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2.10 Irradiation and Consumers Acceptance

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2.10.1 Introduction

New food technologies touch our lives in a unique way because we are literally what we eat. Uncertainty and insufficient or incorrect information on the perceived risks and benefits of such technologies contribute to the hesitation of the public to accept the new technologies.

Although not necessarily “new”, the progress of food irradiation as an accepted commercial technology has been slow. The safety of irradiated foods has been established by regulatory agencies and other health authorities with development of international standards for food irradiation covering human health, labeling, delivery of dose, quality assurance, and management of irradiation facilities (Codex, 2003).

Scientists have studied ionizing radiation as a means of food preservation more in-depth than any other food preservation technique (Gross, 1969; Diehl, 1995; Cleland, 2006; Eustice and Bhrun, 2006; Farkas and Mochasi-Farkas, 2011; Moreira and Castell-Perez, 2012; Farkas et al., 2014; Miller, 2015; Koutchma et al., 2018; Prakash, 2020).

Approximately 60 countries permit irradiation of one or more foods or food types. The irradiation process results in foods with improved shelf life due to reduced microbial loads and improved safety of the food due to the elimination of pathogens responsible for foodborne illnesses. Nevertheless, although food irradiation has been around for more than one hundred years, irradiated foods are not yet fully embraced by consumers. This challenge is further complicated by the confusing messages that are either anti-

irradiation (Louira, 2001; Epstein and Hauter, 2001) or pro-irradiation (Morrison and Roberts, 1987; Lutter, 1999; Osterhiolm, 2004) found in all kinds of publications.

The ongoing food safety issues and associated illness still need to be addressed at the level of the consumer. Efforts should continue to demonstrate the benefits of irradiation technology while addressing concerns and fears. Food irradiation processors, retailers and regulatory and health agencies should actively promote irradiated foods so that consumers are fully informed of the choices they can make to further protect themselves from foodborne illnesses (Hoefler et al., 2006; Eustice, 2018).

The aim of this article is to provide an overview of how consumers perceive irradiated foods, the factors affecting their acceptance of irradiation technology, and methods to obtain accurate data on consumers perceived risks and trust issues about irradiated foods.

2.10.2 Background

Irradiation of foods has been tested and validated for different applications at different dose exposure levels such as inhibition of sprouting in potatoes, insect disinfestation, treatment of spices, and pathogen decontamination for food safety. When properly done, irradiation does not impart negative effects on the quality and wholesomeness of the foods (Diehl, 1995; Fernandes et al., 2018; Prakash, 2020).

In 1997, the FAO/IAEA/WHO Study Group on High Dose Irradiation concluded that foods irradiated with doses above 10 Kilo-gray (kGy) were safe and wholesome (JSGHDI, 1999; Feliciano, 2018). Even more, in addition to producing shelf-stable meats and multi-component foods that are shelf-stable, irradiation at high-doses (25–44 kGy) produces sterile foods which are critical to those individuals with compromised immune systems and is the common method used to sterilize food items for astronauts. In other words, without irradiation, these target populations could not be well served (Mohács-Farkas, 2016; USFDA, 2016). In 1999, the same body concluded that irradiation of foods at any dose appropriate to achieve the intended technological effect (e.g., disinfestation, pathogen elimination, etc.) was (JSGHDI, 1999; Koutchma et al., 2018).

In spite of all the scientific evidence that irradiated foods are safe, the technology - in particular gamma-rays irradiation - still has a negative connotation for consumers (Maherani et al., 2016a, b; Spaulding et al., 2006; Eustice and Brhun, 2006; Eustice, 2018). Categorization of food irradiation as an additive and the need to label irradiated packaged foods has contributed to the lack of trust in the technology by consumers (Koutchma et al., 2018).

2.10.2.1 Consumers Acceptance of New Food Processing Technologies

As consumers demand fresher, more nutritional and tastier foods, advances in food production and processing technology have steadily developed. The benefits of technologies such as genetic manipulation and animal cloning in breeding techniques, nutrigenomics, radio frequency (RF), nanotechnology, biotechnology, high-pressure processing (HPP), pulsed electric field processing (PEF), microwave and ohmic heating, and ultrasound are indisputable in terms of longer product shelf-life, better quality and reduced waste (Maherani et al., 2016a, b). Some technologies could even enhance environmental sustainability and increase food product acceptance (Matin et al., 2012). Good summaries of the different novel technologies are available (Spaulding et al., 2006; Maherani et al., 2016a, b; Demirci et al., 2020).

In addition to the nutritional value and cost of foods, food safety has been a major driver for the development of new food technologies that reduce, control, and eliminate foodborne pathogens such as atmospheric cold plasma, ozone treatment, and food irradiation (Maherani et al., 2016a, b). Nevertheless, consumers frequently reject newly developed food technologies that are controversial, mainly the genetic modification of crops (GMOs) and irradiation. The reason behind this behavior is that consumers perceive the risks of new technologies differently from the producers, processors and other experts in the technology (Bauer, 1960; Hoekstra, 1974; Slovic, 1987, 1993).

Consumers make decisions about food based on feelings, rather than fact. This qualitative behavior, in addition to the lack of knowledge, makes the poor acceptance of irradiated foods by consumers a constant challenge to food processors.

2.10.2.2 The Case of Food Irradiation

A recent World Health Organization report (WHO, 2017) concluded that foodborne disease is a significant threat to human health and contributes to a reduction in economic prosperity (Bevilacqua et al., 2010). With the increasing risk of microbial contamination in food products and the threat of new foodborne illnesses due to greater demands for food and greater international trade, the application of irradiation in assuring the safety and quality of food has become more relevant.

There is no question about the safety and nutritional adequacy of irradiated food. In addition to research on irradiation for phytosanitary purposes (Hallman and Loaharanu, 2016), the effectiveness of irradiation technology to produce foods that are microbiologically safe while maintaining their quality attributes and nutritional value is well documented. Extensive research has produced significant amounts of scientific evidence in the wholesomeness of properly irradiated beef and animal products (Brewer, 2009; Nam et al., 2016; Nam, 2019) and fresh produce (Moreira and Castell-Perez, 2012; Prakash, 2016), among others. Nevertheless, in addition to stringent labeling requirements, regulatory approvals needed and lack of harmonization in irradiation-related regulations between countries, the use of irradiation treatment for foods remains hampered due to poor consumer acceptance. The benefits of food irradiation are well described in Prakash (2020).

2.10.2.2.1 Myths About Irradiated Foods

2.10.2.2.1.1 Irradiated Foods are Radioactive and Cause Cancer

Many consumers around the world still fear possible damage to their health from the consumption of carcinogenic compounds formed during irradiation (Nayga et al., 2005; Watanabe and Kawata, 2017; Withwoth et al., 2017). Most of the fear comes from the word “irradiation” and consumers view it as something added to the food. There is also the association with the effects of “radiotherapy” or “radiation” which are closely associated with cancer (Daly, 1989; Alston et al., 1995). However, scientific evidence proves the contrary. For instance, although 2-dodecylcyclobutanone may be formed during the irradiation process, it is in amounts too small to cause health damage (WHO, 2003; Watanabe and Kawate, 2017). Furan, another carcinogenic compound, may be found in some irradiated fruits but it is also found in baked foods (Groth, 2007). Overall, irradiation does not leave any residues in the food even when irradiated at high doses (Feliciano, 2018; Fernandes et al., 2018).

Irradiation of foods using nuclear technology is very controversial and this association with nuclear energy dangers has affected the wide acceptance of the technology. Consumers perceive the food as damaged or contaminated (the devastating effects of radiation on DNA) and therefore unsuitable to eat.

Acceptance of irradiation technology is closely related to the consumer beliefs as many of them will boycott irradiated food in an attempt to change policies concerning nuclear technology. These consumers are unaware of the fact that food irradiation is also carried out in facilities that do not use nuclear/radioactive sources such as the high-energy electrons or X-rays (Miller, 2015). Moreover, the unavailability of a direct method to detect irradiated food has raised consumer wariness about irradiated foods being sold without their knowledge (Daly, 1989). Thus, the lack of trust in the food industry and especially of what consumers perceive as risky food processing technologies.

Initially, although the industry resisted the use of the word “irradiated” label on its meat products because it would unnecessarily scare consumers from buying irradiated food, consumer groups strongly advocated irradiation labeling, saying consumers have a right to know if a product has been irradiated (Sparks and Shepherd, 1994). Today, all irradiated packaged foods must be labeled “treated with irradiation” and have the radura logo on the package, with the exception of spices, some ingredients, irradiated foods served in restaurants, schools, nursing homes, and hospitals (Komolprasert, 2016). So, consumers can make a conscious choice and they should be able to buy irradiated foods if they wish.

2.10.2.2.1.2 Irradiation is a Substitute for Good Practices

Consumers think that if the food processing facilities followed good hygiene and cleanliness practices, there would be no need for food irradiation. However, the threat of cross-contamination with microorganisms – some of which are pathogenic – through the food processing supply chain is a reason why intervention strategies such as irradiation are required. This is particularly important in the processing of fresh fruits and vegetables which do not undergo a lethality step using heat. Fresh produce have been related to many foodborne illness outbreaks in the USA and worldwide in the past years (CDC, 2018). Consumers do not understand that irradiation is not an end-of-the-line “clean-up” for a sub-optimal production process.

The thought that irradiation can be used to make spoiled foods marketable has crossed consumer minds as they do not trust both the technology and the food industry.

2.10.2.2.1.3 Compared to Other Processed Foods, Irradiated Food has less Nutritional Value

This is one of the most common misconceptions about food irradiation. All food processing technologies cause changes in the foods and irradiation is not an exemption. The impact of irradiation in the food’s macro and micronutrients is comparable to that of other preservation technologies. Even more, irradiation does not heat up the foods and preserves the nutrients better than some thermal processes (Prakash, 2020). Additionally, the effect of irradiation on the organoleptic properties of foods has been demonstrated to be minimal (Loaharanu, 2003; Fernandes et al., 2018).

2.10.2.2.1.4 Irradiated Foods are Expensive and They Only Benefit the Food Industry

Most consumers do not understand the principles behind the technology and believe it only benefits the food industry (Daly, 1989). Furthermore, they do not see personal gains from the benefits of the technology such as (a) more shelf-stable and longer shelf life; (b) delay of fruit ripening; (c) decontamination of ingredients, and (d) the ability to process foods in packages or large containers.

Consumers see the above benefits only help the producers, processors and retailers. That is the reason why they are not willing to pay for the products and demand that irradiated foods not be more expensive. The lack of trust in the industry also hampers its acceptance as consumer’s perception of risks are similar for all new or controversial food technologies. For instance, people afraid of GMO’s are also afraid of irradiated food (Siegrist, 2003; 2008).

2.10.3 Factors Affecting Acceptance of Irradiated Foods by Consumers

Although acceptance of irradiated foods has increased drastically over the past 20 years, there is still a lot of resistance from consumers to embrace these foods. A number of factors may explain this reluctance (Siegrist, 2008; Hashim et al., 2001). This poses a challenge because the individual’s approach to technology, life style, food and risks may be related to the individual perceptions of food risks (Roosen et al., 2004).

A 2008 Canadian study of consumers acceptance of food technologies including irradiation used scaling data techniques to analyze questionnaire responses to learn which are the major factors determining which food technologies are accepted by consumers (as well as those that are not). The goal of the study was to predict reactions to future product and process technologies that might be applied to foods (Henson et al., 2008).

A graphic display of how consumers perceived traditional and new technologies (Fig. 1) shows that the food irradiation was placed negatively in the risk-benefits continuum (e.g., harmful, dangerous, risky) while traditional technologies, nutrient fortification, and vacuum packing were placed at the positive end of the graph (e.g., useful, safe, trusted). Similarly, when technologies were associated with the continuum from known and controlled to unknown and ignorant, most food technologies fall toward the negative end (e.g., unknown, uncertain), and especially pesticides, food irradiation, and genetic engineering applied to both animals and plants. The “well understood” (positive) and “unknown/uncertain” (negative) responses had a major weight (19.5%) of the variation among the samples (Henson et al., 2008).

What is very interesting that the food technologies were located in more negative spaces than the non-food technologies. For instance, X rays are used to irradiate foods but are not considered as bad when used in health applications. These results confirm that perceptions of risk and benefit are multidimensional and help determine consumer attitudes toward irradiation technology across a nation. The derived scales for perceived risk and perceived benefit of technology are reliable and unidimensional, with good predictive ability with respect to attitudes toward technologies. Henson et al. (2008) also evaluated consumers attitudes toward non-food technologies which were not included in this article.

Similar studies at a large scale across countries would be extremely helpful and more research efforts are needed (De Barcellos et al., 2010; Perrea et al., 2015).

2.10.3.1 The Knowledge Deficit

Even today, public awareness is not high about food irradiation, and many people do not even know what irradiation is (Fox, 2002). It has been shown that awareness about the nature and benefits of food irradiation lead to positive changes in consumers' perception and influence their decisions to buy irradiated food (Nayga, 1996; Fox et al., 2002; Mehta, 2002; Jaeger et al., 2015; Nayga et al., 2005; Deliza et al., 2010). The more aware the consumer is about the benefits of irradiation, the higher the probability that the irradiated food will be accepted and purchased. So, if information is given to correct the “knowledge deficit” consumers will have a more positive attitude toward the technology (Resurreccion et al., 1995; Teisl et al., 2009; Lima Filho et al., 2017; Finten et al., 2017). However, other studies contradict this position of the knowledge “fix” (Frewer et al., 2003; Eden et al., 2008). Results depend on how the instruments used to collect data include cultural and socio-demographic values such as information on not only the level of education of the consumer but also on the level of “science” education (Frewer et al., 2003; Lusk and Briggeman, 2009).

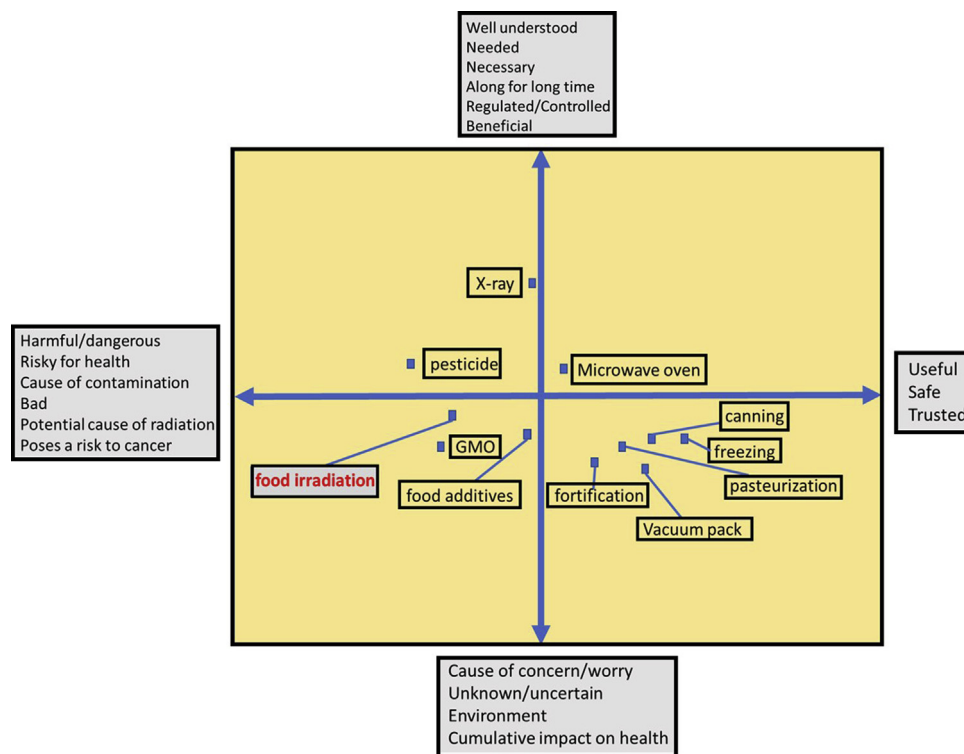


Figure 1 Perception of technologies according to risk/benefit and known/unknown continuums. Based on Henson et al. (2008).

2.10.3.2 The Outrage Factor

Food is now widely recognized as risky and consumer concern about the safety of their food has grown considerably in recent years (Breakwell, 2000). Regarding food safety, food irradiation is identified as a low-hazard, high-outrage risk (Groth, 1991), while food microbes are a high-hazard, low-outrage risk (Groth, 1991; Laminack et al., 2006; Sandman, 2012).

Outrage is the acceptability of a risk that can be influenced by the characteristics of the risk such as familiarity, voluntariness, control and dread. A risk is the sum of hazard and outrage (Sandman, 1987, 1993). So, while consumers put so much emphasis on the outrage side of a risk, scientists and food irradiation experts may utterly ignore it (Sandman, 1987).

A hazard is determined by the estimated severity and probability, while outrage is equal to the emotional response elicited by risk characteristics recognized and not by technical evaluation of severity and probability (You et al., 2018).

A high-outrage, low-hazard risk is a big risk, the sort of risk that typically leads to controversy between experts and the public (Sandman, 1993). People do not listen too much about the hazard and are not objective when the outrage is high. Thus, the need for programs to guide food irradiation professionals on how to educate consumers appropriately because consumers are more worried about pesticides or hormones in their foods and different processing technologies, than food poisoning itself (Kher et al., 2011; You et al., 2018; Bolek, 2020). In other words, they must find ways to reduce the outrage level associated with food irradiation. Some studies have demonstrated that given the choice, consumers will purchase irradiated food if available to them because of their enhanced safety attributes (Siegrist and Sutterlin, 2017).

2.10.3.3 Consumer Preferences

Consumers' lifestyle preferences including concerns about the environment and fears of technology may also drive their food choices. Consumers will evaluate irradiated foods in the context of their pre-existing knowledge of the technology and eating preference. For instance, vegans and consumers who prefer foods to be natural and minimally processed, will not consider purchasing irradiated foods, unless they know more about the process (Wormwood et al., 2019). Similarly, since irradiation is a prohibited practice under the National Organic Program rule, consumers who prefer organic foods do not have the option of buying irradiated organic fresh produce (Groth, 2007).

Other groups roughly united by their interest in pesticide elimination, alternative medicine, and anti-nuclear activities also have concerns regarding the safety of irradiation (Hunter and Brooks, 2002; Bearth and Siegrist, 2019).

The U.S. Army has played a key role in the development of irradiation technology to ensure safety and shelf-stability of military rations and Meals-Ready-to-Eat components. A strict requirement for most of the Army's food supply is that it must be shelf stable for 3 years at room temperature. The current thermal processes used to manufacture the rations produce the usual quality problems of loss of nutrient and appeal. The fact that irradiation extends the shelf life of most foods has therefore strategic implications for all of the armed services (Keith, 2001). Unfortunately, as of today, the technology has not been entirely accepted though the safety and shelf-stability aspects of the technology is driving efforts to expand its use. Shelf stable MREs are essential components of food packages delivered to people who have been evacuated to refugee camps or during national disasters.

2.10.3.3.1 Food Neophobia vs. Food Neophilia

Food neophilia refers to individuals that are willing to try new foods while food neophobia describes those individuals who are reluctant to try novel or unfamiliar foods. Neophobes may also be averse to new food processing technologies, thus the term technical neophobia (Barrena and Sanchez, 2012; Matin et al., 2012; Demartini et al., 2019; Faccio and Fovino, 2019).

In evolutionary terms, humans learned to reject foods that were poisonous. Thus, food neophobia provides a means of guiding a child toward foods that are already familiar, and rejecting those that are new and might be dangerous (Rozin and Rozin, 1981; Rozin and Vollmecke, 1986). As children age, they are less willing to accept new foods (Cooke et al., 2006) but this behavior disappears during adolescence (Benton, 2004; Cox and Evans, 2008).

Some individuals may simply reject irradiated foods because they reject everything that is new. However, a consumer with little access to information (residents of small cities) with little purchasing power will probably not intend to purchase irradiated foods. Neophobia in older adults is more prominent in lower income, lower education adults living in rural areas or small cities (Siegrist et al., 2013; Roberts and Hénon, 2015).

No conclusive results have been made about neophobia and gender (Fox, 2002; Faccio and Fovino, 2019). Although results from studies in effect of gender alone in consumer purchase decisions are inconclusive, Sapp (2003) found that men were more willing to accept food irradiation than women and that trust and perceived risk were significant factors in acceptance of the new technology (Teisl et al., 2007; Siegrist, 2008; Brady et al., 2009).

Regarding age groups, younger consumers are more accepting of new food technologies including 3D printed foods and insects as foods (Spaulding et al., 2007; Tan et al., 2015; Vidigal et al., 2015; Manstan and McSweeney, 2020). Nevertheless, refusal of new foods is rarely motivated by neophobia and the relationship between new food processing technologies and neophobia is more complex. Regarding food irradiation technology, it seems to be more of a case of technical neophobia and not of an aversion to new foods (Kortei et al., 2020; Pliner and Hobden, 1992).

2.10.3.3.2 Cultural Values

Food is an important part of our culture. Different societies use food differently and choose different foods to eat and some food items have higher “moral” value than others, lime met for Americans, rice for the Chinese, and bread for the Greeks. Culture sets the stage for what consumers determine to be good food and cooking traditional foods is one way of preserving one’s culture and values (Lee, 1957; Hohl and Gaskell, 2008). Culture and social norms influence the way people eat and also how they trust new food processing technologies. Hence, some consumer groups will bluntly reject irradiated foods because it goes against their culture (Siegrist, 2008).

As natural disasters occur and war conflicts arise, thousands of people get displaced from their homes and cannot prepare or access the foods they prefer. The lack of access to familiar foods is very concerning during these humanitarian crises because refugees, especially children, are reluctant to eat the military rations –or meat-based items for some ethnic groups—offered in the camps. Culture is tenacious (Lee, 1957). Authorities worldwide have even considered irradiation of ready-to-eat ethnic food meals to give a sense of familiarity and prevent malnutrition in refugee camps (Zi et al., 2016).

Social identity is a determining factor in consumers’ new product adoption behavior (Bartel and Reinders, 2010; Barrena et al., 2015). Bearing this in mind, product managers should consider using different strategies for different cultures in order to increase their chances of positioning new products. An understanding of these issues also enables producers to improve their production and marketing strategies worldwide (Rozin et al., 2012; Barrena et al., 2015; Bolek, 2020).

2.10.3.3.3 Acceptance of Food Irradiation Around the World

Acceptance of irradiated foods varies in terms of the type of products that can be irradiated in particular regions of the world.

Worldwide, the most common irradiated products are herbs, spices, and dry seasonings. Koutchma et al. (2018) provide an excellent summary of the type of foods irradiated in different countries and the regulations or standards they use. Studies show that Europeans have a greater distrust of irradiated foods than U.S. consumers while acceptance in China and Korea is growing (Roberts and Henon, 2015; Hohl and Gaskell, 2008; Galati et al., 2019). EU consumers and legislators still need a lot of convincing about the benefits and safety of the technology although some Eastern European countries like Hungary embrace it (Mohácsi-Farkas, 2016). The problem lies on the current state of EU legislation which hinders the widespread implementation of food irradiation, even though EU consumers perceive irradiation as an effective technology for microbial safety of foods (Koutchma et al., 2018).

Today, the U.S. allows irradiation of fourteen different types of foods why only six products can be irradiated in Canada. The fact that the allowable doses to irradiate the foods are different, create international trade challenges. Mexico follows the Codex Alimentarius Standards and allows irradiation of any food with a maximum dose of 10 kGy, as do Brazil, Cuba and Chile (Koutchma et al., 2018). In the European Union, irradiation is limited to dried ingredients and not all the EU members authorize the use of this technology in foods. Russia allows irradiation of herbs and spices, meat and other agricultural products while Australia and New Zealand only allows irradiation for phytosanitary treatment of spices and fruits (Koutchma et al., 2018). The acceptance of irradiation technology in Asian countries is very diverse with Japan only allowing gamma irradiation of potatoes to inhibit sprouting while Iran is exploring its applications (Mostafavi et al., 2010). Countries in Africa are working at establishing food irradiation programs using gamma ray’s technology.

Harmonization of labeling regulations and irradiation treatment legislation is still needed to broaden the use of irradiation technology worldwide (Koutchma et al., 2018; Prakash, 2020).

2.10.3.4 The Food Itself

If consumers have the opportunity to find irradiated foods in the market, their physical appearance and price and tangible benefits such as “the food is safer”, will influence their willingness to purchase the foods (Frewer et al., 1997; Siegrist, 1986). Perceived benefits and costs are major factors influencing consumer’s acceptance of a new technology (Siegrist, 1986).

2.10.4 Methods to Explain and Understand Consumers Perception of Risk and Benefit Regarding Food Irradiation

Consumer studies scholars seek a greater understanding of how consumer opinions about a food safety technology can run counter to scientific support for and health-related agency endorsements of this technology. Not one single approach may be sufficient to predict consumer acceptance of controversial technologies and economists and social scientists have explored methods to increase the scientific understanding of consumer opinions about controversial technologies such as food irradiation (Sapp and Downing-Matibag, 2009; Withworth et al., 2017).

2.10.4.1 Experimental Approaches

Many experimental studies have been conducted to determine consumers attitudes toward food irradiation as they present costs and benefits of the technology to try to understand how consumers perceive irradiation of foods and its risks (Teisl et al., 2009).

2.10.4.1.1 Surveys and Other Instruments

Instruments such as surveys, focus groups with open-ended and specific questions are commonly used to assess consumers acceptance of new technologies (Cardello et al., 2007; Rozin et al., 2012; Lima Filho et al., 2015; Earth and Seigrist, 2016; Bolek, 2020). These instruments have different forms including market surveys, retailer surveys, and mailed surveys, and ask different questions to determine how information drives consumer purchases. Some of these surveys have limitations because the questions are presented as hypotheticals and do not directly translate into consumers purchasing behavior. Consumer acceptance studies in simulated market settings have the advantage of obtaining detailed data about the participants' purchasing preferences and patterns (Shogren et al., 1999; Arvanitoyannis, 2010).

Psychometric studies have been conducted to determine consumers' perception of food hazards (Fife-Shaw and Rowe, 1996; Frewer et al., 1998a, b). However, there is still a gap of validated instruments to evaluate the consciousness regarding the consumption of irradiated foods. Rusin et al. (2017) developed and validated the Awareness Scale for Consumption of Irradiated Foods (ASCIF), a psychometric instrument in the form of a questionnaire that included concepts, awareness, labeling and safety of irradiated foods, and measures the changes in positioning of the system of awareness regarding the consumption of irradiated foods in Brazil. This instrument has the potential to be adapted to other languages and cultures, being an unprecedented instrument to measure knowledge in the food domain, indicating potential challenges and opportunities for the commercialization of irradiated foods.

2.10.4.1.2 Heuristics

Studies on what affects bias when consumers use heuristics to make decisions are a necessary tool to the food industry as it relates to new technologies (Siegrist, 2008; Gigerenzer and Gaissmaier, 2011). Consumers use heuristic judgments, that is, easy to judge attributes, when making decisions about foods which can result in biased decisions (King and Slovic, 2014; Siegrist and Sutterlin, 2017). Consequently, a food's attribute (e.g., naturalness), may influence consumers evaluation of the food's other attributes (e.g., color, texture, taste, nutritional value). Perceived naturalness is an example of a heuristic attribute that biases consumers toward a favorable, positive evaluation of the food and it influences how they will perceive new technologies (Siegrist and Sutterlin, 2017).

2.10.4.1.3 Conjoint and Choice-Based Conjoint Analysis

Choice-based conjoint analysis is a preferred means to design experiments to determine preference of consumers. This type of analysis is a variant of the traditional conjoint analysis methodology as it differs in that consumer responses are elicited as choices (Frewer et al., 1997, 2011). The choice-based conjoint analysis also has the desirable feature that rather than rating products one at a time, several are presented together and the participant must choose among these. This is exactly what people face when they go grocery shopping and the reality that choice-based conjoint analysis emulates (Deliza et al., 2010).

2.10.4.2 Theoretical Approaches

2.10.4.2.1 Quantitative Risk Assessment

Models developed using mathematical tools and engineering principles to quantitatively assess risk may result in accurate technical risk assessments to inform consumers about the competence of those involved in technology development and management (e.g., Starr, 1969). However, this approach does not consider many societal-related elements that affect technical risk assessments (Sapp and Downing-Matibag, 2009). In contrast, social science theories stress the fact that social-related elements also affect trust and are effective in understanding consumer perception of controversial technologies. In the risk management field, several risk assessment models of trust and consumer confidence (Eiser et al., 2002; De Jonge et al., 2007; 2008a,b) could eventually be useful tools in assessment of consumer acceptance of new technologies (Earle, 2010).

2.10.4.2.2 Means-End Chain and Technology Acceptance Modeling (TMA) Theory

Means-end chain theory involves people's cognitive structures of purchasing behavior and it has been successfully applied to new product development, and advertising strategy development (Ajzen, 1980; Gutman, 1982; Byrd et al., 1992). A means-end chain model results from the linkages between product attributes, consumption consequences or benefits produced by the product, and personal values. Means-end data is gathered through a probing process or laddering, which is an in-depth, one on-one interviewing technique to determine those linkages from consumers (Chiu, 2004).

2.10.4.2.3 Social Science Models

Methods associated with the disciplines of psychology, anthropology and sociology have been proven effective in understanding how consumers form their opinions regarding the technologies. In other words, how much do consumers understand the technology. Examples include the psychometric approach (Covello et al., 1988; Frewer et al., 1998a, b; Slovic, 2000a, b; Crowley et al., 2013), which postulates that personal emotional heuristics such as control and fear of the unknown affect interpersonal trust. A heuristic is a mental shortcut that allows individuals to solve problems and make judgments quickly and efficiently. In brief, they are cognitive rules of thumb (Herbert, 2010). Unfortunately, heuristics can lead to bias.

Psychological evidence suggests that risk evaluation is often emotion based (Loewenstein et al., 2001; Slovic et al., 2004; Kahneman, 2011). Slovic (2000a,b) observed that risk perceptions by laypeople diverged from those of experts and that the deviation depended on the technology under consideration (Lusk et al., 2014; Lusk and McCluskey, 2018.). This behavior is described

by the affect heuristic that suggests that the overall feeling about an object determines a person's perception of risks and benefits related to that object (Finucane et al., 2000; King and Slovic, 2014; Erdem and Rigby, 2013). Thus, if the technology is perceived as safe and necessary, it will be perceived as less risky and more accepted, as that is defined as the "halo effect" (Lusk et al., 2014).

The anthropological approach (Douglas and Wildavsky, 1982) asserts that the nature of culturally located customs, beliefs and social organization affect what people consider as risky. Opinions are affected by culture. The diffusion of innovations approach (Rogers, 2010) assumes that consumers will accept new technologies endorsed by respected leaders whom they trust (Sapp and Downing-Matibag, 2009).

Loewenstein et al. (2001) summarize the state of knowledge on emotions and decision making under risk in a meta-model that became known as the risk-as-feelings hypothesis which postulates that both cognitive and affective processes influence consumers judgments and perceived risks (Lusk et al., 2014). An excellent summary of other models is available in Lusk et al. (2014).

2.10.4.2.3.1 The Recreancy Theorem

More recent approaches investigate consumer confidence in the abilities of institutions to effectively protect the public within a technologically advanced, global trade system (Giddens, 1990, 1992; Beck, 1992). The recreancy theorem (Freudenburg, 1993; Alario and Freudenburg, 2003) represents one example of this approach to understanding consumer opinions. The premise of this sociological approach is that citizens living in technologically advanced societies might have become more dependent upon their technologies and thereby trust is explained by people's perceptions of the competence of institutions responsible for technology development and oversight and their confidence that these institutions will behave with honesty and integrity, and with the consumer in mind (Freudenburg, 1993). Thus, the recreancy system explains acceptance as a function of public trust in societal institutions to effectively manage a technology (Sapp and Downing-Matibag, 2009).

Recreancy refers either to a lack of available knowledge (expertise) to control technological risks or, to a perception by the public that societal institutions are not understanding consumer values in technology development or regulation (Sapp and Downing-Matibag, 2009). This method suggests that perceived risks and trust in proponents of a technology and acceptance of the technology primarily reflect people's evaluations of the performance of the institutions responsible for the technology. In other words, risk assessments are related to consumers' evaluations of the ability of individual specialists within institutions and institutional operating systems as a whole to fulfill their responsibilities, i.e., responsibilities related to competence and to treating consumers responsibly (Freudenburg, 1993). Sapp et al. (2009) found that confidence and fiduciary responsibility explained approximately 70% of the variance in consumer trust in institutional actors within the US food system.

Sapp and Downing-Matibag (2009) developed a theoretical model of acceptance of both irradiated meat and food irradiation technology using the recreancy theorem to explain U.S. consumers acceptance of food irradiation while statistically controlling for perceived risk and social-demographic characteristics such as sex, education level, age and household income.

According to the recreancy theorem, on this model, a key factor affecting acceptance was the consumers' trust in institutions and individuals responsible for food irradiation processing and regulation. The central factors affecting perceived risk and trust were (1) the perceived competence of institutions and individuals responsible for food irradiation and, (2) the perceived fiduciary responsibility of these institutions to behave responsibly in the development and management of the technology. The study collected data from a panel of one adult each in 116 households twice during a three-month period after subjects were introduced to the topic of food irradiation during a market test in the Minneapolis, MN metropolitan area. Participants were given both favorable and unfavorable information about irradiation technology and irradiated meat in the form of pamphlets, brochures and videotapes area (Sapp and Downing-Matibag, 2009).

In this model, acceptance was measured by participants' responses to questions that assessed the extent to which they thought that eating irradiated food would be good, desirable and beneficial and that the technology was a good idea. Trust was measured with how much participants expressed their trust in public health officials, industry professionals and scientists who support food irradiation. Perceived risk was measured with responses to questions that assessed the likelihood of experiencing health problems, getting cancer, or having a less nutritional, along with answers to a question that asked participants if eating irradiated food was safer compared to non-irradiated food. That is, is consuming irradiated food risky?

Competence of institutions was assessed with responses to questions about preparedness and expertise of those promoting the technology. Lastly, participants were asked to express how much these "experts" shared similar values – fiduciary responsibility (Sapp and Downing-Matibag, 2009).

Changes in perceptions of competence before and after receiving information about irradiation significantly affected changes in perceived trust, but not in perceived risk. One important finding was that presenting consumers with a variety of information about irradiation from alternative perspectives was directly related to their increase in acceptance of the technology. Having the information and being able to share it with others changed their assessment of trust, perceived risk, competence and fiduciary responsibility in favor of food irradiation (Sapp and Downing-Matibag, 2009.)

The results of this study support the argument that the two key determinants of trust as specified by the recreancy theorem – competence and fiduciary responsibility – can explain trust in societal institutions, with about equal effects on trust. This also suggests that risk communication strategies might be expanded to include partnership between citizens and the societal institutions responsible for development, promotion, and oversight of the new technology to increase consumers acceptance. Such as approach was first recommended by Fischhoff (1995).

2.10.4.2.4 Economic Models

An excellent description of the use of economic models to assess consumers' attitudes toward food irradiation is provided by Lusk et al. (2014). This article only summarizes some of the concepts relevant to its topic.

Expected utility theory, a traditional economic approach, argues that consumers evaluate risks on the basis of the perceived probabilities of observing bad and good outcomes multiplied by the utility that consumers will experience should the bad or good outcome occur. So, when consumers associate a food technology with higher probabilities of significant bad outcomes, the technology is avoided. However, this approach does not explain why consumers believe a particular food technology is risky (Lusk et al., 2014).

Research has shown that consumers' risk perceptions and day-to-day food decisions are also influenced by intuitive judgments and heuristics, as described before. This is what behavioral economic theory addresses: that subjective probability judgments often deviate from objective probabilities (Lusk et al., 2014).

As Lusk et al. (2014) describe it, behavioral economics models describe two heuristics (subjective probabilities) relevant to the acceptance of food technology as they relate to the misperception of the objective probability of the occurrence of an outcome. The "representative heuristic" refers to when consumers rate unknown hazards on the basis of perceived similarities between qualitative characteristics of unknown and known risks, whereby judgments about risk similarity are often based on semantic similarity of the two risks (Kahneman and Tversky, 1974; Lusk et al., 2014). This is relevant if consumers do not know much about the technology in question.

Consumers' judgment is also influenced by the "availability heuristic" or the ease with which they can retrieve knowledge regarding the risk. These relations led to the "prospect theory" developed by Kahneman and Tversky (1979) where consumers assign a probability weighting function to the objective probability of an outcome. In this case, individuals tend to overweight the low-probability events (e.g., risks). Since food technologies involve low-probability risks, people may pay more attention to such risks (Lusk et al., 2014).

Prospect theory also posits that people are averse to loss. The perception of loss has more influence on choice than a perceived gain. This loss aversion explains why people tend to stick with what is familiar to them (e.g., the status quo) and, in the case of food technologies, consumers will prefer to continue consuming foods made with conventional technologies (Lusk et al., 2014). Prospect theory also states that people are risk averse over high-probability gains, risk seeking over high-probability losses, risk seeking over low-probability gains, and risk averse over low-probability losses, where food technologies are placed (Lusk et al., 2014).

2.10.5 Communication Methods to Increase Consumer Knowledge and Awareness

Consumers' practices must be first understood to understand their perceived risks of technology (Wirtz et al., 2006). For instance, substituting irradiated raw meat and poultry for non-irradiated products would reduce an individual's risk of acquiring a foodborne illness (Hoefler et al., 2006). Irradiation processing of meat was approved in 2000 and its benefits to human health proven in terms of the prevention of thousands of hospitalizations and hundreds of deaths each year due to foodborne illnesses (Tauxe, 2001). However, commercial irradiation of beef has been minimal and it has shown slow progress, mostly due to consumers' perception of the technology as risky (Hoefler et al., 2006).

There is a general lack of awareness among consumers regarding the availability of irradiated meat and misunderstandings about the safety of irradiated meat. Nevertheless, consumers' interest in irradiated meat is changing. A 1998–1999 Survey found that nearly 50% of respondents were willing to buy irradiated meat and poultry (Frezen et al., 2001). A 1997 study found 52% of consumers believed food safety was a more important issue than it was in the prior year (AVMA, 1997; Hunter and Brooks, 2002). Johnson et al. (2004) found that 69% were willing to buy irradiated meat, compared to only 29% in 1993. In part, this can be attributed to the media interest in food-borne illnesses. However, opponents of food technology continue sending negative information about the technology and slowing down its acceptance by the public (Hoefler et al., 2006).

It would seem that receiving negative information about a subject has a more prevailing effect on consumers than the science-based information. That is why food industry professionals must become knowledgeable on the science behind the irradiation process and its scientific basis for food safety so they can advocate to the public to consume irradiated foods while countering the negative information spread by interest groups or the media (Fox et al., 2002).

Studies suggest that risk communication may make people more discerning about food risks and consumers' general perception of risks should be considered if policy makers want to succeed (Roosen et al., 2004). Efforts to increase consumers' trust and their involvement in new irradiated products development may increase the perceived benefits of irradiation technology (McFarlane, 2002).

2.10.5.1 Favorable vs. Unfavorable Information

Hayes et al. (2002) and Fox et al. (2002) analyzed how favorable and unfavorable information about irradiation affected the willingness-to-pay to control the pathogen *Trichinella* in irradiated pork. The favorable description emphasized the safety and benefits of the process while the unfavorable description stressed the potential risks. One of the observations from the study was that when the same favorable and unfavorable descriptions were presented to the subjects (200 households) simultaneously, the negative information was dominant and consumers rejected the irradiated product. This finding has tremendous implications

for public policy for technologies as food irradiation because, even though the scientific evidence is favorable, negative claims by opposing groups, whether inaccurate, will reduce consumer demand for irradiated foods (Hayes et al., 2002; Fox et al., 2002).

As the media tends to provide both sides of every story, the negative information associated with advocacy and other groups is widely available. The food industry has been slow to introduce the irradiation process because it fears an adverse reaction from consumers. However, research shows that the anti-irradiation message can be effectively counteracted (Eustice and Bruhm, 2006) and pro-irradiation information could help reduce the value of anti-irradiation information by 68% per person (Rousu and Shogren, 2006).

2.10.5.2 Differences in Dissemination of Information

Messages on the benefits and advantages of food irradiation may be perceived differently by consumers due to their individual knowledge of the science behind the technology or individual factors (age, gender, willingness to pay, etc.) (Groth, 1991; Costa-Font and Gil, 2012). Differences in the dissemination of information between the USA and the European Union may impact trade relations (Carreno and Vergano, 2012; Teisl et al., 2009).

Science and technology heavily rely on effective communication strategies for its development. Dissemination of the risks and benefits of the technology must be disseminated in a clear and understandable fashion to increase the potential of acceptance by the public (Costa-Font and Gil, 2012).

2.10.5.2.1 Teaching at Schools and Scientific Events

The science of food irradiation should be introduced to students early enough in science and political science courses, for example. In that manner, the idea of irradiated foods becomes familiar and students get to discuss it (Peaslee et al., 1998). Food irradiation is taught at the college level as part of the Food Science and Technology and Food Engineering curricula in the US and around the world. However, this valuable information does not reach the general student population. There is still great need for college-level educated students with sound knowledge on this technology.

Presentations of research studies on irradiated foods at conferences and professional societies offer the opportunity to reach a wider audience. Extension and outreach professionals with expertise on food irradiation provide very useful services to their communities through short courses and workshops.

2.10.5.2.2 The Internet

Although most of the results from the education efforts outlined above are available online, they are not clearly organized to make them more accessible to the general public.

The Internet is giving consumers tremendous power over corporations as websites allow informed consumers to interact and become more aware of an industry's or technology's shortcomings. Interested consumers now have instant access to accurate, current, unbiased, and technical information on a particular company, technology or product (Pitt et al., 2002). Companies must view the virtual world as different from the print and broadcast media and eventually, the real world, and acknowledge the impact of the Internet on consumer's access to information, both favorable and unfavorable.

Food irradiation companies should create informative websites to inform the public about the benefits of the technology while addressing consumers concerns. Preliminary studies indicate that new foods may be made familiar to consumers with the help of dichotomous thinking (e.g., - trust/distrust, safe/unsafe, etc.) (Bakstrom et al., 2003).

2.10.5.2.3 E-Shopping

Along with means-ends-chain analysis, the Technology Acceptance Modeling (TAM) theory has been used to predict and explain people's acceptance of information and other technologies and, more recently, to understand how online shopping affects consumer's perception of risk regarding brand names and therefore their purchasing decisions (Huang et al., 2004; Lin and Huang, 2009; Kim et al., 2017). Similar analyses could be applied to evaluate how readily access to information and online shopping opportunities may influence an individual's acceptance of irradiated foods. Online shopping patterns are increasing and food irradiation processors and retailers should carefully examine them to develop successful marketing programs.

2.10.6 Future Directions

As the food irradiation community works on means to increase consumer acceptability of their products, scientific-based evidence of its safety is still needed. Studies to enhance the sensory quality of high-dose irradiated food and the combination of irradiation with other technologies need to be continued. Irradiation of fresh fruits and vegetables is still the best pathogen decontamination technology to use; however, with the exception of some fruits, these foods are not commercially available, mostly due to processors and consumer poor acceptance of the technology.

There is still a lot of work to do to enhance the appeal of the technology as a food safety technology. Processors and retailers must be exposed to factual knowledge conveyed as positive, favorable information that reduces the perceived risks. Policy makers, regulators and scientific experts must collaborate to find effective methods to achieve that.

The instant information world of today and the surge on online shopping may serve as an advantageous platform to increase consumer acceptability of irradiated foods as they become available. The increasing importance of online shopping during worldwide crises such as the COVID-19 pandemic cannot be underestimated. As everyone else, food irradiation promoters must develop action plans for online-only purchasing.

2.10.7 Closing Remarks

Food irradiation technology and consumer acceptance of irradiated foods has been extensively studied. On this article, an attempt was made to highlight the more relevant factors affecting consumers choices, the type of information they receive and how they process it to make decisions, methods to assess why consumers find irradiated foods risky, and how different forms of communication may influence consumers idea of the technology. The number and types of methods used to measure consumer attitudes toward irradiate foods are too large to cover on this article. Therefore, this is not a comprehensive review and the reader is encouraged to access the cited and suggested references for further understanding of this complex issue.

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