quality of the environment. For example, nanotechnology can be applied to the efficient delivery of agri-chemicals (i.e., pesticides, herbicides and fertilisers) by using nanoscale carriers; they have controlled release mechanisms which allow the active ingredient to be taken up slowly, thus improving its effectiveness while reducing the amount applied (Chen and Yada, 2012; Ditta, 2012). Reductions in agri-chemical use will provide additional benefits to public health. Nanotechnology can also be utilised to provide effective solutions to animal production by minimising losses from animal diseases, including zoonoses, as well as improving production efficiency, animal health, feed nutritional efficiency and product quality and value (Chen and Yada, 2012; Ditta, 2012).

Moreover, in developing countries, nanotechnology has the potential to sustain food production in a way that will reduce poverty and improve public health and nutrition, and, hence, increase food security (Chen and Yada, 2012). Improvements to public nutrition could be achieved by increasing the bioavailability of nutrients in typical dietary components or food aid through techniques such as nanoencapsulation to improve the absorption of nutrients in the body. NPs could also be incorporated into food and beverage products, so that nutrients are released upon consumption. This application would be beneficial in products such as orange juice, which have substantially depleted vitamin C levels after the juicing process.

Nanopackaging can also aid the globalised, trade-orientated and supermarket-dominated food system by extending product shelf life, facilitating long-distance transportation, tracking the supply chain and monitoring the quality and safety of the food supply (Lyons et al., 2011). The primary objectives of nanopackaging are to reduce the amount of resources used (e.g., of energy, antibiotics, preservatives and pesticides) and the quantity of packaging materials in the environment, which can subsequently help to alleviate environmental pollution. Extending the shelf life of products can also significantly reduce loss in the supply chain as a result of product spoilage/waste, thereby resulting in possible reductions in food poverty. Nanopackaging also offers other advantages in terms of preserving the taste, colour and flavour of food products, as well as delaying the deterioration of the nutritional value.

In summary, nanotechnology has a potentially important role in sustaining the global food supply system through agricultural techniques that can offer improvements to crop yield and animal production efficiency and the development of novel food and beverage products which target the dietary and health requirements of consumers, while nanopackaging can extend product shelf life, lower resource costs and reduce food wastage.

4.6 Relevance to the Island of Ireland

Agri-food (including fisheries) is the IoI's leading indigenous sector. In RoI, it contributes approximately €24 billion to the economy, accounting for approximately 6.3% of gross value added. It produces almost 10% of all of the RoI's exports, and provides 7.2% of the total employment (Department of Agriculture, Food and Marine, 2011). In recent years, this sector has moved from commodity-based supply to one that is more brand and consumer focused. The main agricultural commodities on the IoI include dairy products, meat (beef, lamb and pork), cereals (barley, wheat and oats) and potatoes. At present, beef and milk account for more than 50% of agricultural production. In 2012, the value of food and beverage exports from RoI reached €9 billion, which was a substantial growth of 27% over the previous three years. Furthermore, the scope of Irish exports is continuously growing, with a remarkable increase in trade to international markets, including North America, Africa and Asia (Department of Agriculture, Food and Marine, 2012). The IoI exports more than 80% of the beef and dairy it produces, and is currently the largest net exporter of beef, dairy and lamb in Europe, and the fourth largest exporter of beef worldwide. The IoI is also the largest net exporter of infant formula in Europe, providing 25% of the global supply (European Parliament, 2013; Food and Drink Industry Ireland, 2013).

As a global producer and exporter, the IoI has the potential to contribute to a more proficient and sustainable global food supply system through implementing sustainable operations. In recent years, the Irish government has invested much research into novel food technologies (NFT), as it is widely recognised that emerging technologies will play an important role in delivering effective solutions to long-term challenges such as global population growth, changing diets/consumption patterns and global warming and climate change. By implementing NFTs, including nanotechnology, the IoI can add and create economic value to Irish exports and improve its international competitiveness.

In agriculture, the primary application for nanotechnology would be in animal production, since meat and milk production contribute a signification fraction of agricultural commodities produced on the IoI. Nanotechnology offers opportunities of minimising production input while maximising output. Feedstock is one of the most significant inputs in animal production, yet most animal feeds are not nutritionally optimal. Nanotechnology may substantially improve the nutrient profiles and efficacy of minor nutrient delivery of feeds, thereby lowering feed demand, reducing waste, alleviating environmental stresses, decreasing the financial burden of the producers and ultimately increasing production yields. The modification of animal feeds could also be effective in improving the quality and value of animal products, for example, by restructuring animal-derived foods (e.g., milk) to improve their nutrient profiles (Chen and Yada, 2012; Ditta, 2012). Nanotechnology can also be applied to minimise losses from animal diseases, including bovine mastitis, tuberculosis, Johne's disease and respiratory disease complex, which do not only cause great economic losses for farmers, but can also pose serious threats to human health. Farmers can benefit greatly from applying nanotechnology for detection and diagnostics, benefiting from its high specificity and sensitivity, and that it is rapid, robust, convenient to use and inexpensive. Other potential animal-based applications include improved animal reproduction and fertility, and conversion of animal by-products and waste into value-added products, thereby alleviating environmental problems (Chen and Yada, 2012). The overall advantages arising from the application of nanotechnology in animal production include increased productivity, a higher value output and improved market performance. As crops contribute a significantly smaller fraction of agricultural production on the IoI, there is not a great need for plant-based applications such as smart field-sensing systems. However, the application of nanotechnology-enabled delivery of agrichemicals could be beneficial in reducing the amount of agricultural chemicals used and minimising input and waste.

Within the food industry, nanotechnology offers vast potential, with prospects of increased production efficiency, product differentiation and new market opportunities. In the dairy industry, nanotechnology could be utilised to protect processing equipment and conserve energy. Nansulate protective coating has already been used in the US dairy industry to coat dairy processing tanks and pipes, safeguarding them against corrosion and providubf thermal insulation to prevent heat loss. The protective coating increases the efficiency of the production process by reducing energy loss and expenses associated with corrosion (Momin et al., 2013; Alfadul and Elneshwy, 2010). Nanotechnology also offers great potential to the actual processing of dairy products. For instance, nanoemulsion technology could be employed to develop ice cream or yoghurts with a lower fat content whilst retaining their flavour and fatty texture. Nanotechnology could also be utilised in infant formula to increase its nutritional composition so that it is more comparable to breast milk, thereby adding economic value to the product and improving its international market competitiveness.

Food companies on the IoI could also apply nanotechnology to develop innovative and novel food and beverage products by improving their organoleptic and nutritional profiles according to consumers' desires and/or health and dietary requirements. A key development would be nanoencapsulants for preservatives, flavourings and nutrients in a wide range of food and beverage products. For example, in meat production, nano-micelle based carrier systems could be employed to encapsulate vitamins and fatty acids, which can be used as preservatives, thereby extending product shelf life. These nanocarriers also offer additional advantages of cheaper ingredients, faster meat processing and higher colour stability (Rashidi et al., 2011; Alfadul and Elneshwy, 2010).

Nanopackaging is another application that has enormous potential for the IoI's agri-food sector in terms of exporting. By improving the barrier properties of food packaging to reduce gas and moisture exchange and UV light exposure, product shelf life can be greatly extended. Manufacturers have opportunities to develop effective, aesthetic packages, which have several advantages, including long-distance shipment, less frequent supplies, significant reductions in food waste, reductions in packaging materials in the environment, a competitive advantage in the international market and economic gains. Nanotechnology also offers opportunities for manufacturers to track the supply chain and monitor the quality and safety of the food supply, thus reducing the risks of foodborne illnesses (Alfadul and Elneshwy, 2010).

In summary, nanotechnology has vast potential in the agri-food sector on the IoI, especially in terms of increasing production efficiency, product differentiation through novel food and beverage products, creating new market opportunities and adding economic value to commodities for exports. The main issues that are likely to emerge are in the small and medium-sized enterprise (SME) sector, as companies at this level are likely to experience difficulties in implementing nanotechnology due to a lack of funds.

4.7 Current gaps in knowledge

While the literature assessment has identified a number of potential applications and benefits of nanotechnology in the global agri-food sector, it has also become evident that there are scientific gaps in knowledge in relation to consumer and environmental safety, which are impeding regulation and market uptake, and , thus, further research is required. The following needs have been identified:

- A clear, uniform definition of NMs and nanotechnologies is lacking. The EC has established a definition of NMs for use by member states, EU agencies and companies. Efforts are currently underway to implement a more comprehensive international definition;
- Validated techniques for the detection and characterisation of NMs in food matrices are required. The ongoing EU NanoLyse project is dedicated to the development of analytical methods for the detection and characterisation of engineered NPs in food (EU Nanosafety Cluster, 2013);
- Additional toxicological studies of sufficient design and duration on different types of NMs are required to establish potential health risks to humans;
- Adsorption, distribution, metabolism and elimination profiles of NMs may differ from larger particles, and more research is required on how ingested NPs behave once they enter the human body;
- More exposure assessment methodologies are needed to assess the long-term health consequences of ingestion of NPs via food, which are at present unknown;
- There is a lack of risk assessment data, and guidance on risk assessment methodologies is unclear and inconsistent;
- Similar to GM, the application of nanotechnology in the agri-food sector raises questions of an ethical nature. If NPs are incorporated into foodstuffs, should these foodstuffs have labelling to indicate what nano has been used and for what purposes?

- There are uncertainties over the adequacy of current global regulations of nanotechnology applications for food and related products. The development and implementation of legislation at the international level is also of great importance to set liabilities and establish clear limits for any nano-foods and nano products.

4.8 Concluding remarks

An overview of the current and potential applications of nanotechnology in food and related products indicates that it offers a range of benefits to the entire agri-food sector, from improved precision-farming practices to food products with enhanced flavour, texture and nutrition, as well as novel packaging which can extend product shelf life and increase the quality and safety of food. Many of these benefits will enhance the range, quality and quantity of food products, enable new international market opportunities to be taken and improve profit margins. It also offers great potential for improvements to food and water safety and nutrition in developing countries. The current level of nanotechnology development in the global food sector is still relatively small, with most products still at the R&D stage, and limited successful applications of nanotechnology to food. At present, there are uncertainties regarding food companies' levels of awareness and attitudes towards the use of nanotechnology for food application. Existing scientific gaps in knowledge in relation to potential health risks and environmental safety are impeding the implementation of effective legislation. These issues must be addressed in order for the technology to be successfully adopted by industry.

5 An online survey to investigate industrial awareness and perceptions of nanotechnology in the agri-food industry on the island of Ireland

5.1 Introduction

The application of nanotechnology in the agri-food industry has the potential to offer a vast range of benefits to both manufacturers and consumers, and , thus, increasing research in this area is attracting investment by governments and industry worldwide (Food Safety Authority of Ireland, 2008). Nevertheless, given the scale of investment required to implement nanotechnology, there are a number of factors that can greatly impede an agri-food organisation's willingness to adopt such technologies, including concerns over existing uncertainties regarding the long-term human health and environmental implications, as well as organisation specific issues, i.e., insufficient resources and a lack of technical expertise to implement the technology effectively.

The agri-food industry is the largest indigenous industry on the IoI, making a significant contribution to the economies in the North and South. It encompasses thousands of agri-food companies, ranging from micro-enterprises and small and medium-sized enterprises (SMEs) to large organisations, with over 90% of these being SMEs. In the South, the food and drink industry exports approximately 85% of its agricultural output in processed form to in excess of 160 countries globally. Dairy is the largest exporting food sector, followed by prepared consumer foods, beverages and beef (http://www.teagasc.ie/agri-food/).

The agri-food sector in the North is one of the most important contributors in terms of revenue and employment and is the largest manufacturing industry. Nearly 66% of food and drink from the North is bought by retailers and food service organisations in other parts of the UK, and increasingly buyers in the leading grocery retailers from further afield are purchasing these products. The IoIs reputation as a source of quality foods is also spreading worldwide.

The governments on the IoI are funding research institutes and initiatives to support agri-food organisations to implement innovative technologies (e.g., nanotechnology) in order to build up wide-ranging expertise and expand on their capabilities. Collaboration between government, academia and industry is seen as fundamental to the development of nanoscience and nanotechnology on the IoI so that agri-food organisations can withstand the increasing demands of the global food supply chain. The Collaborative Centre for Applied Nanotechnology (CCAN) network was established to help Irish-based companies enhance their competitive advantage through nano-enabled product innovation. CCAN acts on behalf of companies to help them access expertise and funding from across the Irish nanotechnology network so that companies can use and develop the technologies and skills required to drive product innovation in a number of areas, and not only agri-food (http://www.ccan.ie/). Organisations working with nanoscience from academia and industry have also come together to form NanoNet Ireland to further enable the development of nanoscience and nanotechnology in Ireland. The network aims to encourage and facilitate all the stakeholders involved in nanoscience to achieve growth in nanotechnology-related markets, and , thus, deliver significant economic benefits for the IoI (http://www.nanonetireland.ie/).

In December 2013, a qualitative investigation of the industry's awareness and perceptions of nanotechnology in the agri-food industry on the IoI using face-to-face and telephone interviews. Personnel (n = 12) from primary production, food processing, food packaging and regulatory bodies from both the North and the South participated in the study. The conclusions from the qualitative investigation indicate that the current awareness of nanotechnology applications in the agri-food sector is low amongst industry personnel on the IoI. Furthermore, knowledge of the practical examples of agricultural and food-related applications was limited. Nonetheless, opportunities were identified in precision-farming techniques, innovative packaging, functional ingredients and nutrition of foods, processing equipment and safety testing. Cheesestrings and Denny deli ham were the only products identified which use nanotechnology currently. Industry personnel that were interviewed had a low awareness of nanotechnology currently being applied within their organisation, but it has had some applications in the ingredients sector on the IoI. However, it was suggested that nanotechnology could have been used unknowingly, due to a lack of awareness and understanding amongst industry personnel of what applications this technology could be used for. This work highlighted that perceived risks are major obstacles to nanotechnology implementation amongst agri-food organisations, including consumer acceptance, negative media perceptions, and human health and environmental impacts, amongst others. As a result, those industry personnel interviewed identified a range of needs prior to the implementation of nanotechnology within their organisation. Such requirements included a clear, transparent and comprehensive regulatory framework for the use of nanotechnology in food and food-related products with a risk assessment framework incorporated into the legislation. Further research into the long-term health effects was also identified as a key factor before its implementation, in tandem with better communication between scientists, government bodies and the agri-food industry. For SMEs, funding by external bodies was a further requirement identified.

The aim of this study was to exploit the information obtained from this qualitative research study and, as a result of a dedicated dissemination workshop held in January 2014, to design a quantitative survey to examine on a broader scale the agri-food industry's awareness and perceptions of nanotechnology for food and food-related applications on the IoI. The quantitative study would be used to determine if the findings from the qualitative research study, when applied on a wider scale, were generic across the sectors and across the IoI.

5.2 Research objectives

The research objectives were specifically to:

- Determine industry's awareness and understanding of nanotechnology and its applications;
- Identify the primary sources of information that industry personnel access for information on nanotechnology;
- Examine industry's awareness and perceptions of nanotechnology in relation to food and food-related applications and the issues surrounding the use if nanotechnology;
- Investigate the differences in awareness and perceptions of food nanotechnology and the factors underpinning these, including sectoral differences, industry scale, scope and nature of the manufacturing/production;
- Explore the information and knowledge deficits that underpin industry concerns regarding nanotechnology;
- Ascertain industry's attitudes and confidence regarding the regulators of science and technology and the providers of information;
- Establish the agri-food industry's attitudes towards communication strategies for applying new technologies to the consumer.

5.3 Methods

Enhancement of the stakeholder database

Agri-food industry contacts for this component of the research were collated in the same way as for the qualitative phase of the study. The existing Institute for Global Food Security (IGFS) stakeholder database for the IoI stakeholders was expanded further following a search of numerous internet sites, including An Bord Bia (the Irish Food Board), the Northern Ireland Food and Drink Association (NIFDA), Invest Northern Ireland Food Directory, Food and Drink Export Ireland (IEA), the Food Standards Agency (FSA), the Food Safety Authority of Ireland (FSAI), the Top 1000 Food and Beverage Companies Site, the Yellow Pages, the Golden Pages, Ireland's Mushroom Community Online, Euro-Toques Ireland, Irish Biz, Naturally North Coast, the Organic Trust Ltd and Food NI.

Respondent selection

Agri-food organisations (n=1035) that were directly targeted by e-mail for the study comprised of large organisations, SMEs and micro enterprises, of which 43.7% were in NI and 56.3% in RoI. These organisations are involved in agriculture/primary production, manufacturing/processing/packaging, wholesale and distribution, retail/marketing, and/or regulatory/monitoring across the various agri-food sectors, including animal feed and grains, pesticides, beef and/or lamb, pork, poultry, dairy, bakeries, fruit and vegetables, beverages, confectionary, food ingredients, food additives, fish, eggs and nutraceuticals.

Questionnaire design

The questionnaire design was informed by a systematic literature review conducted to ascertain the industrial ramifications of nanotechnology in the agri-food industry and based on similar questions used for the qualitative survey, in addition to building on its findings. Therefore, demographical questions (specific to the respondent and their organisation) were asked to evaluate differences in sector, industry scale and scope and business nature. A series of questions were asked to ascertain levels of awareness and perceptions of nanotechnology and its applications in general followed by more probing ones in relation to agriculture and the food industry. In addition, the perceived risks and benefits of nanotechnology in relation to food were also explored. Finally, a series of questions were asked to determine the current use of nanotechnology amongst agri-food organisations, opportunities for nanotechnology implementation and obstacles to the adoption of nanotechnologies.

The questionnaire was piloted to identify potential problems relating to the understanding of terminology and possible ambiguities. The final questionnaire (Appendix 4) was 10-15 minutes in length and was administered electronically (via Kwik Surveys) to agri-food industry contacts on the IoI from the enhanced IGFS stakeholder database, as well as through ***safe*food** Knowledge Networks, NIFDA and the Northern Ireland Grain Trade Association (NIGTA) via an e-mail link. The survey was also circulated to agri-food organisations worldwide through social media (i.e., Twitter, Facebook and LinkedIn). The survey link was distributed in February and March 2014 via these means several times to maximise response rates, with the incentive of winning an iPad added. A screenshot cover of the online version of the survey is provided in Appendix 5.

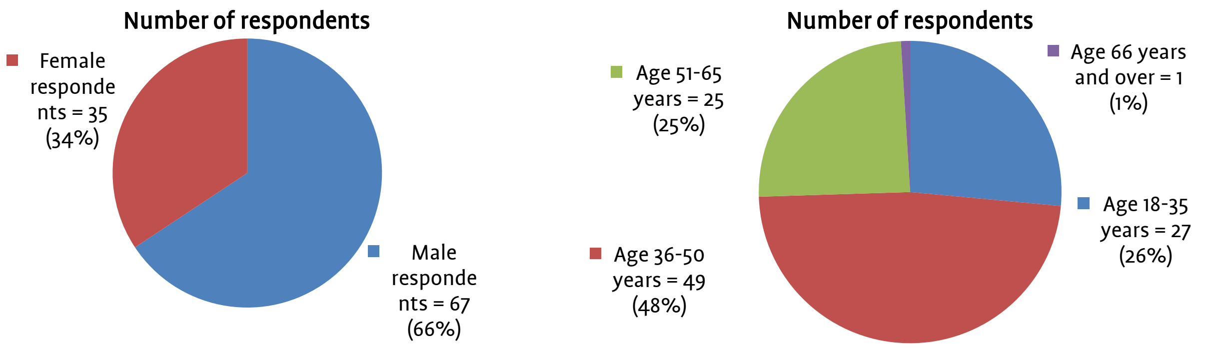
Analysis of quantitative data

A total of 142 respondents completed details for the online survey; however 40 responses were eliminated due to insufficient data. Therefore, the final response rate was n=102, of which 90 respondents provided a fully completed survey and 12 respondents provided almost complete surveys worthy of inclusion at this stage. In comparison to the targeted database, a useful response of 9.8% was achieved. Quantitative data from the online surveys was managed and analysed using the IBM Statistical Package for Social Sciences (SPSS) Base 21 (SPSS Inc., Armonk, New York, USA). The data entries were checked for errors or missing data. The distribution frequencies as the number and percentage of a given response per question were determined in addition to the central tendency of the data, as determined by the mean.

5.4 Results

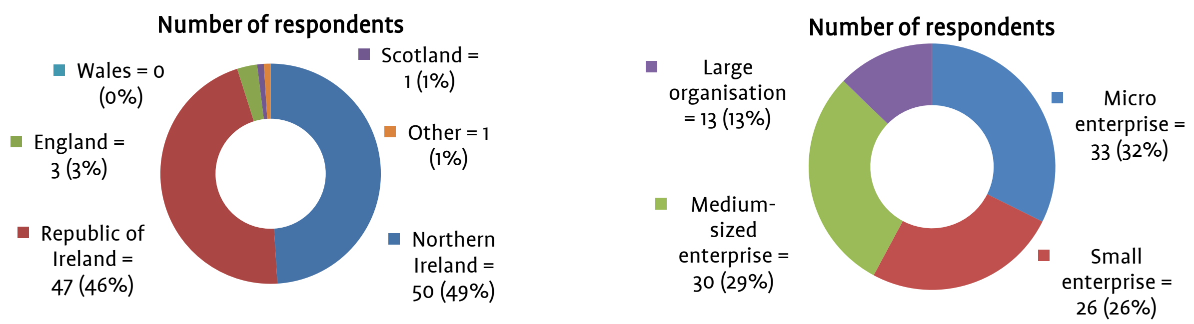
The descriptive statistics for the sample and the different segments of the survey are presented in Appendices C to H. In relation to the demographics, respondents were mostly male (65.7%) and aged between 36-50 years (48%) (Figure 5.1).

Figure 5.1: Gender and age demographics



Most of the respondents were from an agri-food organisation located in NI (49%) or RoI (46.1%) with more than half of the cohort from an SME (54.9%), while only 13% of respondents were from a large organisation (Figure 5.2).

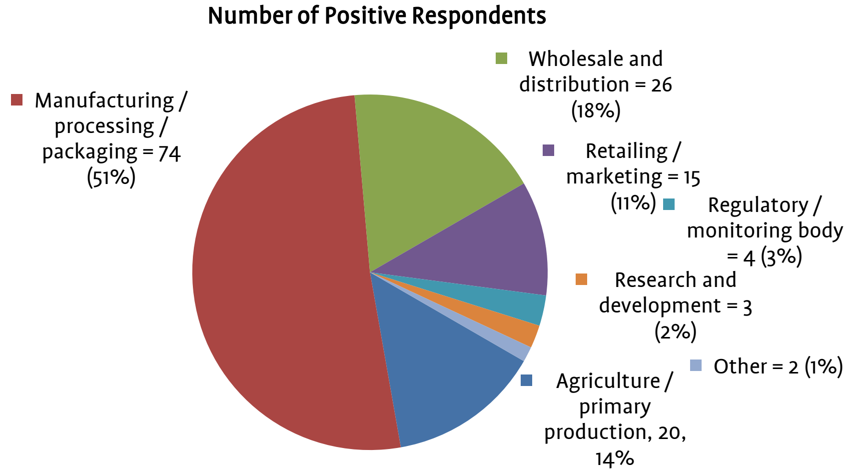
Figure 5.2: Location and size of responding organisations

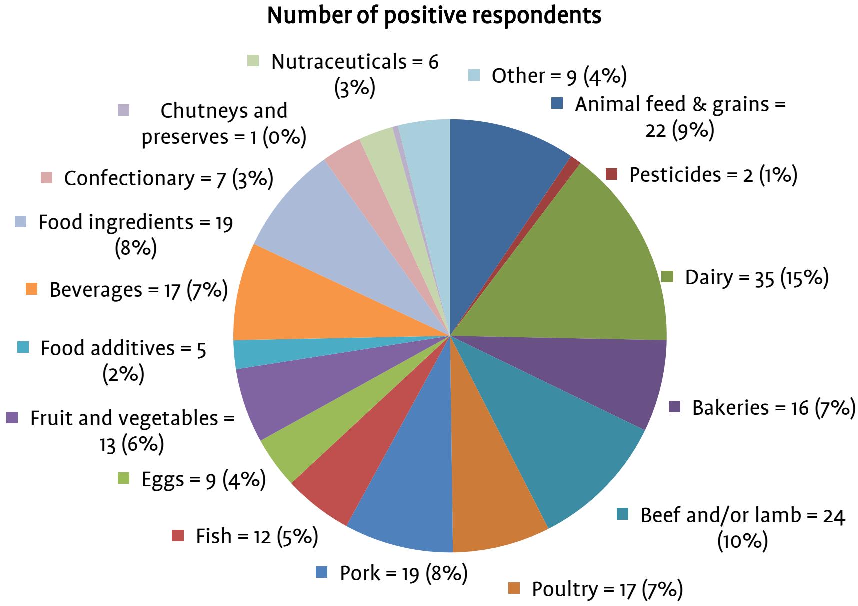


In terms of business size, the following definitions apply: Micro enterprise (<10 employees), Small enterprise (11-50 employees), Medium-sized enterprise (51-250 employees), and Large organisation (>500 employees).

Furthermore, more than two-thirds of respondents were from organisations that were established less than 35 years ago (68.6%). A vast majority of agri-food organisations were involved in manufacturing/processing/packaging (72.5%). However, many of the respondents surveyed were from organisations that are multi-sectored. More than a third were involved in dairy (34.3%), and about a quarter were in the beef and/or lamb sector (23.5%). However, from the responses obtained, all agri-food sectors as listed were covered in the survey (Figure 5.3).

Figure 5.3: Agri-food sector participation in the survey





There were wide variations in the respondents' company positions, with approximately a third operating as managing director (32.4%). Table 5.1 shows the main sources accessed for information on new technologies (including nanotechnology) by the organisations surveyed. The internet was the predominant source of information (78.4%), followed by scientific organisations/research institutes (40.2%). Other common sources included government agencies or regulators (37.3%), scientific publications (36.3%) and scientists presenting at conferences (34.4%). Only 5.9% of the cohort used books for information on new technologies.

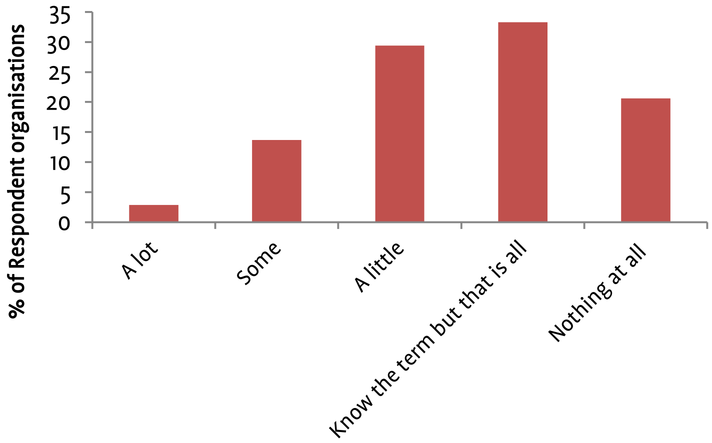
Table 5.1: Sources of information respondents use to get information on new technologies (including nanotechnology)

Source of information	Number of positive respondents	% of positive respondents
Mass media	17	16.7
Searching the internet	80	78.4
Government agencies or regulators	38	37.3
Scientific publications	37	36.3
Books	6	5.9
Scientists presenting information at conferences/training workshops	35	34.3
Scientific organisations/research institutions	41	40.2
Patents	5	4.9
Industry contact suppliers	2	2
Trade publications	-	-
Investment bodies	1	1
Unsure	4	3.9

Awareness and attitudes towards nanotechnology and its applications

Approximately 80% of respondents surveyed indicated that they had previously heard of nanotechnology. Knowledge of nanotechnology ranged from respondents knowing the term only (33%) to others knowing a lot about nanotechnology (2.9%) (Figure 5.4).

Figure 5.4: Respondent organisations' level of nanotechnology knowledge



Respondents indicated that they were mainly familiar with the term "nanotechnology" in the context of atoms and molecules (19.6%), physical/chemical/biological processes (19.6%), very small science or technology (15.6%) or micro or small science or technology (17.6%). Awareness of industrial applications of nanotechnology was primarily confined to packaging (24.5%) and food and beverage products (23.5%). Some of the other known applications were in computing (13.7%), paint (12.7%), electronics (10.8%), agriculture (9.8%) and medicine (7.8%). Applications to sunscreens/cosmetics and sporting goods were less known, at 1%.

Table 5.2 illustrates the respondent organisations' attitudes towards nanotechnology; mean attitude scores for nanotechnology in general indicate that the majority of respondents had neutral attitudes towards nanotechnology (3.1 ± 0.7), this represented about three-quarters of the cohort (75.5%). Positive attitudes comprised 16.7% of the sample and 7.9% of respondents had a negative attitude towards nanotechnology.

Table 5.2: Mean scores for the respondent organisation's attitudes towards nanotechnology in general and towards its food and food-related applications

Application field	Attitudes	Scale range	Mean ± SD
General	General nanotechnology	1-5	3.1 ± 0.7
Agriculture	Animal disease diagnostics	1-5	3.4 ± 0.8
Agriculture	Animal feeding efficiency	1-5	3.2 ± 1.0
Agriculture	Genetic engineering of crops	1-5	2.8 ± 0.9
Agriculture	Agrichemicals	1-5	3.0 ± 0.9
Agriculture	Smart sensors	1-5	3.4 ± 0.8
Food	Nutrition of food	1-5	3.1 ± 1.0
Food	Food ingredients	1-5	3.0 ± 1.1
Food	Nutrient delivery	1-5	3.1 ± 1.0
Food	Processing equipment	1-5	3.4 ± 0.9
Food	Food packaging	1-5	3.4 ± 1.0
Food	Food safety	1-5	3.6 ± 0.9

A five-point Likert scale is used to assess attitudes towards nanotechnology in general, and in relation to agricultural and food application (1= 'very negative' to 5= 'very positive').

More than half of the cohort was not aware of any agricultural applications of nanotechnology (57.8%); the use of nanocapsules to improve the feeding efficiency and nutrition of animals was the most widely application known (18.6%). Table 2 displays the mean attitude scores for agricultural applications of nanotechnology; respondents were mostly neutral towards most applications but on average expressed a marginal sway towards negative in the use of nanotechnology for targeted genetic engineering of crops, with a mean of 2.8.

The descriptive statistics for the respondents' awareness and perceptions of nanotechnology (Appendix 7; Q15) indicates that the respondents had a slightly higher level of awareness of food industry applications of nanotechnology; the use of nanoparticles in food packaging to extend product shelf life was the most widely known application (30.4%), while the least known application was in processing equipment (15.7%). Respondents were also neutral towards food and food-related applications of nanotechnology (Table 2), such as food packaging and processing equipment but with a slightly positive sway to applications using nanosensors for food safety monitoring and traceability with a mean of 3.6. The overall awareness of current food or beverage products on the market that have been produced using nanotechnology or nanomaterials was extremely low (8.9%) amongst the respondents, but some of the known products included yoghurts (3.9%), slimming products (3.9%), mayonnaise (3.9%), sports drinks (2.9%), spreads (2.9%) and milk (2.9%).

Factors influencing the application of nanotechnology

The descriptive statistics for the respondents' views on the risks and benefits of nanotechnology in relation to agri-food applications are included in Appendix 8. Figure 5.5 illustrates the respondent organisations' description of the relative risks and benefits of nanotechnology in relation to agri-food; 15.7% of respondents were of the opinion that the benefits of nanotechnology would outweigh the risks, while 13.7% believed the risks to be greater than the benefits. However the highest response was for "Not sure at all", at 55%.

In relation to the rank order profiling of the benefits of nanotechnology for the agri-food industry, the production of safer food was viewed as the most important number one important benefit arising from the application of nanotechnology in the agri-food industry (36.3%), followed by more efficient precision-farming techniques (22.5%). Increased product shelf life ranked highly as a number 2 priority, followed by reduced waste at 3, healthier products as 4, lower costs for the industry, then cheaper food and improved distribution and sales, with more traceability on products having the highest incidence of response at the lowest level of importance, at 9.

Figure 5.5: Respondent organisations' description of the relative risks and benefits of nanotechnology in relation to agriculture and food

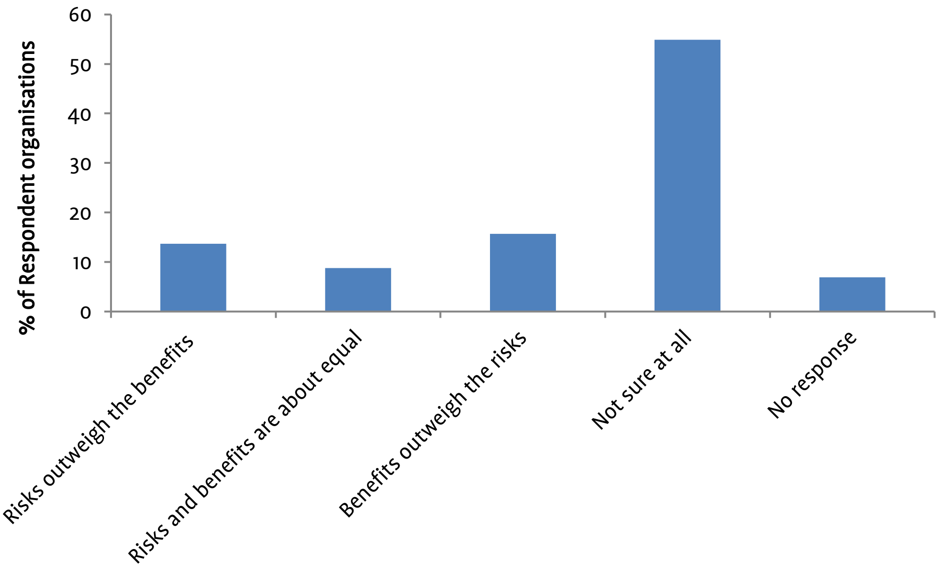


Table 5.3: Mean scores for the main risk Issues and need for risk reduction associated with the use of nanotechnology for agri-food products

Issues associated with food nanotechnology	Scale range	Mean
Inadequate regulation of nanotechnology	1-5	3.2 ± 0.7
Information and knowledge deficits	1-5	3.8 ± 0.9
Public acceptance	1-5	3.7 ± 0.8
Media perceptions	1-5	3.5 ± 0.8
Long term health effects	1-5	3.7 ± 0.8
Risks to health and safety of workers	1-5	3.4 ± 0.7
Environmental impacts	1-5	3.6 ± 0.8

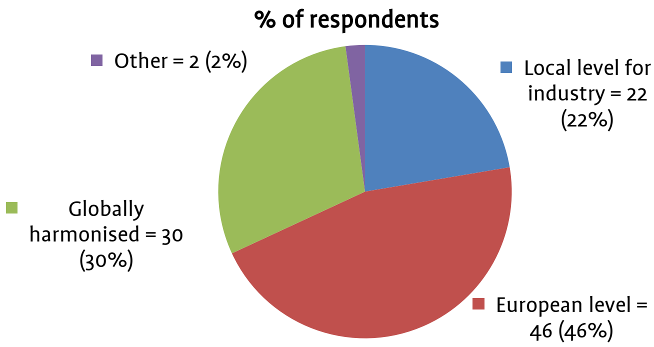
Needs for risk reduction of nanotechnology	Scale range	Mean ± S.D.
Transparent and open research activities	1-5	4.2 ± 0.8
Government funding for more research on nanotechnology related risks	1-5	3.9 ± 0.8
Ongoing communication between stakeholders	1-5	4.0 ± 0.7
International research collaborations and networks	1-5	4.0 ± 0.8
Adequate guidance on risk assessment	1-5	4.2 ± 0.7
Implementation of regulation for nanotechnology related risk issues	1-5	4.2 ± 0.7
Development of a globally harmonised risk approach	1-5	4.0 ±0.8

A five-point Likert scale is used to assess the respondent organisation views on what should be done for risk reduction (1= 'strongly disagree' to 5= 'strongly agree').

However, a quarter of the respondents indicated that improved distribution and sales is the least important benefit of nanotechnology. Mean scores (Table 5.3) for the main issues regarding the use of nanotechnology for food and food-related products indicate that the information and knowledge deficits relating to nanotechnology is the primary concern, followed by fears over public acceptance of nanotechnology, and uncertainties regarding the long-term human health consequences. Other issues include the potential environmental impacts of nanotechnology and media perceptions. Respondents were also provided with a list of possible solutions for risk reduction. Mean scores (Table 5.3) indicate an agreement for the need for transparent and open-research activities, international research collaborations and networks, adequate guidance on risk assessment and the implementation of regulations for nanotechnology-related risk issues.

When respondents were asked about how nanotechnology should be regulated for the agri-food sector, nearly half of the respondents were in favour of regulation at the European level (Figure 5.6), while 30% were of the view that legislation should be globally harmonised, and 22% of respondents thought that regulation at the local level for industry would suffice.

Figure 5.6: Indication of views of how nanotechnology should be regulated



Current application of nanotechnology amongst agri-food organisations

The current application of nanotechnology amongst agri-food organisations surveyed is tabulated in Appendix 9. For the respondents, the existing level of use of nanotechnology is extremely low, with 80.4% of respondents indicating that nanotechnology is not used within their organisation at the present time. Nanotechnology, however, has had some application in animal production (3.9%), food processing (2.9%), processing equipment (2.9%), food packaging (2%) and food safety monitoring (2.9%).

Respondents were then asked if their organisation plans to use nanotechnology or nanomaterials at any future stage in the agri-food supply chain. 8.9% of respondents stated that their organisation is currently researching nanotechnology or has future research development plans in place. The use of nanotechnology in plant processing equipment was the only potential use provided (1%); exploring research opportunities was another response (1%). Finally, respondents were asked if they would label products which have been developed using nanotechnology. 15.7% of the sample indicated that they would always label nano-products, while 14.7% stated that it would be dependent on the process/use, and 19.6% of respondents specified that they would do so only if they were legally obliged to.

Opportunities for nanotechnology implementation

For the ranking of items in terms of their importance to their organisation, product innovation (i.e., products that offer 'healthier' alternative or target specific needs) was identified as the most important objective when considering investing in new technologies (45.1%); this was followed by reduced costs/resource use (31.4%). Over a quarter of respondents viewed the development of environmentally friendly products/services as the least important objective to their organisation (27.5%)(Appendix 10; Q27). Food safety monitoring (36.3%), food packaging (34.3%) and food processing (30.4%) were shown to be the most promising areas of nanotechnology application amongst agri-food organisations. Potential nanotechnology application in crop production was shown to be lower (14.7%), which is reflective of the number of the sample involved in primary production.

Table 5.4: Mean scores for the respondent organisations for the level of importance for requirements needed prior to nanotechnology implementation

Needs for nanotechnology implementation	Scale range	Mean
More information and enhanced knowledge	1-5	4.3 ± 1.0
Training from nanotechnology experts	1-5	4.0 ± 1.0
Nanotechnology regulation for food and related products	1-5	4.2 ± 1.0
Adequate safety assessment	1-5	4.2 ± 1.0
More research into human health risks	1-5	4.5 ± 0.9
Collaboration among scientists, industry and government	1-5	4.1 ± 1.0
More resources	1-5	3.9 ± 0.9
Public engagement	1-5	4.2 ± 0.9
Consumer perceptions of nanotechnologies	1-5	4.1 ± 1.0

A five-point Likert scale is used to assess the respondent organisation level of importance for the list provided prior to nanotechnology implementation (1= 'very unimportant' to 5= 'very important').

Table 5.4 provides the mean scores for respondent organisations' views on what is needed prior to nanotechnology implementation. Further research into the long-term health effects to human health associated with the consumption of nano-foods was the most important requirement, followed by more information and enhanced knowledge on nanotechnology, the implementation of regulations on nanotechnology for food and related products, and adequate safety assessment on a case-by-case basis where nanotechnology alters existing products.

Obstacles to the adoption of nanotechnologies amongst agri-food organisations

About a third of the cohort project an increase in the application of nanotechnology in the agri-food sector in the future (29.4%), while only 2% of the sample do not expect to see an increase (Appendix 11).

Table 5.5: Mean scores for the respondent organisations' level of agreement for the main obstacles to nanotechnology implementation

Obstacles to nanotechnology implementation	Scale range	Mean
Cost of nanotechnology implementation	1-5	3.9 ± 0.9
Lack of information and knowledge	1-5	4.3 ± 0.9
Availability of expertise	1-5	4.1 ± 0.8
Time and long term value of nanotechnology.	1-5	3.9 ± 0.8
Need for risks assessment framework.	1-5	4.2 ± 0.8
Public acceptance	1-5	4.3 ± 0.8
Media perceptions	1-5	4.1 ± 0.9
Unknown risks to human health and the environment	1-5	4.3 ± 0.9

A five-point Likert scale is used to assess the respondent views on what they consider to be the main obstacles to the implementation of nanotechnology at their organisation (1= 'strongly disagree' to 5= 'strongly agree').

Table 5.5 provides the mean scores for respondent organisations' views on the main obstacles to nanotechnology implementation. Unknown risks to human health and the environment were accepted as the main impediment for the agri-food organisations surveyed, followed by the public's acceptance of nanotechnology, and a lack of information and knowledge on nanotechnology.

Respondents were asked about how much trust their organisation places on the information received on nanotechnology from various bodies, using a scale of zero to ten.

Table 5.6: Respondent organisation level of trust placed on the information received about nanotechnology from the following bodies. A 0-10 scale is used, where 0 is "do not trust at all" and 10 is "trust completely".

	1	2	3	4	5	6	7	8	9	10	No response
Government agencies or regulators	4	3	5	5	12	14	11	**20**	7	9	12
	3.9	2.9	4.9	4.9	11.8	13.7	10.8	**19.6**	6.9	8.8	11.8
Agri-food industry associations	1	8	5	12	14	12	9	**15**	7	6	13
	1	7.8	4.9	11.8	13.7	11.8	8.8	**14.7**	6.9	5.9	12.7
Scientists	1	1	5	5	7	12	17	**21**	10	10	13
	1	1	4.9	4.9	6.9	11.8	16.7	**20.6**	9.8	9.8	12.7
Mass media	15	19	20	14	11	5	1	-	2	-	15
	14.7	18.6	19.6	13.7	10.8	4.9	1		2		14.7
Non-government organisations	4	5	9	13	25	14	7	6	3	2	14
	3.9	4.9	8.8	12.7	24.5	13.7	6.9	5.9	2.9	2	13.7
Scientific institutes and organisations, e.g., universities	1	1	2	4	6	11	15	**26**	15	7	14
	1	1	2	3.9	5.9	10.8	14.7	**25.5**	14.7	6.9	13.7

Table 5.6 demonstrates that the respondent organisations placed the highest level of trust on information provided by scientific institutes and organisations (i.e., universities), as well as scientists, and government agencies or regulators, with the highest proportion of respondents giving these sources a score of eight. About a third of the cohort indicated a score of between four and six for the level of trust placed on agri-food industry associations (37.3%), while more than half of respondents gave a rating of between four and six for non-government organisations (50.9%). The lowest level of trust was placed on the mass media, with more than two-thirds of the sample indicating a score between one and four (66.7%). Table 5.7 illustrates the mean scores for respondents' views on how improvements could be

made to their organisation's knowledge base. Better communication and information from scientific organisations was indicated to be of greatest importance to enhancing understanding of nanotechnology, followed by information from government bodies. Respondents also specified the importance of seminars/training workshops, as well as training from nanotechnology experts.

Table 5.7: Mean scores of the respondent level of importance for approaches in improvements to their organisation's knowledge base (1= 'very unimportant' to 5= 'very important').

Improvements to knowledge base	Scale range	Mean ± S.D.
Seminars/ training workshops	1-5	4.0 ± 0.8
Training from nanotechnology experts	1-5	4.0 ± 0.9
Better communication and information from government bodies	1-5	4.1 ± 0.8
Better communication and information from scientific organisations	1-5	4.2 ± 0.8
Networking with universities	1-5	4.0 ± 0.9
Better communication throughout the company	1-5	3.7 ± 1.0
More technical experts in the company	1-5	3.5 ± 1.0

5.5 Discussion

Overall, respondent organisations demonstrated a high awareness of the term "nanotechnology", which is probably due to it already being commercialised in a wide range of areas (Doyle, 2006). However, the respondents' level of knowledge regarding nanotechnology was limited, particularly in the context of agriculture and food applications. This is most likely due to the fact that the use of nanoscience and nanotechnology is still an emerging area of research and development in the agri-food industry (Kalpana Sastry et al., 2013).

As anticipated from the qualitative research, the awareness of agricultural applications of nanotechnology was relatively low amongst the agri-food organisations surveyed, which is in line with the scientific literature, which suggests that many of the agricultural applications are still at the research and development phase (Chen and Yada, 2011; Ditta, 2012). From the qualitative findings, it was also expected that the respondents would have a slightly higher level of awareness of food industry applications since food/beverage products and food packaging are already commercialised worldwide, even though the number of products is still relatively low (Momin et al., 2013; Rashidi and Khosravi-Darani, 2011). In line with the qualitative findings, the respondents indicated a greater awareness of the application of nanotechnology in food packaging, which is one of the most active areas of nanotechnology in the food sector, with forecasts that nanopackaging will account for more than 25% of food packaging within the next ten years (Lyons et al., 2011). Attitudes towards this application were also particularly positive due to the abilities to extend product shelf life and reduce waste, which were seen as one of the most important benefits of nanotechnology application to the agri-food industry.

Overall, respondents were able to indicate an awareness of dairy products, slimming products, mayonnaise and sports drinks as products on the current market that have applied nanotechnology, though the level of awareness was low; this was consistent with the qualitative findings and the scientific literature. For example, Unilever has produced an ice cream with reductions in fat gained from 8-16% to 1% while not compromising on the flavour (Alfadul, & Elneshwy, 2010) and RBC Life Sciences® Inc has developed a slimming product based on cocoa nanoclusters, which offers consumers an effective weight loss solution while appealing to their taste preferences.

Respondents' attitudes towards nanotechnology in general, and in relation to agriculture and food applications, were on average more neutral, with sways in negativity towards the use of nanotechnology for targeting engineering of crops, which is probably due to negative associations with genetic modification (GM). In relation to food applications, respondents were slightly more positive towards the use of nanotechnology in food safety and food packaging, which coincides with their views on the most important benefits being the production of safer food. This is line with the qualitative findings, which also indicated safer food as a primary benefit. Conversely, respondents expressed more negative responses towards the application of nanotechnology in food ingredients and in improving the nutritional properties of food compared to other applications, which may be due to the potential human health implications associated with the consumption of nano-foods/nano products (Magnuson et al., 2011).

As expected, the current application of nanotechnology is very low amongst agri-food organisations on the IOI, which is reflective of the limited understanding of nanotechnology. However, most organisations indicated a potential for nanotechnology to be incorporated into one or more areas of their business (i.e., in crop production, animal production, food processing, processing equipment, food packaging or food safety). Nevertheless, in line with the qualitative findings, there are a number of impediments to nanotechnology implementation within the agri-food organisations. The requirement for more information and knowledge was considered to be one of the primary concerns for many organisations. Respondent organisations specified the importance of training from nanotechnology experts, the availability of seminars/training workshops and better communication and collaboration from government bodies and scientists in order to encourage the uptake of nanotechnologies amongst agri-food organisations. The perceived risks of nanotechnologies in relation to uncertainties regarding potential human health effects and environmental impacts, media perceptions of nanotechnology and fears over public acceptance of nanotechnology were also major obstacles for many organisations. In line with Frewer et al. (2011), and outcomes from the qualitative research, some respondents indicated that knowledge deficits amongst consumers might lead to the outright rejection of nanotechnologies through negative comparisons to genetic modification. Therefore, the importance of public engagement was expressed to firstly identify consumer needs and wants, and secondly to inform and educate consumers about the different potential nanotechnology applications to establish consumer perceptions, which would, in turn, help organisations to determine which applications to prioritise. Furthermore, the respondents specified the need for more research into the long-term human health effects associated with the consumption of nano-foods. The identification and control of potential risks associated with the use of nanotechnology for different food and food-related applications was also seen as highly important through effective communication and collaboration among government bodies, scientists and industry. Respondents also specified that risks could be controlled by conducting adequate safety assessments on a case-by-case basis, where nanotechnology alters existing products or processes. In addition, the development and implementation of regulations on nanotechnology for food and food-related products, with an adequate risk assessment framework, was seen as an important means of controlling and monitoring potential risks associated with the use of nanotechnology. This is in line with Momin et al. (2013), who indicated that current laws worldwide are inadequate for assessing the risks posed by nano-foods and nanopackaging. The respondents, however, had differing views as to how nanotechnology should be regulated; most were in favour of regulation at the European level, while others suggested that global harmonisation is the best form of regulation due to the food supply chain being globalised, and the remaining respondents viewed regulation at the local industry level as the most reasonable option. Moreover, the implementation of a comprehensive regulatory framework may also be an effective means of increasing consumer trust and acceptance of nanotechnology provided that the information given is clear, easy to understand and unbiased, so that consumers can make informed choices about the products that they are consuming.

Finally, many organisations specified that the costs and time associated with implementing nanotechnology on a commercial scale, as well as its long-term value, were major obstacles. Respondents specified a need for additional resources, i.e., financial investment by external bodies, as well as the availability of more expertise and collaboration with scientific organisations/research institutes to prove the effectiveness and safety of nanotechnology to facilitate its use in their business.

5.6 Conclusion

While, the current awareness of nanotechnology amongst the agri-food sector is relatively limited, it has shown promising application in a wide range of areas, and, therefore, has the ability to successfully address the challenges associated with a globalised food supply system. However, this research has highlighted the necessity of more effective communication and collaboration amongst all stakeholders (i.e., scientists, government bodies and industry) in order to enhance awareness and understanding of nanotechnology so that it can be implemented effectively and safety. Furthermore, it is imperative that there is public engagement and that consumers are informed and educated about nanotechnology at the initial stages in order to increase their acceptance of the technology.

6 A review of the literature concerning consumer perceptions and the factors that influence acceptance of nanotechnology

6.1 Introduction

National and regional governments have invested significantly in nanotechnology research. However, the future development and successful commercialisation of novel nanotechologies will be determined by consumer acceptance (Fischer et al., 2013; Currall et al., 2006; Macoubrie, 2006). The increased application of nanotechnology in manufactured goods and, indeed, the food system (Duran and Marcato, 2013; Frewer et al., 2011, Siegrist et al., 2007a), the rising number of nano-food products on the market (Bieberstein et al., 2012; Stampfli et al., 2010), and the increasing public exposure to relevant information indicate that it is timely to review the state of play regarding consumers' current awareness, knowledge and concerns regarding nanotechnology, and to obtain an understanding of the factors influencing their likely acceptance of nanotechnology in the food system.

The influence of public attitudes and perceptions has been shown to influence (both positively and negatively) the direction and pace of scientific activity in a number of fields, e.g., genetically modified organisms, biotechnology and functional foods (Stampfli et al., 2010; Siegrist et al., 2008; Siegrist, 2010). Thus, there is an ongoing need for social scientists to provide insights into how the public perceives risks and benefits (House of Lords, 2010).

This part of the review will focus on consumer perceptions and the factors that influence their acceptance of nanotechnology. This knowledge will support the development of effective research and governance strategies (Fischer et al., 2012), as well as risk management strategies.

6.2 Approach

There is limited information available on nanotechnology, less on nanotechnology in the context of food (Fell et al., 2009) and even less on nanotechnology in the context of food in Ireland. However, the Department of Agriculture, Food and the Marine funded a project, involving a collaboration between Teagasc, University College Cork and Dublin Institute of Technology, to examine consumer and industry acceptance of novel-food technologies (DAFM Reference Number: 08RDTAFRC659). Nanotechnology was one of the technologies examined. Thus, this review on consumer perspectives on nanotechnology will largely draw on outputs from this project, supplemented by Eurobarometer reports, Food Standards Authority reports and references to the academic literature on consumer acceptance/attitude formation and public engagement. It will be concerned with nano-food, which is defined as food or food packaging produced using nanotechnology techniques (Greehy et al., 2013). It is not concerned with nanobiotechnology. No primary data collection will be undertaken for this consumer study.

While this report is concerned with the IoI, a lack of available data on an all-island basis means that separate findings are reported for RoI and NI, as available. Where specific NI data are not available, UK data will be presented if available. Some comparison will be made with the situation internationally where data exist and it is appropriate to do so.

Acceptance of technologies can be evaluated from a consumer (with the individual concerned with individual preferences) and a citizen (with the individual concerned with wider societal implications) perspective. This has implications for assessing the acceptance of nano-foods. For example, citizens may be willing to accept the technology if it results in particular benefits, for example, in terms of the environment, but may not be willing to purchase and consume it themselves due to a lack of perceived personal benefits. For simplicity's sake, this report will refer to consumers to address both citizen and consumer perspectives unless such a distinction is deemed critical to any recommendations that may result for ***safe*food**.

6.3 Consumer perceptions and attitudes

Consumer awareness/knowledge of nanotechnology

Awareness of nanotechnology is low (Gaskell et al., 2010; Kahn et al., 2007) but increasing slowly over time. Eurobarometer (European Commission, 2010a) reports that the average EU awareness of nanotechnology is at 33%. Figures for the UK were higher than average, at 48%, while the ROI figures were average at 33%. This is higher than survey findings by Henchion et al. (2013) indicating that 22% of ROI respondents had heard of nanotechnology. Awareness in the specific context of food is even lower; only 7% of ROI consumers were aware of the potential application of nanotechnology in food or in food packaging (ibid.).

Awareness of nano-foods needs to be understood in the context of consumers' awareness and knowledge about food production and processing, which is generally low. A British study (Food Standards Agency, 2010) found that self-assessed knowledge of how the food industry manufactures and prepares food varies; 9% felt they had a good knowledge, 38% believed they had a reasonable basic knowledge, 31% reported their knowledge as very patchy, while 21% felt they knew little or nothing. Hallman (2000) believes that the majority of consumers are probably unaware of the actual number of novel food technologies currently used in food production and processing. According to UK research (Leatherhead, 2012), a relatively high proportion of consumers are not aware of science and technology in food. It concluded that consumers may be apathetic about the level of science and technology in food. Scheufele and Lewenstein (2005) use the term "cognitive misers" to describe consumers who, while possibly acknowledging their limited knowledge, do not actively seek information. An absence of active information seeking seems to be the case particularly where consumers place high levels of trust in the regulatory system (Greehy et al., 2013).

Research from the US indicates that demographic factors influence levels of awareness of nanotechnology. These factors include gender (males more aware than females), income (people with higher income levels are more aware than those with lower income levels), education (college graduates are more aware) and ethnicity (African-Americans less aware) (Hart Research Associates, 2009).

While there are indications of an overlap in the awareness of new technologies (research in the US found that those with high levels of awareness of nanotechnology had high levels of awareness of other technologies (Hart Research Associates, 2009)), research at the EU level has found a higher level of "don't knows" for more questions relating to nanotechnology than other questions (European Commission, 2010a).

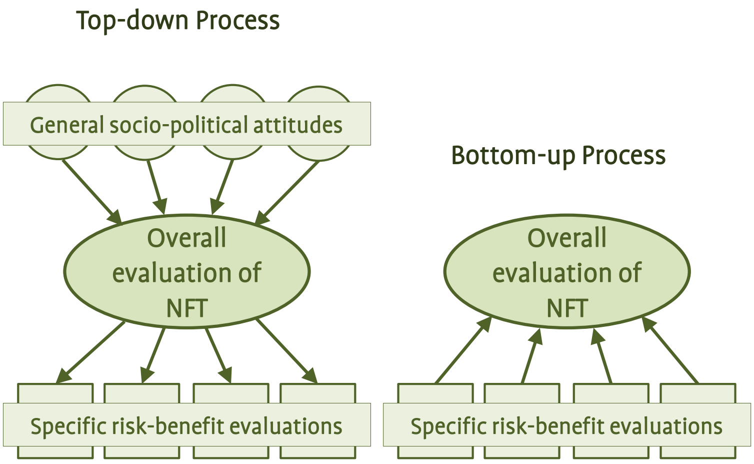
Low levels of awareness correspond to low levels of knowledge. Public knowledge of nanotechnology (and other novel and emerging technologies) is very limited (Cobb and Macoubrie, 2004; Yawson and Kuzma, 2010; Fischer et al., 2012). However, a level of knowledge has been found to be unrelated to support for nano-food (Vandermoere et al., 2010).

Furthermore, awareness seems to be related to interest in obtaining more information. While consumers in the ROI report that they are interested in obtaining more information about the application of nanotechnology to food, those who were unaware of the technology were less likely to be interested in obtaining more information than those who were aware (60% vs 74%) (Henchion et al., 2013).

Low levels of awareness and knowledge mean there are high levels of uncertainty, making it difficult for consumers to decide on the possible risks associated with foods produced with these novel technologies. Thus, many consumers have unformed or unstable attitudes. Fischer et al. (2013) state that while there are a large group of individuals who are slower in forming opinions, the debate on nanotechnology will hinge on how and when they crystallise their opinions.

Knowledge levels influence how attitudes are formed and the nature of responses. Attitude formation theory suggests that low levels of knowledge mean “top-down” attitude formation processes tend to dominate, i.e., a stronger influence of a system of general attitudes and values (e.g., general socio-political attitudes) as opposed to product attribute based “bottom-up” (e.g., about potential risks and benefits) (Figure 6.1). Reliance on top-down appraisals generally results in more emotive/affective-based responses. Grunert et al. (2003) assert that in the case of novel food technologies, where bottom-up knowledge is limited (as is the case of nanotechnology), top-down processes are more influential in shaping public attitudes. In the case of GM, authors such as Gaskell (2006) assert that a perceived lack of knowledge causes the majority to give an emotional or affective response rather than a reasoned position. Low levels of knowledge also mean that consumers tend to use heuristics (rules of thumb) to process new information and to evaluate a new technology (Bieberstein et al., 2012).

Figure 6.1: Top-down and bottom-up attitude structures towards a novel food technology



Source: Søndergaard et al. (2005), based on Scholderer et al. (2000)

Consumer concerns regarding nanotechnology

Consumer attitudes towards novel food technologies, such as nanotechnology, are sometimes explained by the evaluative criteria applied, which Cardello et al. (2007) describe as involving perceived rather than actual risks. (This highlights the different approach to risk undertaken by scientists as opposed to consumers.)

Despite low levels of awareness of nanotechnology, there are indications that some consumers are concerned about nanoparticles being found in food (Eurobarometer, 2010a). This concern, however, has to be put into the context of other concerns consumers have.

In the context of other potential risks that are likely to affect them personally, EU consumers view the economic crisis (20% of respondents) and environmental pollution (18%) as risks very likely to affect their lives compared to food-related problems (11%) (European Commission, 2010b). This pattern is also true for the ROI and the UK. (However, there is increased awareness of the potential of food to damage health (there was a 3 percentage point increase in the level of concern regarding food possibly damaging one's health between 2005 and 2010)). Furthermore, in the specific context of food-related risks, consumers are less concerned with the ability to deal with possible problems with new technologies than many other risks (e.g., pesticides, food additives, allergies or BSE (European Commission, 2010b)).

Specific concerns consumers have about nanotechnology have been identified in the US, New Zealand and the EU. In the US, concerns relate to its potential impact on employment, social freedom, personal control and potential long-term unintended effects (Hart Research Associates, 2009). In New Zealand, concerns relating to compliance with regulations, animal welfare, the equitable distribution of benefits and perceived unnaturalness have been identified (Cook and Fairweather, 2006). The provision of biased information and conflicting public information about new technologies was also of concern in New Zealand. Concerns relating to food safety and a perceived lack of benefits have also been identified in the EU (European Commission, 2010b). Uncertainty and a fear of future unknown consequences as a result of a lack of knowledge amongst scientists present a difficulty for consumers. Sentiment analysis of Twitter by Veltri (2013) found that negative sentiments associated with nanotechnology mainly related to uncertainty and a fear of the unknown rather than open hostility

Amongst individual consumers, research has found a relationship between engagement/familiarity and unease about the technology (e.g., Bieberstein, et al., 2012). The nature of the relationship was found to depend on the technology in EU research. It is an inverse relationship for nanotechnology, i.e., higher familiarity and engagement lead to lower levels of unease. The effect, however, is not the same for GM and cloning – higher familiarity and engagement does not lead to lower levels of unease (European Commission, 2010a). Nonetheless, consumers overall associate more risks with novel food technologies than with traditional food technologies (Siegrist, 2008).

6.4 Other factors influencing acceptance

Greehy et al. (2013) present a review of studies which indicate that consumer acceptance of novel food technologies is influenced by factors such as awareness of the technology; individuals' risk and benefit perceptions; heuristics, particularly trust and perceived control; general attitudes and values; the specific technology, application and product in question; and individuals' socio-demographic characteristics.

These factors can influence attitude formations through top-down or bottom-up processes. As previously outlined, the low level of awareness of nanotechnology means that the top-down processes are likely to be more influential.

Individuals' benefit and risk perceptions

Beliefs about risks and benefits are important determinants of attitudes, i.e., perceived risks are expected to influence attitudes negatively and perceived benefits to influence attitudes positively (Bredahl, 2001). Information about the risk and benefits of a technology play an important role in the initial attitudes consumers form about technologies in particular (Cobb and Macoubrie, 2004, cited in Fischer et al., 2012).

In their study of the public risk-benefit perceptions of nanotechnology, Ho and colleagues (2013: 610) illustrate the "complex process[es] of how people form benefits and risks judgements about emerging technology". Other research suggests that consumers do not consider risks and benefits independently; rather, they perform trade-offs in making decisions (Fischer et al., 2012). However, much of the current debate about the future of nanotechnology focuses on the types and magnitudes of risk (Currall et al., 2006). As the risk of a technology is only one aspect of the "complex calculas" consumers engage in (Currall et al., 2006), it could be argued that greater attention needs to be paid to benefits, particularly as Stampfli et al. (2010) have found that the perceived benefits are more important than the perceived risks for acceptance of nano-foods. Leatherhead (2012) goes further and argues that consumers need to be able to "see, feel and believe the benefits".

A further complication in trading off perceived risks and benefits in the case of nanotechnology is that many of the risks are unknown, with consumers concerned about potential unknown future consequences. Greehy et al. (2013) highlighted consumers' fear of unknown consequences in the case of nanotechnology.

Consumers' views of the risks (benefits) influence their views on the potential benefits (risks), i.e., if consumers believe the benefits are low, they are more concerned about the risks than if the benefits are perceived to be high (Currall, et al., 2006). Furthermore, consumers who perceive a higher number of benefits perceived fewer risks and vice versa (Siegrist et al., 2008). This interdependence between risk and benefits is known as the halo effect. A lack of familiarity with the object will amplify the halo effect (Vandermoere et al., 2011).

While consumers can trade off benefits and risks, they may also trade off these against other issues, e.g., benefit distribution (Frewer et al., 2011). Benefits that accrue to manufacturers, for example, are not received as favourably as benefits that accrue to consumers. This has been found in the case of GM but also is indicated for nanotechnology (Greehy et al., 2013).

As there are still many unknown risks associated with nanotechnology, the influence of the perception of known risks to judge unknown risks is important (Visschers et al., 2007). Furthermore, Scholderer (2009) argues that general perceived uncertainty, rather than specific risk perceptions, can lead to technology resistance.

Heuristics, including trust and perceived control

In the context of high levels of uncertainty, consumers tend to rely on trust to ease decision-making complexity. Stampfli et al. (2010) report that in the case of limited knowledge, as is the case for nano-foods, perceived risks and perceived benefits are influenced by social trust. They report that the more consumers trust in science (including its institutions and scientists), consumerism, the food industry and retail, the higher they perceive the benefits and the lower the risks. Siegrist et al. (2008) found that trust was a significant predictor of perceived risks and benefits associated with nano-outside applications. It should be noted, however, that experts tend to place a higher level of trust in governmental agencies to protect consumers' health from nanotechnology risks that consumers themselves do (Siegrist et al., 2007b) Trust can directly influence public perception of risk and benefits and indirectly influence consumer acceptance of nanotechnology. Leatherhead (2012) also highlights that trust in new science and ultimately the food industry is essential to the future widespread adoption of nano-foods. They identify the important role of effective communication of all the relevant facts in underpinning this trust and supporting informed consumer decision-making.

Regulators have been found to be important in Irish research; positive evaluations are based on the assumption that the novel-food technology will be adequately regulated (Greehy et al., 2013). The answer to who should be responsible for the governance of such technologies, however, can vary from technology to technology. If an issue is perceived as a scientific one, consumers want governance by experts only, based on evidence relating to risks and benefits. However, if they see it as a scientific and other (e.g., ethical) issue, they want governance principles to be influenced by moral concerns, with the public having a central role (European Commission, 2010a). This has implications for acceptable forms of governance (commission of risk assessment, consensus conference, ethics committees, public deliberation) (European Commission, 2010a). The wide range of applications for nanotechnology in food (and food packaging), however, potentially complicates regulation (Frewer et al., 2011).

It is argued that labelling provides consumers with more control, as they can choose, or not, to consume the particular product if they are provided with such information. Under new EU food information regulations, from 2014, any ingredients contained in food or drink in the form of engineered nanomaterials must be indicated as such on the packaging (European Parliament and Council, 2011). The influence of labelling on consumer risk perception in the context of nanotechnology has been studied by Siegrist and Keller (2011). These authors found that labelling may change public perception of these products. In particular, they highlight that if such labelling is mandatory, it may result in higher perceived risks and lower perceived benefits. They suggest that consumers may infer that a precautionary measure is a signal that risks are associated with that product. This may be because consumers rely on the default heuristic, i.e., when a product is labelled as "produced using nanotechnology", it is interpreted as a warning as the non-labelled (the default) is inferred to be the recommended option. They conclude that providing information on the label alone that the product contains synthetic nano-particles may not provide sufficient information to result in informed decision-making as it would represent an over-simplification of the process and associated issues.

General attitudes and values

Given the low levels of knowledge, general attitudes are the most important driver of acceptance; consumers seem to rely on pre-existing knowledge and values to form judgements about technologies. In the case of novel food technologies, various authors have identified such general attitudes and values to include attitudes towards nature and natural content, attitudes to science and technology, cultural values/world outlooks, attitudes towards health and nutrition, and attitudes towards food, e.g., food neophobia. De Jonge et al. (2007) and Bredahl (2001) also include risk sensitivity, as they found that individuals who worry more in general are more concerned about the safety of their food, indicating that general risk sensitivity impacts on acceptability of specific food-related risks.

A wide range of studies (e.g., Bieberstein et al., 2012; Vandermoere et al., 2011; Kahan et al., 2009) found that consumers' views on science, technology and nature influence their perceptions of nanoscience. Lee et al. (2005) postulate that public affective responses to nanotechnology are somewhat impacted by individuals' prior experiences with, and perceptions of, previous scientific controversies. Scientific socialisation generally means consumers are more accepting of technologies. However, this is not universally the case (European Commission, 2010a). Cobb and Macoubrie (2004) found that those with a positive view of science were likely to have a positive reaction to nanotechnology. According to Irish research (Greehy et al., 2013), those reacting positively to novel food technologies, including nanotechnology, often portray themselves as "techno-enthusiasts", while those acting negatively tend to view nature as fragile and value the protection of nature.

Stampfli et al. (2010), in a survey in Switzerland, found that attitudes towards gene technology were a strong predictor of acceptance of nanotechnology; the more positively they were disposed towards gene technology, the more positive they were towards nanotechnology as they perceived more associated benefits and less associated risks. These authors also found that consumers who had a preference for natural and healthy food associated more risks and fewer benefits with nanotechnology food products compared to consumers who did not have such preferences.

Greehy et al. (2013) found that consumers can often have conflicting beliefs that result in "conundrums" for them. For example, consumers who value natural processes and tradition may simultaneously be keen to support scientific progress and development. This results in positive and negative forces simultaneously influencing nanotechnology acceptance within individuals, which, in turn, can lead to ambivalent attitudes as opposed to simply positive or negative attitudes.

The specific technology, application and product in question

Consumer acceptance of technologies is influenced by the technology, its application (Henchion et al., 2013; Bieberstein et al., 2012) and the product. Frewer et al. (2011) found that consumers perceive different characteristics to be associated with different technologies; one reason for this may be differences in the level of public debate about different technologies. Assessment of a new food technology also depends on the concepts and images that are associated with to the technology (Siegrist, 2008). Consumer often make comparisons between the risks and benefits associated with other technologies in seeking to “make sense” of the technology (Greehy et al., 2013). Irish research has found that Irish consumers associate “tiny robots” and computers with nanotechnology. Frewer et al. (2011), while reporting previous research that suggests that consumers will apply existing attitudes towards GM to foods produced using nanotechnology, believe that this contention is not yet supported.

EU consumers tend to be more optimistic than pessimistic about the role of nanotechnology when asked about nanotechnology in terms of products close to everyday life (cosmetics, sun creams and household cleaning fluids) (European Commission, 2010a). They are, however, more reluctant to accept nanotechnology when products are closer to the human body (Siegrist et al., 2007) and perceive higher risks to be associated with applications in the food and health domains compared to other applications (Frewer et al., 2011; Siegrist and Keller, 2011; Yawson and Kuzma, 2010; Cook and Fairweather, 2006). Even within food, applications that affect the product packaging (nano-outside) are generally more accepted that applications that affect the actual food product (nano-inside) (Henchion et al., 2013; Stampfli et al., 2010; Fell et al., 2009). This is because people buy products not the technologies that go into them, i.e., consumers acceptance of new foods is strongly influenced by perceived benefits of the food product as compared to the processing technology (Frewer et al., 2003, cited in Yawson and Kuzma, 2010). It may also be due to differences in perceived personal control (Stampfli et al., 2010). Bieberstein et al. (2012) in a study of German and French consumers found that application-specific reactions differ between countries and suggest that this may depend on prior beliefs and familiarity. They further link this to country-specific traditions and on differing views on the role of the state in ensuring consumer protection.

Several studies in the food domain have highlighted the influence of taste and healthfulness as predictors of food product acceptance (McCarthy and McCarthy, 2007). Enhancing the sensory qualities of food produced using novel and emerging food technologies has been found to increase consumer acceptance and its success on the market (Siegrist, 2008).

Price is a key element used in trade-off negotiations between risks and benefits (Greehy et al., 2013). In the context of GM, it has been found that lower price enhances acceptance (Spence and Townsend, 2006, cited in Yawson and Kuzma, 2010). Price premiums may be acceptable for a nano-food conferring health benefits that are apparent, for example (Greehy et al., 2013).

Attitude change

High levels of scientific uncertainty affect the stability of attitudes (Greehy et al., 2013). Attitude change/information processing theory argues that the attitudes that consumers currently hold towards nano-food can be assumed to change over time, partly because of the increased availability of nano-foods, which results in increased experience, and partly as a result of increased knowledge about the technology, which reduces uncertainty. Communication theory suggests that the impact of information from various sources on consumer attitudes and acceptance is likely to be heavily influenced both by factors relating to the information itself (contents, style, etc.) and by factors relating to the sender of the information (e.g., industry, consumer organisation, or government).

Siegrist and Keller (2011) report that new information about nanotechnology shapes public perceptions and, therefore, public acceptance. The provision of additional information may affect attitudes in one or two ways: it may influence the direction of the attitude, i.e., positive or negative, or it may influence the certainty of the attitude, i.e., become more or less certain about their attitude (Fischer et al., 2012).

The kinds of information consumers want mainly relates to information about the risks and benefits of the technology, but they also want to know about issues such as distribution, funding sources, etc. In the case of nanotechnology, health is the most sought after additional information; environmental or social information is less sought after (Bieberstein et al., 2012). The type of information required may differ according to levels of acceptance; opponents are mainly concerned about safety (European Commission, 2010).

According to European research, there is a strong relationship between confidence in information sources, the evaluation of national and EU food safety agencies and the perception of possible food-related risks (Eurobarometer, 2010). The preferred source of information varies based on socio-demographic characteristics. UK research has found older consumers were more likely to cite daily newspapers and younger consumers are more likely to cite social media as a source of information on new technology and science. Similarity in world outlook and values between the information source and the recipients has also been found to be important, with those with similar world outlook/values being viewed as more credible (Rollin et al., 2011).

High levels of uncertainty means the influence of the media will be higher. Therefore, given the high levels of uncertainty associated with nanotechnology, the development of attitudes towards nanotechnology will potentially be based on media reporting (Fischer, 2012). As more information becomes available in mass media about how nanotechnology can be applied in food production, views and attitudes will form and crystallise which will subsequently influence consumer acceptance (Dudo et al., 2011).

The relationship between information and attitudes is not simple. It is mediated by pre-existing knowledge, values and associations, which may lead to a biased assimilation of new information. Evidence suggests negative information carries more weight (Druckman and Bolsen, 2011). Furthermore, as positive information can have a greater effect on those who already have a positive attitude, and those with pre-existing negative attitudes are less likely to assimilate positive information, views on novel-food technologies in general can become polarised

Accoding to research by Veltri (2013) on the extent of conversation about nanotechnology on Twitter, there has been very little conversation on the topic to date. However the research also found that positively loaded words were predominant. The importance role of opinion leaders in such an environment has been identified by Fischer et al. (2013).

Individuals' socio-demographic characteristics

While Lee et al., (2005) found that females perceive nanotechnology to be riskier than males, Henchion et al. (2013) found that age, gender, social class, income or education did not have a significant impact on acceptance of nano-foods. Furthermore, Siegrist et al. (2007b) found that gender does not influence perceived risk when perceived benefit, trust and general attitudes towards technology were controlled for.

The European Commission (2010a) found that consumers with a science degree tend to more supportive of nanotechnology and GM than those without. However, simultaneously they reported that a large number of those with a science degree who do not support the development of GM foods. The reason for this is not clear; it may be that consumers believe that better alternatives are available on the market or it may just be that they have a negative view of GM. This suggests that consumers do not consider nanotechnology in the same way as they consider GM (European Commission, 2010a)

7 Project discussion and key findings

The key findings from the project are based on industry perspectives and consumer perspectives and, most importantly, how these two populations can have improved interactions to have greater awareness of and get assurance on emerging technologies in the future.

7.1 Industry perspective

Nanotechnology has the potential to develop and transform the entire agri-food industry by helping to sustain the global food supply chain and contributing to improved food and nutritional security.

The industry's present level of awareness of nanotechnology for food and food-related applications on the IoI is low, which is probably due to the fact that it is a relatively new concept for the agri-food industry. However, a wide range of agricultural and food-related applications and opportunities were identified by industry personnel, including nanotechnology's use in precision-farming techniques, active or smart packaging, functional ingredients and nutrition of food products, processing equipment, and for the detection of contaminants in food. Awareness of foods/beverages that have been produced using nanotechnology that are currently available on the global market is limited: Cheesestrings and Denny deli ham were the only two products known, and were identified by one participant only.

The application of nanotechnology amongst agri-food companies on the IoI is low, with indications of some use in the food ingredients sector by multinational companies. However, the limited awareness and understanding of nanotechnology amongst industry personnel suggest that this technology might have been employed unknowingly.

The perceived risks of nanotechnologies, such as consumer acceptance, negative perceptions and unknown side effects to human health and the environment, are impediments to the implementation of nanotechnology for agri-food companies. Further research into the long-term health effects associated with the consumption of nanotechnology food products is considered to be important by industry personnel. Other needs include the development of a risk assessment framework to monitor and control potential risks, and more effective communication and collaboration between scientific organisations, government bodies and the agri-food industry. For SMEs, funding by external bodies, such as Invest NI, is also needed in order to buy the equipment to implement the technology

7.2 Consumer perspectives

"Factors affecting consumer acceptance of agri-food nanotechnology are dynamic, complex, interactive and interdependent, and consumer decisions to accept agri-food nanotechnology were found to be the results of complex feedback structure" (Yawson and Kuzma, 2010).

Attitudes to nanotechnology are still undecided and in a flux (European Commission, 2010a). Public organisations, such as ***safe*****food**, NGOs and industry, will have a significant influence on consumer reactions to nanotechnology (Siegrist et al., 2008). Institutional activity has been highlighted by Fischer et al. (2013) as "the standard for ethically sound practice", resulting in increased institutional activity focused on openness and transparency about science and its applications. Openness and transparency is critically important when uncertainty persists about potential associated risks (Greehy et al., 2013). This highlights a potential role for ***safe*****food**.

Consumers' perception of risk associated with nanotechnology will be strongly influenced by how government agencies regulate nanotechnology (Siegrist et al., 2007b). Bieberstein et al. (2012) suggest that it may be hard for regulators to act at a European level given the differences in prior beliefs and familiarity. This highlights the special importance of national agencies, such as ***safe*****food**, for communication and consumer information at the early stages of nanotechnology adoption. European research (European Commission, 2010a) has found that national regulation within the framework of European laws seems to be accepted by the public. However, as consumers become more familiar with the technology, a more unified European approach may be more efficient (Bieberstein et al., 2012).

A recent study suggests that some companies may not be adequately addressing possible risks associated with nanotechnology. Measures to increase trust in the food industry, such as voluntary initiatives, will be important if the aim is promote consumer acceptance of nano-foods (ibid.; Siegrist et al., 2007b). The influence of trust on perceived risks highlights the imperative to avoid events with significant negative consequences as their impact on trust could be severely detrimental to acceptance of nanotechnology (Seigrist et al., 2007b).

It should be noted that much of the current debate about the future of nanotechnology focuses on risks, and the types and magnitude of risks (Currall et al., 2006). Siegrist and Keller (2011) suggest that providing information to consumers on technologies, about which they have a low level of knowledge/familiarity, may evoke a negative effect, resulting in higher risk perceptions and lower benefit perceptions. Thus, it seems that the balance is weighted against acceptance of nanotechnology. While it is important to assess risks, and national governments, for example, need to consider short-, intermediate and long-term risk priorities. according to Currall et al. (2006), the debate should also perhaps address the significant benefits the technology can bring to individuals, industry and society. This highlights the potentially important role for ***safe*****food** in contributing to the development of debate and publishing research findings. It is, however, important that biased information and conflicting public information are addressed to support informed decision making by consumers. Furthermore, as consumers display rational and emotional responses to information and concepts, it will be important for ***safe*****food** to remain neutral and contribute to balanced debate.

While research has shown that consumers have low levels of awareness and knowledge, and some research has been conducted on consumer concerns and attitudes, very little is known about their actual behaviour. There is some evidence that attitude-behaviour inconsistencies may exist between individuals' perceptions of how they would act/react and how they actually act/react within a specific situation (Smith and Hogg, 2008). This may extend to consumers' willingness to purchase nano-foods in real-life purchase situations.

While there is a relationship between the acceptance of nanotechnology and other technologies, not all technologies are viewed in the same way by consumers (Frewer et al., 2011). Thus, it is useful to consider nanotechnology in isolation from other novel technologies. This review highlights the common evaluative criteria that can be used by the public when evaluating novel food technologies. However, the emphasis of the criteria used can vary across technologies and, consequently, both general and technology -pecific research is warranted. This logic can be further applied to different applications of nanotechnology based on research findings, so it is also likely to be useful to distinguish between nano-inside and nano-outside.

8 Project conclusion

Despite the presence of nano-foods on the market, the future development of nano-foods, and the extent to which the technology might reach its potential in the food sector, particularly on the IoI, is still uncertain. This is largely due to a number of "unknowns". The unknowns relate to both the industry and to the consumer. It is still very much unknown what the true potential for nanotechnology will be as many applications are still at R&D phases or patent phases. For the industry, there is the uncertainty of legislation as it may become too restrictive to allow the best use of the technology, but there is also the potential cost-benefit analysis that will need to be performed in a valid manner to demonstrate efficacy for each product and sector on an individual basis. There are also the unknowns in relation to safety and to consumer uptake, which need to be considered as a risk in the cost-benefit analysis.

From the consumer perspective, there are mainly two "unknowns". The first relates to uncertainty that persists from a scientific perspective regarding potential risks. The second arises from the uncertainty that exists regarding likely consumer acceptance. How consumers will react to applications of this technology is still difficult to accurately predict due to low levels of consumer awareness about nano-foods, and resulting high levels of uncertainty and largely unformed attitudes regarding the technology. These issues indicate that there is an important role to be played by organisations such as ***safe*****food**, both individually and in collaboration with other actors, such as universities/research institutions, industry, NGOs, etc., in influencing consumer reactions.

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10 Appendices

Appendix 1: Expression of interest

Call for expressions of interest in the use of nanotechnology in the agri-food industry on the island of Ireland: applications, opportunities and challenges

Nanotechnology is an emerging technology based on the knowledge of what happens at the "nano" scale of 100nm, one billionth of a metre, atomic or molecular level. It involves the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with novel or dissimilar properties.

Some examples of key areas where nanotechnology is being explored within the agri-food industry are:

- Agriculture (New pesticides; targeted genetic engineering of crops, agrochemical delivery)
- Processing (Nanoencapsulation; gelation and viscosifying agents; nanoemulsions; sanitisation of equipment)
- Novel Products (UV protection; antimicrobials; new textures and tastes)
- Intelligent packaging (high barrier plastics; food contact materials)
- Nutrition (Nutraceuticals; nutrient delivery; fortification of vitamins and minerals)
- Safety (Sensory diagnostics; security/anti-counterfeiting devices)

The Institute for Global Food Security at Queen' University, Belfast, in collaboration with Teagasc Food Research Centre, Dublin, is undertaking a ***safe*****food**-sponsored investigation to evaluate the applications, opportunities and challenges presented by nanotechnology across the agri-food sector on the IoI.

This five-month study will be performed through one to one interviews and discussion with the agri-food industry on a confidential basis to gather information on the applications currently in use, to discuss future opportunities and applications and to address challenges that might be prohibitive to allowing the technology to be implemented.

One of the benefits to industry is that the general findings from the study will be presented at a workshop to be held in Dublin in November 2013 for open forum discussion to help promote opportunities and resolve issues of concern.

Expressions of interest in this study are invited from companies and organisations across the entire IOI agri-food sector. Interested organisations should submit their expression of interest to take part in an interview by completing the details below and e-mail to: Dr Katrina Campbell at Queen's University (katrina.campbell@qub.ac.uk)

The deadline for expressions of interest to be submitted is 15th September 2013:

Name of organisation:

Address of organisation:

Main Business:

Point of contact:

Contact telephone:

Contact e-mail:

Appendix 2: Interview protocol for industry's awareness and perceptions of nanotechnology for food and related products.

I want to thank you for taking the time to meet with me today.

*My name is [**Interviewer**] and I am from the Institute for Global Food Security.*

I would like to take some time to find out what you think about nanotechnology in general and the link to food.

The interview should take less than 30 minutes. I will be taping the session because I don't want to miss any of your comments, so please speak up for the recording.

All responses will be kept confidential. This means that your interview responses will only be shared with the research team members and we will ensure that any information we include in our report does not identify you as the respondent. If the question is not clear, please do not hesitate to ask for further clarification.

Do you have any questions regarding what I have just explained?

Thank you

Part I: Demographics

Q1. Gender (Male/Female)

Q2. What is your name?

Q3. Approximately, what age are you?

- a) 18-25
- b) 26-35
- c) 36-45
- d) 46-55
- e) 56-65
- f) 65+

Q4. What is your position within the company?

Q5. Which area of the food industry is your company involved in?

Q6. Approximately, how old is the company?

Q7. Where do you seek information regarding new technologies (including nanotechnology)? (Probes- research institutions, reps, etc.)

Part II: Awareness and understanding of nanotechnology and its applications

Q8. How much have you heard about nanotechnology (Showcard A)?

- a) A lot
- b) Some
- c) A little
- d) Know the term but that is all
- e) Nothing at all

Q9. Where did you hear about nanotechnology? (Trying to find sources such as internet, TV, shows, TV, news programmes, magazines, newspaper, friends, family, professionals, radio, journals, conferences or meetings)

Q10. Based on what you have heard, what is nanotechnology?

DEFINITION: "Nanotechnology is the manipulation of self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. It modifies production processes and can allow for advances in some industries, and, products."

Q11. Are you aware of any industries researching or using nanotechnologies? (Probes)

Q12. How/why is nanotechnology used within these industries? (Probes)

- Nanotechnology has already been used in various industries, including construction, modern textiles, electronics, cosmetics, medicine, wastewater treatment, textiles, sports, and more recently in agriculture and the food industry.
- For example, in cosmetics, and specifically sunscreens, nanoparticles have been added to increase UV protection.
- In sporting goods, for example, baseball bats, nanotechnology has been used to reinforce the resin in them to make them lighter and so improve performance.
- In textiles, engineered nanofibres are used to make clothes water and stain repellent, or wrinkle free.

Q13. I'm particularly interested in the use of nanotechnology in agriculture and the food industry, and for the remainder of this interview that's what I want to focus on. Are you aware of how nanotechnology can be used in agriculture? (Probe: crop production, animals)

Q14. How can nanotechnology be used in the food industry? (Probe: cultivation, production, processing or packaging of the food.)

Q15. Are you aware of any food or beverage products currently on the market that have been produced using nanotechnology? (Probe)

Part III. Risks/benefits of nanotechnology in relation to food

Q16. As an industry how would you convey the use of nanotechnology to your customer/consumer?

Q17a. Based on what you know, how would you describe the relative risks and benefits of nanotechnology in relation to agriculture and food (Showcard B)?

a) Risks outweigh the benefits
b) Risks and benefits are about equal
c) Benefits outweigh the risks
d) Not sure at all

Q17b. Can you explain your choice?

Q18. What are the benefits for the agriculture and food industry? (Probe: for consumers and industry)

Q19. What are the risks for the agriculture and food industry? (Probe: human health, environment)

Q20. What can be done to reduce the risks? (Probe: risk assessment, regulation)

Q21. What do you think about the regulation of nanotechnology in the agri-food sector?

Q22. Should nanotechnology be regulated at the local level for industry or at the European level or harmonised globally?

Part IV. Company's current use of nanotechnology

Q23a. Is nanotechnology used within your company? (Examples if not used)

Q23b. If yes, how/why is it used? And for what products? (Prompt: benefits to consumers and company)

Examples for non-users of nanotechnology

- Meat & fish- Aquanova (Germany Company) has developed a nanocarrier system that uses 30 nanometre micelles to encapsulate vitamins and fatty acids, which can be used as preservatives.
- Dairy- Unilever has used nanoemulsion technology to develop an ice cream with reductions in fat from 16% to 1% while not compromising on the flavour or fatty texture.
- Bakeries- George Weston Foods (one of Western Australia's leading bakeries) has incorporated nanocapsules containing fish oils into their bread. The nanocapsules are secreted once they enter the stomach, thereby avoiding the unpleasant taste of the fish oil.
- Food ingredients/additives- Titanium dioxide is a food whitening and brightening additive- used by Kraft, Hershey's, Mentos, Coca-Cola, etc. Shemen Industries has used micelles in the

development of canola active oil. The micelles work as a liquid carrier, enabling the penetration of vitamins, minerals and phenolic compounds that are insoluble in water or fats. The micelles are added to food products, and so pass through the digestive system efficiently, without breaking up, to the absorption site.

- Fortified food/beverages- BioDelivery Sciences International has introduced their Bioral™ nanocochleate nutrient delivery system for micronutrients and antioxidants, to prevent their degradation during manufacture and storage.
- Packaging- Durethan KU2-2601 (Bayer AG) is a hybrid plastic that is enriched with numerous silicate NPs. The plastic incorporates Nanocor's clay to produce a film that is lighter, stronger and more heat resistant than traditional packaging materials. The film is intended to prevent the entrance of oxygen and other gases, and the exit of moisture, thus preventing food spoilage.
- Fruit juices/beers bottles- Aegix ® OX (Honeywell Speciality Polymers) has also successfully engineered plastic beer bottles that integrate nanocomposites to enhance the barrier properties and extended shelf life of up to 26 weeks.
- Nutraceuticals- Nutralease Ltd Company has developed novel carriers for nutraceuticals to be incorporated into food systems, thereby enhancing the bioavailability of the product. Lycopene, beta-carotenes and phytosterols are some of the nutraceuticals incorporated in the carriers, and are used in the production of healthy foods, especially to prevent the accumulation of cholesterol.
- Processing equipment-Nansulate has developed thermal insulation coatings which protect equipment from corrosion and mould growth with benefits for heat loss and energy costs.

Q24. Do you follow any guidelines in relation to its use? (Ask for source and description detail)
Q25. Does your company conduct risk assessments in relation to nanotechnology processes/products?
Q26. As a company, where did you first hear about nanotechnology? How did you implement this new technology?
Q27. If you do or were to use nanotechnology would you label products accordingly?
Q28. How would you as a company promote the use of nanotechnology to consumers?

Part V. Nanotechnology opportunities

Q29. When deciding on whether to invest in new technologies to advance your products, what do you need to consider?
Q30. Based on what you know about nanotechnologies, do you think it would potentially be useful for any area of your company? (Probe: processing, preservation, packaging)
Q31. If your company was to consider implementing nanotechnology, what would you need?

Part VI. Obstacles to the adoption of nanotechnologies

Q32a. Do you foresee the application of nanotechnology in the agri-food sector increasing in the future (Showcard C)?

a) Definitely
b) Yes
c) Maybe
d) No
e) Not at all
f) Unsure/ can't say

Q32b. Why?
Q33. What would you consider to be the impediments regarding the implementation of nanotechnology in your company? (Probe: cost, resources, public acceptance, regulation, risk assessment, need for more scientific research)
Q34. As a company, do you have any concerns about introducing new technologies? (Probe: health & environment risks, lack of regulation, public acceptance)

Q35. As a company, what improvements do you think can be made to your absorptive capacity to encourage the adoption of new technologies? (Probes: education, training, experience, investment)

Q36. How do you think nanotechnology can be made less complex for companies?

Appendix 3: Themes and sections for quantitative online questionnaire

Part I: Demographics

Q1. Gender (Male/Female)

Q2. Approximately, what age are you?

18-25
26-35
36-45
46-55
56-65
65+

Q3. Which area of the agrifood industry is your company involved in?

Agriculture/primary production
Manufacturing/ processing/packaging
Wholesale & distribution
Retailing/marketing

Q4. Which food sector is your company involved in?

Dairy
Bakeries
Beef and lamb
Poultry
Fish
Eggs
Fruit and vegetables
Beverages

Q5. What is your position within the company?

Q6. Approximately how old is the company?

≤ 5 years
5-15 years
15-30 years
30-45 years
45-60 years
60-75 years
75 years+(please specify)

Q7. Where do you seek information regarding new technologies (including nanotechnology)?

Press/newspapers
Television
Radio
Searching the internet
Government agencies or regulators
Government websites
Scientific publications
Science magazines
Books
Scientists presenting information on nanotechnology (i.e., at conferences)
Research institutions
Other (please specify)
Unsure/don't know

Part II: Awareness and understanding of nanotechnology and its applications

Q8. How much have you heard about nanotechnology?

a) A lot
b) Some
c) A little
d) Know the term but that is all
e) Nothing at all

Q9. Where did you hear about nanotechnology?

a) Internet
b) Radio
c) TV shows
d) News programmes
e) Magazines
f) Family
g) Friends
h) Journals
i) Professionals
j) Someplace else (please specify)

Q10. Based on what you have heard, what is nanotechnology?

a) Atoms and molecules
b) Very small measurements
c) Measures of 1x10-9 units
d) Very small science or technology
e) Manipulation of substances at sizes in the nanoscale range
f) Physical/ chemical/ biological processes
g) Other (please specify)

Q11. From what you understand of nanotechnology, how would you describe your attitude?

Very positive
Positive- but I need more information about nanotechnology
Positive – but more R&D should be conducted
Nanotechnology has vast potential if the risks are controlled
Positive – other comments
Not positive nor negative
Nanotechnology is a concerning concept
Negative – due to health risks
Negative- due to environmental risks
More regulation is required
More research is needed regarding the safety of nanotechnology
Clearer information regarding nanotechnology is needed
Negative – other comments
Don’t know much about nanotechnology
Other comments (please specify)
Unsure/don’t know

Q12. Are you aware of any industrial applications of nanotechnologies?

Cosmetics/moisturisers
Sunscreens
Medicine
Electronics
Batteries
Fuels
Construction materials
Wastewater treatment
IPod nanotechnology
Food
Agriculture
Sporting goods
Textiles
Others (please specify)
Unsure/can’t say

Q13. Are you aware of how nanotechnology can be used in agriculture and the food industry?

Primary production- nanobiosensors for animal disease diagnostics.
Primary production- targeted genetic engineering.
Primary production- agrochemical delivery
Primary production- new pesticides
Primary production- smart sensors to monitor crop growth and field conditions.
Primary production- other (please specify)

Food processing- nutrient delivery
Food processing- nutraceuticals
Food processing- vitamin and mineral fortification.
Food processing- nanoencapsulation of flavours/aromas.
Food processing- development of interactive foods.
Food processing- other (please specify)
Food packaging- antimicrobials.
Food packaging- contaminant sensors.
Food packaging- high barrier plastics
Food packaging- other (please specify)
Others (please specify)

Q14. Are you aware of any food or beverage products currently on the market that have been produced using nanotechnology? {If B/C, GO TO Q16}

a) Yes
b) No
c) Can't say/ Don't know

Q15. What products are you aware of?

Ice cream
Milk
Cream
Yoghurts
Bread
Soft drinks
Crisps
Chocolate
Butter
Spreads
Dressings
Sauces
Mayonnaise
Sports drinks
Slimming products
Others (please specify)

Part III. Risks/benefits of nanotechnology in relation to food

Q16. Based on what you know, how would you describe the relative risks and benefits of nanotechnology in relation to agriculture and food?

a) Risks outweigh the benefits
b) Risks and benefits are about equal
c) Benefits outweigh the risks
d) Not sure at all

Q17. On a scale of 1-5, how positive is what you have heard about the use of nanotechnology in food, with 1 being very positive to 5 being very negative.

a) Nanoparticles to improve nutritional properties in food
b) Nanoparticles in food packaging to increase shelf life and quality
c) Nanostructuring food ingredients to improve flavour, aroma, colour or texture of foods
d) Nanoparticles for the development of slimming products
e) Nano-based delivery systems for nutraceuticals
f) None of the above

Q18. What are the benefits for the agriculture and food industry?

Enhanced absorption efficiency
Improved flavour/ aroma
Improved colour
Improved texture/consistency
Increased nutritional value (i.e. vitamins and minerals)
Enhanced reactivity
Enhanced solubility

Enhanced transparency
Enhanced stability
Detection of contaminants by food containers
Sterilisation, antimicrobial, preserved freshness by packaging materials/container
Others (please state)

Q19. In your opinion, what are the underlying issues associated with the use of nanotechnology for food and related products?

High toxicological risk to humans
Uncertainties regarding long term human health consequences
Risks to health and safety of workers
Risks to the environment
Existing regulation of nanotechnology is insufficient
Lacking information regarding nanotechnology
Others (please specify)
Unsure/don't know

Q20. Please state to what level you agree or disagree with the following statements? Use a 1-5 scale where 1 is strongly disagree and 5 is strongly agree. If you are unsure, just say so.

Nanotechnology is a complex term to understand
With nanotechnology being a new concept, there might be concerns relating to consumer safety
Novel processes might cause concerns for workers safety
Information about nanotechnology is easily accessible
Nanotechnology legislation is keeping up with the development of nanotechnology
Product labelling should provide information about any nanotechnology used
I have concerns regarding nanotechnology

Q21. In your opinion what can be done for risk reduction? Please rank in order of importance.

Transparent and open research activities
Government funding for independent research on nanotechnology related risks
Effective on-going communication between stakeholders
Development and implementation of international regulations
Adequate guidance on risk assessment
Regulation of nanotechnology related risk issues
Development of a globally harmonised risk governance approach
Others (please specify)

Q22. To what level do you agree or disagree with the following statements about the regulation of nanotechnology in the agrifood sector?

Use a 1-5 scale where 1 is strongly disagree and 5 is strongly agree.
Development of clear and consistent guidelines for risk assessment is necessary
Globally harmonised regulatory systems should be implemented to set clear limits for nano-foods/products
Need for international research collaborations and networks
Current regulation of nanotechnology is inadequate for food and related products
Others (please specify)
Unsure/don't know

Q23. How should nanotechnology be regulated for the agrifood sector (please specify reasons for choice)?

a) Local level for industry
b) European level
c) Globally harmonised

Part IV. Company's current use of nanotechnology

Q24. Does your company currently use nanotechnology for the manufacture/processing of any food or beverage products?

a) Yes
b) No
c) No- development plan
d) Unsure/ can't say

Q25. If yes, how/why is it used?

Crop production (nanoformulated chemicals, smart sensors)
Animal production (fortification of animal feed, disease diagnostics)
Food processing (food ingredients, nutrient delivery)
Food processing equipment (insulation, sanitisation)
Food packaging (sensors, antimicrobials)
Others (please specify)

Part V. Nanotechnology opportunities

Q26. Please rank the order of which objectives are the most important to your company when considering investing in new technologies?

1. Product innovation
2. Cost saving
3. Reduced resource use
4. Generating new customers
5. Retaining customers
6. Products that offer 'healthier' alternatives or target specific dietary needs
7. Expansion in core markets
8. Focus on emerging markets
9. Increasing consumer spending
10. Changed pricing and promotional strategies
11. Innovative merchandising strategies
12. Development of environmentally friendly products/services

Q27. Based on what you know about nanotechnologies, do you think it would potentially be useful for any area of your company?

a) Crop production
b) Animal production
c) Food processing
d) Processing equipment
e) Food safety
f) Food packaging
g) Food preservation

Q28. If your company was to consider implementing nanotechnology, what would you need?

a) More effective regulation of nanotechnology for food and related products
b) Guidance on risk assessment
c) More research into unknowns regarding the use of nanotechnology in food and related products
d) Effective communication among all stakeholders
e) Effective dialogue with the media
f) Financial investment in nanotechnology by the government
g) Public engagement- awareness of benefits of applying nanotechnology for food application
h) Others (please specify)

Part VI. Obstacles to the adoption of nanotechnologies

Q29. Do you foresee the application of nanotechnology in the agrifood sector increasing in the future?

a) Definitely
b) Yes
c) Maybe
d) No
e) Not at all
f) Unsure/ can't say

Q30. What would you consider to be the impediments regarding the implementation of nanotechnology in your company?

a) Cost
b) Lack of resources to implement nanotechnology
c) Need more information on nanotechnology
d) Need for more effective regulation of nanotechnology

e) Need for clearer guidelines for risk assessment
f) Issues regarding public acceptance of nanotechnology
g) More scientific research is need into risks to human health and the environment
h) Others (please specify)

Q31. As a company, how do you think your knowledge base can be improved to encourage the adoption of new technologies?

a) Education on nanotechnology
b) Training from professionals
c) Experienced personnel
d) Investment
e) Communication throughout company
f) Others (please specify)

Appendix 4: Quantitative online survey

Nanotechnology in the agri-food industry: Applications, opportunities & challenges

Thank you in advance for taking the time to complete this survey. The questionnaire is part of an on-going *safe*food-sponsored initiative to evaluate the applications, opportunities and challenges presented by nanotechnology to institutions and industries across the agri-food sector. The study is being conducted by the Institute for Global Food Security at Queen's University, Belfast, in collaboration with Teagasc Food Research Centre, Dublin. The purpose of the questionnaire is to gather information from representatives of industry and institutions involved in the agri-food sector on the awareness of nanotechnology and its applications, its current use in the agri-food sector and attitudes towards its current use or potential future use. The questionnaire is not designed to obtain your personal views but those of the organisation in which you work. Your organisation has been identified as a key stakeholder in the agri-food sector and as such your participation is very valuable to us and much appreciated. The survey should take about 10-15 minutes of your time. Your answers will be completely anonymous and will be published only in summary, in statistical form. You will not be identified in anyway. All survey results will be published in a report by *safe*food in April 2014.

By filling out this survey, you will also have the opportunity to win an iPad by providing your name and contact details.

If you have any questions or concerns about the survey or would like to find out further information about this research, please contact Caroline Handford, PhD student at IGFS, at chandford01@qub.ac.uk.

Many thanks

Dr Katrina Campbell

Lecturer in Bioanalytical Systems

Institute for Global Food Security

Queen's University Belfast

For ethical reasons we wish to obtain confirmation of your voluntary consent to participate in our study, informed by your understanding of its purpose and nature.

Having read the information provided, I agree to participate in this survey

Part I: Demographics

Q1. Please indicate your gender? (Male/Female)

Q2. Please indicate your age bracket?

18-35 years
36-50 years
51-65 years

66 years or over

Q3. In which country is your organisation located?

Northern Ireland
England
Scotland
Wales
Republic of Ireland
Other
Please specify

Q4. Which type of organisation do you work for?

Micro enterprise (<10 employees)
Small enterprise (11-50 employees)
Medium- sized enterprise (51-250 employees)
Large organisation (>500 employees)

Q5. At which stage of the agri-food supply chain is your organisation involved? (Select all options that apply)

Agriculture/primary production
Manufacturing/ processing/packaging
Wholesale & distribution
Retailing/marketing
Regulatory/monitoring body
Other
Please specify

Q6. In which agri-food sector is your organisation involved? (Select all options that apply)

Animal Feed & Grains
Pesticides
Dairy
Bakeries
Beef and/or Lamb
Poultry
Pork
Fish
Eggs
Fruit and Vegetables
Food Additives
Beverages
Food Ingredients
Confectionary
Nutraceuticals
Other
Please specify

Q7. What is your position within the company?

Managing Director
General Manager
Technical Manager
R&D Manager/NPD Manager
Quality Control Manager
Production Manager
Administration
Other
Please specify

Q8. Approximately, how old is the company?

- ≤ 5 years
- 6-20 years
- 21-35 years
- 36-50 years
- 51-75 years
- 76 years and over
- Please specify

Q9. When your company wants to find out information about a new technology (including nanotechnology), where is the information sourced? (Select all options that apply)

- Mass media (i.e., TV, newspapers
- Searching the internet
- Government agencies or regulators
- Scientific publications
- Science magazines
- Books
- Scientists presenting information at conferences/Training workshops
- Scientific organisations/ research institutions
- Patents
- Unsure/don't know
- Others
- Please specify

Part II: Awareness and perceptions of nanotechnology and its applications

Q10. Please select how you would describe the knowledge of nanotechnology at your organisation.

- A lot
- Some
- A little
- Know the term but that is all
- Nothing at all

Q11. In what context would the organisation be familiar with nanotechnology? (Select all options that apply)

- Atoms and molecules
- Paint
- Measures of $1x10^{-9}$ units
- Very small science or technology
- Medicine
- Manipulation of substances at sizes in the nanoscale range
- Physical/ chemical/ biological processes
- Micro or small science or technology
- Electronics
- Food/beverage products
- Computing
- Sunscreens/cosmetics
- Packaging
- Fuels
- Agriculture
- Clothing
- Shampoo products
- Sporting goods
- Aeroplanes
- Construction materials
- Unsure/don't know
- None
- Other

Please specify

Q12. In relation to the knowledge of nanotechnology, how would you describe your organisation's attitude towards it?

Very Negative
Negative
Neutral
Positive
Very Positive

Q13. As an organisation have you heard of any of the following agricultural applications of nanotechnology? (Select all options that apply)

Using nanobiosensors for animal disease diagnostics
The use of nanocapsules for improving feeding efficiency and nutrition of animals
Using nanoparticles for targeted genetic engineering to improve plant traits
Nanosizing agrochemicals (i.e. pesticides) for improved delivery and better efficacy
The use of smart sensors to monitor crop growth and field conditions
None of the above
Others
Please specify

Q14. Please indicate the view of your organisation to the following agricultural applications. Using a 1-5 scale where 1 is very negative and 5 is very positive.

The organisation	Very Negative	Negative	Neutral	Positive	Very Positive
Using nanobiosensors for animal disease diagnostics.					
The use of nanocapsules for improving feeding efficiency and nutrition of animals					
Using nanoparticles for targeted genetic engineering to improve plant traits.					
Nanosizing agrochemicals (i.e. pesticides) for improved delivery and better efficacy.					
The use of smart sensors to monitor crop growth and field conditions.					
Others (please specify)					

Q15. As an organisation have you heard of any of the following food industry applications of nanotechnology? (Select all options that apply)

Using nanoparticles to improve the nutritional properties of food
Nanostructuring food ingredients to improve taste/texture
The use of nanocarrier systems for the delivery of nutrients and supplements
Using nanosilver as antimicrobials in processing equipment (i.e., fridges
The use of nanoparticles in food packaging to extend shelf life
Using nanosensors/nanoparticles for food safety, monitoring or traceability
None of the above
Others
Please specify

Q16. Please indicate the view of your organisation for the following food industry applications. Using a 1-5 scale where 1 is very negative and 5 is very positive.

The organisation	Very negative	Negative	Neutral	Positive	Very Positive
Using nanoparticles to improve the nutritional properties of food.					
Nanostructuring food ingredients to improve					

taste/texture.					
The use of nanocarrier systems for the delivery of nutrients and supplements.					
Using nanosilver as antimicrobials in processing equipment (i.e. fridges).					
The use of nanoparticles in food packaging to extend shelf life.					
Using nanosensors / nanoparticles for food safety, monitoring or traceability.					
Others (please specify)					

Q17. As an organisation are you aware of any food or beverage products currently on the market that have been produced using nanotechnology or nanomaterials? (Select all options that apply)

Ice cream
Milk
Cream
Yoghurts
Bread
Soft drinks
Crisps
Chocolate
Butter
Spread
Dressings
Sauces
Mayonnaise
Sports drinks
Slimming products
None
Can't say/don't know
Others (specify)

Part III. Risks/benefits of nanotechnology in relation to food

Q18. How would your organisation describe the relative risks and benefits of nanotechnology in relation to agriculture and food?

Risks outweigh the benefits
Risks and benefits are about equal
Benefits outweigh the risks
Not sure at all

Q19. Rank order the following list of what your organisation would consider to be the most important benefits (1) to the least important benefits (9) arising from the application of nanotechnology in the agri-food industry?

More efficient precision-farming techniques
Increased shelf life of products
Reduced waste (food and packaging)
Healthier products
Safer food
Lower costs for industry
Production of cheaper food
Improved distribution and sales
More traceability on products

Q20. Please indicate to what level your organisation agrees or disagrees with the following issues associated with the use of nanotechnology for food and related products. Use a 1-5 scale where 1 is strongly disagree and 5 is strongly agree.

The organisation	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
There is inadequate regulation of nanotechnology for food and related products.					
There are information and knowledge deficits relating to nanotechnology.					
There are concerns that the public will not be accepting of nanotechnology.					
There are concerns about the media's perception of nanotechnology.					
There are concerns about the uncertainties regarding the long term human health consequences associated with nano-foods/nano products.					
There are concerns about the risks to health and safety of workers of nanotechnology.					
There is apprehension about the environmental impacts of nanotechnology.					
Others (please specify)					

Q21. Please state to what level your organisation agrees or disagrees with the following concerning what should be done for risk reduction. Use a 1-5 scale where 1 is strongly disagree and 5 is strongly agree.

The organisation	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
There is a need for transparent and open research activities.					
The government should provide more funding for independent research on nanotechnology related risks.					
There is a need for effective on-going communication between stakeholders.					
It is important to have international research collaborations and networks					
There should be adequate guidance on risk assessment.					
Regulation should be implemented for nanotechnology related risk issues.					
There is a need to develop a globally harmonised risk governance approach.					
Others (please specify)					

Q22. As an organisation how should nanotechnology be regulated for the agrifood sector?

Local level for industry
European level
Globally harmonised
Other
Please specify

Part IV. Organisation's current use of nanotechnology

Q23. Does your organisation currently use nanotechnology or nanomaterials at any stage in the agri-food supply chain? (Select all options that apply)

Crop production (nanoformulated chemicals, smart sensors)
Animal production (fortification of animal feed, disease diagnostics)
Food processing (food ingredients/additives, nutrient delivery)
Food processing equipment (insulation, sanitization)

Food packaging (sensors, antimicrobials)
Food Safety monitoring
Not in use
Other
Please specify

Q24. Does your organisation plan to use nanotechnology or nanomaterials at any future stage in the agri-food supply chain?

Yes
No
Current researching/development plan
Future research development plan
Unsure/ can't say
Not applicable

Q25. If yes, how will it be used?

Q26. As an organisation would you label products which have been developed using nanotechnology?
Always

Yes- but depends on the process/use
No- unless it had to be declared by law
Unsure/don't know
Not applicable

Part V. Nanotechnology opportunities

Q27. Please rank the items from 1-8 according to what objectives are important to your organisation when considering investing in new technologies? (Select option and move to chosen position)

Product innovation (i.e. products that offer 'healthier'
Alternatives or target specific dietary needs
Reduced costs/ resource use
Retaining customers'
Expansion in core markets
Focus on emerging markets to generate new customers'
Increasing consumer spending
Changed pricing and promotional strategies
Development of environmentally friendly products/services

Q28. Based on the knowledge of nanotechnology at your organisation do you think it would potentially be useful for any area of your business? (Try to please select as many options as applicable).

Crop production (nanoformulated chemicals, smart sensors)
Animal production (fortification of animal feed, disease diagnostics)
Food processing (food ingredients, nutrient delivery)
Food processing equipment (insulation, sanitization)
Food packaging (sensors, antimicrobials)
Food Safety monitoring
None
Others
Please specify

Q29. As an organisation how important are the following prior to the implementation of nanotechnology in your company? Using a 1-6 scale, how important are the following statements where 1 is very unimportant and 6 is not applicable.

The organisation	Very unimportant	Unimportant	neutral	Important	Very important	Not applicable
More information and enhanced knowledge on nanotechnology						
Training from experts of nanotechnology						
Regulation of nanotechnology for food and related products (including risk assessment framework)						
Adequate safety assessment on a case-by-case basis where nanotechnology alters existing products or processes						
More research into long term effects to human health						
Effective communication and collaboration among scientists, industry and government						
More resources i.e. financial investment by external bodies						
Public engagement- identify consumer needs and wants						
Consumer perceptions of potential nanotechnology applications to help determine which applications to prioritise						
Others (please specify)						

Part VI. Obstacles to the adoption of nanotechnologies

Q30. As an organisation do you foresee the application of nanotechnology in the agrifood sector increasing in the future?

Definitely
Maybe
No
Unsure/can't say

Q31. Please indicate to what level you agree or disagree with the following as to what you consider to be the main obstacles to the implementation of nanotechnology at your organisation. Use a 1-6 scale where 1 is strongly disagree and 6 is not applicable.

The organisation	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	Not applicable
Cost of nanotechnology implementation						
Lack of information and knowledge						
Availability of expertise						
Time and long term value of nanotechnology						

Need for risk assessment framework						
Public acceptance of nanotechnology						
Media perceptions						
Unknown risks to human health and the environment						
Others (please specify)						

Q32. How much trust does your organisation place on the information you receive about nanotechnology from the following bodies? Using a 0-10 scale where **0 is do not trust at all** and **10 is trust completely**. Please select the appropriate option.

	1	2	3	4	5	6	7	8	9	10
a) Government agencies or regulators										
b) Agri-food industry associations										
c) Scientists										
d) Mass media										
e) Non-government organisations (NGO's)										
f) Science Institutes and organisations such as universities										

Q33. Please rate the importance of the following to improving your organisation's knowledge base to encourage the adoption of new technologies. Use a 1-6 scale where 1 is very unimportant and 6 is not applicable.

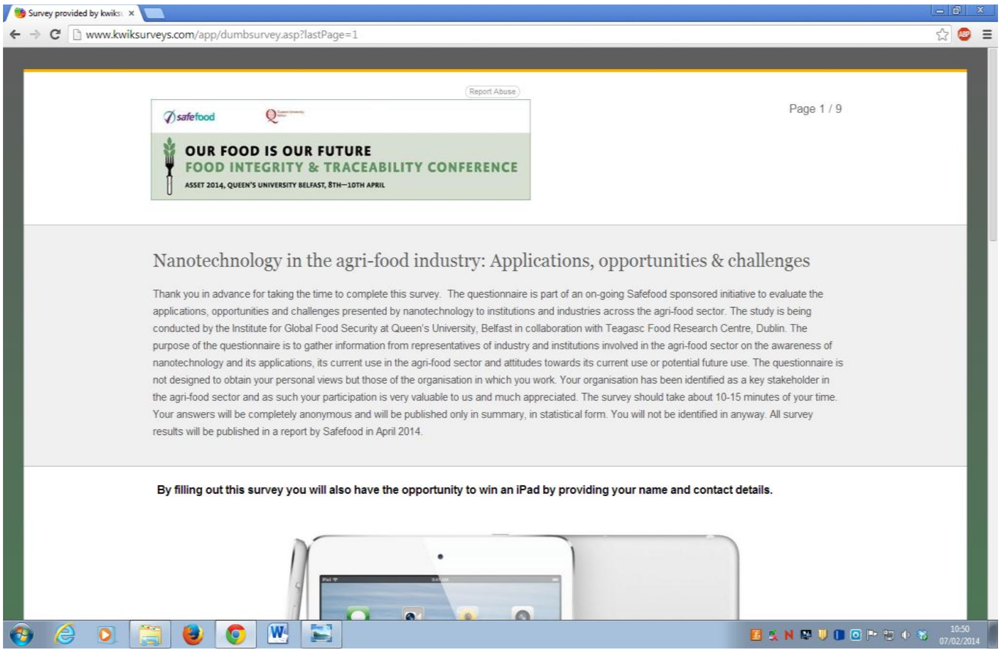
The organisation	Very unimportant	Unimportant	Neutral	Important	Very important	Not applicable
Seminars/training workshops						
Training from nanotechnology experts						
Better communication and information from government bodies						
Better communication and information from scientific organisations						
Networking with universities						
Better communication throughout company						
More technical experts in the company						
Others (please specify)						

The survey has been successfully completed. Thank you very much for your participation.
If you would like to add any final comments, we would be very pleased to include them in our analysis. Please write them in the box below.

Your comments:

Once again, thank you very much for your time.

Appendix 5: Screenshots of online survey



Appendix 6: Descriptive statistics for demographics of respondent organisations

The total number of responses received for this report was 102, and the demographic profile of the respondents and information on the organisations that they represent are illustrated in the following tables.

Gender of the respondents

Gender	Number of respondents	% of respondents
Male	67	65.7
Female	35	34.3

Age range of the respondents

Age bracket	Number of respondents	% of respondents
18-35 years	27	26.5
36-50 years	49	48
51-65 years	25	24.5
66 years and over	1	1

Location of organisations per country

Country of organisation	Number of respondents	% of respondents
Northern Ireland	50	49
England	3	2.9
Scotland	1	1
Wales	-	-
Republic of Ireland	47	46.1
Other	1	1

Size of the organisation

Type of organisation	Number of respondents	% of respondents
Micro enterprise (<10 employees)	33	32.4
Small enterprise (11-50 employees)	26	25.5
Medium-sized enterprise (51-250 employees)	30	29.4
Large organisation (>500 employees)	13	12.7

Stage of the agri-food supply chain at which organisations are involved. Some organisations are involved in multiple stages due to the nature of their business

Organisation stage in agri-food sector	Number of positive respondents	% of positive respondents
Agriculture/primary production	20	19.6
Manufacturing/processing/packaging	74	72.5
Wholesale and distribution	26	25.5
Retailing/marketing	15	14.7
Regulatory/monitoring body	4	3.9
Research and development	3	2.9
Other	2	2

Agri-food sector in which organisations are involved. Some organisations are involved in multiple sectors due to the nature of their business

Type of agri-food sector	Number of positive respondents	% of positive respondents
Animal feed and grains	22	21.6
Pesticides	2	2
Dairy	35	34.3
Bakeries	16	15.7
Beef and/or lamb	24	23.5
Poultry	17	16.7
Pork	19	18.6
Fish	12	11.8
Eggs	9	8.8
Fruit and vegetables	13	12.7
Food additives	5	4.9
Beverages	17	16.7
Food ingredients	19	18.6
Confectionary	7	6.9
Nutraceuticals	6	5.9
Chutneys and preserves	1	1
Other	9	8.8

Position of the respondents in their organisation

Company position	Number of respondents	% of respondents
Managing director	33	32.4
General manager	10	9.8
Technical manager	19	18.6
R&D/NPD manager	10	9.8
Quality control manager	4	3.9
Production manager	2	2
Administration	5	4.9
Owner	4	3.9
Accounts manager	1	1
Marketing co-ordinator	2	2
Business development manager	2	2
Sales manager	2	2
Food technologist	1	1
Other	7	6.9

Age of the organisation

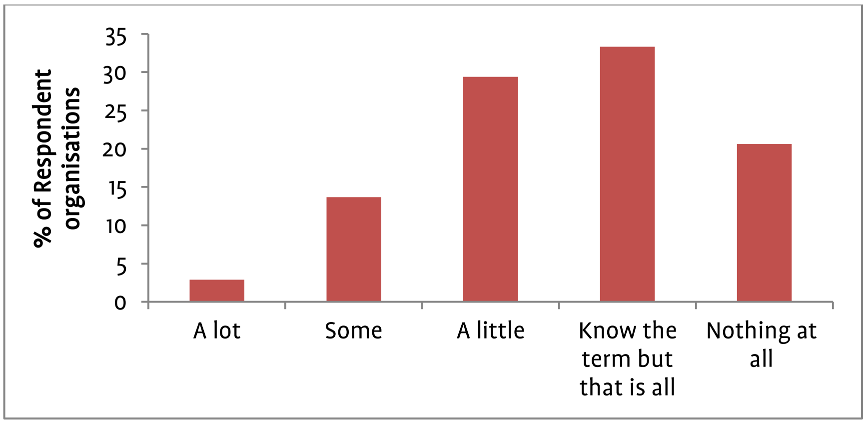
Company Age	Number of respondents	% of respondents
$\leq$ 5 years	20	19.6
6-20 years	26	25.5
21-35 years	24	23.5
36-50 years	9	8.8
51-75 years	7	6.9
76-90 years	3	2.9
91-105 years	3	2.9
106 years plus	10	9.8

Sources of information respondents use for information on new technologies (including nanotechnology)

Source of information	Number of positive respondents	% of positive respondents
Mass media	17	16.7
Searching the internet	80	78.4
Government agencies or regulators	38	37.3
Scientific publications	37	36.3
Books	6	5.9
Scientists presenting information at conferences/ training workshops	35	34.3
Scientific organisations/ research institutions	41	40.2
Patents	5	4.9
Industry contact suppliers	2	2
Trade publications	-	-
Investment bodies	1	1
Unsure	4	3.9

Appendix 7: Descriptive statistics for respondents' awareness and perceptions of nanotechnology and its applications

Q10. Please select how you would describe the knowledge of nanotechnology at your organisation?



Q11. In what context would the organisation be familiar with nanotechnology? (Select all options that apply)

Familiarity with nanotechnology	Number of positive respondents	% of positive respondents
Atoms and molecules	20	19.6
Paint	13	12.7
Measures of 1x10^{-9} units	8	7.8
Very small science or technology	16	15.7
Medicine	8	7.8
Manipulation of substances at sizes in the nanoscale range	1	1
Physical/ chemical/ biological processes	20	19.6
Micro or small science or technology	18	17.6
Electronics	11	10.8
Food/ beverage products	24	23.5
Computing	14	13.7
Sunscreen/ cosmetics	1	1
Packaging	25	24.5
Fuels	2	2
Agriculture	10	9.8
Clothing	-	-
Shampoo products	2	2
Sporting goods	1	1
Aeroplanes	-	-
Construction materials	-	-
Unsure/ don't know	15	14.7
None	19	18.6

Q12. In relation to the knowledge of nanotechnology, how would you describe your organisation's attitude towards it?

Respondent organisations' attitude towards nanotechnology	N (%)
Very negative	2 (2)
Negative	6 (5.9)
Neutral	77 (75.5)

Positive	12 (11.8)
Very positive	5 (4.9)

Q13. As an organisation, have you heard of any of the following agricultural applications of nanotechnology?

(Select all options that apply)

Respondent organisations' awareness of agricultural applications of nanotechnology	Number of positive respondents	% of positive respondents
Using nanobiosensors for animal disease diagnostics	17	16.7
The use of nanocapsules for improving feeding efficiency and nutrition of animals	19	18.6
Using nanoparticles for targeted genetic engineering to improve plant traits	15	14.7
Nanosizing agrichemicals (i.e., pesticides) for improved delivery and better efficacy	16	15.7
The use of smart sensors to monitor crop growth and field conditions	16	15.7
Identification of contaminants in feed	1	1
None of the above	59	57.8

Q14. Please indicate the view of your organisation to the following agricultural applications. Using a 1-5 scale where 1 is very negative and 5 is very positive.

Organisation attitudes towards agricultural applications of nanotechnology (Total number & percentage)	Very negative	Negative	Neutral	Positive	Very positive
Using nanobiosensors for animal disease diagnostics.	2 2	3 2.9	58 56.9	28 27.5	11 10.8
The use of nanocapsules for improving feeding efficiency and nutrition of animals	8 7.8	10 9.8	50 40.9	25 24.5	9 8.8
Using nanoparticles for targeted genetic engineering to improve plant traits.	12 11.8	16 15.7	54 52.9	19 8.6	1 1
Nanosizing agrichemicals (i.e., pesticides) for improved delivery and better efficacy.	9 8.8	11 10.8	56 54.9	23 22.5	3 2.9
The use of smart sensors to monitor crop growth and field conditions.	2 2	2 2	57 55.9	32 31.4	9 8.8

Q15. As an organisation, have you heard of any of the following food industry applications of nanotechnology? (Select all options that apply)

Respondent organisations' awareness of food applications of nanotechnology	Number of positive respondents	% of positive respondents
Using nanoparticles to improve the nutritional properties of food	27	26.5
Nanostructuring food ingredients to improve taste/texture	25	24.5
The use of nanocarrier systems for the delivery of nutrients and supplements	21	20.6
Using nanosilver as antimicrobials in processing equipment (i.e., fridges)	16	15.7
The use of nanoparticles in food packaging to extend shelf life	31	30.4
Using nanosensors for food safety, monitoring or traceability	23	22.5
None of the above	49	48

Q16. Please indicate the view of your organisation for the following food industry applications. Using a 1-5 scale where 1 is very negative and 5 is very positive.

Organisation attitudes towards food applications of nanotechnology (Total number & percentage)	Very negative	Negative	Neutral	Positive	Very positive
Using nanoparticles to improve the nutritional properties of food	10 9.8	13 12.7	47 46.1	24 23.5	8 7.8
Nanostructuring food ingredients to improve taste/texture	12 11.8	13 12.7	49 48	19 18.6	9 8.8
The use of nanocarrier systems for the delivery of nutrients and supplements	8 7.8	12 11.8	53 52	19 18.6	10 9.8
Using nanosilver as antimicrobials in processing equipment (i.e., fridges)	3 2.9	6 5.9	54 52.9	29 28.4	10 9.8
The use of nanoparticles in food packaging to extend shelf life	7 6.9	5 4.9	48 47.1	28 27.5	14 13.7
Using nanosensors for food safety, monitoring or traceability	3 2.9	2 2	45 44.1	34 33.3	18 17.6

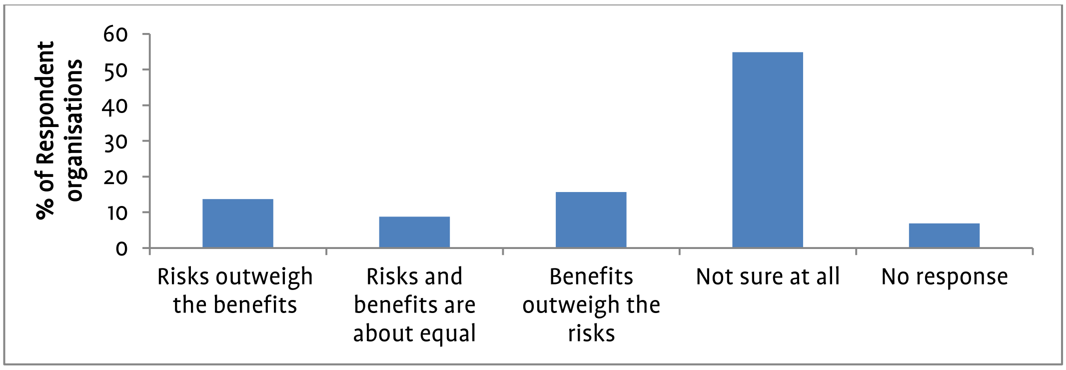
Q17. As an organisation, are you aware of any food or beverage products currently on the market that have been produced using nanotechnology or nanomaterials? (Select all options that apply)

Respondent organisations' familiarity with nano-food/beverage products on the current market	Number of positive respondents	% of positive respondents
Ice cream	2	2
Milk	3	2.9
Cream	2	2
Yoghurts	4	3.9
Bread	1	1
Soft drinks	-	-
Crisps	2	2
Chocolate	1	1

Butter	-	-
Spread	3	2.9
Dressings	2	2
Sauces	2	2
Mayonnaise	4	3.9
Sports drinks	3	2.9
Slimming products	4	3.9
None	34	33.3
Can’t say/ don’t know	59	57.8

Appendix 8: Descriptive statistics for respondents' views on the risks and benefits of nanotechnology in relation to agri-food applications

Q18. How would your organisation describe the relative risks and benefits of nanotechnology in relation to agriculture and food?



Q19. Rank order the following list of what your organisation would consider to be the most important benefits (1) to the least important benefits (9) arising from the application of nanotechnology in the agri-food industry?

Respondent organisation' views on the most (1) to the least (9) important benefits of nanotechnology to the agri-food industry (Total number & percentage)										
Benefits	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**No response**
More efficient precision-farming techniques	**23** **22.5**	5 4.9	11 10.8	10 9.8	10 9.8	10 9.8	7 6.9	5 4.9	14 13.7	7 6.9
Increased shelf life of products	11 10.8	**24** **23.5**	9 8.8	13 12.7	9 8.8	14 13.7	7 6.9	4 3.9	4 3.9	7 6.9
Reduced waste (food and packaging)	5 4.9	10 9.8	**29** **28.4**	17 16.7	17 16.7	10 9.8	6 5.9	1 1	-	7 6.9
Healthier products	4 3.9	14 13.7	6 5.9	**22** **21.6**	13 12.7	11 10.8	11 10.8	8 7.8	6 5.9	7 6.9
Safer food	**37** **36.3**	12 11.8	9 8.8	3 2.9	16 15.7	6 5.9	3 2.9	3 2.9	6 5.9	7 6.9
Lower costs for industry	5 4.9	7 6.9	6 5.9	10 9.8	8 7.8	**22** **21.6**	**24** **23.5**	8 7.8	5 4.9	7 6.9
Production of cheaper food	1 1	2 2	6 5.9	7 6.9	4 3.9	8 7.8	21 20.6	**32** **31.4**	14 13.7	7 6.9
Improved distribution and sales	2 2	6 5.9	3 2.9	6 5.9	7 6.9	6 5.9	10 9.8	**29** **28.4**	**26** **25.5**	7 6.9
More traceability on products	7 6.9	15 14.7	16 15.7	7 6.9	11 10.8	8 7.8	6 5.9	5 4.9	**20** **19.6**	7 6.9

Q20. Please indicate to what level your organisation agrees or disagrees with the following issues associated with the use of nanotechnology for food and related products. Use a 1-5 scale where 1 is strongly disagree and 5 is strongly agree.

Respondent organisation views on the main issues regarding the use of nanotechnology for food and related products (Total number & percentage)

Issues	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	No response
There is inadequate regulation of nanotechnology for food and related products.	2 2	4 3.9	65 63.7	19 18.6	5 4.9	7 6.9
There are information and knowledge deficits relating to nanotechnology.	-	3 2.9	39 38.2	31 30.4	22 21.6	7 6.9
There are concerns that the public will not be accepting of nanotechnology.	-	2 2	42 41.2	34 33.3	17 16.7	7 6.9
There are concerns about the media's perception of nanotechnology.	-	3 2.9	52 51	27 26.5	13 12.7	7 6.9
There are concerns about the uncertainties regarding the long term human health consequences associated with nano-foods/nano products.	-	2 2	45 44.4	28 27.5	20 19.6	7 6.9
There are concerns about the risks to health and safety of workers of nanotechnology.	-	6 5.9	55 53.9	26 25.5	8 7.8	7 6.9
There is apprehension about the environmental impacts of nanotechnology.	-	3 2.9	45 44.1	31 30.4	16 15.7	7 6.9

Mean scores for the main issues associated with the use of nanotechnology for food and food-related products

Issues associated with food nanotechnology	Scale range	Mean ± S.D.
Inadequate regulation of nanotechnology.	1-5	3.2 ± 0.7
Information and knowledge deficits	1-5	3.8 ± 0.9
Public acceptance	1-5	3.7 ± 0.8
Media perceptions	1-5	3.5 ± 0.8
Long term health effects	1-5	3.7 ± 0.8
Risks to health and safety of workers	1-5	3.4 ± 0.7
Environmental impacts	1-5	3.6 ± 0.8

A five-point Likert scale is used to assess the main issues regarding the use of nanotechnology for food and food-related application (1= 'strongly disagree' to 5= 'strongly agree').

Q21. Please state to what level your organisation agrees or disagrees with the following concerning what should be done for risk reduction. Use a 1-5 scale where 1 is strongly disagree and 5 is strongly agree.

Respondent Organisation Views on Risk Reduction of Nanotechnology (Total number & percentage)

Views	Strongly disagree	Disagree	Neutral	Agree	Strongly agree	No response
There is a need for transparent and open research activities.	1 1	1 1	13 12.7	42 41.2	38 37.3	7 6.9
The government should provide more funding for independent research on nanotechnology related risks.	1 1	3 2.9	22 21.6	50 49	19 18.6	7 6.9
There is a need for effective on-going communication between stakeholders.	-	1 1	20 19.6	53 52	21 20.6	7 6.9
It is important to have international research collaborations and networks.	1 1	1 1	21 20.6	46 45.1	26 25.5	7 6.9
There should be adequate guidance on risk assessment.	1 1	-	12 11.8	48 47.1	34 33.3	7 6.9
Regulation should be implemented for nanotechnology related risk issues.	-	1 1	15 14.7	44 43.1	35 34.3	7 6.9
There is a need to develop a globally harmonised risk governance approach.	-	-	27 26.5	42 41.2	26 25.5	7 6.9

Q22. As an organisation, how should nanotechnology be regulated for the agri-food sector?

Respondent organisation views on how nanotechnology should be regulated for the agri-food sector	Number of respondents	% of respondents
Local level for industry	21	20.6
European level	43	42.2
Globally harmonised	28	27.5
Other	2	2
Not applicable	1	1
No response	7	6.9

Appendix 9: Descriptive statistics for the respondent organisations' current use of nanotechnology

Q23. Does your organisation currently use nanotechnology or nanomaterials at any stage in the agri-food supply chain? (Select all options that apply)

Respondent organisations current use of nanotechnology in the agri-food sector	Number of positive respondents	% of positive respondents
Crop production (nanoformulated chemicals, smart sensors)	-	-
Animal production (fortification of animal feed, disease diagnostics)	4	3.9
Food processing (food ingredients/additives, nutrient delivery)	3	2.9
Food processing equipment (insulation, sanitisation)	3	2.9
Food packaging (sensors, antimicrobials)	2	2
Food Safety monitoring	3	2.9
Not in use	82	80.4
Unsure/ don't know	3	2.9

Q24. Does your organisation plan to use nanotechnology or nanomaterials at any future stage in the agri-food supply chain?

Respondent organisation plans to use nanotechnology in the future in the agri-food supply chain	Number of respondents	% of respondents
Yes	-	
No	18	17.6
Current researching/ development plan	3	2.9
Future research development plan	6	5.9
Unsure/ can't say	58	56.9
Not applicable	9	8.8
No response	8	7.8

Q25. If yes, how will it be used?

Q26. As an organisation, would you label products which have been developed using nanotechnology?

Respondent organisations' views on labelling nano products	N (%)	% Response
Always	16	15.7
Yes- but it depends on the process/use	15	14.7
No – unless it had to be declared by law	20	19.6
Unsure/ don't know	29	28.4
Not applicable	14	13.7
No response provided	8	7.8

Appendix 10: Descriptive statistics for nanotechnology opportunities for agri-food organisations

Q27. Please rank the items from 1-8 according to what objectives are important to your organisation when considering investing in new technologies? (Select option and move to chosen position)

N (%) respondents' views on the most (1) to the least (8) important objectives for their organisation when investing in new technologies (Total number & percentage)									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**No response**
Product innovation (i.e. products that offer 'healthier' alternatives or target specific dietary needs.	**46** **45.1**	12 11.8	7 6.9	10 9.8	7 6.9	3 2.9	2 2	3 2.9	12 11.8
Reduced costs/ resource use	17 16.7	**32** **31.4**	13 12.7	11 10.8	8 7.8	6 5.9	1 1	2 2	12 11.8
Retaining customers	7 6.9	13 12.7	**36** **35.3**	16 15.7	12 11.8	5 4.9	1 1	-	12 11.8
Expansion in core markets	4 3.9	3 2.9	12 11.8	**31** **30.4**	14 13.7	11 10.8	6 5.9	9 8.8	12 11.8
Focus on emerging markets to generate new customers	-	3 2.9	1 1	9 8.8	**24** **23.5**	23 22.5	17 16.7	13 12.7	12 11.8
Increasing consumer spending	1 1	3 2.9	3 2.9	2 2	7 6.9	**27** **26.5**	**32** **31.4**	15 14.7	12 11.8
Changed pricing and promotional strategies.	9 8.8	8 7.8	5 4.9	2 2	13 12.7	8 7.8	25 24.5	20 19.6	12 11.8
Development of environmentally friendly products/services	6 5.9	16 15.7	13 12.7	9 8.8	5 4.9	7 6.9	6 5.9	**28** **27.5**	12 11.8

Q28. Based on the knowledge of nanotechnology at your organisation, do you think it would potentially be useful for any area of your business? (Try to please select as many options as applicable).

Respondents' views on the potential use of nanotechnology in their organisation	Number of positive respondents	% of positive respondents
Crop production (nanoformulated chemicals, smart sensors)	15	14.7
Animal production (fortification of animal feed, disease diagnostics)	21	20.6
Food processing (food ingredients/additives, nutrient delivery)	31	30.4
Food processing equipment (insulation, sanitisation)	30	29.4
Food packaging (sensors, antimicrobials)	35	34.3
Food safety monitoring	37	36.3
None	18	17.6
Others	1	1
Unsure/ don't know	4	3.9

Q29. As an organisation, how important are the following prior to the implementation of nanotechnology in your company? Using a 1-6 scale, how important are the following statements where 1 is very unimportant and 6 is not applicable.

Respondents views on the level of importance of the issues raised prior to the implementation of nanotechnology in their organisation (Total number & percentage)							
	Very unimportant	**Unimportant**	**Neutral**	**Important**	**Very important**	**Not applicable**	**No response**
More information and enhanced knowledge on nanotechnology.	4 3.9	-	11 10.8	23 22.5	47 46.1	5 4.9	12 11.8
Training from experts of nanotechnology.	4 3.9	-	20 19.6	28 27.5	33 32.4	5 4.9	12 11.8
Regulation of nanotechnology for food and related products (incl. risk assessment framework).	3 2.9	1 1	13 12.7	24 23.5	41 40.2	8 7.8	12 11.8
Adequate safety assessment on a case-by-case basis where nanotechnology alters existing products or processes.	4 3.9	-	11 10.8	28 27.5	41 40.2	6 5.9	12 11.8
More research into long term effects to human health.	2 2	-	9 8.8	15 14.7	57 55.9	7 6.9	12 11.8
Effective communication and collaboration among scientists, industry and government.	3 2.9	1 1	15 14.7	26 25.5	38 37.3	7 6.9	12 11.8
More resources, i.e., financial investment by external bodies.	1 1	2 2	26 25.5	28 27.5	28 27.5	5 4.9	12 11.8
Public engagement-identify consumer needs and wants.	1 1	2 2	14 13.7	27 26.5	38 37.3	8 7.8	12 11.8
Consumer perceptions of potential nanotechnology applications to help determine which applications to prioritise.	3 2.9	2 2	16 15.7	28 27.5	34 33.3	7 6.9	12 11.8

Appendix 11: Descriptive statistics for obstacles to the adoption of nanotechnologies amongst agri-food organisations

Q30. As an organisation do you foresee the application of nanotechnology in the agri-food sector increasing in the future?

Respondent Organisations views on whether the use of nanotechnology will increase in the future in the agri-food sector	Number of respondents	% of respondents
Definitely	30	29.4
Maybe	38	37.3
No	2	2
Unsure/ can't say	20	19.6
No response	12	11.8

Q31. Please indicate to what level you agree or disagree with the following as to what you consider to be the main obstacles to the implementation of nanotechnology at your organisation. Use a 1-6 scale where 1 is strongly disagree and 6 is not applicable.

Respondent views on the main obstacles to the implementation of nanotechnology within their organisation (Total number & percentage)							
	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree	Non-applicable	No response
Cost of nanotechnology implementation	2 2	-	28 27.5	27 26.5	26 25.5	7 6.9	12 11.8
Lack of information and knowledge	1 1	1 1	15 14.7	25 24.5	43 42.2	5 4.9	12 11.8
Availability of expertise	-	1 1	18 17.6	35 34.3	28 27.5	8 7.8	12 11.8
Time and long term value of nanotechnology	-	1 1	28 27.5	35 34.3	19 18.6	7 6.9	12 11.8
Need for risk assessment framework	-	1 1	17 16.7	32 31.4	33 32.4	7 6.9	12 11.8
Public acceptance of nanotechnology	-	1 1	18 17.6	21 20.6	44 43.1	6 5.9	12 11.8
Media perceptions	-	3 2.9	21 20.6	24 23.5	35 34.3	7 6.9	12 11.8
Unknown risks to human health and the environment	2 2	-	14 13.7	19 18.6	46 45.1	9 8.8	12 11.8

Q32. How much trust does your organisation place in the information you receive about nanotechnology from the following bodies? Using a 0-10 scale where 0 is do not trust at all and 10 is trust completely. Please select the appropriate option.

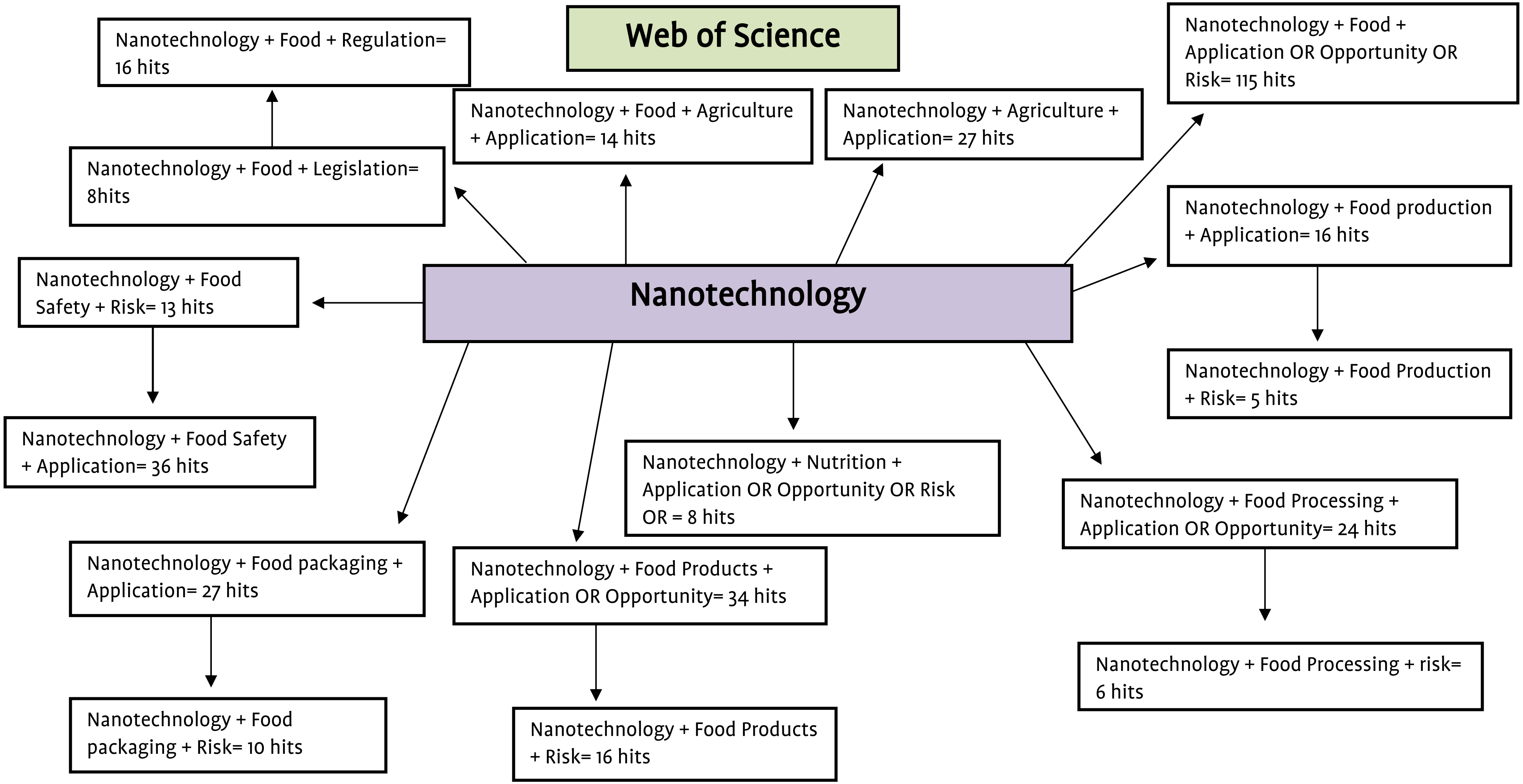
Trust in the information and Source (Total number & percentage)											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**No response**
Government agencies or regulators	4 3.9	3 2.9	5 4.9	5 4.9	12 11.8	14 13.7	11 10.8	**20** **19.6**	7 6.9	9 8.8	12 11.8
Agri-food industry associations	1 1	8 7.8	5 4.9	12 11.8	14 13.7	12 11.8	9 8.8	**15** **14.7**	7 6.9	6 5.9	13 12.7
Scientists	1 1	1 1	5 4.9	5 4.9	7 6.9	12 11.8	17 16.7	**21** **20.6**	10 9.8	10 9.8	13 12.7
Mass media	15 14.7	19 18.6	20 19.6	14 13.7	11 10.8	5 4.9	1 1	-	2 2	-	15 14.7
Non-government organisations	4 3.9	5 4.9	9 8.8	13 12.7	**25** **24.5**	14 13.7	7 6.9	6 5.9	3 2.9	2 2	14 13.7
Science institutes and organisations, e.g., universities	1 1	1 1	2 2	4 3.9	6 5.9	11 10.8	15 14.7	**26** **25.5**	15 14.7	7 6.9	14 13.7

Q33. Please rate the importance of the following to improving your organisation's knowledge base to encourage the adoption of new technologies. Use a 1-6 scale where 1 is very unimportant and 6 is not applicable.

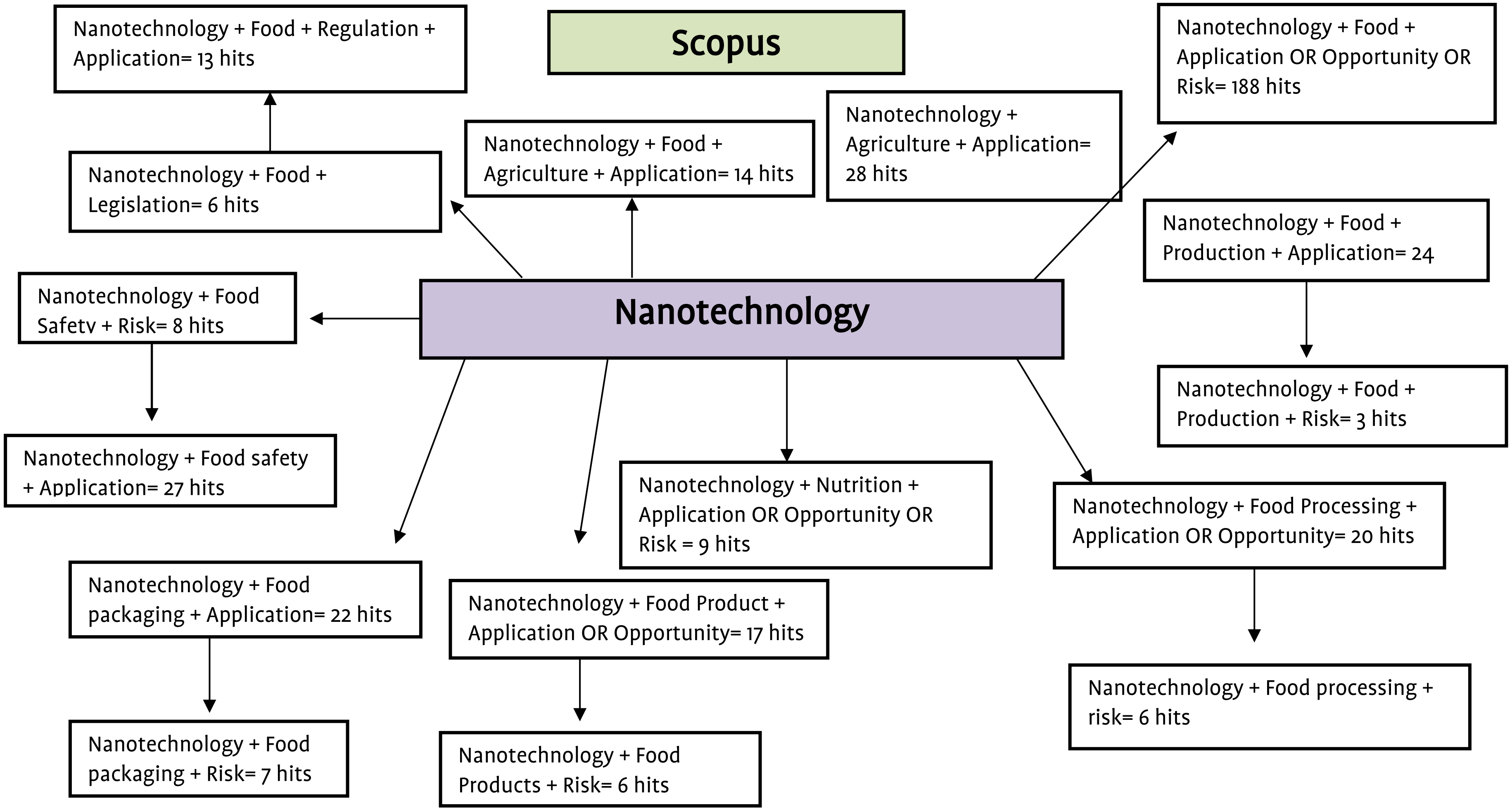
Respondents' views on the importance of the issues raised to improving their organisation's knowledge base to encourage the adoption of nanotechnologies (Total number & percentage)							
	Very unimportant	**Unimportant**	**Neutral**	**Important**	**Very important**	**Not applicable**	**No response**
Seminars/ training workshops	1 1	2 2	17 16.7	42 41.2	26 25.5	2 2	12 11.8
Training from nanotechnology experts	1 1	3 2.9	20 19.6	35 34.3	29 28.4	2 2	12 11.8
Better communication and information from government bodies	2 2	-	14 13.7	43 42.2	29 28.4	2 2	12 11.8
Better communication and information from scientific organisations	2 2	-	11 10.8	40 39.2	34 33.3	3 2.9	12 11.8

Networking with universities	2 2	2 2	20 19.6	34 33.3	28 27.5	4 3.9	12 11.8
Better communication throughout the company.	2 2	7 6.9	20 19.6	37 36.3	19 18.6	5 4.9	12 11.8
More technical experts in the company	2 2	12 11.8	24 23.5	31 30.4	16 15.7	5 4.9	12 11.8

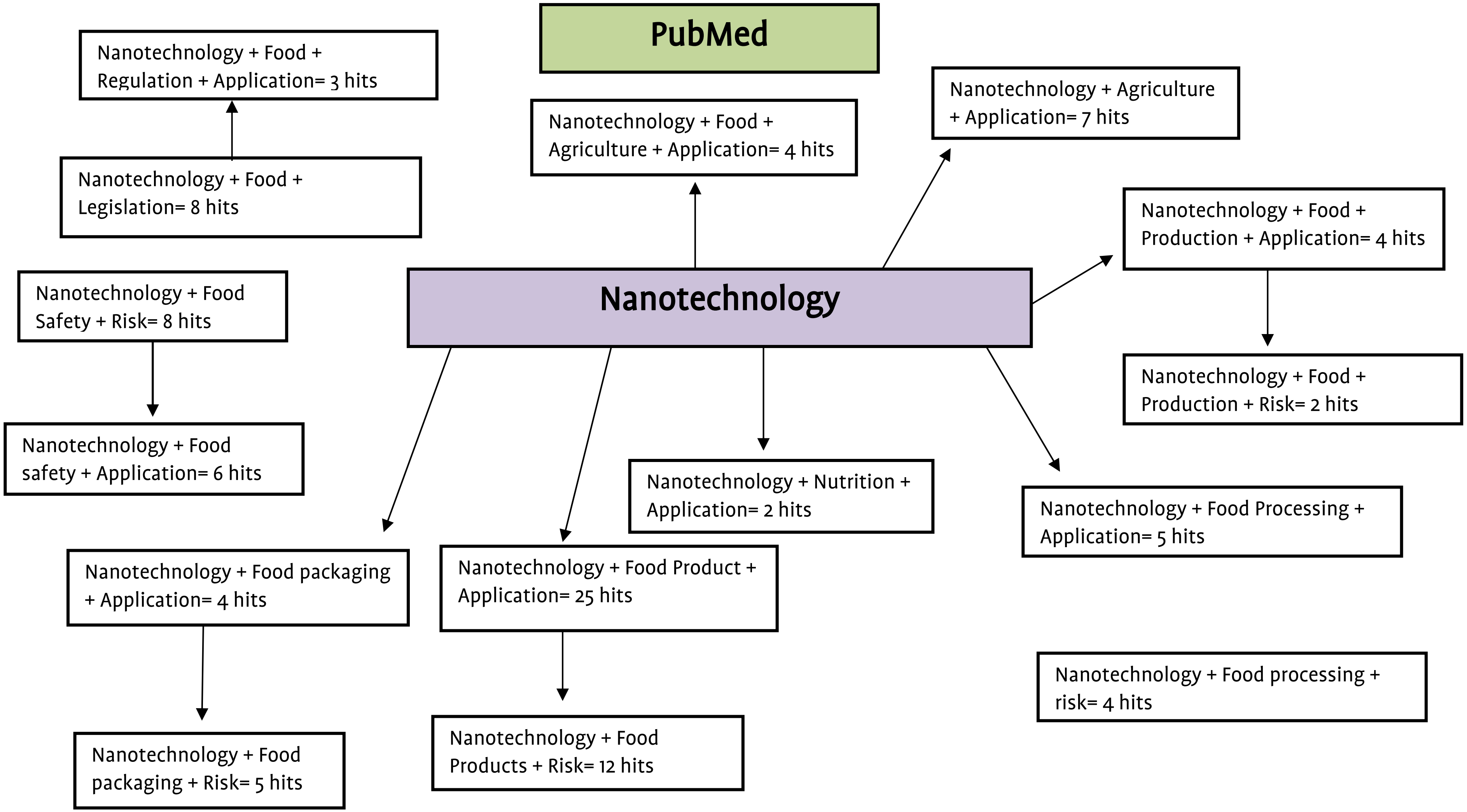
Appendix 12: Specific key word searches and number of hits provided when searching for journals in the Web of Science (ISI) database



Appendix 13: Specific key word searches and number of hits provided when searching for journals in the Scopus database



Appendix 14: Specific key word searches and number of hits provided when searching for journals in the PubMed database



Appendix 15: Study design of the 27 food nanotechnology (NT) studies included in this review

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
APPLICATION STUDIES					
Narrative review	Rashidi and Khosravi-Darani, 2011	-Reviews the application and benefits of NT in different areas of the food industry	- NT may develop devices for rapid identification of nutrient deficiencies (i.e., atomic force microscopy) and the presence of pathogens in food (nanosensors) - Numerous applications developed in many countries, including nano-based food additives, nanosensors, nanocapsules, nano-based smart delivery systems, nanopackaging, health care and medicine	-Good table providing a breakdown of the numerous applications of NT across all food sectors -Regulatory information for NT in food production is given	-No examples of nano-foods/nano-products on the market -Could have discussed applications in greater detail, i.e., the different types of nanopackaging
Narrative review	Momin et al., 2013	-Assesses the application of NT in functional food, with special attention to related regulatory issues	- Emerging applications of NT in the food sector include food antimicrobials, new food packaging materials, nanosensors for monitoring the condition of food, smart delivery of nutrients, bioseparation of proteins, rapid sampling of biological and chemical contaminants and nanoencapsulation of nutraceuticals	-Good overview of the various applications of NT in the food sector -Good use of examples of current nano-food products on the global market	-No aim in main article. -No recommendation for future research
Narrative review	Sozer and Kokini, 2009	-Reviews aspects of NT related to food quality and the development of smart foods and packaging materials, as well as the use of nanosensors for	- Promising results and applications in the areas of food packaging and food safety -Incorporation of nanomaterials (NMs) into food packaging is expected to improve barrier properties	-Very good introduction on NT and use in food industry -Addresses reasons for late incorporation into food sector -Use of diagrams to show NT	-Predominantly focussed on food packaging applications -No examples of companies producing nano-foods/nano

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		microbial and pesticide detection	-Edible nanolaminates can protect food from moisture, lipids, gases, off-flavours and odours -Natural biopolymers can be used for nanoencapsulation of vitamins -Nanosensors for microorganism and contaminant detection	applications in food sector	products currently on the market
Narrative review	Garcia et al., 2010	-Assesses applications of engineered nanoparticles (NPs) in the agri-food production chain.	- Potential applications in the areas of food packaging and food safety -Incorporation of NMs into food packaging can improve barrier properties, thus reducing the use of valuable raw materials -Development of nanosensors to detect microorganisms and contaminants	-Good source for an overview of the current and projected applications of NT across the agri-food sector -Good use of tables -Provides examples of nano-foods/nano products on the market	-No discussion on challenges associated with use of NT in agri-food sector, i.e., food sector, i.e., regulatory issues, health concerns, etc.
Narrative review	Khot et al., 2012	-Summarises the developments and applications of novel NMs in agriculture	-Applications of NT can aid faster plant germination/production and effective plant production -Nanosensors can be used to detect pesticide residues in the field -Further investigation is needed to expand application possibilities	-Detailed source of information for NT applications in agriculture -Good use of tables. -Identifies future research needs	-No initial drawbacks
Narrative review	Chaudhry and Castle, 2011	- Provides an account of the main issues emanating from applications of NT in	-The current level of application in the global food sector is relatively small -Nanocarrier systems for delivery of	-Very detailed table summarising the current and projected applications in the agri-food sector, includes	-No defined aim in the main article -Mainly focussed on food industry

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		food and related sectors, with a particular reference to developing countries	nutrients and supplements -Nanotextured food products with fat reductions -Food packaging with improved barrier properties and antimicrobial properties -Nanosensors for food labelling -Nanosized agrichemicals (i.e., fertilisers and pesticides)	benefits and risks -Examples of some nano-foods/nano products in the research and development (R&D) stage or currently available on the market	applications
Narrative review	Chen and Yada, 2011	-Highlights some of the most promising and important NT applications in agriculture	- Promising applications in agriculture, i.e., improvements to precision-farming techniques through smart delivery systems and wireless nanosensors - NT also has potential benefits for animal production i.e., improved feeding efficiency and nutrition - Most applications in agriculture are at the R&D stage	- Good source of information for potential applications of NT to agriculture-Recommends strategies for advancing the best scientific and technical knowledge presently being examined	-Conclusion doesn't summarise key findings, but rather expands aims of the article
Narrative review	Sekhon 2010	Provides an overview of the application of NT in the food industry	-Main area of application includes food packaging and food products containing nanosized or nanoencapsulated ingredients and additives -Many applications are currently at an elementary stage, and most are aimed at high-value products	-Good source of information on potential applications throughout the food sector	-No defined aim in the abstract and main article
Narrative	Durán and Marcato,	- Examines the	- Development of nanosensors to	-Highlights the vast potential	-Could have provided

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
review	2013	application and the benefits of NT in different areas of the food industry	detect pathogens and pesticides in food -Nanobiosensors can be applied in environmental pollution control in the food industry. -Functionalised food with NPs as flavour and nutrient carriers can enhance food quality and safety	of NT in food packaging in particular -Identifies needs for future research to produce better and safer products	information on current regulations
Narrative review	Ditta, 2012	- Reviews some of the potential applications of NT in the field of agriculture -Recommends strategies for the advancement of scientific and technological knowledge	- Advancement in NT has enabled a number of techniques for the improvement of precision farming -Nanoscale carriers for the efficient delivery of agrichemicals (i.e., pesticides). -Wireless nanosensors to monitor crop growth and field conditions	-Well-structured review article -Very good source for overview of applications in agriculture	-Conclusion is very similar to abstract. Could have summarised key findings. - No defined aim in the main article
Narrative review	Silvestre et al., 2011	Examines the latest innovations in food packaging and discuss the limits to the development of the new polymer NMs	-Applications for polymer NMs can provide new food packaging materials with improved mechanical, barrier and antimicrobial properties, together with nanosensors for tracing and monitoring the condition of food during transport and storage	-Very good source of information for NMs in food packaging -Definition of active, intelligent/smart and improved packaging	-No initial drawbacks
Narrative review	Ileš et al., 2011	- Describes the potential and current NT application in food, as well as their potential impact on	-NT treatment and materials are already used in some food packaging and in food contact materials -Application of NT allows better delivery of functional ingredients and	-Good review of potential uses and benefits of NT for food applications	No conclusion though article ends with current and future developments

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		human body and the necessity to bring in future nano-food regulation	nutrients, increases food safety and extends product life		
Narrative review	Alfadul and Elneshwy, 2010	-Focusses on the use of NT in food processing and packaging with special attention to their reflection on food quality and safety	-NT has potential in all aspects of the food sector including food processing, food packaging, food monitoring, production of functional foods, modified foods with improved nutritional properties and flavours -Need for regulation of NMs before their incorporation into food	-Provides good examples of current nano-foods and nano products on the global market	-No defined aim in the main article -Short conclusion
Narrative review	Restuccia, 2010	-Presents work regarding the new legal aspects introduced by the recent Regulation European Commission (EC) 450/2009 considering also the global market of active and intelligent packaging applied in food and beverage sector	-Regulation 1935/2004/EC and Regulation 450/2009/EC pose new basis for the general requirements and specific safety and marketing issues related to active and intelligent packaging - European Union (EU) regulations are important for food safety and transparency to consumers	- Provides definition of active and intelligent packaging -Examples of packaging applications within the food industry -In depth discussion of EU regulations	-No defined aim in the abstract
Narrative review	Chaudhry et al., 2008	-Reviews the current and projected NT derived food ingredients, food additives and food contact materials in	-The current level of application in the food sector is at an elementary stage, but is expected to grow worldwide. -Most future applications of NT for food are likely to be for high- value products, in particular food packaging	-Very comprehensive overview of applications of NT in the food sector	-Lengthy conclusion

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		relation to potential implications for consumer safety and regulatory controls	and nanocarrier systems for nutritional supplements and nutraceuticals		
Narrative review	Grobe and Rissanen, 2012	-Provides an overview of possible applications of NT in agriculture, food and materials used for food processing and packaging -Developments in risk assessment and regulation are discussed	-Applications in agriculture: nanosensors for monitoring environmental conditions, plant and animal health, novel delivery systems for pesticides, genetic engineering of plants and livestock -Applications in food: nanostructured food ingredient, nanodelivery systems for nutrients and supplements, organic and inorganic nanosized additives for food, health food supplements and feed applications, food packaging, nanosensors for food labelling	-Considers applications in the entire agri-food sector -Discusses definitions of NT and NMs	-No conclusion -Aim in the main article is quite longwinded. -Applications not discussed in great detail
OPPORTUNITY STUDIES					
Narrative review	Rashidi and Khosravi-Darani, 2011	-Reviews the application and benefits of NT in different areas of the food industry	-The potential of NT makes it suitable for developing countries as these countries could potentially engage in new markets for new NMs and production processes -NT enables changes in existing food systems and processing to ensure product safety, creating a healthy food culture and enhancing the nutritional value of food	-Considers benefits of using NT in food to developing countries	-Mainly focussed on applications.

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
Narrative review	Chaudhry and Castle, 2011	-Provides an account of the main issues emanating from applications of NT in food and related sectors, with a particular reference to developing countries	-NT in the food sector offers many benefits to developing countries, as to developed nations -More efficient food production methods -More hygienic food/feed processing -Novel food products with improved tastes, flavours, texture, and nutritional properties -Shelf life extension of food products -Smart labelling to ensure food authenticity, safety, and traceability -Innovative lightweight, stronger, functional packaging	-Discussion of opportunities for developed and developing countries	-No defined aim in the main article. -Could have discussed opportunities for developing countries in greater detail.
Narrative review	Meetoo, 2011	-Provides an overview of NT and its potential application in agriculture and food systems	-Applications of NT in agriculture and food systems have great benefits to society - Promising results being developed in such areas as food packaging and food safety -Incorporation of NPs into food packaging can improve barrier properties, thereby helping to reduce the use of valuable raw materials and the generation of waste	-Good definition of NT -Use of tables to show opportunities of NT across the entire agri-food sector -Examples of food companies currently applying NT in their products	-No aim in the abstract.
Narrative review	Ravichandran, 2010	-Assesses the developments in NT and their applicability	- Successful applications of NT to foods are still limited, but an emerging area.	-Very good source of information for an overview of	-No defined aim in the main article.

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		to food and nutraceuticals systems	- Most aspects of NT are likely to enhance product quality, choice and food safety. -The success of these advancements will depend on consumer acceptance and the exploration of regulatory issues	NT in the food sector - Good use of examples of current applications of NT in food	
Narrative review	Sekhon, 2010	Provides an overview of the application of NT in the food industry	-NT can be used to enhance food flavour and texture, to reduce fat content or to encapsulate nutrients, such as vitamins, to ensure they do not degrade during a product's shelf life -NMs can be used to make packaging that keeps the product inside fresher for longer -Intelligent packaging containing nanosensors can provide consumers with information regarding the state of the food inside	-Benefits of use of NT to the whole food sector addressed -Provides a wide range of examples of opportunities	-No defined aim in the abstract and main article
Narrative review	Momin et al., 2013	-Assesses the application of NT in functional food with special attention to related regulatory issues	-Use of NT to manufacture processed foods with enhanced processing, health and packaging functionalities, flavour, texture, shelf life, transportability, reduced costs and nutritional traits, which will facilitate the expansion of the range, quality and quantity of processed foods -Also enables the development of food safety and food quality aspects	-Good examples of current nano-food products on the global market	-No aim in main article -No recommendation for future research

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
Narrative review	Sonkaria et al., 2012	-Discusses the recent innovations of nano-based food technologies, future trends and the impact on the food industry	- Globally, nations will profit from increased food productivity -NT can be used in food products to enhance bioavailability of nutrients and prevent diseases. Intelligent packaging systems provide better food protection	- Aim well addressed -Good table providing an overview of applications in the entire food chain -Good discussion of current and future developments in food NT	-Could have provided examples of current nano-foods on the market
Narrative review	Cushen et al., 2012	-Reviews recent developments in NT in the food sector -The manufacture of NMs, their uses, applicable legislation and associated risks are discussed	-NT has the potential to enhance companies' product ranges and expand their geographical market boundaries -Beneficial applications to the food industry include improved supplements, novel packaging and targeted crop pesticides -Benefits to developing countries, especially in the area of increased agricultural productivity, improved food and water safety and nutrition	-Discusses opportunities for developing countries	-No initial drawbacks
Narrative review	Bradley et al., 2011	-Describes the science and technology developments made towards applications of NMs in food packaging materials	-NT could have real relevance to the needs of poor people in developing countries. For instance, incorporating active packaging ingredients into bulk packaging could be used to reduce the post-harvest spoilage of food by moulds and fungi that produce mycotoxins	-Considers opportunities and benefits of food NT in developing countries	-No initial drawbacks

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
Narrative review	Kuan et al., 2012	-Examines the use of biopolymers in the production of NMs and the propensity of NT in food and bioactives	-The advancement in NT is beneficial to food and nutraceutical manufacturers and consumers in terms of resources, costs, and functional and nutritional requirement	-Good use of diagrams -Very detailed information on the various potential applications and opportunities in the food sector	- No examples of food companies employing nanotechnology in their products
RISK STUDIES					
Systematic review	Kuzma et al., 2005	-Evaluates the technological products of agri-food NT that are soon to be on the market -Considers oversight issues and risk issues of each individual application	-Current regulations are not adequate to oversee products of NT -key stakeholders should have more direct and active inclusion at various stages of risk analysis and policy evaluation -Issues with information provided to consumers of nano products given lack of labelling requirements -Consumers should be informed in areas of uncertainty such as risk assessment	-Upstream oversight assessment approach taken -Identifies research and information needs as well as larger regulatory and oversight issues associated with use of NT in agri-food sector	-Case studies in the US
Systematic review	Cockburn et al., 2012	-Provides practical guidance to inform scientists on how to address potential safety issues if new food products resulting from the application of nanoscience and NT are developed	-Standardised definition of engineered NMs needed for regulatory purposes -Systematic approach to safety assessment of engineered NMs for use in foods -The safety testing strategy is considered applicable to variations in engineered NM size	-Systematic approach to safety assessment of NMs in foods -A decision tree used to identify engineered NMs needing nano-specific safety assessment -Further testing follows a	-No initial drawbacks

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
			-Recommends use of validated OECD toxicological testing methodologies combined with focused, standardised *in vitro* studies	tiered approach for subsequent hazard identification and characterisation	
Narrative review	Bouwmeester et al., 2009	-Provides an overview of scientific issues that need to be prioritised in order to improve the risk assessment for NPs in food	-Scientific knowledge gaps hinder current risk assessment of application of NPs in food -For regulatory purposes, there is a need for a strict definition of NPs -Need to establish dose metrics -Development of analytical tools for the detection and characterisation of NPs in food matrices -Need for toxicological assessment of NPs	-Very good review of the scientific issues -Addresses issues to improve the existing risk assessment methodology, good governance and regulatory framework of the application of NT within food	-No conclusion
Narrative review	Cushen et al., 2012	-Reviews recent developments of NT in the food sector -The manufacture of NMs, their uses, applicable legislation and associated risks are discussed	-Need to address regulatory issues before adoption -Risk assessment, exposure assessment and risk management urgently required for existing products available on the global market -Existing uncertainties regarding toxicity, behaviour and bioaccumulation of NMs have implications for effective regulation	-Good background into applications of food NT -Very in depth discussion of risk assessment including potential health risks, exposure routes and toxicological effects -Addresses regulatory issues	-No initial drawbacks
Narrative review	Han Wei et al., 2011	-Summarises the research literature,	-Technical applications include nano-composite food packaging, which	-Identifies current problems hindering the success of NT in	-No defined aim in the abstract

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		scientific reports and resources of the internet on the applications of NMs in food packaging, as well as its risk assessment	combines the NMs and conventional packaging, is at the forefront of applications in NT -Limited scientific data on migration, exposure sources and toxicities indicate the difficulties and problems in properly understanding the nature of NPs -Need to develop an understanding of toxicity following oral intake of a wide range of NMs for which there is likely human exposure	food applications -Makes recommendations for future research	-Could have discussed regulatory issues in detail -No conclusion in the main article
Narrative review	Ileš et al., 2011	- Describes the potential and current NT application in food, as well as their potential impact on human body and the necessity to bring future nano-food regulation	-Increased nano-food applications can lead to health risk for consumers. - Limited knowledge on NPs impact on the human body. -Consumers will ultimately dictate the success of NT food applications	-Stresses the importance of new scientifically-based regulations to define usage of food NT	No conclusion, although article ends with current and future developments
Narrative review	Magnuson et al., 2011	-Determines the current state of knowledge regarding the safety of the potential uses of NMs	-Food NT is a continuously growing area of research with great potential -Toxicological literature on oral exposure to food-related NMs is limited -Need for further research on food-related applications and human health impacts	-A method of assessment of reliability of toxicology studies was developed for the review -Identifies need for further research and studies on food-related applications and human health impacts	-Could have provided introduction into NT -No defined aim in the main article

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
			-Such research will continue to advance NM-specific detection and measurement tools, and well-designed safety studies of NMs with adequate characterisation will provide additional information		
Narrative review	Momin et al., 2013	-Assesses the application of NT in functional food with special attention to related regulatory issues	-NMs incorporation into foods presents new risks to the public. -Existing laws are inadequate to assess risks posed by nanobased foods and packaging as: toxicity risks remain very poorly understood and current exposure and safety methods are not suitable for NMs	-Addresses gaps in knowledge regarding health risks to humans -Need for improved regulation of NMs in food applications	-No aim in main article -No recommendation for future research
Narrative review	Silvestre et al., 2011	Examines the latest innovations in food packaging and discuss the limits to the development of the new polymer NMs	-Limited information available in relation to aspects of toxicokinetics and toxicology -Limited knowledge of current usage levels and likely exposure from possible applications and products in the food sector -Public acceptance will determine the success of nano-foods/nano products	-Consumer perception is important for the success of NT in food applications -Detailed information on regulatory issues -Identifies gaps in knowledge regarding environmental and health impacts	-No initial drawbacks
Narrative review	Bradley et al., 2011	-Describes the science and technology developments made towards applications of NMs in food packaging	-Limited understanding on how to evaluate the potential hazard of NMs by food -Lack of tools to use to estimate exposure to humans -Limited knowledge on the impact of	-Identifies needs for future research	-No initial drawbacks

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		materials	NMs on the environment such as in waste disposal streams		
Narrative review	Chaudhry Q et al., 2008	-Reviews the current and projected NT derived food ingredients, food additives and food contact materials in relation to potential implications for consumer safety and regulatory controls	-Lack of information regarding potential health risks from consumption of nano-foods -Uncertainties and lack of knowledge will cause public concern -Need for an effective regulatory framework to ensure safe products on the market	-Addresses issues and concerns dictating future success of NT in food applications	-Lengthy conclusion
Narrative review	Chaudhry and Castle, 2011	- Provides an account of the main issues emanating from applications of NT in food and related sectors with a particular reference to developing countries	- Gaps in knowledge regarding the properties, behaviour and effects of NMs -Need for consideration of the safety of the products to the consumer health and the environment -Need for pragmatic regulatory oversight in some developing countries	-Identifies areas of application of most concern -Addresses current gaps in knowledge, identifying future research needs	-No initial drawbacks.
Narrative review	Kuan et al., 2012	-Examines the use of biopolymers in the production of NMs and the propensity of NT in food and bioactives	-Need for regulatory agencies to provide clear guidelines and regulations in applications of NMs -Assessment of toxicological impacts to humans and environment	-Detailed overview of safety assessment and challenges -Good diagram showing exposure routes and types of nanotoxicity in humans	-Could have discussed global regulations in greater detail
Narrative review	Grobe and Rissanen, 2012	-Provides an overview of possible applications	- Deficiencies in characterisation, detection and measurement of NMs	-Identifies gaps in scientific knowledge in relation to	-No conclusion -Aim in the main article

Type of Study	Reference	Aims	Authors' Conclusions	Strengths	Limitations
		of NT in agriculture, food and materials used for food processing and packaging -Developments in risk assessment and regulation are discussed	in food -Limited information on toxicokinetics and toxicology. -Limited knowledge on exposure assessment -EU have recommended a wide definition for NMs	health risks associated with NMs -Addresses the need for more toxicology studies for risk assessment	is quite longwinded -No information provided on current regulations in EU or worldwide

Abbreviations: EC, European Commission; EU, European Union; NMs, nanomaterials; NPs, nanoparticles; NT, nanotechnology; R&D, research and development.

Appendix 16: Stakeholder conference

Nanotechnology in the agri-food industry: Applications, opportunities & challenges

9th January 2014

Teagasc Food Research Centre, Ashtown, Dublin

Presented by ***safefood***, the Institute for Global Food Security, Queen's University Belfast, and Teagasc Food Research Centre

Background:

The Guardian recently captioned an article "**Nanotechnology in food: more than a question of taste**" whereby the use of nanotechnology in food was debated. Nanotechnology has emerged as a technological advancement that has the potential to develop and transform the entire agrifood sector, offering opportunities to increase global food production, in addition to the nutritional value, quality and safety of food and reduce waste. Though there is concern over safety and regulation of emerging technologies in addition to negative public opinion as in the case for GMOs which may prevent its uptake by the agri-food industries.

This workshop is dedicated to raising awareness of the potential applications of nanotechnology in the agri-food sector (including feed & food ingredients, intelligent packaging and clever detection systems), examining factors influencing consumer acceptance and improving understanding of the potential impacts of nanotechnology across the agri-food sector on the island of Ireland.

Invited speakers include international scientific experts and stakeholders:

Prof. Lynn Frewer, Professor of Food & Society, School of Agriculture, Food and Rural Development University of Newcastle, UK

Dr Frans Kampers, Co-ordinator of innovation Technologies & Director of BioNT, Wageningen biotechnology centre for food and health innovation, Netherlands

Dr Patrick O'Mahony, Food Safety Authority Ireland, Dublin

Dr Maeve Henchion, Teagasc Food Research Centre, Ashtown

Dr Mary McCarthy, Department of Food Business and Development, University College Cork

Dr Olivia McAuliffe, Senior Research Officer, Teagasc Food Research Centre, Co. Cork

Ms Caroline Handford, Institute for Global Food Security, Queen's University Belfast

Attendance at the workshop is free

Please register with katrina.campbell@qub.ac.uk

Nanotechnology in the agri-food industry on the island of Ireland: applications, opportunities and challenges

9th January 2014 at Teagasc, National Food Centre, Ashtown, Dublin

CONFERENCE PROGRAMME

08:45 - 09:00	Registration and arrival refreshments
09:00 - 09:10	Welcome address Dr James McIntosh, *safefood*
	Meeting Chair: Prof Chris Elliott, Institute for Global Food Security, Queen's University Belfast
09.10 - 09.40	Societal acceptance of nanotechnology Prof Lynn Frewer Newcastle University
09:40 - 10:05	State of play on European regulations for the use of nanotechnology in food and feed Dr Patrick O'Mahony Food Safety Authority Ireland Dublin
10:05 – 10:30	Examples of nanotechnologies in the Agri-food sector Dr Frans Kampers Wageningen UR
10:30 – 10:50	Phage-derived nanomaterials: Applications in food and medicine Dr Olivia McAuliffe Teagasc, Cork
10:50 – 11:10	Use of nanosensors to monitor food safety Dr Katrina Campbell Institute for Global Food Security, Queen's University Belfast
11:10 – 11:30	Coffee Break
11.30 - 11.50	Industry's awareness and perceptions of nanotechnology in the agri-food sector on the island of Ireland. Caroline Handford Institute for Global Food Security, Queen's University, Belfast
11.50 - 12.10	What do we know about Irish consumer acceptance of Novel Food Technologies? Dr Mary McCarthy University College Cork
12:10 - 12.30	Nanotechnology: consumer perceptions and factors influencing acceptance Dr Maeve Henchion Teagasc, Ashtown
12:30 – 13:00	Opportunities & challenges of nanotechnology for the agri-food industry Discussion /Horizon scanning Session Chair: Dr Moira Dean
13:00 – 14:00	Lunch and networking
14:00	Close the meeting

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