Understanding Consumer Knowledge, Perception, and Attitudes Towards Irradiated Foods: Insights for the Mango Industry

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The International Food Irradiation Symbol – The Radura

Treated with Radiation
Treated by Irradiation

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1. Introduction

Food irradiation is a process in which food is exposed to a controlled source of ionizing radiation to extend food shelf life and reduce food spoilage by eliminating pests, parasites, and bacteria that cause food poisoning (D'Souza et al. 2021; Shea and Committee on Environmental Health 2000; Wood and Bruhn 2000). Although ionizing radiation has been applied commercially in food, as well as medical and pharmaceutical devices, consumers still lack widespread knowledge of this technology. Irradiation has been applied successfully to red meats, poultry, produce, and grains (Tauxe 2001). The effects of irradiation are subject to the type of food being treated, the dosage level of irradiation, temperature, surrounding environment, and other external factors (Rusin et al. 2018). Usually, consumers express strong aversion towards new food technologies (Bearth and Siegrist 2019). Like other introductions of new food technology, food irradiation has been debated publicly, with questions raised about its safety, wholesomeness, and potential risks to consumers (Fox et al. 2002).

Food irradiation has been recognized by several international agencies, including the World Health Organization (WHO), the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA), and the general principles of food hygiene of the Codex Alimentarius (Galati et al. 2019). Codex Alimentarius Commission accepted Codex General Standard for Irradiated Foods in 1984 (D'Souza et al. 2021). More than 60 countries worldwide have regulations allowing irradiation in one or more food products commercially (International Atomic Energy Agency, 2021). Globally, irradiated foods must be labeled with the international symbol for irradiation (i.e., Radura symbol), along with a statement indicating this

information (e.g., treated with irradiation, treated by irradiation, irradiated, treated with gamma radiation to extend shelf life, or this treatment does not induce radioactivity).

Commerical food irradiation is regulated differently across countries. The first commercial application of food irradiation was for the decontamination of spices in Stuttgart, Germany, in 1957. However, food irradiation was legislatively prohibited in Germany during that time, and prohibition lasted until 2000 (Diehl 2001). In 1960, Canada initially approved the irradiation of potatoes to inhibit their sprouting process (Bashir et al. 2021). In Japan, irradiation was approved on potatoes under specified conditions by the Ministry of Agriculture, Forestry and Fishery in 1967. Korea authorized food irradiation in 1985, and it was commercialized in 1987, without labeling requirements (Byun et al. 2009). In the UK, food irradiation was not allowed until January 1991. On the other hand, irradiated apples have been sold in Shanghai, China, since 1984. Overall, although food irradiation was invented in the EU and the US, there was an increasing trend in commercial food irradiation in Asia and a decreasing one in the EU (Shahbaz et al. 2016).

In the US, the Food and Drug Administration (FDA), the US Department of Agriculture (USDA), and the Centers for Disease Control and Prevention (CDC) have endorsed the safety of irradiated food (Nayga et al. 2006). Souces of irradiation were considered as food additives mentioned in the 1958 Food Additives Amendment of the Public Law 85-929. In 1963, the FDA authorized the first use of irradiation to treat food in the United States, in which wheat and wheat flour were the targeted products for insect treatments. The early 1960s was characterized as a time of optimism and a focus on the benefits of food irradiation (Bord and O'Connor 1989).

Using irradiation to control insects and inhibit growth and ripening in fresh fruits, vegetables, and grain was not approved in the US until April 1986 (Terry and Tabor 1988). At the same time, the FDA also required all irradiated food products sold in retail packages to be labeled ″treated by irradiation″. However, this labeling requirement was removed in April 1988. The 1980s were considered the modern period of renewed interest in irradiated foods. However, irradiated foods were still not familiar to many consumers during this time. As a result, information provision about food irradiation led to a positive view by the public and health professionals (Christine M. Bruhn 1995; Feng et al. 2016).

Mangoes from Puerto Rico are one of the first fruits irradiated and sold in Florida in 1986 (Bruhn 1998). In 1987, irradiated Hawaiian papayas were available in California (Bruhn and Noell 1987). Irradiated apples were marketed in Missouri in 1988 (Terry and Tabor 1988; 1990), and irradiated strawberries were later introduced in Florida in 1992 (Marcotte 1992). During the same year, irradiated strawberries, grapefruit, and oranges were sold by a retailer in Chicago. Thereafter, numerous irradiated fruits, vegetables, and spices were marketed in different states in the US (International Consultative Group on Food Irradiation, ICGFI, 1999; Bruhn 2001).

In 1992, the USDA approved a rule to permit irradiation of raw, fresh, or frozen packaged poultry to control certain common bacteria in raw poultry. The first US commercial food irradiation facility operated in the US was Vindicator of Florida, Inc. in Mulberry, Florida, in 1992. [1] During that year, irradiated strawberries, citrus, mushrooms, and onions were marketed

[1] Vindicator of Florida is the company created by Sam Whitney, a successful and well-known businessman in Florida. Initially, Vindicator of Florida focused on irradiating and commercializing citrus fruit, strawberries, spices, dried ingredients, and beehives (Fraser 1993).

at a small grocery store in Illinois by Carrot Top Inc. (Malone 1990). In 1992, the US also authorized the ionization treatment for dried or dehydrated herbs, spices, and vegetable seasonings used in small amounts as food ingredients (Sadecka 2007). FDA approved irradiation of refrigerated or frozen raw meat and meat products in 1997. The first commercial packages of irradiated beef (including frozen beef patties/hamburgers) reached the retail consumer market in 2000 (Diehl 2002). Later in 2002, the USDA began to allow more imports of irradiated fresh fruits and vegetables. Overall, species, fresh produce, and ground beef are the most important irradiated products in the US (Maherani et al. 2016).

The popularity of irradiated foods remains controversial. Consumer acceptance of irradiated foods has varied around the world. Food irradiation received strong opposition in the UK. In 1989, Neilson/Henry Centre for Forecasting survey showed that 70% of UK consumers were not willing to buy irradiated produce, and an additional 20% were undecided. In the same year, irradiated strawberries were introduced in French supermarkets, and 60% of shoppers were opposed to buying those strawberries (Barnes 2004). In Turkey, consumers' awareness and acceptance of the irradiation process are relatively low (29%) compared to developed countries like the US (Gunes and Tekin 2006). [2] China is one of the largest producers of irradiated foods, followed by the US (Bashir et al. 2021; Kume et al. 2009; Galati et al. 2019; Shahbaz et al. 2016). According to a consumer survey, Chinese consumers' acceptance of this type of product was relatively high, reaching around 84% of surveyed consumers (ICGFI, 1999). In Brazill, the majority of consumers are not ready for irradiated foods and hold doubts about

[2] Gunes and Tekin (2006) cited and compared their results with one of the results by Resurreccion et al. (1995) indicating that 72% of consumers in the US were aware of irradiation.

this type of technology (Behrens et al. 2009). However, when information about food irradiation is provided, Brazilian consumers are more likely to purchase irradiated foods (Deliza et al. 2010).

Although consumer perceptions of food irradiation have improved since its introduction, knowledge and awareness of irradiated foods are relatively higher among US consumers compared to other countries. By the 1990s, 41% of US consumers were aware of the irradiation process, but the majority showed a negative attitude to irradiated foods (Kwon et al. 1992). However, US consumers' attitude toward irradiated foods has been relatively consistent over the past five decades. The progress in commercializing and accepting irradiated foods in US markets has been slow (Castell-Perez and Moreira 2021). This is a result of insufficient available information on irradiated products, which provokes concern about the potential risks of irradiation.

The labeling of irradiated products is still undergoing reevaluation in the US (FDA 2018). The FDA only requires to label "treated with irradiation" or "treated by irradiation" if whole foods are irradiated, while no labeling is required for irradiated food additives such as spice and herb ingredients. However, dried spices and herbs are the food most likely to be irradiated in the US as well as worldwide (Duncan et al. 2017; Sadecka 2007).

Understanding consumer perceptions and attitudes toward irradiated foods is critical to the success of this technology in the food sector, which brings numerous benefits to the mango industry. This report takes a significant step forward in strengthening this understanding through a thorough literature review, where we organize the large body of work on this topic and highlight the main takeaways from previous studies. The effectiveness of a literature

review relies heavily on its ability to organize the current knowledge base, inform on the main findings and related implications, and guide the future direction of work in the area. Our research has achieved these goals as follows:

1. We organized the current literature on consumer awareness, understanding, perceptions, and attitudes related to irradiated food technology in general and irradiated mangoes in particular, both in the US and the rest of the world.
2. We reported key findings from the literature that can strengthen the current understanding of consumer opinions and preferences for irradiated food and provide recommendations for improving the market opportunities of irradiated mangoes.
3. We identified remaining gaps in knowledge that present a critical need for future research that can further increase market penetration by improving consumer familiarity with, acceptance of, and valuation for irradiated mangoes.

This report will help the National Mango Board (NMB) get up-to-date on consumer views and attitudes toward food irradiation. It will also inform on the main barriers to acceptance and how current consumer trends affect consumer perceptions and behaviors toward this technology. Furthermore, the information presented in this report will provide a scientific foundation to support the design of research-based strategies to nudge higher consumer understanding, trust, and acceptance of irradiated mangoes. Finally, it will highlight critical needs and direct future research to address those needs. Therefore, this work provides great benefits to all players in the mango industry.

2. Methods

The literature search was conducted during the period August 1 to December 20, 2021. The systematic literature search strategies and article eligibility criteria are presented in this section.

2.1. Eligibility criteria

We aimed to access as many published scientific articles as possible to minimize common biases in narrative summaries of past research (Littell, 2008). The following eligibility criteria were used to collect literature covering consumer knowledge, perceptions, and attitudes related to food irradiation:

- *Inclusion criteria*: the literature review includes (1) consumer studies in the US, and globally, determining consumer awareness, knowledge, perceptions, preferences, willingness-to-pay (WTP)/willingness to eat/willingness to try irradiated foods/food products; (2) empirical surveys, policy/strategy discussions, reviews, and case studies/reports; and (3) published in peer-reviewed journals from 1980 to 2021 in English.
- *Exclusion criteria*: the literature review does not include (1) personal opinions, book chapters, letters, and other articles published in nonpeer-reviewed journals; (2) studies on irradiation of nonfood products; and (3) studies that are not related to humans.

2.2. Systematic literature search strategy

The database sources used for this search are from (1) Google Scholar, (2) EBSCOhost, (3) ScienceDirect, (4) Scopus, and (5) Pubmed. All related articles were collected using the keywords presented in Table 1. Overall, 1,383 papers were collected.

The selection of qualified studies was completed in two steps. In step 1, we reviewed the titles and abstracts of all identified studies. After removing all duplicates and filtering based on exclusion criteria, 250 studies remained. In step 2, we comprehensively evaluated abstracts and methods sections. A total of 94 studies satisfied all three inclusion criteria. However, one was a duplicated research study published in two different journals. Therefore, this report covers 93 articles in total.

3. Results

Consumers' knowledge, perception, and attitudes toward irradiated food were initially considered at the first conference on Marketing, Market Testing, and Consumer Acceptance of Irradiated Food convened in Vienna, Austria by FAO/IAEA in October 1982. Therefore, the research related to consumer perception, preferences, and WTP for irradiated food was not available until the 1980s. Most research studies targeted US consumers. Specifically, 62 of the 93 research studies reported here were conducted in the US (Table 2). The first article on US consumer acceptance of irradiated foods was published in 1983 by Titlebaum and Dubin (1983).

Researchers have applied various approaches to study consumer attitudes toward irradiated foods. Consumer surveys, laboratory experiments, and supermarket simulations are the main methods used to examine consumer knowledge, perception, and attitude toward food irradiation (Figure 3). However, consumer surveys are the most prevalent, as they are applied in 97% of the 93 studies reviewed here. Consumer surveys were conducted using different data collection methods, including mall intercept surveys/interviews (21%), online surveys (16%), mail surveys (7%), lab-designed surveys (16%), phone interviews (9%), in-person interviews (14%), and focus group discussions (14%).

Most research used hypothetical scenarios to elicit consumers' responses since irradiated products were not yet available in the market. However, there is a gap between the results obtained from hypothetical surveys and retail trials. For instance, the actual purchase proportion is normally lower in retail trials than in hypothetical surveys. Specifically, while 60% of the participants in a hypothetical survey indicated that they intended to buy irradiated food, only 21.7% actually purchased irradiated food products during simulated shopping trips (Rimal et al. 2004; Fox and Olson 1998). One reason for this divergence is that respondents to hypothetical surveys did not have an opportunity to see or otherwise examine the irradiated food products. Moreover, actual purchases are normally affected by product quality attributes – such as package labels, fat content, and marbling – while purchase intentions in hypothetical surveys are primarily influenced by socio-economic variables (Rimal et al. 2004).

As shown in Figure 2, previous studies have covered various specific commodities, although a large number of studies investigated food in general (44 studies). Among specific commodities, beef and chicken were the most frequently used to explore consumer perceptions and attitudes toward food irradiation, with 16 studies investigating each commodity. Many researchers investigated irradiated meats or poultry products because of their higher availability in local markets. In addition, the meat industry showed more interest in irradiation technology compared to other food market sectors.

Research participants are essential to understanding how preferences vary across different consumer segments. Previous studies worked with different groups of consumers, but primarily with adult consumers representing primary shoppers in their household (i.e.,

responsible for the majority of food purchase decisions). Other consumer groups used include store owners, managers, and students (Figure 4).

3.1 Consumer Knowledge of Irradiated Foods

The consumers' degree of knowledge of irradiation technology affects their perceived health risks, and consequently, their acceptability and WTP (Crowley et al. 2013). Therefore, it is critical to understand the level of knowledge of food irradiation among US consumers.

From 93 studies covered in this report, 21 have studied consumers' knowledge of irradiated foods or food irradiation. These studies cover information related to the general level of consumer knowledge about irradiated foods, consumer interest in receiving knowledge about irradiated foods, consumer awareness vs. understanding of the technology, and the main individual characteristics that affect this level of knowledge.

Overall, US consumer awareness of irradiation has steadily increased over the past 20 years. Among US consumers, 23% reported awareness of irradiation in 1984 (Bord and O'Connor 1989), compared to 87.5% in 1995 (Potakey et al. 1996). However, the majority of research in the 1980s and 1990s shows a lack of proper knowledge of such technology among consumers, which drove suspicion about the health effects of consuming treated products (Galati et al. 2019). Consumers usually associate food irradiation with high technology, nuclear power, radioactivity, cancer, Chernobyl, X-rays, and cell destruction (Bearth and Siegrist 2019; Galati et al. 2019; Diehl 1993). Although consumer knowledge of irradiated foods has increased recently, some confusion exists when differentiating irradiated foods from radioactive foods. Moreover, some consumers might have heard about food irradiation but still don't know any details about this technology and its effects. For instance, Bhumiratana et al. (2007) surveyed

US consumers and found that 49% have heard about food irradiation, while more than 70% had little or no knowledge about the irradiation process.

Consumer knowledge in other countries is much lower, especially in developing countries. Although Brazil has approved food irradiation since 1973, most Brazillian consumers do not know about food irradiation, and this technology still remains underutilized (Behrens et al. 2009; Filho et al. 2015). A similar result was found for consumers in Korea (Han et al. 2014). Flores and Hough (2008) also find that 79% of consumers in Argentina had never participated in any educational training on food irradiation and hence indicated a limited understanding of irradiated foods. The literature points towards the need to establish more educational programs to improve consumer awareness and knowledge of irradiated foods.

3.2. Consumer Perception of Irradiated Foods

Consumer perception covers general consumer views about the technology and changes over time, the main consumer concerns with the technology, and comparing consumer concerns about irradiating foods to other food-related safety issues (e.g., pesticide residues, animal drug residues, food additives, microbiological contamination). The majority of the articles covered in this literature review (81 out of 93) have investigated consumer perceptions of food irradiation.

When asked about irradiation, consumers question product safety, nutritional quality, potential harm to employees, and potential danger from living near an irradiation facility (Bruhn 1998). Information provision can induce perceptions that irradiated food products are safe and beneficial (Hayes et al. 2002). However, for most consumers, the word "irradiation" triggers concerns for health risks (Bearth and Siegrist 2019; Galati et al. 2019; Diehl 1993). These perceived health risks affect consumers' acceptability of irradiated foods,

although consumers are generally interested in learning more about this technology and its effects.

In the 1980s, several studies used focus groups, telephone interviews, mailed questionnaires, and in-person surveys to determine consumer attitudes toward irradiated fresh produce, fish, and poultry. During this period, the information on irradiation and irradiated food was still limited to consumers, and most consumers were confused or did not know about irradiation. Therefore, the proportion of people willing to try irradiated food was 20-25%. Educational campaigns on irradiated foods included providing irradiation information on package labels (logo of irradiated foods), samples at grocery stores, media, and store owners' opinions. [3] As a result, in the 1990s, consumer knowledge of irradiated food was improved, and consumers were more concerned about irradiated products' safety, nutritional quality, potential harm to employees, and potential danger from living near an irradiation facility. However, most consumers had never seen irradiated commodities in their local grocery stores, although 50% of consumers indicated that they were willing to purchase irradiated foods if they were available (Frenzen et al. 2000).

Consumer concern about irradiation was less than that for other food-related concerns, such as the safety of food additives, pesticides, herbicides, animal drug residues, antibiotics, antibiotic-resistant bacteria, and hormones. This led to an increase in acceptance of irradiated

[3] The first TV news show on food irradiation was hosted by John Stossel of ABC News for the 20/20 news program on December 13, 1991 entitled "The Power of Fear" in which the protests at a food irradiation facility in Florida was focused (Spiller 2004). Overall, the report concludes that food irradiation is a safe process. Similarly, the New York Times declared on December 4, 1997 that "the use of irradiation on red meat to kill disease-causing micro-organisms in beef, lamb and pork is an important and overdue step toward improving food safety for consumers." (New York Times Editorial, 1997).

foods to 45%-54% (Cottee et al. 1995). However, during this period, the majority of consumers were undecided about food irradiation because of the lack of technology base, market base, and regulation (Henson 1995). From the 2000s to the present, consumers' awareness of irradiated foods increased steadily but was correlated with sociodemographic characteristics such as age, education level, gender, prior knowledge about irradiation, information, trust, and expert opinion. As a result, consumers are more willing to purchase irradiated fresh produce, meat, seafood, and other foods. Grocery store owners consider irradiated foods as an additional choice for consumers, but food manufacturers have been slow to adopt irradiation partly because of the perception that relatively few consumers are willing to purchase irradiated foods (Frenzen et al. 2001).

Recent research has suggested that information about the nature and benefits of food irradiation leads to positive changes in consumer perception and buying decisions (Hayes et al. 2002; Fox et al. 2002; Nayga et al., 2005). In addition, information on alternative food technologies impacts consumers' perception and acceptance of irradiated foods. Specifically, favorable perceptions of organic production and biotechnology negatively affect perceptions of food irradiation (Teisl et al. 2009). Kwon et al. (1992) show that if the benefits of irradiated foods were provided to consumers, they would prefer food irradiation to other chemical treatments. Moreover, consumers are more likely to purchase irradiated foods if they are safer, less costly, and have higher quality, longer shelf life, and broader product availability (Castell-Perez and Moreira 2021).

Consumer perceptions of food quality are highly associated with labeling terminology. For instance, the terminology, *food irradiation*, had a detrimental effect on consumers' views,

while *food ionization* did not (Bearth and Siegrist 2019), although both terms refer to the same technology. Moreover, consumer education programs regarding irradiation are crucial to consumer acceptance of irradiated food products (Hashim et al. 1995; Thompson et al. 2007), especially for consumers from developing countries, such as Korea (Byun et al. 2009; Han et al. 2014), Brazil (Behrens et al. 2009), Chile (Junqueira-Gonçalves et al. 2011), and Argentina (Finten et al. 2017).

3.3. Consumer Attitudes Toward Irradiated Foods

Consumer attitudes toward irradiated food include consumer acceptance and willingness to purchase irradiated foods, changes in consumer acceptance over time, and consumer WTP for irradiated foods. These topics were investigated in 91 of the 93 articles studied in this literature review.

Overall, findings on consumer acceptance of irradiated foods or food irradiation have varied nationwide (Sapp et al. 1995). During the 1960s to the 1980s, consumers were reluctant to purchase irradiated foods because of the limited information and availability of irradiated foods in the marketplace (Loaharanu 1997). Titlebaum et al. (1983) were among the first researchers to survey consumers about their acceptance and attitude toward irradiated foods, including produce, fish, and poultry products. At that time, consumers perceived the only benefits of food irradiation were keeping food fresh and extending its shelf-life. They, therefore, saw no need for this technology because of the availability of fresh foods in markets and their ready access to refrigeration. During this period, the information on irradiation and irradiated food was still limited to consumers, and the majority of consumers were confused or

did not know about irradiation. Therefore, the proportion of people willing to try irradiated food was 20-25%.

A few years later, a survey by Brooker et al. (1986) on irradiated seafood showed that consumers were not interested in irradiated products. One of the seafood products used in their survey was not available in the market yet, so consumers were not quite sure about its freshness and quality after irradiation. However, 72% of the 400 interviewed consumers in their study indicated that they are willing to try irradiated seafood products if they are available in the market. Bruhn and Noell (1987) conducted one of the first empirical surveys to determine consumer preference and acceptance of real Hawaiian papayas available at the local grocery stores in California in 1987, a year after the US FDA approved the commercialization of irradiated fruits and vegetables. Their results show that most grocery shoppers could not recognize the difference between irradiated and unirradiated papayas. Approximately 74% of the 200 consumers surveyed in their study were willing to buy irradiated papayas.

In the 1990s, consumers became more interested in food irradiation information due to the higher availability of irradiated foods in local markets. However, the majority of consumers were still unaware of the safety and benefits of irradiated foods. In addition, labeling irradiated foods could positively affect consumers' purchase behavior (Hashim et al. 2001), but this labeling was not mandatory. Therefore, consumers' willingness to purchase irradiated foods declined slightly during the late 1990s (Frenzen et al. 2001).

In the 2010s, information about the nature and benefits of food irradiation was a major factor affecting consumers' perceptions and attitudes toward irradiated foods. For instance,

consumer willingness to purchase irradiated foods increased from 8.5% to 94% after presenting food irradiation information (Aiew et al. 2003; Nayga et al. 2005).

In reality, however, consumption of irradiated foods was still limited because of the insufficient information on food irradiation and its relatively low availability in the market. On the other hand, consumers were still resistant to food irradiation despite scientific evidence and professional testimonies pointing to its safety and benefits (He et al. 2005). Moreover, the unwillingness of major retailers to sell irradiated products was one of the factors contributing to the slowdown in the adoption of this technology (Macfarlane 2002). Since the acceptance of irradiated foods was still slow, researchers emphasized the determining factors influencing consumer perception and attitudes toward irradiated foods. This body of work pointed to consumer trust in government and the food industry as dominant factors affecting consumer attitudes toward irradiated foods (Castell-Perez and Moreira 2021). The high costs associated with irradiation are another factor that is likely to constrain the irradiated food market (Ferrier 2010).

Overall, irradiated foods are more acceptable in upscale markets (Bruhn 1998). Health authorities worldwide hesitated to approve the marketing of irradiated foods, and only 16% of interviewed consumers indicated that irradiated foods are safer than unirradiated foods (Diehl 1993). However, consumers' reported acceptance of irradiated food varied significantly, ranging from 16% to 92% across studies (Nayga et al. 2005). Information provision played a significant role in increasing consumer acceptance of irradiated food over time, as consumer willingness to purchase irradiated food increased from 43% to 80% after reading information about irradiation (Fox and Olson 1998).

High fixed cost is one of the constraints for the widespread use of food irradiation (Ferrier 2010). For example, initial estimates showed that the cost of irradiating fruits ranged from 4.6 cents per lb in the US to 24 cents per kg in Thailand. In addition, the estimated cost of irradiation ranged from 5-6 cents per pound of beef (Bogart and Tolstun 1999) and 0.5-1.5 cents per pound of meat or poultry (Frenzen et al. 2000). Therefore, it is critical to determine whether consumers are willing to pay a price premium for irradiated foods compared to conventional foods.

Our systematic review found 16 research studies that estimated consumers' WTP for irradiated food products. Those studies differed in their measurement of WTP, with some measuring WTP as a percentage of a given food product's price and others measuring WTP per pound of food purchased or per meal (Table 4). Two separate studies by Giamalva et al. (1997) and Donaldson et al. (1996) conducted simulations and found that consumers' aggregate WTP greatly exceeds the estimated direct costs of foodborne disease and irradiation costs for many food products. Overall, consumers were willing to pay an 11.1% price premium for irradiated food. In terms of absolute monetary value, consumers were willing to pay a premium of 32 cents per pound for irradiated food (Table 4). This premium WTP exceeds the estimated irradiation costs. Moreover, irradiation mitigates the vexing environmental problem of invasive species and ozone depletion and reduces food waste, all of which can provide significant benefits to both producers and consumers (Ferrier 2010).

3.4 Factors Affecting Consumer Acceptance and Valuation of Irradiated Foods

This section covers information campaigns educating about the technology compared to highlighting benefits of irradiated foods, the interaction between positive and negative

information related to the technology, and their combined effect on consumer preferences. We also discuss sociodemographic factors (e.g., age, sex, income, education level, etc.), experience factors (e.g., tasting), social influences (e.g., public opinion), and product-related factors (e.g., packaging, information displays).

Of the 93 articles covered, 21 have studied factors that influence consumers' perceptions and attitudes toward irradiated foods or food irradiation. These studies report that gender, age, educational level, income, prior knowledge, trust, and expert opinion are the main factors influencing consumer acceptance of irradiated foods (Sapp et al. 1995). Although gender is one of the most important factors affecting consumers' perception and acceptance of irradiated foods (Nayga 1996), evidence on the effects of gender is still inconsistent. A number of studies found that females generally have more negative views toward irradiated foods compared to males (Malone 1990; Nayga 1996; Lusk et al., 1999; Fox et al. 2002; Siegrist 2008; Teisl et al. 2009;) since they are usually responsible for health matters in the household, which makes them more concerned about the safety and health effects of irradiation (Steger and Witt, 1989). However, a study by Sapp et al. (1995) indicated no statistically significant gender differences in the likelihood to consume irradiated food, and other studies found females are more likely to pay a premium for irradiated foods (Nayga 2003). Age was found negatively correlated with acceptance of irradiated foods (Feng et al. 2016). Specifically, younger consumers are more likely to accept irradiated foods than are older consumers (Castell-Perez and Moreira, 2021). Income and prior knowledge were found positively associated with consumer acceptance of irradiation. Higher-income adults are more likely to accept irradiated foods than lower-income individuals (Nayga 2004; Siegrist 2008; Castell-Perez and Moreira,

2021). Overall, irradiated food neophobia was found more prominent among older adults, lower-income individuals, and lower education in rural areas or small cities, but was not significantly related to gender (Wolfe et al., 2005; Castell-Perez and Moreira, 2021).

Consumers' trust and perceived risk influence their perception of food irradiation (Sapp and Downing-Matibag 2009). Consumers were usually untrusting of the information about irradiated food provided by government agents. Rodriguez (2007) and Spaulding et al. (2007) indicate that family doctors, primary healthcare providers, and food scientists are the most trusted source of food safety information. In addition, consumer educational programs about irradiation are key to consumer acceptance of irradiated foods (Hashim et al. 1995; Thompson et al. 2007), especially for consumers from developing countries such as Korea (Byun et al. 2009; Han, Kim, and Choi 2014), Brazil (Behrens et al. 2009), Chile (Junqueira-Gonçalves et al. 2011), and Argentina (Finten et al. 2017). Information about the benefits of irradiation can increase the preference ratings of irradiated foods (Vickers and Wang 2002).

4. Conclusions and recommendations

The market potential for irradiated food is strong (Bruhn 1995). However, a lack of proper knowledge of irradiation technology among consumers drives suspicions about the health effects of consuming treated products (Galati et al. 2019). Therefore, it is essential to inform and educate consumers about food irradiation. Overall, consumers are conservative about food irradiation, so favorable information provision can significantly improve their attitudes toward irradiated foods. For instance, only around one-third of US consumers are willing to buy irradiated red meats, poultry, fruits, and vegetables without information on irradiated foods or food irradiation (Nayga 1996; Rusin et al. 2018). Therefore, providing information on the safety

and benefits of food irradiation can increase consumers' acceptance of irradiated food from 50% to 89% (Nayga et al., 2005).

Food irradiation has been considered as a solution for food loss and food waste in a number of countries (Thayer 1990; Prakash 2016). However, the popularity of irradiated food products at local stores is limited, and consumers' acceptance of these foods is still low. The demand and supply of irradiated foods depend on the approval of the foodservice industry as well as consumers (Frenzen et al. 2001; 2000). Therefore, promoting higher acceptance of irradiated foods from both consumers and supply-side stakeholders is crucial for the market success of food irradiation.

One of the main reasons for the limited acceptance of food irradiation by consumers is that many hold inaccurate or biased information about this technology, leading to negative perceptions and attitudes toward irradiated food products (Finten et al. 2017). Negative information dominates positive information about new food technology, and irradiated foods are no exception. Therefore, claims made against new technologies, such as food irradiation, can significantly influence consumer perceptions even in the presence of favorable information from expert sources. Critics of food irradiation and consumer activist groups argue that the process is unnatural, results in lower nutritional value in food, and presents health risks for workers (Nayga et al. 2005; Rodriguez 2007). Dissemination of such negative information affects consumer acceptance of irradiated food (Gunes and Tekin 2006), and leads to a lower WTP for irradiated food products (Fox et al. 2002).

Consumers want the features that irradiation offers, such as the destruction of harmful bacteria. They also need information about the safety of irradiated food, the effect of

irradiation on nutritional value, and the opinions of health experts (Bruhn 2001). Information disclosure is important for marketing foods produced using these manufacturing practices (Nayga 2003; Schroeter et al. 2001). Information on food irradiation should be presented clearly, concisely, and consistently to consumers. The more information that is provided, the more receptive consumers may be to the technology (Pohlman et al. 1994).

Consumer perceptions of food quality are highly associated with labeling terminology, such that the term *food irradiation* has a detrimental effect on consumer views, whereas the term *food ionization,* referring to the same technology, does not (Bearth and Siegrist 2019). Previous studies show that the term irradiation itself constrained consumer acceptance (Castell-Perez and Moreira 2021; Bearth and Siegrist 2019; Galati et al. 2019; Diehl 1993). Therefore, replacing the term irradiation with another term, like *ionization* or *cold pasteurization,* can potentially help avoid negative connotations with the name of this technology. Moreover, labeling irradiated foods will enhance consumer confidence by assuring consumers' right to choose the type of product that fits their preferences (FDA 2018). Providing information about the benefits of food irradiation seems the most effective form of communication for improving consumer attitudes toward the technology while informing about authorities – such as FDA, WHO, CDC, and USDA – approving the technology seems least effective (Feng et al. 2016).

The next question is how to deliver this information to consumers effectively. Although store-level information about irradiation at point of sale led to a significant change in beef purchasing behavior (Rimal et al. 2004), very few consumers picked up or took time to read the available information about food irradiation at grocery stores (Fox and Olson 1998). Therefore

other educational or training programs should be implemented to provide information to consumers before they go shopping. More information is needed to prevent the negative effects of not providing enough information (Hashim et al. 2001)

Restaurant menus are an important vehicle for restaurateurs to communicate information to consumers about the food sold in their restaurants (Ozdemir and Caliskan, 2014). In addition, the information presented in the restaurant menu informs and influences customers' awareness and perception of food items, purchase intentions, and ultimately choices (VanEpps et al., 2016; Kim and Ham, 2016; Fakih et al., 2016; Wei and Miao, 2013; Yoon and George, 2012). Therefore, accurate and concise information provided in menus can be an effective way to inform consumers (Shafieizadeh and Tao, 2020).

Consumers expressed the highest level of trust in information provided by health professionals and food scientists, not government agents (Bruhn 1995; Rodriguez 2007; Spaulding et al. 2007; Feng et al. 2016). Therefore, educational programs should be coordinated with health organizations to help convey information that is better trusted by the wide public (Rodriguez 2007).

Retailers play a major role in the food irradiation industry by selecting to offer irradiated foods in their stores. However, retailers and processors have not really been interested in selling this type of product. Giamalva et al. (1997) indicate that although the USDA has approved the sale of irradiated meat products, major poultry processors have initially announced that they have no immediate plans to irradiate their products or indicated they do not irradiate and sell those foods. Therefore, to better market irradiated foods, it is important

to earn retailers' approval and work with them to ensure the higher availability of irradiated food alternatives.

From 2002 to 2004, around 20% of supermarket managers held negative opinions about the potential profitability of irradiated red meat (Jensen and Jaenicke 2004; Jaenicke et al. 2006). The decision to sell irradiated foods by supermarket managers depends on their store commitment to supply chain technologies, consumer service offerings, product variety, store size, and the extent of an informational campaign associated with the introduction of an irradiated food (Jaenicke and Chikasasa 2008). Therefore, retailers should understand the nature of irradiated foods and their benefits so they can relay this information to consumers and promote higher acceptance (D'Souza et al. 2021; Nayga 2003).

5. Potential research on consumer behavior and preferences for irradiated mangoes

While several studies have looked into consumer perceptions, attitudes, and WTP for irradiated foods, research on US consumer acceptance and valuation of irradiated mangoes remains lacking. Thus, the National Mango Board could greatly benefit from a nationwide marketing survey shedding light on consumers' level of knowledge of food irradiation and awareness, acceptance, and WTP for irradiated mangoes. This research can help uncover different consumer segments that differ in their knowledge and attitudes toward food irradiation and irradiated mangoes and the main behavioral and sociodemographic factors that characterize each consumer segment. When considering this future research direction, it is important to consider psychological characteristics relating to risk aversion, adventurousness, risk perceptions, ambiguity tolerance, and personality factors, and to study their correlation with consumer acceptance and valuation for food irradiation and irradiated mangoes.

The information collected from the first survey can inform the design of information campaigns that can help alleviate consumer concerns about food irradiation and increase their acceptance of this technology. The content of the different information treatments would be determined from the results of the first survey and tested in a second nationwide survey that would shed light on the effectiveness of the different treatments. Aside from content, the source of information (e.g., governmental agencies, health institutions, academic/research institutions, etc.) and mode of delivery (e.g., text, picture, video, etc.) can be tested to determine the most effective information provision mechanism.

The literature on food irradiation has focused on hypothetical preference elicitation methods, where research participants report their preferences and WTP in a hypothetical, inconsequential environment. While this is very helpful in providing general insights on consumer perceptions and preferences for irradiated foods, it is prone to hypothetical bias, where research subjects would misreport their preferences and valuations. Future research on consumer preferences for irradiated mangoes could greatly benefit from incentive-compatible experimental designs that induce consequentiality by having subjects participate in real decisions, thereby ensuring a higher level of accuracy in the reported preferences.

Recent scientific advancements have improved access to neurobehavioral research tools that are now being used in marketing research to gain deeper insights into consumer preferences and feelings. Examples of such tools include eye-tracking to monitor individuals' gaze and measure their pupil dilation (which is often used as a proxy for arousal or excitement), facial expression analysis to assess emotional responses to objects and experiences, and analysis of the electrical activity in the brain to assess neurophysiological responses to stimuli.

Utilization of these tools can help to further uncover the inner workings of consumer preferences and valuation for irradiated foods. We possess all the required equipment and expertise to carry out the potential research ideas discussed in this section.

Tables and Figures

Table 1. Database Sources and Search strategy

Database sources	Keywords	Number of articles
Google Scholar	(“*food irradiation*” OR “*irradiated food*”) (“*consumer*”) (“*willingness to pay*” OR “willingness to purchase”) (“preferences” OR “perception” OR “attitude” OR“knowledge”) (“meat” OR “seafood” OR “produce”)	136
EBSCOhost	(“*food irradiation*” OR “*irradiated food*”) (“*consumer*”) (“*willingness to pay*” OR “willingness to purchase”) (“preferences” OR “perception” OR “attitude” OR“knowledge”) (“meat” OR “seafood” OR “produce”)	425
ScienceDirect	(“*food irradiation*” OR “*irradiated food*”) (“*consumer*”) (“*willingness to pay*” OR “willingness to purchase”) (“preferences” OR “perception” OR “attitude” OR“knowledge”) (“meat” OR “seafood” OR “produce”)	716
Scopus	TITLE-ABS-KEY (“irradiated food” OR “food irradiation”) TITLE-ABS-KEY (“willingness to pay”) TITLE-ABS-KEY (“preferences”) TITLE-ABS-KEY (“perception”) TITLE-ABS-KEY (“attitude”) TITLE-ABS-KEY (“knowledge”)	77
Pubmed	(“*food irradiation*” OR “*irradiated food*”) (“*consumer*”) (“*willingness to pay*” OR “willingness to purchase”) (“preferences” OR “perception” OR “attitude” OR“knowledge”) (“meat” OR “seafood” OR “produce”)	31

Table 2. Research on Irradiated Foods Published by Country from 1983 to 2021

Country	Number of Publications
USA	62
Worldwide	11
Brazil	3
Korea	3
Argentina	2
Australia	2
EU	2
Italy	1
Chile	1
Ghana	1
Japan	1
Scotland	1
Turkey	1
UK	1
Total	93

Table 3. Responses of Consumer Participants on Irradiated Food/Food Irradiation

Consumer Behavior towards Irradiated Foods/Food Irradiation	Number of Studies	Proportion of Studies
Positive (*60% or more respondents willing to purchase/accept to try irradiated food*)	51	54.8
Either positive or negative (*41-59% or more respondents willing to purchase/accept to try irradiated food*)	25	26.9
Negative (*less than 40% or more respondents WTP/willing to purchase/accept to try irradiated food*)	17	18.3
Total	93	100

Table 4. Consumer WTP Price Premium for Irradiated Products

Premium WTP by	Mean	Min	Max
$/lb	0.32	0.05	0.77
% of a given food price	11.07	0.10	40.00
$/sandwich meal[a]	0.25	0.01	0.50

Notes: [a] In the research by Fox et al. (2002) and Hayes et al.(2002), the WTP values were derived from asking the consumers to bid for an irradiated pork sandwich as a meal.

Figure 1. Number of Published Articles on Irradiated Foods/Food Irradiation

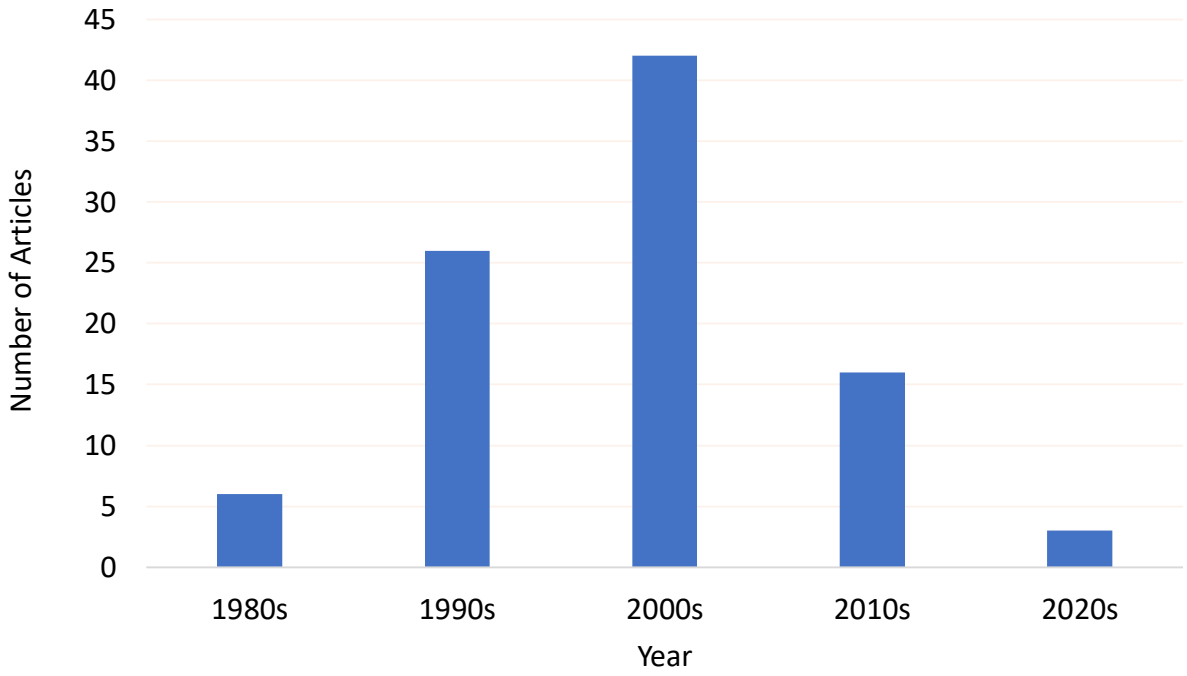


Figure 2. List of Irradiated Food Products Included in the Reviewed Research

Figure 3. Data Collection Methods Used in Previous Studies

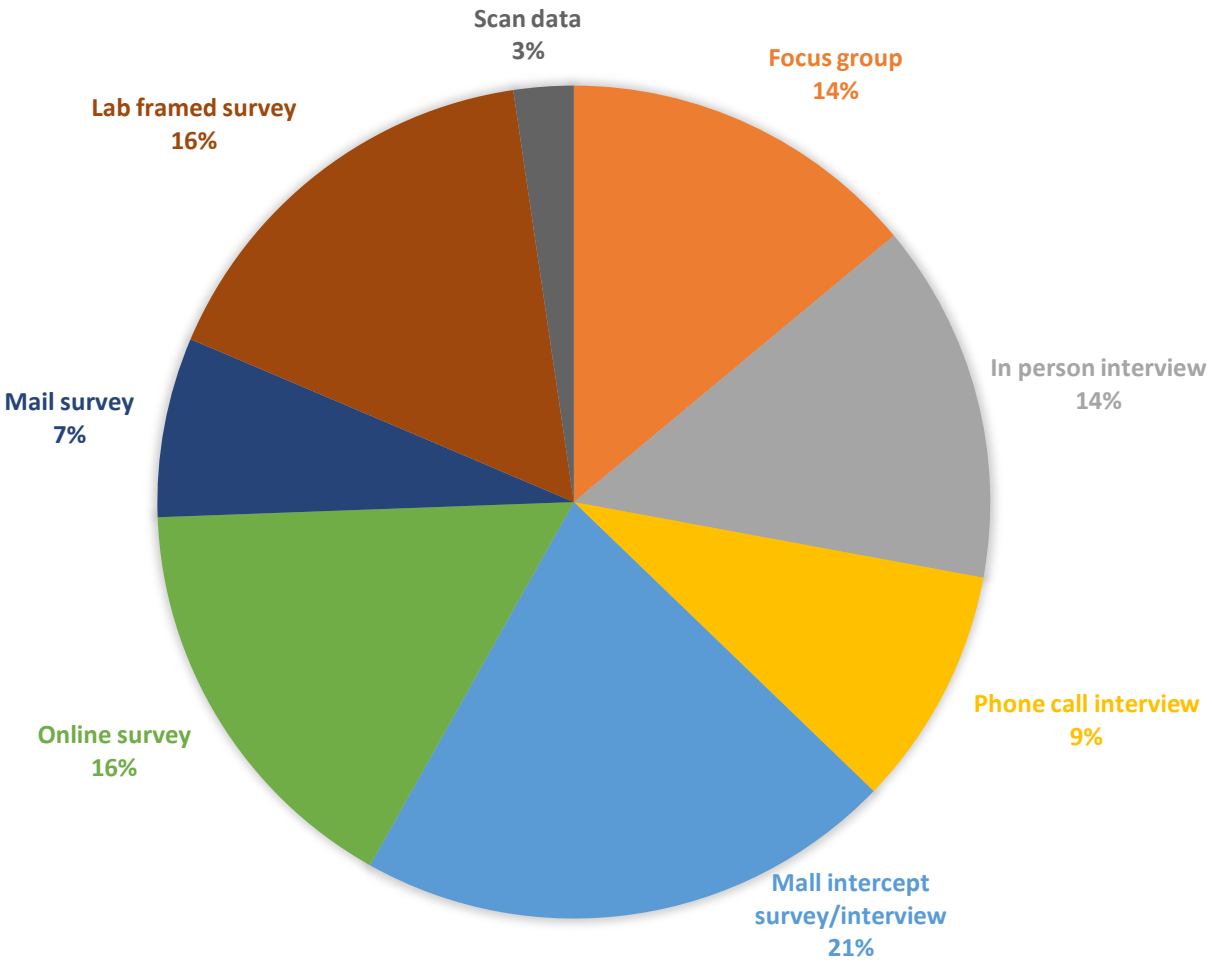


Figure 4. Type of Survey Respondents in Previous Research

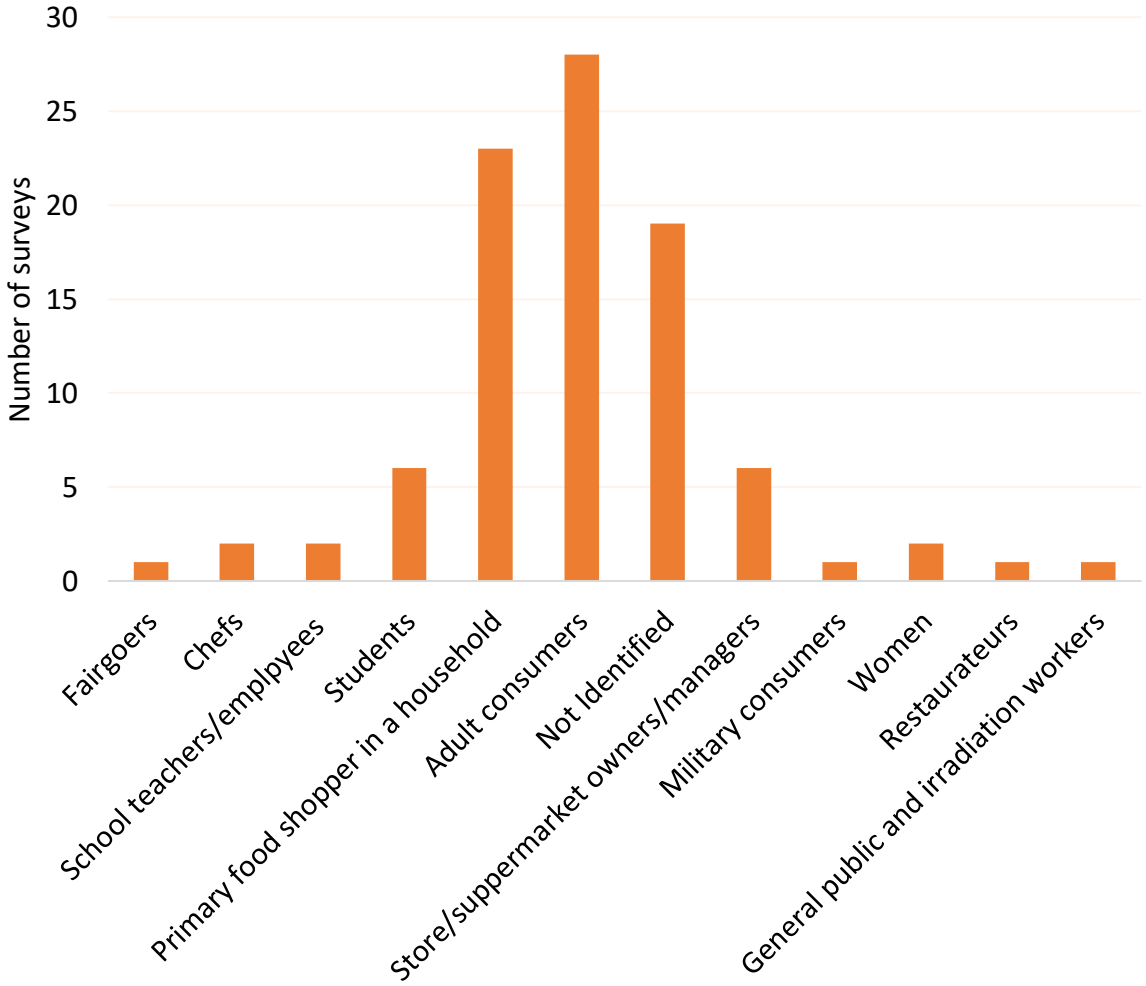
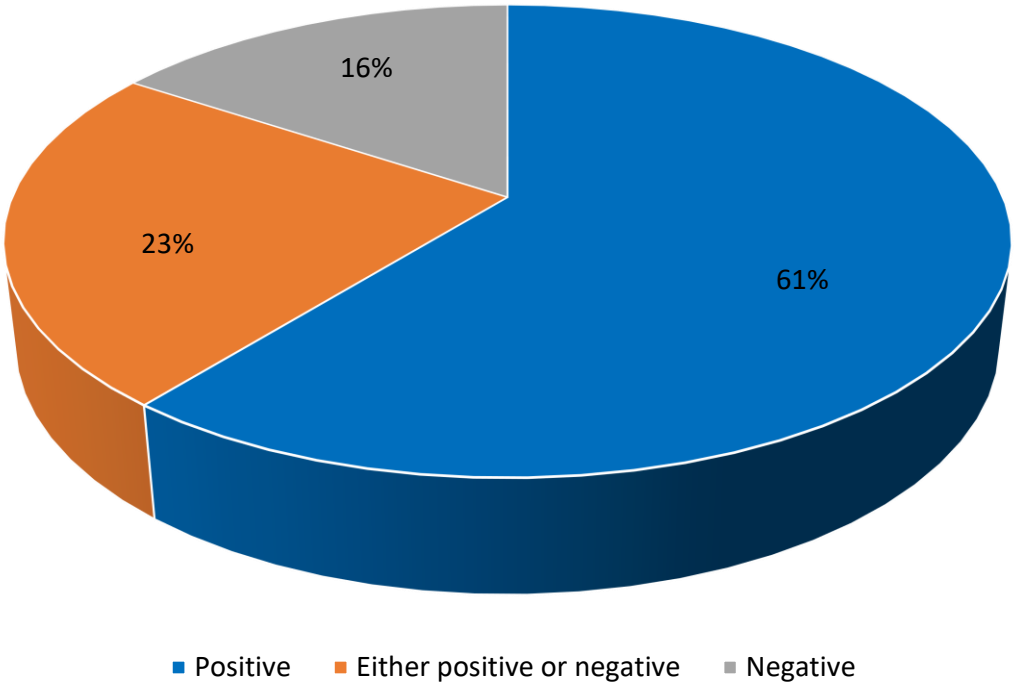


Figure 5. Consumer Attitudes Toward Irradiated Foods by the Proportion of the Reviewed Articles



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