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Big issues for a small technology: consumer trade-offs in acceptance of nanotechnology in food

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Abstract

Nanotechnology offers many potential applications across the supply chain which could result in a more sustainable agriculture and food system. However, considerable challenges still exist in realising its potential, including consumer acceptance. This research examines consumer perspectives on two different nanotechnology applications (in packaging for chicken fillets and in cheese) using conjoint analysis. A face-to-face survey of 1,046 Irish adults was undertaken. It finds that technology has a significant impact on consumer food choices (higher levels of acceptance with traditional technology rather than nanotechnology), that different applications of a technology can result in varying levels of acceptance (higher acceptance for nanotechnology in packaging of chicken fillets rather than in the cheese product) and that offering salient benefits (e.g. health or lower price) can off-set technology concerns in some but not all instances. Differences amongst consumer segments also exist with price having low utility for “health focused consumers” but having high utility for “conventional consumers”.

Industrial relevance

This research provides industry with an overview of consumer perceptions around two potential nano-inside and nano-outside product applications elicited through a nationally representative quantitative survey (n=1,046). The results from this work can contribute to the development of a research commercialisation strategy that will yield products and processes of value to consumers, and thus will have greater likelihood of acceptance. Moreover, this work points to the need to involve consumers at an early stage in the product development process and in considering potential commercialisation pathways, particularly with regard to food production where consumers may be especially sensitive or risk-averse. Appreciating the concerns and preferences of consumers and eliciting their overall level of acceptance with regard to particular technologies and product applications is crucial for their success.

Key words: nanotechnology, consumer acceptance, sustainability, agriculture and food, conjoint analysis

1. Introduction

Much has been written about the so-called *"grand challenge"* of sustainably increasing global food production in the face of growing concerns around resource use and the environmental impact of agriculture. The situation is nuanced; the ability to produce food for a growing global population (estimated to be nine billion by 2050) is complicated by existing pressures around, for example, food security, food waste, malnutrition and obesity. Recent technological innovations have resulted in considerable structural change within agriculture and a general intensification in global food production. Similarly, the further advancement of science and technology can help address the numerous challenges currently facing sustainable agriculture and food systems (Scott et al., 2018).

Emerging technologies, such as nanoscale science and nanotechnology, have been demonstrated to have great potential in this context (Rossi et al, 2014; Chen & Yada, 2011). Nanotechnology is recognised by the European Commission as one of its six *''Key Enabling Technologies''* that contribute to sustainable competitiveness and growth in several industrial sectors (Parisi et al., 2015) and is compatible with a number of UN Sustainable Development Goals (Bakker et al., 2016), including Good Health and Well-being (Goal 3), Clean Water and Sanitation (Goal 6), Responsible Production and Consumption (Goal 12) and Climate Action (Goal 13)The purported benefits of nanotechnology to agriculture are multi-faceted, offering amongst other things, the potential to *"develop and transform the entire agri-food sector"*, to *"increase agricultural productivity, food security and economic growth for industries"* (Handford et al., 2014, p226) and to improve the nutritional value, quality and safety of food (Mousavi & Rezaei, 2011).

As with any emerging technology, it is important to clarify what it actually involves, particularly if it is to be used in the production of food. Furthermore, the definition and classification of nanotechnology is important, as it can be used to identify materials for which special provisions (concerning for example risk assessment or ingredient labeling) might apply, i.e. specific legislation may be developed in which the definition will be used. At its simplest, nanotechnology is often defined in terms of size, e.g. from 100nm down to the atomic level of approx. 0.2nm (de Francisco & García-Estepa, 2018). It can also be defined by method of production, with a distinction made between natural nanomaterials (e.g. ocean spray, casein micelles, lactose (Handford et al, 2014)) and engineered nanomaterials. The latter are further divided into those that are manufactured using a bottom-up approach (whereby individual components self-assemble using physical and chemical techniques, e.g. crystallisation) and a top-down approach (involving mechanical-physical particle production processes such as milling and homogenisation (Ravichandran, 2010)). Structure (e.g. tubes, spheres, etc.) serves as a useful distinction, as it can provide an indication of the likely properties of the material in question; the United States Environmental Protection Agency classifies engineered nanomaterial according to the physical arrangement of the material and their chemical composition (de Francisci & García-Estepa, 2018).

Nanotechnology applications in the context of food or feed may also be classified as nano-inside whereby the product is ingested by the target (e.g. human or animal) or nano-outside e.g. packaging (Siegrist et al., 2008). It should be noted that the European Commission's (2011) regulatory definition of nanotechnology is subject to review in light of future market development *(European Commission, 2018).* At present, nanotechnology is defined as *"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 1nm - 100nm"*. It is clear that the technology is a multidisciplinary science, encompassing chemical and material engineering, biotechnology and industrial processing technology and the range of potential applications for nanotechnology is vast (Handford et al, 2014; EFSA, 2009).

As an emerging technology, there remain considerable knowledge gaps relating to, for example, the impact of nanotechnology on human and environmental health, as well as on agricultural production (Erdem, 2018). Likewise, some concern exists relating to industry and consumer acceptance of the technology, both of which are crucial to its success (Rossi et al, 2014), and certain social, political and ethical issues of relevance have not yet been full explored (Siegrist et al., 2009; FAO/WHO, 2012, Bajpai et al., 2018; Patra et al., 2018; Scott et al., 2018; Zhou & Hu, 2018). Furthermore, the continued development of regulatory frameworks relating to the technology is required (FAO/WHO, 2012) and cost and scale-up challenges also exist (Kim et al., 2017).

Following on from the brief description of the technology above, this paper outlines some of the current applications of nanotechnology in the agri-food sector. It then provides an overview of consumer perceptions around two potential nano-inside and nano-outside product applications elicited through a quantitative survey (n=1,046), the results of which can contribute to the development of a research commercialisation strategy that yield products and processes that provide value to consumers, and thus will have greater likelihood of acceptance. The paper contributes to the literature that examines public acceptance of nanotechnology (e.g. Cobb & Macoubrie, 2004; Siegrist et al., 2009) which is seen as crucial to ensure *"smooth transitioning of these techniques"* to industry (Zhou & Hu, 2018, p220) and indeed the market, and is the ultimate barometer of success for innovative technologies such as nanotechnology.

2. Current and potential applications of nanotechnology

The potential benefits of nanotechnology are widely recognised as evidenced by the significant growth in public and private expenditure on research and development relating to the technology, the increased interest and research activity by academics, larger governmental and agency financial support and conceptual backing, and the rise in media attention surrounding the technology (Chen & Yada, 2011; FAO/WHO, 2012; Handford et al., 2014; Kim et al., 2017; Dudefoi et al., 2018; Scott et al., 2018; Zhou & Hu, 2018). Indeed, there has been a ten-fold increase in the number of patent applications from nanotechnology in the last two decades (Kim et al., 2017), in addition to several commercial applications in agriculture and food processing, with many more at various stages of development (Duncan, 2011; Handford et al., 2014; Chaudhry et al.,2017; Scott et al., 2018; Zhou & Hu, 2018). While a crowdsourcing platform seeks to document consumer products that use nanotechnology in the global market (Vance et al., 2015), and has identified 1,831 products in 2018 with 118 categorised as *"food and beverage"*[1], a number of factors contribute towards it being difficult to determine the extent to which nanotechnology is actually applied in the industry. These factors include: (1) the lack of any legal requirement to declare the use of such ingredients on

[1] The Nanotechnology Consumer Products Inventory: http://www.nanotechproject.org/cpi, accessed 24/10/18

product labels (despite policy debates about this in the EU and US (Chuah et al., 2018)); (2) industry reluctance to talk about research in this area (Davies, 2010); and, (3) all nano-products not necessarily being consumer products.

Figure 1 identifies a wide range of applications that are applicable across all points in the food supply chain from production through to consumption. It draws upon a 4-category classification for nanotechnology consumer products, as suggested by Duncan (2011) and de Francisco and García-Estepa (2018), i.e. agriculture/primary production, food processing, food packaging and food/nutrient supplements, but uses a wider 5-category classification based on Handford et al. (2014) which has an additional category related to food safety. In Figure 1, this 5th category has been re-labelled as "food safety and quality", since it encompasses technologies which are related to the food manufacturing process but are not actually part of processing operations. These categories are elaborated on briefly in turn.

[Insert Figure 1 here]

Primary production: Nanotechnology has application in crop and animal production systems (Chen & Yada, 2011), as well as in broader environmental systems. It can be used to monitor and control soil cultivation conditions, observe crop growth and field conditions, reduce the need for pesticides, enhance nutrient utilisation, prevent, diagnose and treat animal diseases, and eliminate toxic pesticide residues and absorb environmental pollutants (Handford et al., 2014; Kim et al., 2017; de Francisco & García-Estepa, 2018; Scott et al., 2018). Sensor-based applications are envisaged to aid decision-making by farmers by providing real-time data. Moreover, applications in this area present significant environmental benefits alongside productivity and efficiency gains, food security and human health gains. While there are few examples of commercially available products, due to low returns in the agricultural sector inhibiting research and development and the high production costs of nano-enabled products (Kim et al., 2017), nanoscale active ingredients in pesticides are commercially available, e.g. Primo MAXX® by Syngenta (Agrawal & Rathore, 2014). Formulations that offer an opportunity to replace petroleum by-products in agrochemicals with biodegradable nano-composite materials based on biopolymers (e.g. chitin, starch and cellulose) are also being investigated to improve agricultural sustainability (Chen & Yada, 2011; Kim et al., 2017). Post-harvest processing, which results in value-added products from industrial and agricultural waste, is an emerging area of research, presenting opportunities to bring circularity to agricultural production processes and help to mitigate global climate change (Chen & Yada, 2011; Kim et al., 2017).

Food processing: Nanotechnology has many functional applications in food processing, including nanoencapsulation of flavours and aromas, and nanoemulsions to improve flavours, aromas, textures and consistency (Cushen et al., 2012; Chaudry et al., 2017). Such applications may result in products with improved health attributes without compromising on sensory characteristics, e.g. low fat mayonnaise which is as creamy and flavoursome as conventional alternatives (Sekhon, 2010) or they may more simply mask undesirable odours and flavours from healthy ingredients such as fish oils (Handford et al., 2014). The latter has found commercial application in a bread product with enhanced levels of omega-3 in Australia. Nanofiltration offers the potential to develop products which are similar to their fresh equivalents with less processing, e.g. orange juice. Nanofiltration is currently used in the dairy industry for whey concentration, lactic acid separation and lactose recovery (de Francisco & García-Estepa, 2018). The nanomaterial titanium dioxide is widely used in commercially available food and beverages by companies such as Nestlé, Coco Cola, Kelloggs and Unilever as a whitening and brightening additive (Handford et al., 2014). Nanotechnology can also enhance processing operations, e.g. it can be applied as an anti-caking agent, a functionality which has value for granular or powdered processed foods (Alfadul & Elneshwy, 2010). The thermal insulating properties of some nanomaterials (e.g. nansulate) also enable processors to reduce heat loss and lower their energy costs.

Nutrition: Nanotechnology in this area aims to produce foods that have better quality, safety and nutritional value at a lower cost (Handford et al., 2014). A number of applications support this aim, e.g. nanosizing food ingredients and additives to achieve greater efficacy in addressing certain nutrient deficiencies and treating chronic diseases, nanotechnology based nutrient and supplement delivery systems (nutraceuticals), and microencapsulation of nutrients and supplements to enhance their sensory characteristics or to protect bioactive compounds and enhance their stability (de Francisco & García-Estepa, 2018). The German company Aquanova produces NovaSOL: this is a product which uses a nano-carrier system to encapsulate two active substances for fat reduction and satiety, thus functioning as a weight management solution for consumers (Alfadul & Elneshwy, 2010). New research has identified the potential of nanoemulsions to trigger the “ileal brake” - the mechanism that controls satiety - so that, for example, people will be able to consume low-fat ice cream with the same sensory properties as full-fat ice cream, and feel full (Davies, 2010).

Packaging: Nanotechnology can influence the barrier and mechanical properties of food packaging, (affecting for example gas and water vapour permeability), thereby offering potential for improved food safety, shelf-life extension and reduced packaging (Chaudhry et al., 2017). For example, nano-ZnO has been applied to packaging to improve the shelf-life of fresh-cut apples (Bajpai et al., 2018). Aluminium nanoparticles can also protect against ultraviolet radiation (de Francisco & García-Estepa, 2018). Furthermore, nanotechnology can have antimicrobial properties that protect the food from food spoilage and pathogenic microorganisms (Duncan, 2011). Chitosan, silver, zinc oxide, magnesium oxide and titanium dioxide are the most common nanoparticles used for their antimicrobial properties (de Francisco & García-Estepa, 2018). A wide range of nanoparticles are being investigated to support active and intelligent packaging, including oxygen absorbers and smart labels (Dudefoi et al., 2018; de Francisco & García-Estepa, 2018) and biosensors have been developed to detect food borne pathogens, food spoiling materials and allergens (Bajpai et al., 2018). These applications can contribute to reducing food loss, with environmental as well as economic benefits.

Food safety and quality: Chemical contaminants, microbiological hazards and pathogens are of significant concern to the food industry and other stakeholders. Nanotechnology applications (e.g. silver nanoparticles) are being developed for use within food processing systems to kill microorganisms without adding to the problem of growing antibacterial resistance (Handford et al., 2014; Duncan, 2011). Furthermore, sensor diagnostics involving nanosensors and nanomaterial-based assays can help to detect analytes, such as contaminants and pathogens (Duncan, 2011). In addition to presenting food safety benefits, such techniques can be used to guarantee food safety and quality (Kim et al., 2017) thus offering market differentiation opportunities. In future, it is expected that nanoscale science and nanotechnology will contribute to developing tools and systems for identification, tracking and monitoring along the entire food chain (Scott et al., 2018). Nanotechnology (enscapsulation and emusions) also facilitates shelf-life extension, masks unpleasant tastes and odours and can make some ingredients invisible so that they do not affect the food's appearance (Davies, 2010). A number of food storage containers that use silver nanoparticles are available on the market: these offer consumers the benefit of high quality food for a longer period of time and thus reduce wastage (Handford et al., 2014).

3. Methodology

A face-to-face survey with 1,046 Irish consumers was undertaken using a questionnaire. The questionnaire contained a conjoint analysis section, whereby hypothetical products comprising different attribute level combinations were presented, and additional questions that facilitated more indepth analysis (e.g. cluster analysis).

3.1 Questionnaire design

In conjoint analysis, the product is described as a combination of a set of attributes and levels from which the consumer derives benefit (utility) so that as consumers indicate preferences for alternative products they trade-off between a set of multi-attribute products. The survey addresses two broad categories of nanotechnology applications, i.e. nanotechnology inside (applications that form an integral part of the food) and nanotechnology outside (applications that do not form an integral part of the food but form part of the overall product offering) through investigating applications in a cheese product and applications in packaging for chicken fillets. These products are selected as they are well-established, everyday products that form part of the routine shopping basket for most Irish consumers. Additional product attributes were Taste, Health (through lower fat content), Safety and Value (through longer shelf-life) as these are some of the purported benefits of nanotechnology.

The nano-inside (cheese concept) conjoint consisted of four product attributes: price (2 levels); taste (2 levels); health (2 levels) and technology (2-levels) and the nano-outside (packaged chicken) consisted of three product attributes: price (2-levels); method of production/packaging (4 levels) and technology (2-levels). The hypothetical products were presented as full profile cards. Fractional, factorial design was used to reduce the number of hypothetical products that were presented to consumers to 11 (see Table 1). This design means that the factors become orthogonal and their effect on preference can be separated (Green & Srinivasan 1990; Shan et al., 2017). Consumers were asked if they would eat the presented hypothetical product as a binomial variable (yes/no) and if they would be happy for such a product to be available for sale on a scale from 1 to 10, where 1=not at all happy and 10=very happy.

To simulate a buying situation as closely as possible to a real-life purchase situation (Cox et al., 2008), significant effort was put into ensuring realistic product concepts were presented. In addition to selecting products that were consumed with high levels of frequency and including attributes that were realistically associated with the product, product images containing both visual and textual information were created. Showcards presented to participants were designed with the support of a graphic designer. Given the low level of awareness of nanotechnology in the population, similarly to the approach adopted by Siegrist et al. (2009), a brief (neutral) definition of nanotechnology was presented to consumers before evaluating the hypothetical products to ensure all respondents had the capacity to provide a knowledge-based response.

A range of attitudinal statements (see Table 3) were also included in the questionnaire relating to top-down and bottom-up attitude formation processes (Cobb and Macoubrie, 2004; Søndergaard et al., 2005; Siegrist et al., 2009; Greehy et al., 2013). Measures relating to trust in stakeholders were also included, along with an assessment of respondents' level of awareness of nanotechnology and its application in food production. Many of these statements were taken from validated instruments. A range of statements were used to measure general attitudes (ethical issues, food safety, new food technology, etc.). These measures were subjected to principal component analysis with varimax rotation. All measures for the same attitude loaded on the one component. Constructs were then generated for each of the attitudes, taking the mean score of the combined statements to generate a more robust measure of the attitude. This was completed for ethical issues, food safety, involvement, label usage, nature and environment, new food technology, social norm influences, and traditional food. Attitudes towards the use of nanotechnology were measured on a seven point Likert scale, where 1 was strongly disagree to 7 strongly agree, with a neutral point of 4. Trust was measured on a five point Likert scale, where 1 = do not trust at all and 5 = trust completely, with 3 as a neutral point.

3.3 Survey Sample

Prior to data collection, ethical approval was received from the University College Cork Social Research Ethics Committee. The sample was quota controlled to be nationally representative in terms of gender, age, and socio-economic group. The sample was divided into two groups, with half of the respondents evaluating the nano-inside cheese concepts and the other half evaluating the nano-outside packaged chicken concepts. The order of presentation of each of the concepts was rotated for each respondent, so as to eliminate viewing order bias. The survey, administered by a trained interviewer, took approximately forty-five minutes to complete and respondents were only included if they consumed cheese or chicken (depending on the survey administered) and/or purchased it at least once a month. A number of additional screening questions were also included, whereby those employed in the areas of food science, food regulation or market research were excluded.

3.4 Statistical Analysis

Statistical analyses were carried out using IBM SPSS Statistics 24 (Chicago, IL, USA). Following the conjoint analysis, cluster analysis was used to categorise individuals based on utility scores from the conjoint analysis. Separate cluster analyses were carried out for nano-inside and nano-outside. Hierarchical cluster analysis determined the optimal number of clusters (Burns & Burns, 2008). The appropriate number of clusters was determined by profiling the clusters to ensure they were clearly distinct and meaningful, while also maintaining a reasonable sample size. Mean attitude scores were determined across the clusters. ANOVA was used to test for significant differences across the cheese nano-inside clusters, while t-tests were used to test for differences across the chicken nano-outside clusters.

4. Results

Table 1 presents the mean acceptance score for all of the hypothetical products presented for both the cheese (nano-inside) and chicken (nano-outside) packaging products, along with the percentage willing to eat the products. In both applications (nano-inside and nano-outside), products produced using conventional technology were more acceptable that those produced using nanotechnology. Consumers' acceptance and willingness to eat decreased as nanotechnology was introduced and as the attributes were viewed as less beneficial. All of the mean scores for nano-outside (i.e. packaging) were above neutral, indicating a general acceptance level, which was also reflected in the willingness to eat score with 64% willing to consume a product with nanotechnology packaging at a lower price, with no other attributes outlined. However, in the case of nano-inside the mean score for the hypothetical products dropped to an unacceptable level with the introduction of nanotechnology, despite having the benefits of superior taste, lower cost and lower fat. However, despite this, it is noteworthy that 43% of respondents indicated that they were still willing to eat the cheese product with no attribute other than nanotechnology outlined.

[Insert Table 1 here]

Table 2 presents the utility scores and relative importance in determining acceptance/rejection of the hypothetical products presented. The technology used to produce the cheese was the most important of the four attributes for acceptance of the cheese prototypes, with a negative utility score for nanotechnology. Health and price were of similar importance, with positive utility scores for health benefits and negative utility scores for higher price. Taste benefit was of little to no importance, with a very low but positive utility score for a taste benefit.

[Insert Table 2 here]

In the case of nano-inside, technology was also the most important of the three attributes influencing acceptance at 52%, followed closely by the packaging benefit at 46%. Similar to the findings for nano-inside, price was of little importance, although lower price was preferable. Although, conventional packaging was preferable, as indicated by the positive utility score, there was potential for acceptance for nanotechnology through improved food safety as indicated by the positive utility score for the nanotechnology sensor.

Figure 2a presents four distinct segments of similar size for nano-inside that were generated using cluster analysis and labelled based on the particular emphasis respondents placed on the attributes presented to them in the prototypes.

[Insert Figure 2a here]

The first segment, the 'nano-sensitive' segment (26%), displayed the highest rejection of nanotechnology and were more inclined towards traditional production methods. They were less interested in product attributes such as fat content, health endorsement or taste and did not want to pay more for their product. The second segment (25%) also had a negative perspective on nanotechnology and sought the use of traditional methods in production. Fat content was not a strong motivation and while they had a preference for a superior tasting product, they were unwilling to pay a price premium for the benefits offered. Essentially, they displayed a preference for a conventional cheese product and were labelled as the 'conventional consumer'. The third segment (21%) was the only one willing to pay a premium for information on fat content with an endorsement. They also desired a superior tasting product. This segment (labelled 'health focussed') was negative towards the use of nanotechnology in cheese but to a lesser degree compared to the conventional or the nano-sensitive consumers. The fourth segment (28%) was labelled 'no frill neutrals'. They were relatively neutral to the use of either traditional or nanotechnology production methods, were not swayed by taste, fat or endorsement information and were unwilling to pay a premium for their cheese.

[Insert Figure 2b here]

In the case of nano-outside, the cluster analysis generated two segments as illustrated in Figure 2b. The first segment (35%) was named 'concerned citizens' since for this group outright rejection of nanotechnology was evident. Less packaging or improved shelf life, achieved using conventional packaging, was welcomed by this group. The food safety sensor did not appeal to these individuals. The second segment (65%) was accepting of nanotechnology packaging and was very positively disposed to the food safety sensor and thereby labelled 'benefit driven' consumers. This group was swayed by the concept of a food safety sensor and would accept this attribute using nanotechnology.

The clusters for nano-inside and nano-outside were further profiled by demographic characteristics, level of trust in relevant stakeholders, relevant beliefs and attitudinal differences as presented in Table 3. There were no significant differences in demographic measures (age, gender, social class etc.) across the consumer segments as described above for either nanotechnology product presented. (Data not shown[2]).

[Insert Table 3 here]

Across all of the segments, GPs and the Food Safety Authority of Ireland were the most trusted sources of information for information regarding nanotechnology. Government departments were neither trusted nor distrusted with a neutral score of 3 for most respondents. Tabloid newspapers were the least trusted, which was evident across all consumer segments. Levels of trust varied across some of the nano-inside segments, where trust in consumer organisations and scientists was very important for the health focussed segment. This is an important finding especially in relation to future endorsement of products by agencies or scientists. The no frills neutrals segment had the highest trust in food manufacturers compared to the other segments.

Attitudinal differences were observed across the segments, with nano-sensitive consumers displaying the strongest attitudes. They displayed the strongest feeling of unease concerning nanotechnology in food and strongly believed that the government should regulate its use in food. Their level of food involvement (shopping, cooking, etc.) was very high and they also used labels when making their food choices. Ethical purchasing and consumption was also important to this group, as was protecting nature and the environment. Traditional food attitudes were also highest

[2] Details available in Appendix 5 at the following link: https://www.teagasc.ie/media/website/publications/2013/Summary-Report.pdf

for this segment, with this group also being the least positively disposed to the benefits of new food technologies. The no frills neutrals segment displayed the opposite attitudes to the nano-sensitive segment, as well as displaying the lowest food involvement scores.

The health focussed segment also held strong attitudes. This group differed from the nano-sensitive segment, in that these individuals also held the most positive attitude to new food technology. The former were more likely to have heard of nanotechnology previously and felt less uneasy about its application in food. They were also most inclined to find out more information regarding the technology.

The benefit driven consumer segment of the nano-outside hypothetical product were more positive towards new food technology and were less likely to feel uneasy about the application of nanotechnology in foods. They were more likely to have heard of nanotechnology and were most open to finding out more about the technology. Conversely, the nano-outside concerned citizen segment held stronger attitudes with respect to nature and the environment, which was also evident in that they favoured the less packing product attribute. In addition, they had significantly higher scores for ethical food production and food involvement.

5. Discussion and Conclusions

Clearly, consumer acceptance of nanotechnology and other emerging technologies is key to their successful development and commercialisation. Research of this nature is thus important to gain a better understanding of the determinants of consumer acceptance or rejection of such technologies. Results from this research are consistent with those of Zhou & Wu. (2018) who conclude that the use of conventional technology was preferred to that of nanotechnology in both food and packaging applications. The data here indicate that consumer acceptance and willingness to eat (a hypothetical product) decreased when nanotechnology was introduced. They also indicate that nano-outside applications have higher levels of acceptance than nano-inside applications consistent with Giles et al (2015). However the results also indicate that consumers evaluate products in terms of a combination of attributes and that negative utilities for some attributes (i.e. the use of nanotechnology) can sometimes be offset by the presence of other consumer-relevant benefits. Our results indicate that such off-setting is dependent on technology application and benefits offered, and that it is likely vary across consumer segments depending on which benefits find favour. In relation to application, our results found that the negative value on nanotechnology packaging (nano-outside) could be offset by particular benefits, e.g. improved food safety and a lower price, whereas, such a trade-off in favour of nanotechnology was less likely in the case of nano-inside (food) applications (Table 2). With regards to different segments, varying utility scores for nanotechnology as well as for different purported benefits are clear in Figures 2a and 2b with different scores and even signs (positive vs negative) evident across segments.

These insights point to the need to involve consumers at an early stage in the product development process (as also argued by Fewer et al, 2011 and others) and in considering potential commercialisation pathways, particularly with regard to food production where consumers may be especially sensitive or risk-averse. According to Raley et al. (2016), increased input by consumers into the product development process, when concrete and tangible consumer benefits are being incorporated into specific products, is required to ensure what is being developed is also what consumers want. Indeed new food technologies can prove to be very sensitive to consumers as there is a rather low degree of public knowledge about how food is produced, and especially about novel food production technologies or processing methods. Experience with technologies such as GM indicates that potentially useful technologies can be rejected by consumers without deep consideration and there is a hierarchy of acceptance depending on the particular product application (Hallman, 2000). Parisi et al. (2015) suggest that as consumer acceptance of nanotechnology is particularly influenced by perceived benefits and usefulness, products with clear benefits and acceptable/low risks, like medical and environmental applications, if introduced first into the market could drive the acceptance of other applications introduced later. Emerging technologies such as nanotechnology have a wide range of potential applications with diverse benefits, some of which will not be of direct relevance to consumers, however, they may still have an indirect impact on the development of the technology though the rules and regulations applied.

The finding that there were no significant differences in demographic characteristics (such as age, gender and social class) across the consumer segments identified is consistent with that of Giles et al. (2015) and Zhou & Wu (2018). According to Giles et al. (2015), the available evidence suggests that consumer acceptance of the use of nanotechnology in agri-food applications may increase if there is clarity regarding who takes responsibility for creating and regulating safe nanotechnology products, and who provides information about associated safety assessments to the general public. This paper indicates that the Food Safety Authority of Ireland is well positioned to inform consumers and citizens on particular nanotechnology applications as they and GPs were evaluated as the most trusted sources of information relating to new technologies. Interestingly, research by Schnettler et al. (2014) found that product brand was the attribute of greatest relative importance in influencing consumer acceptance and that brand endorsement could then prove a useful marketing pathway. This aspect could be further explored in future research of this nature.

Overall, this research indicates the need for effective engagement around nanotechnology (and other emerging technologies) and its potential applications, as well as the need to promote awareness, a sentiment echoed by Sekhon (2014) and Scott et al, (2018). In addition, Zhou & Wu (2018) contend that it is crucial for policy makers and other stakeholders to gain sound understanding of public opinion in this relatively early stage of nanotechnology development. Scientific and technological developments in the agri-food sector have the potential to provide real benefits to farmers, processors and consumers in sustainably meeting the requirements of an ever-growing and increasingly growing population. Appreciating the concerns and preferences of consumers and eliciting their overall level of acceptance with regard to particular technologies and product applications is crucial for their success.

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Table 1: Mean consumer acceptance scores for all product prototypes and percentage willing to eat

Technology	Product description nano-inside	Acceptance score	% willing to eat
Traditional	Cheese €2.39 superior taste 2/3 less fat endorsed traditional	8.3	92
Traditional	Cheese €2.39 2/3 less fat endorsed traditional	8.1	92
Traditional	Cheese €2.39 traditional	7.8	87
Traditional	Cheese €3.09 superior taste 2/3 less fat endorsed traditional	7.8	90
Traditional	Cheese €3.09 2/3 less fat endorsed traditional	7.7	87
Traditional	Cheese €3.09 superior taste traditional	7.4	84
Traditional	Cheese €3.09 traditional	7.4	86
Nanotechnology	Cheese €2.39 superior taste 2/3 less fat endorsed nanotechnology	5.5	53
Nanotechnology	Cheese €3.09 2/3 less fat endorsed nanotechnology	5.3	48
Nanotechnology	Cheese €2.39 nanotechnology	5.1	43
Nanotechnology	Cheese €3.09 superior taste nanotechnology	4.9	40
	Product description nano-outside		
Regular	Chicken €4.99 sensor plasticpak	7.7	82
Regular	Chicken €5.99 sensor plasticpak	7.6	79
Regular	Chicken €4.99 less packaging plasticpak	7.4	81
Regular	Chicken €5.99 less packaging plasticpak	7.3	81
Regular	Chicken €5.99 fresher4longer plasticpak	7.2	81
Regular	Chicken €5.99 plasticpak	6.9	79
Nanotechnology	Chicken €5.99 sensor nanotechnology	6.7	66
Nanotechnology	Chicken €4.99 less packaging nanotechnology	6.5	67
Nanotechnology	Chicken €4.99 fresher4longer nanotechnology	6.3	65
Nanotechnology	Chicken €5.99 less packaging nanotechnology	6.3	66
Nanotechnology	Chicken €4.99 nanotechnology	6.3	64

1 = low to no acceptance, 10 = high acceptance

Table 2: Utility scores and relative importance for each attributes for nano-inside and nano-outside

Attributes	**% relative importance**	**Nano-inside (cheese) Attribute Levels**	**Utility**
Price	11	€2.39 per 200g pack	**0.22**
		€3.09 per 200g pack	*-0.22*
Taste benefit	1	No information on taste	*-0.02*
		Superior taste claim	**0.02**
Health benefit	12	No information on fat content or endorsement.	*-0.24*
		2/3 less fat, with 'Heart Association' endorsement*	*0.24*
Technology	76	Traditional methods	**1.5**
		Nanotechnology	-1.5

		Nano-outside (chicken) Attribute Levels	
Price	2%	€4.99 per 500g pack	**0.017**
		€5.99 per 500g pack	0.017
Packaging related benefits	46%	Improved food safety (sensor)	**0.45**
		Less packaging	-0.076
		Improved shelf life (fresher4longer)	-0.022
		No information on benefits	-0.352
Technology	52%	Plastic packaging	**0.46**
		Nanotechnology packaging	-0.46

* hypothetical association

Table 3: Mean scores for trust, attitudes, motives and food choice rankings for the total survey sample and for the nano-inside vs. nano-outside respondents.

	Total population	Nano-inside					Nano-outside		
		Nano sensitive	Conventional	Health focussed	No frills neutrals	Anova	Concerned citizens	Benefit driven	t-test
	n = 1025	n = 113	n=110	n=94	n=125	P Value	n=157	n=298	P Value
^**Sources of Trust**									
Campaign groups (e.g. Friends of the Earth)	3.3	3.5	3.2	3.2	3.3	0.373	3.3	3.2	0.276
Consumers' Associations e.g. Consumers' Association of Ireland	4.0	4.2	3.8	4.2	4.0	0.009	4.1	4.0	0.116
Doctors (GPs)	4.3	4.4	4.2	4.4	4.4	0.251	4.4	4.3	0.416
Food Manufacturers	3.2	2.9	3.1	3.0	3.5	0.000	3.0	3.2	0.169
Government Departments	3.0	3.3	3.0	3.2	2.9	0.200	3.0	3.0	0.639
Scientists working at a university or government laboratory	3.6	3.5	3.5	3.9	3.7	0.011	3.6	3.6	0.845
Tabloid newspapers	2.2	2.0	2.1	1.9	2.2	0.110	2.1	2.3	0.013
Food Safety Authority of Ireland (FSAI)	4.2	4.3	4.0	4.5	4.1	0.001	4.2	4.1	0.279
TV News reports	3.2	3.2	3.1	3.0	3.3	0.220	3.0	3.3	0.006
^^**Attitudes to Nanotechnology**									
Government agencies should regulate use of nanotechnology in food	5.7	6.1	5.7	5.7	5.4	0.002	5.9	5.7	0.264
Interested in finding out more about nanotechnology in food	5.0	4.7	5.2	5.9	5.3	0.000	4.6	4.9	0.208
Nanotechnology in food makes me feel uneasy	4.6	6.2	4.9	4.4	4.2	0.000	5.2	4.0	0.000
^^**General Attitudes**									
Ethical	5.2	5.6	5.1	5.5	5.0	0.001	5.5	5.1	0.001
Food safety	4.9	4.9	4.5	5.0	4.8	0.090	5.2	5.1	0.201
Involvement	5.5	5.8	5.3	5.8	5.2	0.000	5.5	5.4	0.737
Label usage	4.6	5.0	4.3	4.8	4.4	0.006	4.6	4.8	0.361

Nature and environment	5.4	6.0	5.3	5.6	5.1	0.000	5.6	5.3	0.001
New food technology	4.7	4.3	4.6	4.9	4.7	0.000	4.5	4.8	0.012
Social norm influences	3.8	3.1	3.6	3.7	4.1	0.000	3.5	4.0	0.001
Traditional food	5.0	5.2	5.0	5.1	4.9	0.001	5.1	4.9	0.009

^Lower values indicate lower levels of trust

^^Higher values indicate strong agreement with statement/attitude

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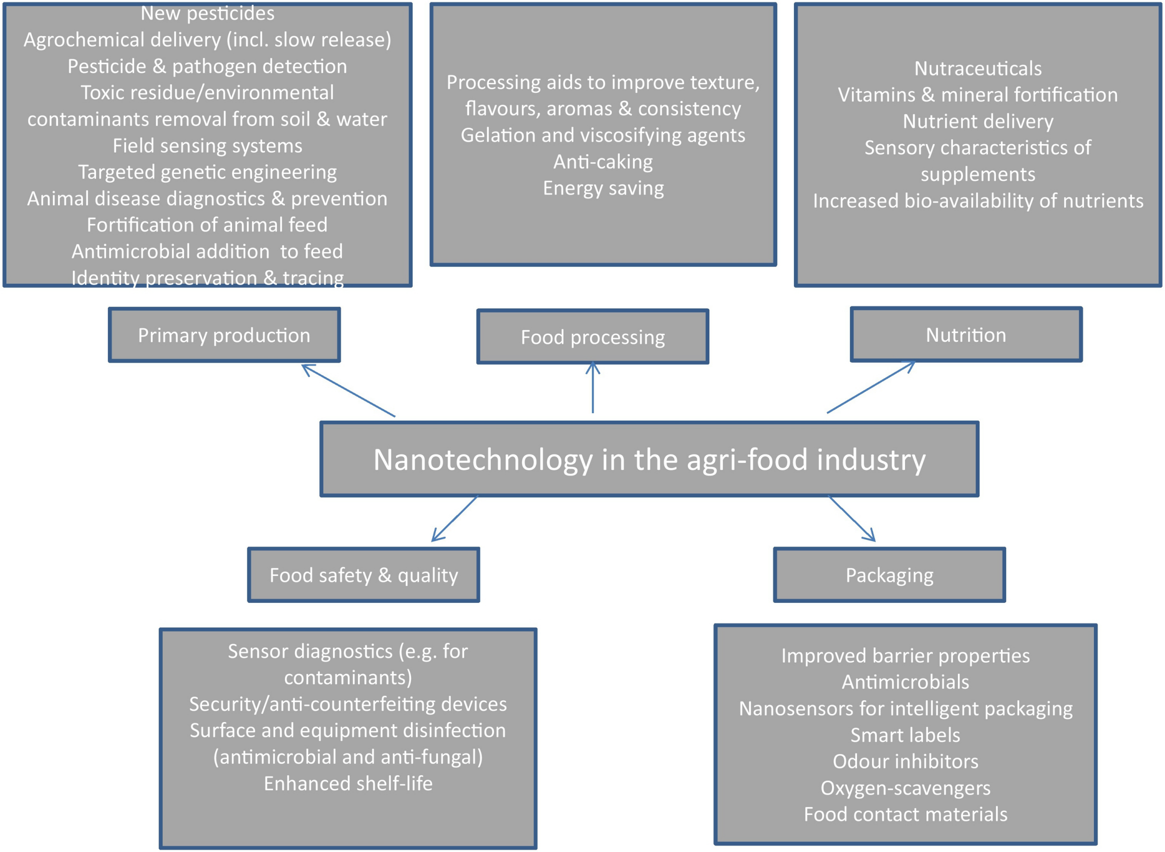
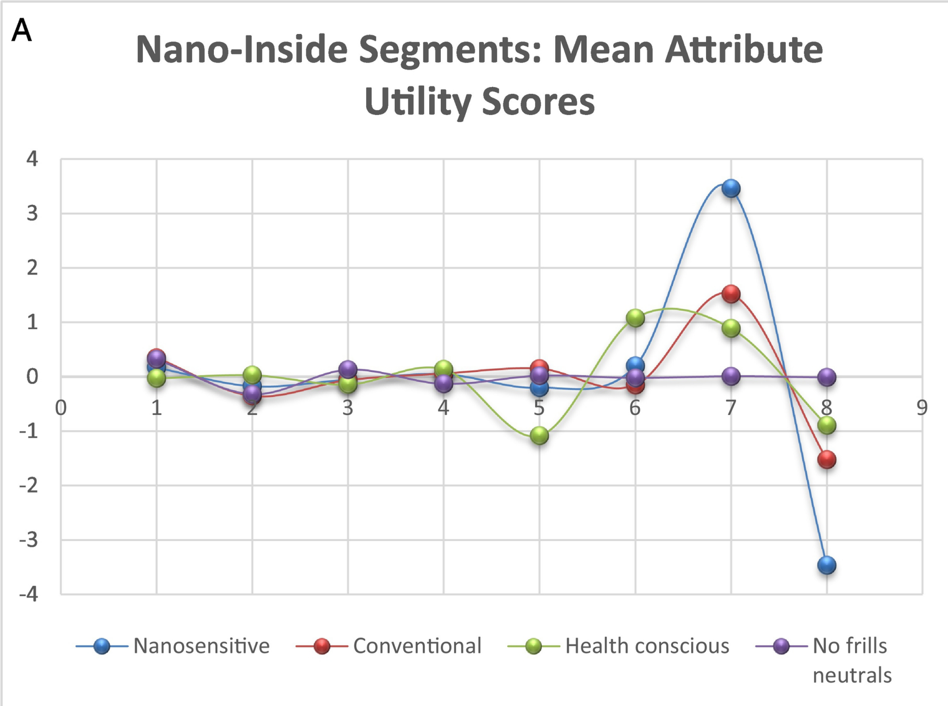
Highlights

- Consumers display varying levels of acceptance to nanotechnology food applications.
- Acceptance is strongly influenced by the particular application and benefits offered.
- Salient benefits can off-set technology concerns in some instances.
- Different benefits find favour with particular consumer segments.

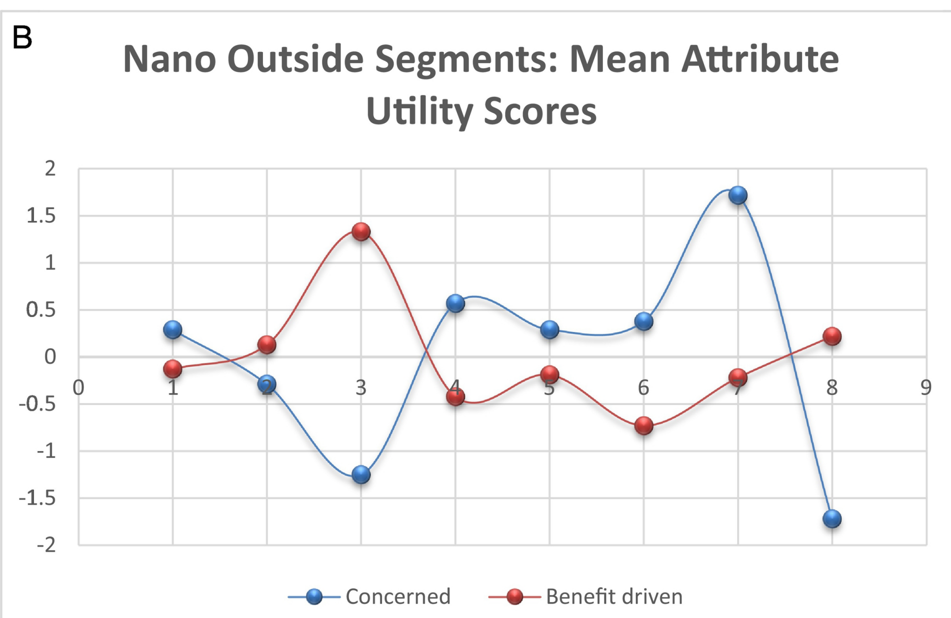


Source: Adapted from Handford et al., 2014

Figure 1



1 Low price 2 High price 3 Food safety 4 Less packaging
5 Longer shelf life 6 No benefit info 7 Plastic 8 Nanotechnology



1 Low price 2 High price 3 Food safety 4 Less packaging
5 Longer shelf life 6 No benefit info 7 Plastic 8 Nanotechnology

Figure 2