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Yawson, Robert M. and Kuzma, Jennifer

Department of Organizational Leadership, Policy, and Development, College of Education and Human Development, University of Minnesota, 330 Wulling Hall, 86 Pleasant Street SE, Minneapolis, MN 55455, Center for Science, Technology, and Public Policy, Hubert H. Humphrey Institute for Public Affairs, University of Minnesota, 301-19th Ave. South; Minneapolis, MN 55455, USA

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Robert M. Yawson[1]* and Jennifer Kuzma[2]

[1]*Department of Organizational Leadership, Policy, and Development, College of Education and Human Development, University of Minnesota, 330 Wulling Hall, 86 Pleasant Street SE, Minneapolis, MN 55455*

[2]*Center for Science, Technology, and Public Policy, Hubert H. Humphrey Institute for Public Affairs, University of Minnesota, 301-19th Ave. South; Minneapolis, MN 55455, USA*

*Corresponding Author: yawso003@umn.edu

Abstract

Nanotechnology is becoming increasingly important for the food sector, and advances and products are already being made in the areas of food packaging and food safety. However, there are several potential issues associated with the commercialization of agricultural and food (agrifood) nanotechnology that may limit its full potential, including uncertainty about whether consumers will accept or reject its products. Thus, this study aims to better understand key variables that are likely to affect consumer acceptance of agrifood nanotechnology, so that policies and programs can be better designed to address issues important to consumers prior to market entry. Factors that may influence consumer acceptance of agrifood nanotechnology were identified by examining historical experiences with other emerging technologies in food and agriculture and eliciting the opinions of experts and stakeholders. In this work, perceived risks and benefits and trust in regulatory agencies and industry were identified as the key factors influencing consumer acceptance. Our results compare favorably with other published studies in this area, and collectively they suggest that increasing consumer knowledge of agrifood nanotechnology products; ensuring high consumer benefits; minimizing risks; and increasing trust in decision makers and producers are important for consumer acceptance and the success of the emerging agrifood nanotechnology industry.

Keywords

Expert Elicitation, Nanotechnology, Risk Perception, Uncertainty, Consumers

1.1 Introduction

Agricultural and food (agrifood) production is essential to the health and well-being of societies. Recently, emerging technologies, like biotechnology, have been deployed to improve food production, processing, quality and safety, as well as to mitigate impacts on the environment. Benefits to society have accrued from their deployment. For example, genetically engineered cotton that is resistant to pests has been cultivated in China, leading to reductions in pesticide use and harmful human health effects (Pray 2002). However, when emerging technologies are deployed, links and interdependencies that exist between environment, people, food, and products in the agrifood system are affected, and in some cases this can lead to controversy and conflict (Jasanoff 2005).

Nanotechnology is a relatively new, enabling technology that has the potential to transform agriculture and food systems. It involves the manipulation and control of matter at the nanoscale (1-100nm) and at this scale, special optical, chemical, and electrical properties emerge (NNI 2009). Nanomaterials can be more reactive due to a higher surface area to mass ratio at this scale and can more easily penetrate through biological systems given their small size. Its recent deployment in agricultural and food spans from better release of pesticides through release of free-standing nanoparticles on the farm to food storage containers made with bound nanomaterials for use in the home (Kuzma and VerHage 2006). Nanotechnology can be used to enhance food safety and security by improving the efficiency of crop production, food processing, environmental impacts of food production, storage, transportation and distribution, as well as to address a more recent concern of food defense. Agrifood systems security, delivery systems for disease treatment in plants and farm animals, novel methods for molecular and cellular biology, development of new materials for pathogen detection and new ways of environmental protection are examples of the importance of interplay of nanotechnology and agrifood systems (USDA 2003). It has been predicted that by 2010, nanofood products worth $20 billion may be on the market (RNCOS 2007). If these trends should continue, nanotechnology is expected to become a prime driver and focus of innovations in the agrifood system in the coming decade (Downey 2006).

Research and development in the area of agrifood nanotechnology is likely to yield products with additional special properties. From a database of funded research in the U.S., Kuzma and VerHage (2006) have identified several potential applications of agrifood nanotechnology in the areas of precision crop and livestock production. Nanomaterials being developed to enhance the precise use of agro-chemicals are of particular interest. An example is a nanotechnology-based pesticide under development that will only become active when inside the target insects (Downey 2006). Nanotechnology has the potential for providing more efficient application of pesticides, fertilizers and other agro-chemicals to alleviate poverty through improved food security, land use, and environmental sustainability (Kuzma & VerHage 2006). In relation to functional foods, the potential engineering of nanomaterials to detect and

block harmful substances in food, such as unwanted cholesterol or allergens, from affecting the body could also prove to be highly beneficial. The development of nanomaterials that can selectively enter cell walls could bring significant nutritional and health benefits (Downey 2006).

The incorporation of nanomaterials into food packaging is expected to improve the barrier properties of packaging materials and should thereby help to reduce the use of valuable raw materials and the generation of waste (Sozer & Kokini 2009). Edible nanolaminates may also have potential uses in encapsulation systems for environmental protection (Chen *et al.* 2006). These applications could be used in fresh fruits and vegetables, bakery products and confectionery, where they might protect the food from moisture, lipids, gases, off-flavors and odors (Sozer & Kokini 2009). Naturally-occurring biopolymers and other biological molecules of nanosize scale, such as oligosaccharides or polysaccharides and proteins, can be used for the encapsulation of vitamins, prebiotics and probiotics formulations, and for drug-delivery systems or nutraceuticals (Sozer & Kokini 2009) and as target-specific-recognition agents that could be used as biosensors in foods (Tarver 2008). These biosensors are envisaged to be used as detectors of pathogens and other contaminants in food and for tracking food products to help facilitate food recalls for example. These innovative devices and techniques being developed are to facilitate the preparation of food samples and their precise and inexpensive analysis (Chen *et al.* 2006). From this point of view, the development of nanosensors to detect microorganisms and contaminants is a particularly promising application of food nanotechnology. Nanosensors can also be used in the formulation of food additives such as flavors and antioxidants (Chaudhry *et al.* 2008). This is aimed at improving the functionality of these additives while reducing their concentration.

However, the applications of nanotechnology in agriculture and the manufacture of food products come with potential risks, social, and ethical issues. Currently, debates over nanofood safety and appropriate regulation have been reported to have slowed the market introduction of nanofood products (Garber 2007). In addition, most of the larger companies are thought to be keeping their activities in agrifood nanotechnology quiet for fear of public backlash (Garber 2007). Some of the nanomaterials used in agricultural or food products may be inherently different from toxicological, exposure and risk assessment perspectives due to enhanced chemical reactivity and unique physical properties in comparison to naturally occurring or micro-scale materials. These properties could lead to unwanted or unanticipated health effects (Downey 2006). The risks associated with nanotechnology in food remain unclear, and in several cases, the way the U.S. regulatory systems will handle nano-food and agricultural products are also unclear (Kuzma et al. 2008).

The public seems to be far less quick to accept nanotechnology applications when it comes to food supply, and in particular, nanoparticles introduced via nanotechnology into food (Siegrist 2008).

Several consumer groups have taken a stand on agrifood nanotechnology, calling for increased precaution, mandatory labeling, and public input and transparency in decision making (ETC 2004; Miller & Senjen 2008). This is not surprising, given the special relationship people have with food, growing natural food and organic movements, and historical experiences with consumer backlash to agricultural biotechnology and genetically engineered food products.

So far, there are not many agrifood nanoproducts on the market, in comparison to other products like cosmetics, sports equipment, and electronics (PEN 2009). Although nanotechnology has the potential to find applications in the entire food supply chain, commercial applications of many of the methods are currently either too expensive or not feasible (Tarver 2008). The most cost-effective applications of nanotechnology in the food industry are currently in the areas of novel functional materials development, food fortification and formulations, food processing at micro and nano scale levels, food product development, and storage (Tarver 2008). However, the applicability of nanotechnology in the agrifood industry is sure to increase as research and developments continue to emerge. Thus, it is a crucial time to consider how agrifood nanotechnology can be deployed safely, sustainably, and ethically so that consumers will have confidence in and ultimately accept beneficial agrifood nanoproducts.

In light of the above, this study aims to better understand key policy and programmatic intervention points in consumer acceptance of food nanotechnology. The ultimate goal is not to convince people to buy or accept agrifood nanotechnology products, but rather to understand issues that are important to consumers so that these issues can be addressed upstream of product development and marketing. Several studies have directly surveyed consumers, but this is the first to ask experts working in areas relevant to agrifood nanotechnology about influences on consumer acceptance, as well as their own opinions about agrifood nanotechnology. Experts can provide unique perspectives from years of experience and observation of food systems, as consumers themselves, and with their in-depth knowledge of the literature. Experts might also be more familiar with where and how policies and programs can intervene to address consumer issues associated with emerging technologies (Yawson & Kuzma 2010). Thus an expert elicitation approach complements direct consumer surveys. To our knowledge, this is the first study to formally elicit the opinion of experts on agrifood nanotechnology.

2. 1 Methodology of Study

This research was conducted in three stages: review of the literature to determine the key theories and policy and programmatic intervention points related to consumer acceptance of agrifood nanotechnology products and applications as suggested by historical experience with other emerging technologies in agriculture and food; elicitation of experts opinion regarding the attributes that affect

consumer attitudes toward agrifood nanotechnology products and applications; and comparative analysis of the literature and experts' opinion.

2.1.1 Methodology for Review of Literature

The methodology for the evidence review of the literature entailed three elements: The initial search for materials; the prioritization of materials; and the full review. For the initial search for materials, literature synthesis was done using text mining to extract technical intelligence from the global nanotechnology, nanoscience and agrifood nanotechnology research literature. An extensive agrifood nanotechnology/ consumer-focused query was applied to the ISI Web of Knowledge/Science Citation Index/Social Science Citation Index (ISI/SCI/SSCI) databases. A variety of terms and phrases were used in the search for materials on expert elicitation and other related components of the overall study. In addition to web of knowledge and the citation indexes, an expansive search covering several disparate electronic databases, including, Agricola, Google scholar, Wiley Interscience, World Scientific Publishing, Pubmed and Proquest were also used. For the prioritization of materials, the initial searches of all materials were reviewed and then the most pertinent articles were fully read. In order to simplify the evidence collection process, each identified source was rated according to: the quality of the source; the approach to the primary research and the methodology used; the level to which the source discussed the broader research question (i.e. what influences the public's attitudes towards agrifood nanotechnology?). The literature on expert elicitation was reviewed separately and not prioritized.

In order to extract the pertinent evidence from the prioritized literature, a spreadsheet was drawn up with the relevant notes and citations which gave a strong basis for subsequent analysis of the information collected. As the full review was conducted, a handful of new sources were added to initial prioritization list. Experts, stakeholders and policy issues associated with agrifood nanotechnology were also identified from content analysis of the literature.

2.1.2 Methodology for Expert Elicitation

This study is limited in the sense that it relies on a subset of experts and their opinions. Most of the experts were from academe. However, they are a diverse group with varying expertise areas and affiliations. Some of the experts represent stakeholder groups as well (NGOs, government, and industry). Expert opinion on issues that come with great uncertainty can be an important part of initial evidence-gathering and hypothesis generating phases (Morgan & Henrion 1990). There is a high level of uncertainty with regard to the barriers to commercialization and consumer acceptance of agrifood nanotechnology, as the field is young with little experience. Moreover only a subset of experts publishes in the literature, so to ensure broader knowledge is uncovered, broader expert elicitation is important.

A methodology for the collection of expert opinion was developed based on Van der Fels-Klerx et al. (2002) and Kuzma et al. (2009) by focusing on uncertainty and using formal survey methods. The methodology involved both qualitative and quantitative elicitation. A four-step process was followed: selection of experts, development of the elicitation survey instrument, administration of the elicitation survey, and analysis of the survey results. The elicitation protocol developed for this study considered the level of heterogeneity of relevant backgrounds seen in the agrifood nanotechnology context. In many practical decision-analysis problems where multidisciplinary expertise is needed for the study of an issue of uncertainty or risk assessment, this kind of situation is common (Hoffmann *et al.* 2006). The selection of experts was done through the use of agrifood nanotechnology literature infrastructure: prolific authors in key journals, institutions, or countries; most cited authors in journals or documents; and thought leaders in government, NGOs, and industry. The experts were categorized into 5 groups as follows: (1) Academics (2) Industry (3) Government (4) International (5) NGOs. In all, a total of 70 potential experts were identified. The final list of experts described by affiliation, expertise, and degree appears in Appendix A.

Materials developed for the expert elicitation process included a brief project description and introduction to the questionnaire in an email; IRB approval statement for the study (provided to the panelists prior to agreeing to participate in the expert elicitation process); and the elicitation questionnaire (Appendix II). The email and the brief project description stated the reason for conducting an expert elicitation and the expectations of the experts. Experts were given the option to participate in the electronic survey (about 10 minutes) or the phone interview (about 30 minutes), or both. Phone interviews were semi-structured with a guiding set of questions (Appendix B).

Of the 70 potential experts contacted, 21 experts (30% response rate) participated in the study. Four experts initially agreed to participate but later declined due to scheduling conflicts; Eighteen experts declined either due to lack of interest in the study or do not consider themselves as experts; and 27 experts could not be reached despite repeated attempts by e-mail over 3 weeks. Of the 21 experts that participated; nine participated in both the electronic survey and the phone interview; eleven participated in only the electronic survey and one gave qualitative answers to the electronic survey (Appendix A). About 60% of experts whose opinions were elicited in this study are involved in shaping the literature on consumer acceptance.

Selection and preparation of questionnaire was to elicit experts' opinion regarding the attributes that affect consumer attitudes toward agrifood nanotechnology products and applications. For the electronic survey six questions were asked eliciting responses using both ranking and Likerts scale. The questionnaire for the phone interviews was made of 8 semi-structured questions. Analysis of the

quantitative survey results was done using SPSS software (Quantitative Results are in Appendix C). Analysis of the nine interviews was conducted using content analysis and thematic coding (Results in Appendix D). The semi-structured questions for the interviews were:

i. Describe your role or interest in agrifood nanotechnology systems.
ii. Describe one or more examples of agrifood nanotechnology systems. Who are the key stakeholders and actors? What are the flows of information, products, etc.?
iii. What do you think are critical links in agrifood nanotechnology systems that influence consumer acceptance of products and applications? Why?
iv. Does scientific knowledge about risks and benefits influence consumer acceptance? If so, how? In which areas does understanding need to be developed?
v. Are the current regulatory frameworks in the U.S. adequate to assess the risks of food nanotechnologies and nanomaterials for consumers? Should nanomaterials in agrifood products be treated differently from other food products in a regulatory context?
vi. Does regulatory treatment of agrifood nanotechnology products influence consumer acceptance? If so, how?
vii. What is the state of U.S. intra-government cooperation regulations and standards? International government co-operation on regulation and standards? How will such initiatives influence consumer acceptance?
viii. What information should consumers be provided on the use of nanotechnologies and nanomaterials in food products? What is the role of information and its sources in influencing consumer acceptance?

3.1 Results and Discussion

The first question we asked the experts involved their views on the most important potential barriers to commercialization of agrifood nanotechnology products. So far, to our knowledge, there has not been any previous formal ranking by experts on what they view as the greatest barrier to commercialization of agrifood nanotechnology, and this study seems to be the 1st to quantitatively rank barriers to commercialization of agrifood nanotechnology from experts' perspectives. From a list of 10 diverse potential barriers derived from the literature, the majority of the experts were of the view that public attitudes, perceptions, and consumer acceptance are the most significant barriers to the commercialization of agrifood nanotechnology. Regulatory uncertainty and health and safety were ranked second and third respectively.

These results compare favorably with evidence from some of the literature. The Institute of Food Science & Technology in a report submitted to the *House of Lords' Science and Technology Committee*

Inquiry into the Use of Nanotechnologies in the Food Sector 2009; identified consumer acceptance as the most essential barrier to any advances in the processes and development of new agrifood nano-products (IFST 2009). However, other reports, especially in the grey literature, place a stronger emphasis on infrastructure as a barrier to commercialization than what was obtained from this expert elicitation. Many countries include infrastructure as an essential component of their national nanotechnology development plans (PMSEIC 2005). The nature of Nanotechnology R&D activities involves more sophisticated and relatively expensive equipment and other laboratory infrastructure such as clean rooms and electron microscopes (Roseman 2005). This requires substantial capital investment beyond the reach of most start-up firms. However, without access to such facilities it will not be possible for any industrial activities to proceed. In 2004 Lux Research listed 1,500 companies identified as having nanotechnology R&D strategic and business plans. Out of this number, 80% were start-ups (Lux Research 2005). Most start-up companies often require access to these expensive equipment, as well as employees with the required technical know-how to operate such facilities. Unfortunately the cost of acquisition of these facilities makes it difficult for the technical know-how to be developed in-house and the only option most often available to these emerging companies are the well equipped and staffed university and government research centers (Roseman 2005). This makes infrastructure a very significant factor to nanotechnology research, adoption and commercialization.

The U.S. and few other developed countries have a well equipped nanotechnology infrastructure network. This may explain why the experts in this study did not see infrastructure as a significant barrier to nanotechnology commercialization. It may as well be a significant barrier in other jurisdictions especially developing countries. This may also be explained by the fact that about 80% of the experts are not directly involved with the use of technical infrastructure. The two experts directly involved with technical infrastructure also did not see infrastructure as a significant barrier.

In the early days of nanotechnology, workforce readiness and skill development was identified as a very significant barrier to R&D and commercialization of nanotechnology (Roco & Bainbridge 2007). However, this group of experts did not see workforce readiness as significant barrier. Only two experts, one from academia and the other from industry ranked workforce readiness as the 3rd and 4th most important factor respectively. Perhaps if there were more experts from industry, workforce readiness would have been ranked higher. Industry requires highly-skilled labor in addition to sound regulatory framework and acceptable governance structure for responsible and continued development of agrifood nanotechnology. The challenge facing the academic community is how to train students to acquire the necessary know-how, and skills to work and lead the R&D in the vast multidisciplinary, interdisciplinary,

transdisciplinary and evolving field of nanotechnology (OECD 2009). Again, the U.S. focus of this study and the types of experts surveyed may have skewed the results in this area.

The next question in the survey asked experts to rank factors that may influence consumer acceptance of agrifood nanotechnology. Opinions on how likely nine identified factors from literature affect (positively or negatively) consumer acceptance of agrifood nanotechnology products were elicited. Consumer acceptance was defined as "willingness to buy or consume" in the survey instrument. Currently, consumers are not likely to have the knowledge required to willingly accept or consumer agrifood nanoproducts as awareness is low and products are not labeled. However, for the purposes of the survey, experts were asked to assume that consumers would have knowledge that nanotechnology is used for the products about which they are making purchasing or consumption decisions.

Perceived risks and benefits were thought by this expert group to have the highest likelihood of influencing consumer acceptance. Approximately sixty percent of the experts scored them as "very likely" to affect consumer acceptance, and 25% of the experts scored them as "likely". Trust in agrifood nanotechnology industries also seemed important to this group of experts. Fifty percent of them indicated that it was "very likely" to influence consumer acceptance, and 35% that is was "likely". Trust in regulatory agencies came in 3rd with 40% of the experts scoring it as "very likely", 35% as "likely" and 25% as "somewhat likely"

The results on experts' opinions on perceived risks and benefits compare favorably with much of the evidence from literature. In several studies, perceived risks and benefits have been identified as important factors for consumer attitudes and acceptance. Most of the literature suggests that they are negatively correlated with each other (lower perceived benefit is associated with higher perceived risk and *vice versa*, but the weighting of the two differs (Alhakami & Slovic 1994; Siegrist 1999 & 2000; Siegrist & Cvetkovich 2000; Lyndhurst 2009). However, in one study, Lee *et al*.(2005) reported that perceived risk and benefits of nanotechnology were positively correlated. In our semi-structured interviews with experts in this study, they indicated varying viewpoints about the relative importance of risks and benefits reflecting the contrary findings in the literature. One expert indicated that *"Scientific knowledge have very little influence, consumers depend on their own value system and trust."* Whereas another stated *"The entire approval process of products should be made clear to consumers (from when industry submit a product till when the product is approved). So scientific knowledge will definitely influence acceptance"*

One hypothesis for the variation in influence of perceived risks and benefits is that perception of risk and benefits have different values based on a consumer's previously-held cognitive inclinations (Lyndhurst 2009). Cardello *et al*. (2007) are emphatic that risk perception is the most important factor that

determines consumers' acceptance of foods processed using emerging technologies. Regardless of these discrepancies, our study supports the importance of perceived risks and benefits for consumer acceptance.

Trust was also rated by the experts as a key influence on consumer acceptance. Evidence from literature suggests consumers are particularly skeptical about the motives of industry (Ebbesen 2008; Macoubrie 2005a & 2005b). Most consumers perceive the intentions of industry as profit-driven rather than concern for societal wellbeing. Studies have found this to be true even for technologies with high perceived benefits, such as functional foods (Lyndhurst 2009). Consumers are skeptical about the health benefits claimed on the labels of nutraceuticals, suspecting that it may be a ploy by industry to maximize profits (Lyndhurst 2009). This is in line with expert ranking the effect (negative) of trust in industries very high.

Although cultural beliefs were seen by the expert group as having very little effect on consumer acceptance compared to other factors, evidence from literature suggests otherwise. Consumers' preexisting cultural outlook and worldview appear to be a key factor in how consumers perceive nanotechnology in general (Kahan *et al*. 2009). The reasons for this may be twofold. Because of the emergent nature of nanotechnology and lack of knowledge, consumers form their perceptions based on existing cultural beliefs. Secondly, consumers make their judgments by "paying selective attention to nanotechnology's negative or positive aspects, perhaps in part because of preexisting political predispositions or other social factors" (Lee *et al*. 2005). Kahan *et al.* 2007 found that even where consumers are given considerable information about nanotechnologies, perception is strongly influenced by cultural outlooks.

Awareness of agrifood nanotechnology is important for consumer choice. Experts were asked about the level of public awareness of agrifood nanotechnology. Fifty-five percent of the experts were of the opinion that, the public is "not very aware" and 40% said that the public was "not at all aware".

Literature also shows that there is significant lack of awareness of nanotechnologies in general. A 2004 survey in the U.K. found that only 29% have heard the term "nanotechnology" and, just 19% could somehow describe what nanotechnology was about (The Royal Society 2004). Results from a 2007 survey conducted here in the U.S. showed that 92% had heard very little or nothing at all about nanotechnology (Kahan *et al.* 2008). Peter D. Hart Research Associates survey in 2008 indicated that 49 percent of those surveyed had heard nothing at all about nanotechnology (Hart 2008). The survey indicated a strong relationship between public awareness of nanotechnology and preexisting impression that there are more benefits than risks. Those who know more about nanotechnology were more likely to think that there are more benefits than risks. Satterfield *et al*.(2009) pooled results of 11 survey studies

conducted in North America, Europe and Japan and found that more than 51% of all participants know "nothing at all" about nanotechnology.

In the telephone interviews, some experts explained that majority of consumers have the tendency of forming an opinion despite stating that they know little or nothing about the technology, even if it is not a strongly held opinion (Appendix IV). The experts confirmed the general view in the literature discussed above: since consumer perception is not formed exclusively based on knowledge of the technology; consumers rely on pre-existing knowledge and values to form their judgment. Two of the experts have these to say:

> *"I believe majority of consumers do take a view one way or the other, even if those views are not strongly felt, and this is how they will react to nanotechnology."*
>
> And,
>
> *"I don't think consumers' base their decision as to accept or reject a food product solely on knowledge of the technology, I think people generally rely on pre-existing knowledge and values to form their judgment."*

While the level of consumer awareness is currently very low, evidence from the literature indicates that consumer attitudes towards nanotechnology in general are currently fairly positive. Satterfield et al. found from meta-analysis of 9 survey studies on nanotechnology that a third of participants in these studies perceive the potential benefits of nanotechnology to outweigh the potential risks. However, as mentioned earlier, consumers' levels of knowledge are important in determining how they perceive agrifood nanotechnology. Kahan *et al* (2007) for example, reported that consumers who acknowledge their lack of knowledge of nanotechnology were more likely to think that risks outweighed benefits, and vice versa. They postulated that either that consumers adopt more positive attitudes towards nanotechnology when they are exposed to more information or, more likely, that those who are already interested in knowing more about nanotechnology are predisposed to having favorable perception. Priest (2006) also came to similar conclusion. Lee *et al.* (2005) also reported that general support and stronger consumer perceptions of benefits outweighing risks of nanotechnology are correlated to higher levels of scientific knowledge. However, in our study, when experts were asked during the telephone interview as to whether scientific knowledge about risks and benefits influence consumer acceptance, most of them were of the view that scientific knowledge does not necessarily concern consumers (Appendix D)

Experts were asked how likely it would be that certain sources of information could help improve public awareness of agrifood nanotechnology (Appendix D). Regulatory agencies, national governments, and to some large extent intergovernmental agencies were seen by experts to be "very likely" to help

improve public awareness of agrifood nanotechnology. Consumer organizations, environmental organizations, and friends and family were also seen as "likely". In the telephone interviews with the experts they were emphatic that trust in regulatory agencies and national governments was very important for public acceptance of agrifood nanotechnology. To quote an expert: *"Trust in regulatory agencies and national governments was key to public acceptance of agrifood biotechnology and it will be key to acceptance of agrifood nanotechnology"*. There is evidence in the literature to suggest that the consumers' source of information on nanotechnology has a substantial impact on the effect that the information has (Kahan *et al.* 2008). However, there is the need for further empirical work in this area.

Experts' opinions on how likely the same sources of information identified above about agrifood nanotechnology will be trusted by the public showed that regulatory agencies and environmental organizations had the highest score to be "very likely" sources of information to be trusted by consumers, and consumer organizations also scoring very high on "likely". In referring to consumer and environmental groups, one expert noted that "c*onsumers see them as a check on regulatory agencies and excesses of scientists and industry"*

Historical evidence from the literature also shows the importance of trust. While it is generally acknowledged that the nature of information given to the consumer plays a role (Ronteltap *et al.* 2007), it has been reported by some researchers that trust in the source or origin of the information is of more importance than the reliability of the information (Bruhn 2008). In the telephone interviews with experts, several were of the view that the most trusted sources of information vary across location. To quote some of the experts:

> *"Trust in sources of information varies between jurisdictions based on past events."*
>
> *"Consumers differ significantly in terms of their prior knowledge about nanotechnology and personality characteristics. These differences will lead to differences in information processing styles for nanotechnology information. It also depends on the location."*

Chen and Li (2007) have reported that the media is the most preferred source of information on novel food products for most consumers in Asia, contrary to other jurisdictions. As mentioned earlier, in the survey questions the media was advisedly omitted based on the reason that the media is only a medium used by any of the sources identified and is not the primary source of information. However, it must be acknowledged that "investigative journalism" can be categorized as a primary source of information.

It is very clear, based on evidence from literature and experts' opinion, that consumers in the U.S. trust the national government and regulatory agencies more than European consumers. European consumers see 'activists' groups that they perceive to be free from the special interests of industry and government as more trustworthy than government agencies (Lyndhurst 2009). Evidence from literature also indicates that many consumers do not trust scientists, on the basis that they may not know their ethical boundaries and not really care about the consumer, but pursue their personal ambitions and parochial interests (Stilgoe 2007). However, there is an interesting contradiction that requires further analyses: In several surveys, consumers are categorical that they rely on and expect experts (scientists and regulators) to decide on their behalf, but they do not trust these same experts (DTI 2003; Lyndhurst 2009). Most consumers base their distrust in experts on historical crises about food (e.g. Dioxin and BSE in Europe and *E. coli* food recalls in the U.S.) and broader issues (e.g. asbestos and nuclear power) as a proof that regulatory institutions lack sufficient knowledge to guarantee safety and that science like any other discipline may be wrong at times (Mellman Group 2006). It is therefore not surprising that evidence from literature indicates that friends, family, and other sources where consumers attach personal importance are the most trusted information source on agrifood products from applications of emerging technologies (DTI 2003). This however differed from the results of our expert elicitation; friends and family, and scientists were similarly ranked. As most of the experts are social and natural scientists, it makes sense that they would rate trust in these groups higher. According to Lee *et al*. (2005) empirical tests on major claims in the literature about the potential influence consumer trust in scientists has on consumer attitudes toward nanotechnology, have been somewhat lacking despite the major assumptions.

Experts were also asked their opinions on the state of nanotechnology policy in the U.S. and how that affects consumer acceptance. Trust is affected by access to reliable and unbiased information. Currently, there is a problem with transparency and a dearth of information available to consumers. Consumers have little way of knowing that they are consuming or using products of nanotechnology. In the words of one expert "*People need to know whether or not a food product contains potential nanomaterials, to give them the choice"* The transparency of health, safety and environmental impacts should be of concern when dealing with the development of nanotechnology in agrifood systems (Sanguansri & Augustin 2006).

The prominent themes that came out of the experts' interview were that:

- ***Public engagement is critical to consumer acceptance*** and that currently flows of information on agrifood nanotechnology from regulators and industry to consumers are almost non-existent. To address this public education strategies must be designed within cultural and value systems context of particular target groups.

- ***Scientific knowledge about risks and benefits*** has limited influence on consumer acceptance. Most consumers have little motivation to process scientific information, or little ability to understand it, or no time to digest such information; their opinions are normally influenced by value system and trust. Perceptions of risks vary among different categories of people.
- ***Inadequacy of Regulatory frameworks*** **-** All the experts were emphatic that the regulatory frameworks in the U.S. are not adequate in the treatment of nanomaterials. However few think that nanomaterials in agrifood products should be treated differently from other food products in a regulatory context depending on which part of the food supply chain is being regulated**.** Some inadequacies include lack of intra-government regulation and lack of standardized model for regulation. There was a mixed conception about the importance of international regulatory framework.
- ***The role of information*** **–** Most responses reflect the importance of appropriate and trustworthy/credible information to consumer acceptance**.** The lack of access to information combined with lack of ability to process complex nanotechnology information is likely to lead most consumers to engage in more heuristic peripheral processing when forming attitudes toward agrifood nanotechnology. Regulations can also be effective if consumers have the right information.
- Majority was of the view that ***Trust in the information source*** has a significant impact on the attitude and level of acceptance by consumers. Perceived risks and benefits carry different values depending on an individual's pre-existing cognitive predispositions. Admission of a certain amount of risk uncertainty will increase trust in the attributed source by consumers with prior negative attitudes. Generally consumers perceive information provided by industry to be the least credible and are most distrustful of an industry regulated safety system. Therefore, it is critical for the industry to earn consumers' trust.

4.0 Conclusion

Consumer acceptance is for determining the success or otherwise of agrifood nanotechnology commercialization (Siegrist 2008). It is important to note that the field of nanoscience and nanotechnology is emerging and a new area of science and technology, and currently the limitations, advantages and potential applications in the food industry are not fully understood. How to create public awareness, handle public perception, and gain consumer trust and acceptance of the use of nanotechnology in the agrifood industry are important challenges. Several factors and viewpoints need to

be considered. The views of experts working in the area of agrifood nanotechnology can provide important information on influences on consumer acceptance and what should be done to move forward with the technology. The results of our work confirmed the importance of risks and benefits of products and trust in actors in the agrifood nanotechnology system. They also suggest the need to increase information available to consumers and bolster trust in the decision making system.

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Appendix A: Summary of Experts' Responses to Phone Interviews

1.	**Describe your role or interest in agrifood nanotechnology systems.**
•	*Deleted for confidentiality*
2.	**Describe one or more examples of agrifood nanotechnology systems. Who are the key stakeholders and actors? What are the flows of information, products, etc.?**
•	In the first place agrifood nanotechnology is a misnomer. The use of the word 'nano' in products like the Indian "Nanocar" that has nothing to do with nanotechnology may be confusing to consumers.
•	"Agrifood Nanotechnology" (singular) is an oversimplification and potentially confusing from governance/participation perspectives
•	Similar applications of nanotechnologies in the different portion of the food chain are found in pharmacology, medicine, marine science etc, so a homogenous system for agrifood nanotechnology creates a sense of ambiguity in the public sphere.
•	Nanobiosensors have very broad applications both within and without the agrifood system. Within the agrifood system it is used for detection of pathogens, embedded in food packaging, tracking and traceability, animal health, and on-fields to monitor soil health and several other applications.
•	Nanotechnology as related to food includes everything as to do with food supply chain, from production to distribution.
•	There is a lot of information flows and the industries are quite secretive and very difficult to know what they are doing. Flows of information from regulators and consumers is almost non-existent for agrifood nanotechnology and from industry to consumers
•	Popular media channels seem to be having little impact on awareness, while for most consumers; commercial news media is not a primary source of information.
•	Issues relating to seed and input to retailing; tagging and tracing; nano-coding, distributed intelligence; nano-encapsulation in food product are some of the broad examples of agrifood systems
•	Two major issues, food industry started by publicly developing nanoproducts and then they got scared, however, if they don't come out and consumers later find out they will be pretty upset
•	Several industries are involved including Kraft, Syngenta, Unilever, Cargill, Cadbury etc, a
•	It depends on the type of agrifood products one is talking about, but in general it includes industry, regulators, NGOs, researchers, retailers among others.
3.	**What do you think are critical links in agrifood nanotechnology systems that influence consumer acceptance of products and applications? Why?**
•	Public engagement is very important. Public education of different stakeholder groups is key, because understanding cultural and value systems of particular groups is important. What will influence the acceptability by one group of people may not be acceptable to other groups. Participation is as much about educating policy-makers and technologists about the social and cultural contexts of public interactions with nanotechnologies as it is educating lay publics about the science & technology underlying those innovations. Understanding and incorporating public perceptions of nanotechnology, including its potential applications in agrifood systems, is especially critical in this process.
•	Providing information to and seeking input from the public will allow the government to make well-informed decisions and build trust among all stakeholders.

- Industries with their major resources may use the media to influence consumer acceptance
- Consumers are not going to be insulated by the links in agrifood nanotechnology systems

4. Does scientific knowledge about risks and benefits influence consumer acceptance? If so, how? In which areas does understanding need to be developed?

- It depends on who and how the question is asked. What the risk and benefit are is the reflection on who is asking the question Scientist and lay people have very different views and perception of risk. So although scientific knowledge about risks and benefits may influence consumer acceptance it is very narrow. So how do you bring the public to perceive risk like how scientists perceived it? This is an intellectual challenge.
- Consumers need to know that agrifood products on the market have gone through rigorous scientific testing. The entire approval process of products should be made clear to consumers (from when industry submit a product till when the product is approved). So scientific knowledge will definitely influenced acceptance
- It depends on the type of scientific information provided
- I think that the level of trust also depends on the topic at hand, the information provided, and past experiences with that source, e.g. For example, the same industry that provides [trusted] descriptive information about why it uses/produces nanoproducts or processes may be mistrusted if it issues blanket, unsupported statements about the human or environmental health and safety of those products or processes.
- Scientific knowledge have very little influence, consumers depend on their own value system and trust
- Scientific knowledge does not really affect consumer acceptance, it really depends on how the media frames the information on food safety
- Knowledge about risks and benefit basically come from the media which depends on industry, scientists and other sources for their information. Scientific knowledge per se may not affect consumer acceptance.
- Generally consumers perceive information provided by industry to be the least credible and are most distrustful of an industry regulated safety system. Therefore, it is critical for the industry to earn consumers' trust. A self-regulatory effort by the industry may help gain consumer confidence.
- Most consumers have little motivation to process scientific information, or little ability to understand it, or no time to digest such information; their opinions are normally influenced by trust.
- Increased public understanding will not necessarily facilitate acceptance of agrifood nanotechnology. However, better public understanding will facilitate informed choice in the selection or rejection of nanotechnology products and is, therefore, an important facet of the development of the technology.

5. Are the current regulatory frameworks in the U.S. adequate to assess the risks of food nanotechnologies and nanomaterials for consumers? Should nanomaterials in agrifood products be treated differently from other food products in a regulatory context?

- All the experts were **emphatic** that the regulatory frameworks in the U.S. are **not adequate** in the treatment of nanomaterials.
- Definitely no for Canada and I guess the same for the USA.
- Nanotechnology should be treated just as any new or emerging technology
- Differently is a loaded word, but I think it should be treated differently, since we can't continue to do what we have been doing.
- The federal government is just beginning to develop regulatory approaches specific to nanotechnology applications and production. At this critical juncture, it is important that leaders from industry, government, the science and engineering community, and other sectors develop a better understanding of what the public wants and expects in terms of the oversight of these new and emerging technologies, but for now it is definitely no.
- It is debatable as to whether it should be treated the same, but I think it should be treated differently depending on which part of the food supply chain is being regulated.

6. Does regulatory treatment of agrifood nanotechnology products influence consumer acceptance? If so, how?

- Trust and confidence in regulatory agencies are rather what drives consumer acceptance not necessarily the regulatory treatment.
- Difficult because there is no regulatory treatment at the moment
- Two things converges, when consumers are confident that what we eat has enormous importance on health, they see regulatory treatment as a very critical factor that affects their acceptance of any product
- Trust in regulatory agencies seems to reflect past history with certain categories of products. So trust in regulatory agencies is what will drive acceptance rather than how the product is regulated.
- Consumers in the U.S. trust their regulatory agencies. It is less so in Europe. Research shows that acceptance increases significantly when U.S. consumers learn that organizations such as the National Academy of Sciences and the U.S. Food and Drug Administration have determined that biotech-derived foods for example are safe.
- Regulation makes consumers more confident, however, there is another side to it, consumers become alarmed when they hear that a product is being more regulated, it gives a sense that it is not safe. But in the long term it positively influences consumer acceptance
- Regulatory treatment is behind the curve and the only way they can influence consumer acceptance is to go ahead of the curve and embrace labeling.
- Trust in regulatory agencies and national governments was key to public acceptance of agrifood biotechnology and it will be key to acceptance of agrifood nanotechnology

7. What is the state of U.S. intra-government cooperation regulations and standards? International government co-operation on regulation and standards? How will such initiatives influence consumer acceptance?

- Just like Canada, I believe there is lack of intra-government regulation.
- There are some efforts towards International government co-operation but no country has a model to follow.
- Yes! It gives consumers a sense of comfort that all other nanoproducts coming from other countries have gone through similar standards.
- Theoretical international organizations are to give comfort to consumers, in reality they are not.
- Great majority of consumers are not concern about international regulations.

- There is a better cooperation between government agencies in the case of nanotechnology. A lot was learnt from biotechnology. However, intra-government cooperation regulations and standards have no significant influence on consumer acceptance.
- There is pretty good international cooperation however, it does not really affect consumer acceptance. One place that it might have influence is the importation of products from countries they do not trust.
- There is lack of U.S. intra-government cooperation with regards to regulations and standards, it is slightly better in the case of nanotechnologies
- Consumers don't react to international agreement. It does not influence them in anyway

8. What information should consumers be provided on the use of nanotechnologies and nanomaterials in food products? What is the role of information and its sources in influencing consumer acceptance?

- People need to know whether or not a food product contains potential nanomaterials, to give them the choice.
- Labeling is not necessary if the product is substantially equivalent.
- Scientific information is not a major concern for consumers.
- Consumer knowledge and information concerns included "what say will the public have?" government alone should not be making these decisions," "who gets a say in regulation?" "lack of knowledge & disclosure to users," "we should know when food is affected by nano and be told the risks," and "we need to be informed when nanotechnology is in something like cosmetics."
- First consumers should know that nanomaterials or the nanotechnologies were used.
- Information is huge, lack of information is also huge for example the organic food movement in the US is driven by lack of information, we can regulate better if consumers have the right information.
- It depends on which consumer product/s you are discussing and on how apparent the "nano" component is to consumers. People already purchase some food packages that use nanomaterials—likely without knowing they are doing so. "Functional" foodstuffs may advertise their purported effects but not their nano-properties; consumer acceptance may be driven by those functional elements and not at all by things nano.
- In principle I believe in giving people much information as possible, but it is more of ethical question.
- I believe majority of consumers do take a view one way or the other, even if those views are not strongly felt, and this is how they will react to nanotechnology.
- I don't think consumers' base their decision as to accept or reject a food product solely on knowledge of the technology, I think people generally rely on pre-existing knowledge and values to form their judgment.
- Trust in sources of information varies between jurisdictions based on past events.
- Consumers differ significantly in terms of their prior knowledge about nanotechnology and personality characteristics. These differences will lead to differences in information processing styles for nanotechnology information. It also depends on the location.
- There is a correlation between the source of information and the level of consumer acceptance
- The lack of access to information combined with lack of ability to process complex nanotechnology information is likely to lead most consumers to engage in more heuristic peripheral processing when forming attitudes toward agrifood nanotechnology.
- Information from consumer and environmental groups for instance influences consumer

acceptance. Consumers see them as a check on regulatory agencies and excesses of scientists and industry

- Trust in the information source has a significant impact on the attitude change by consumers who initially had negative attitude toward genetic engineering. Admission of a certain amount of risk uncertainty will increase trust in the attributed source by consumers with prior negative attitudes. There is also significant impact of the credibility of the information source on consumer attitudes. Perceived risks and benefits carry different values depending on an individual's pre-existing cognitive predispositions
- Quality press, television documentaries and news broadcasts are also among the most trusted sources of information about food-related risk, in sharp contrast to government and industrial sources, which are highly distrusted
- Another important source of information about agrifood nanotechnology is likely to be the introduction of the nanofood products into the supermarkets. The availability of the products of nanotechnology may be highly influential in crystallizing public attitudes towards the technology, as well as providing information about potential benefits of the technology.
- Credibility and trust in information sources and regulators are likely to play a major part in the determination of consumer reactions to nanofood products.

9. Other responses

- The differential acceptance of novel agrifood products among consumers can be attributed to the different ways in which they process information about the technology and related products. Some people carefully weigh potential benefits more heavily than risks. Others form their attitudes solely based on what they hear on TV or from word of mouth.
- Differences in acceptance of nanotechnology across application domains may arise due to differences in how the benefits and risks are framed, consumer acceptance of food related nanotechnology may be improved by framing the benefits in terms of reduction of potential dietary hazards instead of framing them in terms of enhanced nutrition or quality
- Consumers have pre-disposed attitudes towards particular terminology such as "genetic engineering" and "nanotechnology.
- Perceived benefit is an important factor influencing acceptance of new foods
- I have worked a lot on issues related to genetically modified food and their regulation, and think that agrifood nanotech stakeholders should learn lessons from the GM food debate. It is clear that anti-GM organization have labeled nanotech as the next GM, so they have already decided that they will oppose this technology in food regardless of what it brings to consumers.