CONSUMER-BASED OPTIMIZATION OF ELECTRON-BEAM

IRRADIATED READY-TO-EAT POULTRY PRODUCTS

AND

CONSUMER ATTITUDES TOWARD IRRADIATION

by

ADRIANNE MONIQUE JOHNSON

(Under the Direction of Anna V.A. Resurreccion)

ABSTRACT

Ready-to-eat poultry frankfurters and diced chicken were electron-beam irradiated at medium doses of 1, 2 and 3 kGy and stored under refrigeration (4°C) conditions up to 32 days after irradiation, whereas frozen diced chicken was stored under freezing (-15°C) conditions for >90 days after irradiation. Response Surface Methodology was used to profile and characterize the sensory properties of irradiated frankfurters and to determine the optimum conditions for the irradiation process and storage that would produce high consumer acceptance ratings. An optimum product was processed by irradiation doses of 2.5 to 3.0 kGy and stored no more than 11 days after irradiation and received high acceptance ratings (>6 or like slightly) for overall acceptance and acceptance of flavor, juiciness and tenderness. Consumers' knowledge, attitudes, concerns and feelings toward food irradiation and some food-safety issues over the past ten years have not changed significantly.

INDEX WORDS: Electron-beam irradiation, Ready-to-eat meats, Poultry, Consumer attitudes, Optimization, Response surface methodology (RSM), Consumer acceptance, Descriptive analysis, Sensory evaluation

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DEDICATION

I dedicate this thesis to my family and friends, who have supported me and shown me unconditional love throughout the way.

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CHAPTER 1

INTRODUCTION

Food irradiation is the process of exposing food to high levels of radiant energy to help maintain the food's quality and safety without causing a significant rise in the temperature of food, leaving the food closer to its original state. Food irradiation is gaining acceptance and is endorsed by health organizations, international committees, and scientific societies worldwide and is approved for use by more than 40 countries for over 50 different foods (Sapp, 1995). Food irradiation is used to: inhibit the sprouting of vegetables; delay the ripening of fruits; kill pests in fruit, grains or spices; reduce or eliminate food spoilage organisms; and reduce food poisoning bacteria on meat products (Hackwood, 1991).

Since the 1950s, the use of electron-beam accelerators for the food irradiation process has become more common and has been much improved since then (Diehl 1995). Electron-beam irradiation involves the use of electrical machine sources of energy called accelerators, which produce extremely high voltages of electron-beams to shower the food to be processed and can deliver several tens of kGy per second (Allen et. al., 1990). The energy used (approximately 5 to 10 MeV) in food irradiation is not great enough to cause food to become radioactive. Research demonstrates that foods irradiated with accelerated electrons with energies of less than 10 MeV, will not induce radioactivity in foods (Becker, 1983).

Consumer acceptance is critical to the application of this new technology and the realization of the advantages it offers (Schutz *et al*., 1989). Irradiation of pork and poultry were approved in 1986 and 1992 (Diehl, 1995), respectively, but there are currently no approved regulations for the usage of food irradiation to inactivate food-borne pathogens on ready-to-eat meats. This can be an issue due to the steadily increasing number and volume of refrigerated, precooked, further processed poultry products and ready-to-eat meats offered to consumers (MacNeil and Dimick, 1970). It has been stated that there is insufficient sensory research done on ready-to-eat foods to determine the quality and consumer acceptance of foods treated with irradiation at dosages needed to assure safety (Doyle, 2000). Therefore, quality of ready-to-eat meats by an electron-beam irradiation process needs to be optimized to maximize consumer acceptance, while simultaneously eliminating undesirable sensory, texture and physicochemical aspects of the food.

Sensory and physicochemical measurements of quality are essential in ensuring that a safe and optimal product is assured to the consumer. Consumer acceptance is the complex set of sensory characteristics, including appearance, aroma, taste and texture, which are optimally acceptable to a specific group of consumers or regular uses of the products (Moskowitz, 1983). Descriptive analysis methods are used to detect, describe and quantify all sensory properties of a product (Stone and Sidel, 1993). Instrumental tests are used to accompany the sensory tests to validate the relationships of the instrumental tests to the sensory perceptions (Igene et al., 1985).

The search for the most efficient process is of utmost importance to many food processors (Nakai, 1981). Optimization is defined as a procedure that develops the best possible product in its class (Stone and Sidel, 1983). Predictive equations are developed from the sensory tests of the product by using response surface methodology to give a graphical representation of the data. Optimum ranges are obtained by superimposing contour plots of significant attributes.

The overall objective of this study was to evaluate the effect of electron-beam irradiation on ready-to-eat poultry meats throughout their expected shelf life. The specific objectives of this thesis were to: (1) evaluate consumer acceptance of electron-beam irradiated frankfurters and diced chicken up to 32 days of refrigerated storage after irradiation, (2) optimize irradiation dose and storage conditions of the electron-beam process using consumer acceptance and descriptive attributes for irradiated frankfurters, (3) profile sensory attributes for electron-beam irradiated frankfurters, (4) use multivariate analysis to describe relations between sensory and instrumental measurements to identify determinants of acceptance for electron-beam irradiated frankfurters and refrigerated/frozen diced chicken meat, and (5) investigate current consumer attitudes toward irradiation and evaluate differences, if any, on consumer acceptance of irradiation over the past ten years.

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CHAPTER 2

REVIEW OF LITERATURE

I. Irradiation

A. Introduction

The idea of food irradiation is more than a century old and immediately followed the discovery of radiation by Roentgen in 1895 and the discovery of radioactivity by Becquerel in 1896 (Ehlermann, 1991). In 1896, it was suggested that ionizing radiation could be used to kill micro-organisms in food, but it was not until 1921 that a practical use for food irradiation was established when Schwartz obtained a U.S. patent on the use of X-rays to kill the parasite *Trichinella spiralis* in pork (Hackwood, 1991).

Food irradiation gained significant momentum in 1947 when researchers found that foods could be sterilized by high energy. In the 1950s, the U.S. Army began a series of experiments with fruits, vegetables, dairy products, fish and meats to establish the safety and effectiveness of the irradiation process. Between 1950 and 1970, technological studies were conducted to search for optimal conditions of irradiation (radiation dose, packaging, atmosphere and temperature during irradiation) for various purposes, such as sterilization, pasteurization, insect disinfestations and sprout inhibition of potatoes and onions (Diehl, 2001). From 1970 until the present, studies on the wholesomeness of irradiated food were being conducted, international harmonization of legal regulations was being proposed, and slowly growing commercial application of the process has occurred (Diehl, 2001).

Although the applications of the irradiation process are becoming more commonplace, there is public aversion toward radiation. Some public health officials have proposed that food irradiation be referred to as “cold pasteurization”, an oxymoron when one considers that pasteurization implies heating (Tritsch, 2000). However since food irradiation does not cause a significant temperature change in foods, leaving the food closer to its original state, it may be reasonable to refer to it as a "cold process" (Lecos, 1984).

However, radiation energy of such high levels is produced that causes ejection of electrons from their orbitals, resulting in formation of charged, or ionized, particles (Olson, 1995). Ionizing radiations are energetic charged particles, such as electrons, or high-energy photons, including x-rays or gamma rays (Diehl, 1995). The ions, which form, are reactive for a brief period before stabilizing and becoming deactivated. It is during the short span of this activity that irradiation causes effects, which enable it to be regarded as a means of preserving foods (Murano, 1995b) or inactivating food-borne microorganisms.

B. Benefits of food irradiation

Food irradiation is not a panacea for all food preservation or food safety problems nor is it intended to replace proper food sanitation, packaging, storage and preparation practices (Thayer, 1990). However, irradiation has many benefits. Irradiation can (1) inhibit sprouting in crops like potatoes, onions and garlic, (2) destroy insects and parasites in cereal grains, dried beans, dried and fresh fruits, meat and seafood, (3) delay the ripening and senescence of fresh fruits and vegetables, (4) extend the shelf life of perishable products like beef, poultry and seafood, (5) eliminate disease-causing microorganisms in food, and (6) sterilize herbs, spices, and other ingredients like dried vegetables, in addition to foods prescribed for immuno-compromised hospital patients and astronauts during space flights (Crawford and Ruff, 1996). Irradiation also has been used in many other applications, such as reducing carcinogenic volatile N-nitrosamines content in foods (Ahn et al., 2002), inactivating the hepatitis A virus (HAV) in fruits and vegetables (Bidawid et al., 2000) and pasteurization and sterilization of foods and feeds (Thayer, 1990).

Increase food safety. The increase in food-borne infections and intoxications has been attributed to multiple factors, including mass breeding and fattening of animals used for human consumption, mass production and processing of foods, migration of millions of peoples, changing food habits, increased international trade of food and feeds, and increased environmental pollution resulting in food and feed contamination (Kampelmacher, 1983). The application of irradiation can help to reduce the onset of these food-borne infections and intoxications and make the food supply safer.

Increase shelf life. Despite the various methods used in trying to prevent food deterioration, the Food and Agriculture Organization (FAO) has estimated that a third to a quarter of the world's food production is lost due to this problem (Kampelmacher, 1982). Irradiation can reduce quality losses in foods, which occur during storage and transportation, minimizing the use of potentially harmful chemicals (Radomyski et al., 1994). Reduction of such losses by irradiation would increase shelf life and contribute significantly to food availability, thereby meeting the world's growing need for food (Hackwood, 1991).

Disinfestation. The major cause of post-harvest loss encountered in stored grains and other food products such as cereals, legumes, and their products (flour, semolina), oil seeds, coffee beans, cocoa beans, dry fruits and nuts is by larvae and adults of stored product insects, such as weevils, beetles and moths (Thomas, 2001a). Previously, pesticides and fumigants using chemicals were used to solve this problem, but these chemicals were found to have done serious effects. Many of the post-harvest chemical fumigants used for control of insect infestation, such as ethylene dibromide (EDB), methyl bromide (MB) and ethylene oxide (ETO) are either banned or will be phased out because of their adverse impact on human health and the environment (Thomas, 2001a). Due to the highly toxic nature of these fumigants, irradiation is a good alternative (Murano, 1995a). Practical control of insect pests, regardless of species or stage of development is possible by low-dose irradiation in the dose range of 0.2 to 0.5 kGy (Thomas, 2001a). The action of irradiation on insects is by physiological disturbances such as respiration, and by biological disturbances, such as alteration of enzymatic activity and DNA replication (Murano, 1995a).

Inhibition of sprouting. Sprouting in tuber, bulb and root crops during storage is inhibited by irradiation at doses in the range of 0.02 to 0.15 kGy. The inhibition of sprouting is more effective when these crops are irradiated soon after harvest and when the commodities are in the dormancy period (Thomas, 2001a). Undesirable changes that occur during sprouting include loss of marketable weight, loss of nutritive value, softening, shriveling due to enhanced rate of water evaporation from the sprouts, loss of processing qualities, temperature buildup associated with respiration rate, susceptibility to bruising and enzymatic discoloration, and problems with sorting and grading of sprouted material (Thomas, 2001c).

Delay of post-harvest ripening and senescence. Irradiation of fruits and vegetables involves the extension of shelf life by delaying the physiological and biochemical processes leading to maturation and ripening, control of fungal pathogens causing post harvest rot, inactivation of human pathogens to maintain the microbiological safety and quality of fresh-cut fruits and vegetables that are cut, sliced, or diced and then packaged for commercial and retail use without further preparation and as a quarantine treatment for commodities subject to infestation by insect pests of quarantine importance (Thomas, 2001b). Delaying the processes of ripening and over-ripening in many fruits have been observed following treatment of the fruits in the physiologically mature but unripe state to low doses of irradiation in the range of 0.25 to 1.0 kGy (Thomas, 2001a).

Reduction/elimination of spoilage microorganisms and pathogens. A major interest in food irradiation has been the control of spoilage of meats and meat products, and reduction of pathogenic organisms carried by these foods (Skala et al., 1987). Irradiation doses up to 3.0 kGy (medium dose) are sufficient to eliminate most pathogens found in meats (Radomyski, et al., 1994). Although irradiating foods at medium doses under vacuum may kill pathogens, it does not destroy all the spoilage microorganisms which are able to grow rapidly after irradiation (Murano, 1995a).

When determining the effect of irradiation on microorganisms, some factors should be considered. Factors affecting the radiation sensitivity of microorganisms are: the suspending medium, temperature during irradiation, availability of free water (water activity, a_w), irradiation atmosphere (e.g., nitrogen, vacuum, air), stage of development (e.g., vegetative cell vs. spore), physiological injury (Thayer et al., 1986), intrinsic sensitivity of the species, its potential for repair and the relative proportions of damage channeled into different repair pathways (Moseley, 1990). Each growth phase of bacterial cells has a unique resistance to irradiation. The stationary phase demonstrates higher resistance than the logarithmic phase (Thayer and Boyd, 1994).

Gram-negative bacteria are more sensitive to irradiation than Gram-positive bacteria (Maxcy, 1983). Among the gram-negative pathogens, *Salmonella* may be the most resistant; hence, any irradiation process designed to eliminate *Salmonella* would also eliminate other gram-negative pathogenic bacteria (Monk et al., 1995). However, it has been observed that before irradiation, the normal microbial flora is predominantly gram-negative, whereas after irradiation, the gram-positive bacteria predominate.

E. Coli 0157:H7. *E. coli* along with *Pseudomonas, Salmonella, Moraxella* and *Lactobacilli* has been a serious problem with the consumption of undercooked ground beef. *E. coli* was found to have increased sensitivities to irradiation in vacuum or CO_2 compared with those in air (Patterson, 1988). However, Lopez-Gonzalez et al. (1999) compared the effects of gamma irradiation (0.1 to 3.0 kGy) and electron-beam irradiation (0.2, 0.4, and 0.6 kGy) on ground beef patties inoculated with E coli 0157:H7, and gamma irradiated patties had higher D_{10} values compared to electron-beam irradiated patties. Differences may have been attributed to the dose rate (1.0 kGy/h for gamma, 17 kGy/min for electron-beam) since it is possible that, at low dose rates, microbial enzymes may have more time to repair damage to the cell due to irradiation resulting in higher D_{10} values.

Salmonella. Of the well-known food-borne pathogens, *Salmonella* is the most frequently encountered and, as far as poultry and meats are concerned, the most important causal agent of food-borne infection in most countries (Monk et al., 1995). *Salmonella* is routinely found in 15-70% of poultry (Satin, 2002). It is clear that the use of radiation treatment with a dose of 250 Krad (2.5 kGy) contributes considerably to the elimination of *Salmonella* from chilled and deep-frozen broiler carcasses (Mulder et al., 1977).

Listeria. *Listeria* are gram-positive, non-sporeforming and non-acid-fast rods that are ubiquitous in nature and can be found on decaying vegetation, in soils, animal feces, sewage, silage and water (Jay, 2000). This organism can survive longer under adverse environmental conditions than many other non-spore-forming bacteria of importance in foodborne disease. This resistance, together with the ability to colonize, multiply, and persist on processing equipment makes *L. monocytogenes* a particular threat to the food industry (Fenlon, 1999). Thayer and Boyd (1999) indicated that *L. monocytogenes* on turkey meat was neither more nor less sensitive to radiation under modified atmosphere packaging (MAP) of 20, 40, 60 or 80% CO_2 in the presence of 5% O_2, nor was it more sensitive within oxygen-permeable packaging. The D-value of *Listeria monocytogenes* was calculated to be 0.33 kGy when irradiated in a bacteriological medium, compared with a value of 0.77 kGy in chicken (Huhtanen et al., 1989).

Temperatures likely to be used for refrigerated storage are unable to prevent the growth of *L. monocytogenes*, however refrigerated storage will extend the time before growth occurs and reduce the rate of growth (Walker et al., 1990). It is believed that the survival and multiplication rate of *Listeria monocytogenes* after irradiation is greater on cooked meats than on raw meats during refrigerated storage (Thayer *et al*., 1998).

In a study on cooked pork chops, Fu et al. (1995) found that *L. monocytogenes* counts were reduced by more than two log cycles by irradiation at levels of 0.75-0.9 kGy, and were undetectable following irradiation at 2.0 kGy, which caused a six log reduction. However, Lewis et al. (1991) found that irradiation at 2.5 kGy was ineffective for complete elimination of *Listeria* from naturally contaminated raw chicken.

Clostridium. To maintain the safety of irradiated poultry products from *Clostridium botulinum*, these products are only allowed to undergo irradiation in oxygen-permeable packaging (USDA, 1997). However the effects of packaging on the production of *Clostridium botulinum* seem to be inconsistent. Lambert et al. (1991b) found that toxin production by Clostridium botulinum occurred faster in samples initially packaged with 20% O_2, compared to samples packaged with 100% N_2. Lambert et al. (1991a) studied the combined effect of three initial levels of oxygen (0, 10, and 20%), irradiation dose (0, 0.5 and 1 kGy), and storage temperature (5, 15, and 25°C) on toxin production by *Clostridium botulinum*. For products packaged with 0% oxygen and an oxygen absorbent, toxin was detected after 21 days in nonirradiated samples compared to 43 days for products treated with an irradiation dose of 1 kGy. No toxin was detected in any product stored at 5°C, even after 44 days.

Clostridium botulinum spores have been shown to be more resistant to low-dose irradiation at sub-freezing temperatures (-20°C) than at a temperature of 20°C (Thayer and Boyd, 1994). If a toxin was produced in a food prior to irradiation, it cannot be removed by irradiation, even though the bacteria that produced it can be (Moseley, 1990).

Intoxication of food by *Clostridium botulinum* should not be of much concern, as long as some spoilage microorganisms remain. These spoilage microorganisms are capable of outcompeting *Clostridium botulinum* for nutrients, resulting in the product spoiling before the toxin can be produced. This has been shown by Firstenberg-Eden et al. (1983) who tried to determine if low dose irradiation might cause a health hazard by eliminating the natural flora of chicken skins and allowing *Clostridium botulinum* type E spores, if present, to produce toxin in the absence of typical spoilage. Irradiation at 0.3 Mrad (3 kGy, 5°C) reduced the natural flora from 10^4 - 10^6 to 10 - 5 x 10^2 cells/7 cm^2, whereas *C. botulinum* type E spores were reduced by only one log_{10}. At 10°C, natural flora produced spoilage odors within 8 days well before the toxin was produced, which was 14 days. However, in an earlier study, Firstenberg-Eden et al. (1982) found that at an abuse temperature of 30°C, *C. botulinum* type E spores survived on irradiated at 0.3 Mrad (3 kGy) chicken skins and produced toxin under both aerobic and anaerobic conditions.

Thayer et al. (1995) studied the effects of *Clostridium botulinum* spores on vacuum-canned, commercial, mechanically deboned chicken meat after irradiation of 0, 1.5 and 3.0 kGy and stored at 5°C for 0, 2 and 4 weeks. None of the samples stored at 5°C developed botulinum toxin; however, when these samples were temperature abused at 28°C, they formed toxin within 18 hours and had obvious signs of spoilage, i.e. swelling of the can and a putrid odor.

Prevent post-processing contamination. The cooking process used to prepare the components of a ready-to-eat meal reduces the microbial population to very low levels; however, recontamination can occur after the initial heat treatment and prior to final packaging and storage (Foley et al., 2001). Irradiation would be a good alternative to prevent post-processing contamination, if most foods are irradiated in their original packaging. This prevents bacteriological cross-contamination from occurring during both retailing and transport and contamination will not occur until the package is opened immediately prior to cooking or consumption (McMurray, 1990). However, such an advantage can only be claimed, if the irradiation process alters neither the nature of the packaging material nor induces chemical changes so that residues could be formed which would contaminate the food coming directly in contact with the packaging material (McMurray, 1990).

C. Present Regulatory Status

During the past two decades, the Food and Agriculture Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO) have become closely involved with the issue of food irradiation, because several aspects of food irradiation technology fall within their operating mandates (Satin, 2002). Expert committees, which have been convened by all three organizations, have regularly evaluated studies on the safety and wholesomeness of irradiated foods and have always concluded that the process and the resulting foods are safe (Satin, 2002). Although several regulatory agencies are involved with food irradiation, the Food and Drug Administration

(FDA), however, is the primary agency involved, because it is responsible for setting the criteria for the safe use of irradiation on all foods (Derr, 1996). On September 21, 1992, the USDA, Food Safety and Inspection Service (FSIS), approved guidelines for the use of irradiation in fresh or frozen, raw packaged poultry at 3.0 kGy (USDA, 1992).

The use of irradiation for some specific applications is further regulated by agencies in the U.S. Department of Agriculture (USDA) (Derr, 1993). The Food Safety and Inspection Service (FSIS) regulates the implementation of irradiation on meat and poultry to ensure their continued safety and wholesomeness (Derr, 1996).

Food irradiation has been endorsed by health organizations, international committees, and scientific societies worldwide and is approved for use by more than 40 countries for over 50 different foods (Sapp, 1995). The list of products approved for irradiation in the United States is shown in Table 2.1.

Wholesomeness of irradiated food. Wholesomeness is a term that is used to cover all the aspects of food irradiation that impinge on its acceptability, e.g. including microbiological aspects (benefits and potential hazards); toxicological aspects (radiolytic products; toxicity and mutagenicity); nutritional aspects (effects on major and trace nutrient food components); and induced radioactivity, etc. (Wilkinson and Gould, 1996). The criteria necessary for an irradiated food to be considered wholesome is the absence of induced radioactivity, the absence of viable pathogens or their toxins, the absence of excessive loss of nutrients, and the absence of toxic, mutagenic or carcinogenic radiolytic products (Josephson, 1991).

Thayer et al. (1987) reviewed the literature and studied the toxicological effects of irradiation. They concluded that no evidence of genetic toxicity or teratogenic effects in mice,

Table 2.1. Applications of irradiation accepted in the U.S. by the Food and Drug Administration

PRODUCT	**DATE APPROVED**	**DOSE**	**APPLICATION**
Wheat, wheat flour	1963	0.2-0.5 kGy	Insect disinfestation
White potatoes	1964	0.05-0.15 kGy	Inhibit sprouting
Onion powder, garlic powder and spices	1984	10 kGy	Insect and microbiological control
Pork	1985	0.3-1 kGy	Microbiological control
Dehydrated enzymes	1986	10 kGy	Microbiological control
Fruits	1986	1 kGy	Insect disinfestation, ripening delay
Vegetables, fresh	1986	1 kGy	Insect disinfestation
Herbs and spices	1983-1986	30 kGy	Microbiological control
Vegetable seasoning	1986	30 kGy	Microbiological control
Fresh or frozen packaged poultry	1990, 1992	1.5-3 kGy	Microbiological control
Meat, frozen, packaged	1995	44 kGy (minimum)	Sterilization
Meat, uncooked, refrigerated	1997	4.5 kGy (maximum)	Microbiological control
Meat, uncooked, frozen	1997	7.0 kGy (maximum)	Microbiological control

hamsters, rats, and rabbits was observed; no treatment-related abnormalities or changes were observed in dogs, rats, or mice during multigeneration studies: and that nutritional, genetic, and toxicological studies did not provide definitive evidence of toxicological effects in mammals due to ingestion of chicken meat sterilized by irradiation.

Thayer (1990, 1994) also extensively studied the wholesomeness of irradiated foods and concluded that neither short nor multigeneration feeding studies have produced evidence of toxicological effects in mammals due to ingestion of irradiated foods. The data supported the conclusion that properly processed irradiated foods are wholesome.

Chemiclearance. Where sufficient data about the composition of certain foodstuffs or the radiation chemistry of certain constituents are not known, information from past studies can give an approximate calculation of maximal chemical changes that can occur due to irradiation (Diehl and Scherz, 1975). Although this concept is generally well accepted for chemical effects, it is much less clear for biological effects (Thayer and Boyd, 1996). Evidence has demonstrated that the distribution of radiolytic products is similar for individual members of a given food class and that acceptance of this general principle of radiation-chemistry similarity supports the view that information obtained from toxicity tests on one irradiated food could be extrapolated to other foods of similar chemical composition, or from one set of processing conditions to another for the same food (Elias, 1989). However, in order for regulatory agencies to extrapolate results of irradiation of bacterial pathogens from one meat to another, they must have confidence that similar results can be expected on the meat that has not been tested (Thayer and Boyd, 1996).

D. The irradiation process

Gamma ray irradiation. Gamma rays are electromagnetic radiations produced during the decay of certain radio-isotopes, such as Cobalt-60, a cobalt isotope produced by irradiating cobalt metal in a nuclear reactor or Cesium-137, present as a fission product in the fuel elements used in nuclear reactors (Hackwood, 1991). Cobalt-60, which has a half-life of 5.3 years, is obtained by exposing pure natural cobalt-59 pellets to a neutron source in a nuclear reactor to produce radioactive Cobalt-60 (Woods and Pikaev, 1994). Gamma rays are converted into fast electrons in the medium through which they pass by Compton scattering, photoelectric absorption and pair-production (Hayashi, 1991).

A typical cobalt-60 gamma source can deliver a dose rate of approximately 12 kGy per hour (Allen et al., 1990). The penetrating qualities of gamma rays through packaging are dependent on the energy of rays, the specific mass of the packing material and/or the density of the packed product (Langerak, 1982).

Electron-beam irradiation. Electron-beam irradiation involves the use of electrical machine sources of energy called accelerators, which produce extremely high voltages of electron-beams to shower the food to be processed and can deliver several tens of kGy per second (Allen et al., 1990). In food irradiation, linear accelerators are preferred over static industrial accelerators. The reason for this preference is that the depth dose distribution is more uniform, the electron back scattering is smaller and less variable, and the scanner width is better defined (Brynjolfsson, 1989).

Electrons, which have a small mass, are slowed as they enter a material, resulting in limited penetration (Olson, 1995). At 5 MeV and irradiating from both sides of a product, the maximum thickness that can be penetrated is about 3.8 cm (1.5 inches). At 10 MeV, and with two-sided irradiation, the maximum thickness is about 8.9 cm (3.5 inches) (Woods and Pikaev, 1994). For reason of quality control, electron irradiation is preferably done from one side only and the reason for this preference is that when irradiation is done from one side only, it is possible to have a detector behind the product boxes for monitoring and assuring continuously that the beam is penetrating the product packages (Brynjolfsson, 1989).

Electrons are less penetrating than gamma rays and are only used for products of limited thickness or for surface irradiation (Langerak, 1982). Electron-beams offer an alternative approach for the radiation treatment of pre-packaged foods as an on-line process, provided that due consideration is given to the energy of the incident radiation and to the thickness of the package (Allen et al., 1990).

The dose rates of electron-beam from electron accelerators are 1 - 1000 kGy/s (Hayashi, 1991). Extremely high dose rate of accelerated electrons will bring about anoxic conditions in the reaction system, because the oxygen in the system is depleted at a rate greater than it can be replaced by diffusion process transferring atmospheric oxygen into the system (Hayashi, 1991).

Gamma ray irradiation vs. Electron-beam irradiation. Gamma ray irradiation using cobalt-60 and electron-beam irradiation are the two types of irradiation sources used in the United States for commercial practices. The types of irradiation sources have been studied to see if one type of irradiation was better than the other. Hayashi (1991) reviewed the literature concerning the differences between gamma ray irradiation and electron-beam irradiation. It was concluded that the chemical changes in irradiated foods demonstrated that there was not significant differences in the effect on chemical reactions in foods between gamma-rays and accelerated electrons, suggesting that the chemical reactions caused by gamma irradiation and those by electron irradiation are qualitatively and quantitatively almost the same in food irradiation. It was also found that the difference between gamma-irradiated and electron irradiated foods can not be detected by sensory evaluation methods (Hayashi, 1991). Borsa et al. (1995) studied the recovery effects of E. coli irradiated with either gamma rays or high energy electrons using dose survival curves. Their results showed that recovery was essentially identical for both types of radiation treatment and the efficacy of radiation for inactivation is decreased by about 10% to 15% as a result of the influence of the recovery process.

X-ray irradiation. The yield of x-rays depends upon the atomic number of the metal in the target; tungsten is most commonly used. X-rays produced by 4 to 5 MeV electrons are slightly more penetrating than gamma rays from cobalt-60 (Brynjolfsson, 1989). Although X-rays have several advantages such as high penetration capacity and high dose rate, they are currently not used for practical irradiation of foods and medical products, because of the poor conversion ratio of accelerated electrons to X-rays (Hayashi, 1991). Unfortunately, the yield of bremsstrahlung x-rays is very low, with throughput efficiencies being less than 8% (Olson, 1995).

Dose. In irradiation, dose refers to the amount of energy that has been received or deposited as a result of irradiation (Webb and Lang, 1987). It is the most critical factor in food irradiation (WHO, 1988). It is important that the dose is set at the lowest effective level for regulatory, economic, and product quality reasons (Gupta, 2001). The unit of measure of radiation in the International System of Units is the Gray (Gy), which is equal to the absorption of 1 joule of energy per kilogram of food. The older unit, the rad (which is defined as 100 erg/g) is now replaced by gray, such that 1 Gy =100 rad; 1 kGy = 100 krad; and 10 kGy = 1 Mrad (Olson, 1995).

To make sure that a precise and specific dose is absorbed, it is necessary to know the energy output of the source per unit of time, to have a defined spatial relationship between the source and the target, and to expose the target material for a specific time (WHO, 1988). Under certain conditions, the maximum absorbed dose is observed not at the surface of the target, but at a small depth into it. This arises because more secondary electrons are lost from the surface of the material than are replaced by secondary electrons generated in the air between the source and target (Sharpe, 1990). Therefore, the exact dose required for each individual application should be established by risk analysis, taking into consideration the contamination level, the hazard involved, the efficacy of the radiation treatment and the fate of critical organisms during manufacturing, storage, distribution and culinary preparation of foods (Farkas, 1998).

Dose levels. In food irradiation, foods can be irradiated to low (≤ 1 kGy), medium (1-10 kGy), and high (10 to 50 kGy) doses (Olson, 1995). The doses and their applications are shown in Table 2.2. Low dose irradiation, which is sometimes referred to as radurization, involves irradiation doses usually below 1 kGy. Low dose irradiation is used for inhibition of sprouting, delay ripening of various fruits, and insect disinfestations. Medium dose irradiation, which sometimes referred to as radicidation, involves irradiation doses between 1 kGy and 10 kGy. Medium dose irradiation is used to reduce the number of food-borne microorganisms, therefore extended the shelf life of foods and reducing the risks of food-borne illness. High dose irradiation, which sometimes referred to as radappertization, involves irradiation doses higher than 10 kGy. High dose irradiation is used to sterilize food completely by killing all bacteria and viruses (Hackwood, 1991).

Dosimetry. Dosimetry measurements are essential for process validation and quality assurance, which are necessary requirements of a regulatory framework (Wilkinson and Gould,

Table 2.2. Irradiation Doses and Applications[1]

Irradiation effect	Dosage	Applications	Dose (kGy)	Products
Radurization	Low dose: up to ≈ 1 kGy	inhibition of sprouting	0.05-0.15	Potatoes, onions, garlic, root ginger, etc.
		delay of ripening or of senescence	0.5-1.0	Fresh fruits and vegetables
		infect disinfestation	0.15-0.5	Cereals and pulses, fresh and dried fruits, dried fish and meat, fresh pork, etc.
Radicidation	Medium dose: 1-10 kGy	extension of shelf-life	1.0-3.0	Fresh fish, strawberries, etc.
		reduction of spoilage microorganisms and non-spore-forming pathogens	1.0-7.0	Fresh and frozen seafood, raw or frozen poultry and meat, etc.
		delay of ripening or of senescence	2.0-7.0	Fresh fruits and vegetables
Radappertization	High dose: 10 to 50 kGy	reduction of microorganisms to the point of sterility	30-50	Meat, poultry, seafood, prepared foods, sterilized hospital diets
		decontamination	10-50	Spices, enzyme preparation, natural gum, etc.

[1]Urbain, 1986.

1996). Dosimeters are used for this purpose to ensure that the pre-determined dose has been delivered to the product (Wilkinson and Gould, 1996). Dosimeters ease of use and low cost makes them ideal for the day-to-day monitoring of radiation processes (Sharpe, 1990).

Reference dosimeters are chemical dosimetry systems, which respond not only to radiation but also to other influencing factors, such as temperature and dose rate, are reproducible and well characterized (Sharpe, 1990). Reference dosimeters can be divided into two categories, absolute and relative.

Absolute dosimeters, such as the Fricke, ceric/cerous and dichromate solutions, are systems whose radiation chemical response is characteristic of a particular solution composition and this can be guaranteed, certainly to within a few percent, provided food chemical practice is followed (Sharpe, 1990). Relative dosimeters, such as the alanine/electron spin resonance (ESR) and radiochromic films, are systems which exhibit high precision (Sharpe, 1990). Radiochromic film dosimeters have significant advantages over silver halide film: they have a relatively flat energy response; are self-developing so they eliminate variations introduced by the processing step; are insensitive to visible light, allowing for ease of handling; and the film is fabricated from low-atomic-number materials, so they do not perturb the radiation beam (Shani, 2001).

E. Factors that affect the irradiation process

Temperature. It is apparent that greater attention should be given to the temperature of products during the irradiation process to produce optimum sensory properties (Thayer, 1993). When temperature is reduced, the destructiveness to bacteria as well as the destructiveness to sensory properties are reduced. An increased irradiation resistance of microorganisms at subfreezing temperatures has been attributed to a decrease in a_w (Monk et al., 1995). Hashim et al. (1995b) concluded that the state at which chicken had been irradiated (refrigerated or frozen) did not affect sensory properties.

Heat treatment. During heating, muscle foods undergo many changes including enzyme deactivation, protein denaturation and color changes (Ang and Huang, 1993). Pre-irradiation heating to approximately 80°C also markedly reduced the development of redness and may be a practical way of controlling this change for samples held in the absence of oxygen, especially since chicken must be at least partially cooked to improve flavor and odor stability during storage (Hanson et al., 1963). Although it has been stated that heat treatment prior to irradiation appears to be the best method for the prevention of undesirable enzyme-induced changes in flavor and texture (van Laack, 1994), cooking meat before the irradiation process makes the meat highly susceptible to lipid oxidation because the cooking process denatures antioxidant components, damages cell structure, and exposes membrane lipids to the environment (Ahn et al., 1999). Kirn et al. (1956) found that meat samples, which have had some heat processing prior to irradiation, yielded the more desirable product on long storage.

Packaging material. Killoran (1983) stated that no single flexible material has all the chemical, physical and protective characteristics necessary to meet the requirements for a container for irradiation processed foods; therefore, flexible packages should be fabricated from multilayered materials. Requirements for these packages are that they: (1) must be easily heat sealed, (2) must withstand irradiation processing at temperatures to –40°C without cracking, delaminating, or losing seal strength, (3) must withstand shipment hazards, (4) must protect its contents from microbial or other contamination, (5) will not transfer toxic substances to food, (6) will not transmit off-odors or taint food, (7) must provide an oxygen and moisture barrier, and (8) must be inert to the package contents.

Packaging atmosphere. Ironically, packaging materials, which are designed to preserve the freshness and flavor of foods, can actually be directly responsible for causing flavor defects (Marsili, 1997). The packaging atmosphere can affect the survival of pathogenic organisms in irradiated foods (Radomyski et al., 1994). To ensure that packaging materials used for irradiation do not impart an off-flavor or off-odor, poultry products should be packaged in compliance with the Code of Federal Regulations (21 CFR 179.26) prior to irradiation and remain in the same package throughout the distribution in commerce to the point of purchase (USDA, 1992). A list of packaging materials approved for food irradiation is listed in Table 2.3.

Aerobic packaging. Aerobic packaging is not a good practice for the long-term storage of meat, but aerobic packaging may be useful for short-term storage of irradiated pork patties because compounds that are responsible for irradiation off-odor can be reduced during the storage period (Ahn et al., 2000a). More pronounced oxidative rancidity and less stable display color were noted for pork chops irradiated in aerobic packaging (Luchsinger et al., 1996). Many living organisms, including bacteria, are more readily damaged when oxygen is available to the cells at the time of irradiation than when oxygen is not available (Hayashi, 1991). The availability of oxygen, however, causes undesirable effects to the sensory properties of foods. Oxygen availability during storage has been found to have a more detrimental effect on the lipid oxidation of raw pork patties than irradiation and the high fat content (Ahn et al., 1998a).

Modified atmosphere packaging (MAP). It is difficult, if not impossible, to remove the last traces of oxygen from MAP meats (Thayer and Boyd, 1999). The use of packaging with CO_2 does have an antimicrobial effect in and of itself and is recommended for reducing the

Table 2.3. Food and Drug Administration Irradiation-Approved Polymeric Films[1]

Material	Description of approved material	Maximum radiation dose, kGy
Nitrocellulose or vinylidene chloride coated cellophane	177.1200	10
Wax coated paperboard	176.170	10
Glassine paper	176.170	10
Polyolefin	175.1520	10
Kraft paper	176.170	5
Polystyrene	176.1630	10
Rubber hydrochloride	175.300	10
Nylon hydrochloride	177.1500	10
Polyethylene	177.1530	60
Polyethylene terephthalate	177.1630	60
Polyiminocyproyl (nylon 6)	177.1500	60
Vinylidene chloride-vinyl chloride	175.320	60
Vinyl chloride-vinyl acetate	175.320	60
Vegetable parchment	179.45	60
Ethylene-vinyl acetate	177.1350	80

[1]USDA, 1992.

number of microbial pathogens and for extending the shelf life of foods (Murano, 1995a). Generally, the optimal irradiation package atmosphere for extending shelf life by inhibiting spoilage microorganisms appears to be a high carbon dioxide, low oxygen mixture. Furthermore, there is a carbon dioxide threshold level above which an increase in carbon dioxide appears to have no additional inhibitory effect (Burg and Shalaby, 1996). Carbon dioxide could also delay senescence in some products, further enhancing the radiation-induced shelf-life extension (Kilcast, 1990). A high carbon dioxide environment, however, may be conducive to the formation of toxins such as the botulinum toxin, produced by *Clostridium botulinum* found in meat (Burg and Shalaby, 1996).

Bagorogoza et al. (2001) indicated that nitrogen atmosphere might have a slight protective function on tocopherols, especially in intact muscle of irradiated turkey breasts. A high level of nitrogen in a package appears to have no additional inhibitory effect and, in fact, it allows bacterial growth very similar to that in air (Burg and Shalaby, 1996).

Vacuum packaging. Some advantages of using vacuum packaging during irradiation are that it gives the lowest D_{10} values (Monk et al., 1995), meats have greater color stability and the rate of metmyoglobin was reduced (Sante et al., 1994). Furthermore, meats are often less dehydrated and discolored than samples packaged in modified atmospheres (Silla and Simonsen, 1985). Vacuum packaging is better than aerobic packaging for irradiation and subsequent storage of meat because it minimizes oxidative changes and produces minimal amounts of volatile compounds that might be responsible for irradiation off-odor during storage (Ahn et al., 2000a).

Addition of antioxidants. Addition of antioxidants to meat prior to irradiation provided some protection against lipid oxidation as compared to irradiation in the absence of antioxidants

(Kanatt et al., 1998). Antioxidants are capable of quenching free radicals and thus protect phospholipids and cholesterol against oxidation. Kanatt et al. (1998) found that among the antioxidants tested, including α-tocopherol, citric acid, ascorbic acid, sodium nitrite, butylated hydroxytoluene (BHT) and sodium tripolyphosphate (STPP), BHT and tocopherol were most effective against oxidation.

Antioxidants also have many different functions. The incorporation of α-tocopherol into the cell membrane will stabilize the membrane lipids and consequently enhance the quality of meat during storage (Gray et al., 1996). Phosphates inhibit lipid oxidation by acting as chelators of free metals (Timms and Watts, 1958).

Storage. The success of low-dose irradiation treatment depends upon subsequent storage at refrigeration temperatures at which outgrowth of surviving microorganisms is retarded or prevented (Monk et al.,1995). After an extended time of storage after irradiation, bacteria in foods can divide and can reach the same population levels as in the non-irradiated food (Tritsch, 2000). During storage, it is apparent that oxidation of tissue lipids proceeds at a very rapid rate when meat is sliced and exposed to the air in the refrigerator (4°C) or at room temperature (~24°C) (Chang et al., 1961). Storage conditions can enhance the recovery of certain organisms after irradiation, with different conditions affecting bacterial growth according to the organism (Radomyski et al., 1994).

Irradiation approved packaging materials

The multiple layers of different polymers should not only maintain structural integrity, but also have gas-barrier properties. Both of which are of increasing importance in modern food packaging systems, and in addition, no significant changes to gas permeability must take place

(Kilcast, 1995). Radiation-induced changes in polymers are shown to depend on chemical structure of the polymer, additives used to compound the plastic, processing history of the plastic, and specific irradiation conditions, namely, the absorbed dose, the irradiation atmosphere and, in certain cases, the dose rate (Buchalla et al., 1993).

The major chemical changes that are caused in polymers by ionizing radiation are degradation, simultaneous scission and cross-linking of the polymeric chains, their net effect determining the changes in physical properties, formation of gases and low molecular weight radiolysis products and formation of unsaturated bonds (Buchalla et al., 1993). The predominance of scission over crosslinking depends on the polymer structure, temperature, crystallinity, and the presence of air (Hill et al., 1996). If scission predominates, then degradation of physical properties occurs, and the polymer may become unstable. If crosslinking predominates, then gelation will eventually occur at high enough doses (Hill et al., 1996).

Some chlorinated polymers such as PVC have been shown to be unsuitable packaging materials as a result of depolymerization reactions that reduce strength and generate hydrogen chloride, which taints food (Kilcast, 1995). Another problem that can occur when inappropriate packaging is selected for specific food applications is a phenomenon referred to as scalping, the absorption of flavor-important chemicals from the food product into the packaging material (Marsili, 1997).

The interaction of irradiation with flexible packaging materials forms radiolytic compounds as a result of chain scission within the carbon chains of the polymers involved (Montgomery et al., 2003). Because of the potential negative quality and sensory factors that radiolytic compounds may cause, there is a need for a vacuum-plastic package that will allow radiolytic compounds to escape from the package while minimizing global migration into the packaged meat (Montgomery et al., 2003). To avoid a consumer health hazard from occurring, the U.S. FDA has required that only materials for which they have issued regulations be used (Urbain, 1986).

Studies on the migration of additives from packaging materials into food on irradiation have been carried out, and on the basis of this work, the FDA approved in 1964 a range of films as safe for use for gamma irradiation up to 10 kGy (Kilcast, 1990), and shown in Table 3. As the determination of migrated polymer additives in heterogeneous foodstuffs is a difficult and time-consuming task, it has become common practice to study the migration of polymer additives into a series of homogenous liquids (food simulant media), under standard conditions (Allen et al, 1990). Bourges et al. (1993) concluded that irradiation has no effect on migrational behavior of antioxidants from commercial polypropylene, but leads to the migration of some compounds resulting from the antioxidants' degradation.

Most of the polymers approved for irradiation are stable, but chemical effects may occur. Polystyrene (PS) and polyethylene terephthalate (PET) are stable when irradiated, largely due to the aromatic groups which are able to absorb and dissipate the penetrating energy (Burg and Shalaby, 1996). The degradation of polyethylene film was dependent upon dose rate and the formation of carboxylic acids increased with the decrease in dose rate when polyethylene film was irradiated with accelerated electrons at various dose rates (Azuma et al., 1984). Polypropylene (PP) tends to undergo crosslinking and chain scission (Burg and Shalaby, 1996). Low density polyethylene (LDPE) may release aliphatic hydrocarbons, aldehydes, ketones, and carboxylic acids, a phenomenon that may be reduced by incorporating antioxidants in the polymer (Burg and Shalaby, 1996).

F. Irradiation Effects on food

1. Sensory Effects

Food irradiation produces sensory changes that are much less drastic than canning, pasteurization, freezing, pickling and sous-vide cooking and it carries no serious side effects when a controlled process is applied to appropriate foods (Kilcast, 1995). A major concern in irradiating meat is its effect on meat quality, mainly because of free radical reactions resulting in the possibility of odor generation during irradiation (Al-Bachir and Mehio, 2001). The effect of irradiation on color, flavor, aroma/odor and texture of foods is discussed in detail in the following sections.

Color. Color is one of the three major quality attributes of food along with flavor and texture. However, if the color is unattractive, a consumer may never get to judge the food's flavor or texture (Francis, 1991). Irradiation has been documented as causing either a red or pink discoloration in meats and poultry. These color changes in meats are influenced by the concentration and chemical state of muscle pigments (Bagorogoza et al., 2001). The redness induced by irradiation in cooked breast meat could easily be misconstrued as undercooked by consumers, and thus, cause quality problems (Du et al., 2002) in the cooked food.

Irradiated chicken and pork may develop a pink discoloration after relatively low doses of irradiation, as metmyoglobin is reduced to myoglobin by free radicals (Wilkinson and Gould, 1996). Hanson et al. (1963) found that an objectionable red color developed in irradiation-sterilized chicken meat after storage at elevated temperatures in the absence of oxygen unless adequate heat treatment was given before irradiation. Bagorogoza et al. (2001) also found that on cooking, the globin part of the molecule denatures to expose the central heme iron, which gets oxidized to a ferric form—the brown complex globin myohemichromogen. The redness observed in irradiated turkey may be due to another ferrous myoglobin derivative rather than oxymyoglobin and may be attributable to the simple redox reaction known to affect meat color. Chang et al. (1961) found that the exclusion of oxygen in electron-beam irradiated (34 kGy), sliced roast beef resulted in a bright-pink color, whereas the inclusion of oxygen caused destruction of the pigment, resulting in a gray color.

Akamittath et al. (1990) found that discoloration and lipid oxidation are interrelated, and pigment oxidation may catalyze lipid oxidation. Ahn et al. (1998a) found that changes in heme pigments by irradiation could change color and generate off-flavor in irradiated raw meat. They postulated that heme-pigments can catalyze lipid oxidation in irradiated meat because irradiation can influence the release of iron from heme pigments or the formation of ferryl radicals.

Flavor. There is a general pattern that occurs in off-flavor development in cooked, stored meats: the disappearance of the fresh flavors, the appearance then disappearance of the cardboard flavor, and the final dominance of other flavors by the oxidized/rancid note (Johnson and Civille, 1986). Irradiation causes some undesirable off-flavors in meats. Irradiation off-flavors of meats have been listed as “sweet,” “warm,” “stale,” “acidic,” and “metallic” (Risvik, 1986). In irradiated muscle, the metallic flavor may become more intense due to oxidation of the metal ions and lean tissue phospholipids during processing (Bagorogoza et al., 2001). They also found that irradiation induced a distinct acrid flavor of low intensity in cooked turkey breast (Bagorogoza et al., 2001). However, Shamsuzzaman et. al. (1992) found that irradiation (1, 2, and 3 kGy) combined with sous-vide treatment had very little effect on the flavor of the chicken breast meat samples during a 55 day refrigerated shelf life.

The term “warmed-over” flavor (WOF) was first used to describe the rapid development of oxidized flavors in refrigerated cooked meats, in which a rancid or stale flavor usually becomes apparent within a short period of storage after reheating (Tims and Watts, 1958). Warmed-over flavor also develops in raw meat that is ground and exposed to air at room temperature (Sato and Hegarty, 1971). WOF has been generally accepted to be the result of autooxidation of lipids in cooked meats (Wu and Sheldon, 1988). The use of a trained panel is probably the best way to measure WOF, but even then it is not clearly established that a panel can differentiate between WOF and other types of autoxidative changes (Wu and Sheldon, 1988).

Aroma/Odor. The effect of irradiation on foods has been characterized as imparting an off-odor in the foods. These odors have been characterized as barbecued corn-like odor, burnt, bloody, sweet, old, sulfur or pungent (Ahn et al., 2000b). However, Bagorogoza et al. (2001) observed that the off-odor was most intense on opening of the packages, especially soon after irradiation, and was less intense in packages opened later.

Ahn et al. (2000b) found that irradiation had no effect on the production of volatiles related to lipid oxidation, but produced a few sulfur-containing compounds not found in non-irradiated meat, indicating that the major contributor of off-odor in irradiated meat is not lipid oxidation, but radiolytic breakdown of sulfur-containing amino acids. Hashim et al (1995b) found that raw irradiated (1.66 to 1.86 kGy) chicken to have higher "fresh chickeny," bloody, and sweet aromatic aroma intensities as compared to non-irradiated samples.

Texture. Unlike, color and flavor, texture is used by the consumer not as an indicator of food safety, but as an indicator of food quality (Lawless and Heymann, 1999). Texture changes and liquid exudation frequently occur at the same time in enzyme-inactivated, irradiation sterilized (45 or 46 kGy) chicken during storage at elevated temperatures of 21 or 38°C (Hanson, et al., 1963). Loss of juice and protein denaturation may occur during cooking and storing of uncured meat, which may contribute to undesirable texture (Tims and Watts, 1958). Pearson et al. (1958) found that irradiated (27.9 kGy), precooked, beef, pork, chicken and veal had texture losses after being stored between 4 and 30 days at 100-125°F (38-52°C). These texture changes were associated with breakdown of connective tissues, probably non-enzymatic hydrolysis.

2. Chemical properties of irradiation

The chemicals responsible for off-flavors and malodors in foods and beverages can originate from incidental contamination from environmental (outside) sources, such as air, water, or packaging material and from chemical reactions occurring within the food material itself (Marsili, 1997). The irradiation process can cause undesirable chemical changes in foods, such as lipid oxidation, cholesterol oxidation, formation of free radicals, hydroperoxides and radiolytic byproducts.

Lipid oxidation. Oxidative deterioration is of greatest economic importance in the production of lipid-containing foods due to the production of offensive odors and flavors, as well as, decreased nutritional quality and safety (Frankel, 1980), destruction of vitamins (A, D, E, K, and C), and destruction of essential fatty acids (Aurand et al., 1987) with the development of an offensive off-flavor. Lipid oxidation is one of the primary mechanisms of quality deterioration in foods and especially meat products (Gray et al., 1996). Oxidation off-flavors (rancidity) in meat begins to develop soon after death of the animal and continues to increase in intensity until the meat product becomes unacceptable to the consumer (Gray et al., 1996). Irradiation in the presence of oxygen accelerates the auto-oxidation of fats by one of the three possible reactions: (1) formation of free radicals which combine with oxygen to form hydroperoxides, (2) the breakdown of hydroperoxides, or (3) the destruction of antioxidants (Nawar, 1996). The oxidation of polyunsaturated fatty acids proceeds through the following free-radical mechanisms:

Initiation: $RH + O_2 \longrightarrow R\bullet + \bullet OH$

Propagation: $R\bullet + O_2 \longrightarrow RO_2\bullet$

$RO_2\bullet + RH \longrightarrow RO_2H + R\bullet$

Termination: $R\bullet + R\bullet \longrightarrow RR$

$R\bullet + RO_2\bullet \longrightarrow RO_2R$

$RO_2\bullet + RO_2\bullet \longrightarrow RO_2R + O_2$

Lipid oxidation alone cannot produce the characteristic irradiation odor because meat irradiated in an oxygen-impermeable package, which theoretically stops lipid oxidation, was found to produce the irradiation odor (Ahn et al., 2000a). Ahn et al. (2001) suggested that volatile compounds responsible for off-odor in irradiated meat are produced by radiation impact on protein and lipid molecules and its mechanisms are different from those of lipid oxidation. In a low-fat, high protein food, radiolytic changes in the protein portion may be more responsible for the strength of the irradiation off-flavor than the lipid portion (Bagorogoza et al., 2001).

Any development of lipid oxidation in irradiated raw or cooked meat would be influenced by packaging, storage, and other processing conditions before and after irradiation (Ahn et al., 1998b). Cooked meat is more susceptible to lipid peroxidation than raw meat during refrigerated and frozen storage due to the heating process resulting in acceleration of oxidative reactions with the lipids in meat (Kingston et al., 1998). The oxidative process is not limited to meats containing a relatively high percentage of unsaturated fatty acids, but can occur in meats which contain fewer polyunsaturated fatty acids, and even in meats containing relatively small amounts of fat (Tims and Watts, 1958).

Poultry meat contains polyunsaturated fatty acids and significant amounts of free catalytic iron, which may be responsible for the susceptibility of the muscle tissues to lipid oxidation; thus this concentration of free iron ions increases with storage time two to threefold over fresh samples (Kanner et al., 1988). The unsaturated fatty acid-containing lipids are more prone to oxidation, and storage of irradiated lipids in an oxygen environment leads to enhanced rancidity (Murano, 1995b). As lipids oxidize, they form hydroperoxides, which are susceptible to further oxidation or decomposition to secondary reaction products such as aldehydes, ketones, acids and alcohols (Kanatt et al., 1998). Aldehydes are major contributors to the loss of desirable flavor in meats because of their rate of formation during lipid oxidation and low flavor threshold (Drumm and Spanier, 1991). The other effects of irradiation on lipids include lipid polymerization, typically seen upon storage at some time following treatment with high doses (hundreds of kGy) of irradiation (Murano 1995b).

Lipid oxidation in muscle systems is initiated at the membrane level in the intracellular phospholipids fractions (Gray et al., 1996). Possibly denaturation of proteins during heating may free phospholipids and thus make them more susceptible to oxidative attack (Tims and Watts, 1958). However, there is still some confusion about the nature of the initiation process in lipid oxidation, but spontaneous lipid radical formation or direct reaction of unsaturated fatty acids with molecular oxygen is thermodynamically unfavorable (Gray et al., 1996).

Cholesterol oxidation. As rancidity developed in comminuted and cooked meat during storage, oxidation of cholesterol became more apparent (Park and Addis, 1987). The environment surrounding cholesterol may play an important role in determining the susceptibility of cholesterol to oxidation and the oxidation of nearby unsaturated lipids may result in the formation of free radicals, which can attack cholesterol (Engeseth and Gray, 1994).

Lee et al. (2001) studied the effects of irradiation (0, 1 and 2 kGy) on the formation of cholesterol oxides in raw and cooked chicken meat during storage. The types of cholesterol oxides found in cooked meat were basically those found in raw chicken, but the levels in cooked meats at all storage periods were higher than those of the raw meats.

Formation of free radicals. Free radicals do not appear to be of any physiological or toxicological significance, even in very dry products, in which they would be expected to have long half-lives (Thayer, 1994). It is possible that oxygen is used up by the normal microbial flora of some products, resulting in its unavailability for radical formation and this unavailability can result in shelf life extension of products that initially contained oxygen (Murano, 1995a). The free radicals generated by irradiation can destroy antioxidants in muscle, reduce storage stability and increase off-flavor production in meat (Lakritz et al., 1995).

Hydroperoxides. Hydroperoxides are the predominant, but not exclusive, primary products of autooxidation of unsaturated fats (Aurand et al., 1987). Pure lipid hydroperoxides are fairly stable at physiological temperatures, but in the presence of transition metal complexes, especially iron salts, their decomposition is greatly accelerated (Gray et al., 1996). Hydroperoxides are unstable and undergo decomposition to form short-chain acids, alcohols, aldehydes, and ketones. These end products (secondary oxidation products) are responsible for the development of the odor and flavor of oxidized fats (Aurand, 1987).

Radiolytic byproducts. It is well known that the chemical changes induced by radiation are influenced by temperature, water content and oxygen concentration. Since most foods are composed of much water, the ionization of water is the predominant reaction to occur upon irradiation of a food (Murano, 1995b). Irradiation causes ionization which results in either indirect effects, whereby the chemically reactive products formed from irradiated water (hydroxyl and superoxide radicals, etc) are themselves chemically reactive and result in a cascade of further reactions, or direct effects resulting from chemical changes induced in molecules such as the nucleic acids present in food (McMurray, 1990). When food is irradiated, oxygen can react with various products of radiolysis thus decreasing the concentration of oxygen in the food (Foley et al., 2001).

Production of volatiles. Ahn et al. (2001) found that irradiation (4.5 kGy) increased the production of sulfur-containing volatiles (carbon disulfide, mercaptomethane, dimethyl sulfide, methyl thioacetate and dimethyl disulfide) at day 0 in pork packed with either aerobic or vacuum packaging, but it did not increase hexanal. They also found that by day 10, the majority of the sulfur-containing volatiles produced in meat by irradiation disappeared under aerobic conditions, but with vacuum packaging, the volatiles remained in the packaging bag during storage.

An undesirable ‘irradiation’ odor can develop due to the formation of a complex mixture of volatile compounds, including sulphur containing- and carbonyl compounds (Hannan and Shepherd, 1959). Methyl mercaptan and hydrogen sulfide were found to be important to irradiation odor (Batzer and Doty, 1955). They strongly suggest that the major odor-forming reactions occurring during irradiation involve the water-soluble proteins. Patterson and Stevenson (1995) found that of the sulfur-containing compounds, dimethyl trisulfide and bis(methylthio-) methane as the most potent off-odor sulfur compounds in irradiated chicken meat. Ahn (2002) indicated that many other sulfur compounds could be produced from methionine and cysteine.

Ahn (2002) found that the production of several new volatiles from amino acids upon irradiation indicating that more than one site in amino side chains was susceptible to free radical attack and many volatiles were apparently produced by the secondary chemical reactions after the primary radiolytic degradation of the side chains. Ahn et al. (1997) reported that the amount of total volatiles was not consistently influenced by storage time but was increased by irradiation dose.

G. Sensory properties of irradiated foods

Irradiation can enhance the quality of fresh products by increasing the duration of "freshness," or desirable appearance, odor, and flavor, while maintaining high nutritional value (Radomyski et al., 1994). The changes in sensory properties result mainly from three types of chemical reactions: (1) irradiation initiates the normal process of autoxidation of fats, which gives rise to rancid off-flavors, (2) irradiation of proteins that have sulphur-containing amino acids causing a slight breakdown in the amino acids, resulting in unpleasant off-flavors, (3) irradiation can result in breaking high-molecular-weight carbohydrates into smaller units (Kilcast, 1995). However, the sensory quality of high moisture foods, such as meat, can be protected by irradiation in the frozen state (Farkas, 1987).

Fruits and Vegetables. Sensory evaluation has shown that irradiated fruits and vegetables are preferred over non-irradiated fruits and vegetables. In a consumer in-store survey on irradiated papayas, most consumers preferred the appearance and the taste of irradiated papayas compared to non-irradiated papayas, double-dipped in hot water as a disinfestation procedure (Bruhn and Noell 1987). Prakash et al. (2000a) studied the effects of low-dose gamma irradiation (0.15 and 0.35 kGy) on cut romaine lettuce, packaged under modified atmosphere. A trained panel perceived that the irradiation process did not adversely affect the color, generation of off-flavor and appearance of the lettuce, but they did perceive differences in the firmness of texture of the lettuce irradiated at 0.35 kGy, but only on 18 and 21 days after irradiation throughout the 22 day storage period. Prakash et al. (2000b) also studied the effects of low-dose gamma irradiation (0.5 and 1.0 kGy) on diced celery. Sensory evaluation panelists (consumer and analytical testing) perceived that the irradiated samples maintained their color, texture and aroma longer and that the time for development of off-flavors was also extended as compared to controls. Irradiated diced celery samples were preferred over the non-irradiated diced celery samples.

Red meats and meats. Luchsinger et al. (1997) studied the effects of irradiation (2.0 and 3.5 kGy) on flavor, texture and aroma of frozen raw and precooked, ground beef patties with 10 and 22% fat packaged in vacuum or aerobically; frozen, vacuum-packaged, boneless beef steaks; and chilled, vacuum-packaged, boneless, beef steaks that were repackaged in an oxygen-permeable film (PVC) after 14 days of storage. The results of the study showed that irradiation doses up to 3.5 kGy had minimal effects on the beef products, whereas, the packaging type had the most critical factor effect on the beef sensory attributes.

Byun et al. (2002) found that the sensory quality of hams irradiated with a dose of up to 5 kGy, regardless of the addition of sodium nitrite, was not affected by a high irradiation dose. The treatment of ground beef with gamma radiation at doses of 1.0, 2.5 and 5.0 kGy resulted in extended shelf-life at 4°C of 4, 10 and 15 days, respectively, while the non-irradiated control samples exceeded 10^7 colony forming units (CFU)/g on day 0 (Lefebvre et al., 1992).

Montgomery et al. (2003) found that the production of irradiated beef patties should utilize beef trimmings with the shortest postmortem aging time and a dose of less than 2 kGy to minimize discoloration and off-odors. The irradiated patties (2 kGy) were not significantly different from control patties for cooked aroma intensity, cooked off-odors, overall juiciness, overall tenderness or cooked beef flavor intensity. However in a study by Lefebvre et al. (1994), they found that a non-expert panel (n=10) indicated that the odor and flavor of irradiated (1.0, 2.5 and 5.0 kGy) cooked ground beef was slightly disliked while no difference was perceived in the color and texture. A consumer panel (n=20) indicated that no significant differences were found between irradiated (0,1,2,3, and 4 kGy) and non-irradiated luncheon meat samples in taste and flavor after seven weeks of storage (Al-Bachir and Mehio, 2001). These results are inconclusive due to the small number of panelists used.

Poultry. Poultry products are normally highly desired for their distinctive and highly prized flavors. However, departures from normal flavors are not uncommon in these products and result in poor acceptability or even rejection by consumers (Gray et al., 1996). Meats derived from the more intensively domesticated animals (turkey and chicken) are among the most sensitive to irradiation (Sudarmadji and Urbain, 1972). A dose in the vicinity of 3 kGy would appear to be optimum for use in irradiation of prepackaged chickens for extension of refrigerated storage life (Mercuri and Kotula, 1967).

Mahrour et al. (1998) found that marinating had synergistic effects with irradiation on fresh poultry to reduce the oxidation rate of unsaturated fatty acids. Hansen et al. (1987) found that 14 days after irradiation (0, 3, 6, and 12 kGy), irradiated chicken still had an acceptable odor, whereas non-irradiated chicken had severely deteriorated.

Ready-to-eat foods. The steadily increasing number and volume of refrigerated, precooked, further processed poultry products and ready-to-eat meats offered to consumers emphasizes the expanded use of these products (MacNeil & Dimick, 1970). There are no currently approved regulations for the usage of food irradiation to inactivate food-borne pathogens on ready-to-eat meats. Although irradiation of ready-to-eat foods would be an option for the industry.

Mcateer et al. (1995) used a trained panel to observe the effects of irradiation at 2 and 3 kGy and chilled storage on a ready-to-eat meal. The effects of irradiation were most apparent in the cauliflower and potato components of a cook-chill ready-to-eat meal consisting of roast beef and gravy, cauliflower and sauce together with roast and mashed potatoes and these effects occurred most often in the color, appearance and textural attributes. Stevenson et al. (1995) studied the effects of irradiation on a chilled ready-to-eat meal consisting of beef and gravy, Yorkshire pudding, carrot, broccoli and roast potato. Consumers (n=107) found the irradiated meat moderately to very acceptable and was not significantly different from the non-irradiated meal. Appearance and aroma appeared to be more important than flavor or texture in the overall assessment of the meal.

Foley et al. (2001) studied the effects of irradiation on a prepared meal consisting of Salisbury steak, gravy and mashed potatoes, inoculated with *Listeria* and irradiated at doses of 0.8, 2.9 and 5.7 kGy and stored at 4°C for 3 weeks. Treatment with 5.7 kGy produced a greater than six-log cycle reduction, 2.9 kGy reduced the pathogen by over five logs, but the treatment with 0.8 kGy was not effective, only reducing the counts by approximately one log. For the meal, 0.8 kGy appeared to damage *Listeria* to the degree that the population of survivors experienced a further decline in numbers after 1 week of storage, however, at 4°C by the second week of refrigerated storage, *L. monocytogenes* counts had recovered to the level found at the first time point and continued multiplying through the third week of storage. It was concluded that 5.7 kGy was a good choice to enhance the safety and microbial shelf life of the refrigerated prepared meal.

H. Detection

Regulatory agencies need methods for the detection of foods which have been irradiated in order to allow enforcement of any national prohibition for irradiation of specific foods, the requirement for proper labeling of such foods and for the control of limitations imposed on the process (Thayer, 1990). However, there is no single method of detection to cover the broad range of foodstuffs, and it is also difficult to determine an irradiated product if it is used as an ingredient in foods, such as spices (Hackwood, 1991).

Chemiluminescence (CL). Hasselmann and Marchioni (1991) summarized that some oxidizing substances like hydrogen peroxide and oxidizing radicals are formed in irradiated foods and remain relatively stable if the food is dry. In an alkaline medium and in the presence of a photosensitizer like luminal or lucigenin, an intense light emission (chemiluminescence) is produced. The chemiluminescence (CL) intensity is noticeably proportional to the dose absorbed. The main disadvantage is the lack of specificity, because any oxidizing substance can induce a luminescent signal in the presence of luminal (Hasselmann and Marchioni, 1991). Another disadvantage is that the CL intensity can be reduced by a quenching of the emitted light due to the colored substances, which can be extracted from the irradiated food through the luminal solution parallel to the reaction between the irradiated food and the solution (Bogl and Heide, 1991). The CL method is limited for detection purposes for products sensitive to oxidation (Bogl and Heide, 1991).

Thermoluminescence (TL). The advantages of using thermoluminescence for detection is that it is relatively simple, allows dose assessment from the established dose-effect curve and can also be extended to other irradiated food products which contain adherent inorganic dust (Kiyak, 1995). In TL detection, the delivered radiation energy stored or trapped in the irradiated foods is released when food materials are heated during TL measurements and irradiated foods, in principle, show higher TL emissions than unirradiated foods (Khan and Delincee, 1995). The luminescence intensity, which is proportional to the dose absorbed, can be measured as a function of the heating temperature (Hasselmann and Marchioni, 1991). Due to the stability of the radiation induced signals, TL measured on silicates can be considered always as unambiguous proof for radiation processing of plants (Raffi et al., 2000).

Khan and Delincee (1995) studied the effects of gamma irradiation on spices and herbs of Asian origin. The integrated TL intensities of glow curves from the irradiated samples were found to be much higher than those from unirradiated samples. Their results were normalized by administering a re-irradiation gamma ray dose of 1 kGy and calculating the ratio of the integral of the first glow curve (of non-irradiated or irradiated samples) to that of the second glow curve (after re-irradiation). This showed that the TL of mineral contaminants, comparing the intensities of first and second glow curves as well as shapes of the glow curves, can provide an unequivocal method to determine the irradiation treatment of spices, herbs and their mixtures irradiated to doses equal to or greater than 1 kGy.

Electron spin resonance (ESR). Electron spin resonance (ESR) is the only detection method which enables the possible detection of a unique radical product (Hasselmann and Marchioni, 1991). ESR is a spectroscopic method applicable to compounds possessing an unpaired electron, thus to free radicals, but also to odd molecules, triplet electronic states and transition metal and rare earth ions (Hasselmann and Marchioni, 1991).

Delincee and Soika (2002) improved the ESR detection sensitivity of irradiated strawberries and papayas using an extraction procedure. A radiation dose of 0.5 kGy could be detected in both fruits even after 2-3 weeks of storage. In addition, the ESR detection sensitivity of granulated garlic and parsley was improved, whereas no improvement was obtained for chives, thyme, ground cinnamon and cumin, whole and ground black pepper.

Electron paramagnetic resonance (EPR). Electron paramagnetic resonance (EPR) is the most accurate method for identification of irradiated foodstuffs since radicals are stabilized for a long time in all (or part of) foods that are in solid and dry states. Consequently, EPR can be applied to meat and fish bones, fruit and vegetables (Douifi et al., 1998). The same or very similar responses of the EPR spectra can be found with either gamma ray or electron-beam irradiation in commercial practice (Stachowicz et al., 1998).

Yordanov et al. (1998) showed that the presence of EPR active cellulose free radicals provide an unambiguous indication that the sample has been irradiated. However, the absence of EPR active cellulose free radicals can not provide definitive proof that the samples had not been irradiated. Raffi et al., (2000) concluded that EPR could be used as proof for irradiation treatment for herbs and spices, but only for a limited period of time (70-90 days) because the radiation induced radicals disappear with time storage. However, the application of heating procedures in conjunction with the EPR method could extend this period for up to 5-6 months. They also recommended to first use EPR and only if there is no response, switch to TL of silicates for final proof.

I. Consumer Acceptance

Consumer acceptance is critical to the application of irradiation technology and the realization of the advantages it offers (Schutz et al., 1989). The whole process of how consumers assess the quality of irradiated foods is rather complex and involves social or cultural biases, initial perceptions of benefit or risk, anticipated consequences of eating a food, and comparison with alternate products (Satin, 1993). Consumers' perception has been that there is minimal personal benefit from food irradiation but significant potential for increased profits for the food industry (Adams, 2000).

1. Surveys

Consumer acceptance surveys. Over the past 40 years, surveys and market studies have been conducted to evaluate where consumers stand on the acceptance of irradiation. Nevertheless, the surveys on consumer acceptance of irradiation have shown considerable uncertainties and inconsistencies. In the 70's and 80's, most of the research conducted on consumer acceptance of irradiated food did not truly deal with acceptance, but with hypothetical consumer willingness to purchase such food "if it were available" (Molins, 2001).

Surveys are more accurately interpreted by comparing change over time, contrasting attitudes toward one area with those of another within the same sample (Bruhn 1998). However, consumer attitudes are measured more frequently by recording the number of persons who view a particular situation with major, minor, or no concern (Bruhn, 1998). Studies reporting higher numbers of people expressing major concern about irradiation were, often, surveys that did not also provide information about the process (Conley, 1992). Fox (2002) suggested that higher rates of acceptability are found in controlled retail studies, where more information can be provided. But a second, and potentially more important, consideration in interpreting study results is that when any information is provided, it invariably tends to be favorable to irradiation.

Marketing trials/surveys. Premarket surveys can help estimate how consumers will act, but such estimates may be proven wrong in the marketplace (Pauli, 1991). Marketing trials are difficult to carry out and to interpret because many consumers do not know what food irradiation means. They can lead to uncertain conclusions because they are often carried out under somewhat artificial conditions (Diehl, 1995). Adams (2000) also found that virtually every test market study of irradiated products and market surveys depicts an increasing acceptance of irradiated food products, but this information is misleading because most of the tests are conducted under artificial circumstances.

2. Factors that influence consumer

Labeling. Proponents for labeling of irradiated food have included consumers and government regulatory agencies. Opponents have been the commercial organizations that are concerned with the sale of the irradiated foods and who see marketing problems in a mandatory labeling requirement (Urbain, 1986), shown in Figure 2.1. It has been suggested by others that irradiated food should not be specially labeled, the argument being that other forms of food processing are not identified on the label, that irradiated food does not present any hazard that people need to be aware of, and that consumers might hesitate to buy food products identified with the word "irradiated" (WHO, 1988).

Figure 2.1. FDA-approved labels required for irradiated foods.

TREATED WITH
RADIATION

TREATED BY
IRRADIATION

To be of genuine value to consumers, labeling of irradiated food must be supported by public information and education campaigns designed initially to help consumers decide whether they want to be able to buy radiation-processed foods and subsequently to help them make wise decisions in the selection and use of irradiated food products (WHO, 1988). However, the Grocery Manufacturers of America (GMA, 1999) believe that flaws in FDA's current approach to the labeling of irradiated food may discourage consumers from purchasing irradiated food. Consumers have a strong desire for food to be labeled with the date of irradiation, so that the food's age could be accurately assessed, without relying on appearance (Titlebaum et al, 1983).

Demographics. Bruhn and Noell (1987) found that consumers from upscale markets (Irvine, CA) as compared to a newer middle class neighborhood (Anaheim, CA) showed greater acceptance of irradiated papayas. The greater acceptance was attributed to different attitudes and values. It is typically found that females are more concerned about irradiation than males and that individuals with more formal education are more accepting of the technology. The effects of age and income results are mixed and are generally not statistically significant (Lusk *et al.* 1999).

Economics. Conley (1992) stated that "a closer look at the economics of the irradiation issue may reveal that the industry itself is not entirely favorable to the process". Consumers are skeptical about paying more for safety and quality, because when purchases are made, they already expect a certain level of safety and quality. The consumers' perception has been that there is minimal personal benefit from food irradiation, but significant potential for increased profits for the food industry (Adams, 2000).

Educational information. In the past, the extent to which the public accepted or rejected irradiated food depended on the presence or absence of information (Bord and O'Connor,1989). At present, the "education" obstacle is gradually removed as a result of governments, consumer organizations, and others providing information to help consumers make informed judgments about the value of food irradiation (Barach, 2002). Information may not reduce consumer concern, but it allows choice to be based on fact, rather than suspicion (Bruhn and Schutz, 1989). Consumers want information on the effect of long term consumption of irradiated food, the nutritional value of irradiated food, its use in other countries, and the impact of the facility on the community (Bruhn, 1998).

Hashim *et al.* (1996) conducted a focus group which suggested that consumer's awareness and acceptance can be increased by education programs, informative irradiation label and/or poster, television shows, children interactions, pamphlets or brochures, and in-store sampling. These findings were similar to those of Pohlman et al. (1994), who developed a slide-tape presentation and conducted a consumer test proving its usefulness in increasing consumers' knowledge and positive attitudes toward irradiation. Resurreccion and Galvez (1999) conducted a simulated supermarket setting study on irradiated ground beef in which an educational slide show was presented to consumers. The results demonstrated a positive association between consumer education and purchase behavior of the irradiated ground beef.

Bord and O'Conner (1989) concluded that the degree of acceptability of irradiated food varied with how the question was asked and with the level of knowledge of the respondents. There is evidence to suggest that if irradiated food products offer clear advantages, and if science-based information about the process is readily available, many consumers would likely be ready to buy irradiated food (Bruhn, 1995). The willingness to buy is, however, strongly influenced by the way irradiation is presented such 'deliberately treated with food irradiation' and by information about the process of irradiation (Feenstra & Scholten, 1991). Pszczola (1990) suggested that one way of educating consumers is by redefining education – finding new and perhaps more personal ways to present information, tailoring irradiation to meet the needs of the individual and consider the psychology or psyche of the consumer.

Education may not always be the key factor to ensure consumer acceptance of food irradiation. Sapp (1995) argues that the resolution of consumer apprehension will require more than education on scientific findings about food irradiation because apprehension is based on broader issues than education, such as consumers' trust in the ability of government agencies to regulate safety, their concerns about current food production and processing techniques, and their philosophies about what constitutes acceptable risk. Bruhn et al. (1986) found that alternative consumers, which were ecologically sensitive consumers, showed a higher level of initial concern toward food irradiation than more conventional consumers, and this concern increased after education efforts. Hayes et al. (2002) found surprising results that when consumers were presented with both positive and negative information simultaneously, the negative information clearly dominated.

Opposition Groups. Food industry representatives cannot anticipate the outcome of this controversy and therefore are reluctant to promote food irradiation for fear of backlash by angry consumers (Sapp, 1995). Elias (1987) stated that opposition may be categorized into two forms. One is represented by comments on the FDA proposals in the Federal Register sent in by individual concerned citizens. The other takes the shape of organized petitions, newspaper editorial and literature distributed to the public. Despite the evidence, opponents of food irradiation claim that the irradiation process will be used to mask spoiled food, discourage strict adherence to good manufacturing practices and will preferentially kill "good bacteria and thus encourage greater growth of "bad" bacteria (Satin, 1993). Before the approval of irradiation of poultry and beef, these groups resorted to misinformation campaigns, threats of boycotts, picketing of supermarkets, pressuring of state legislators and actions that prey on the consumer's fear of nuclear accidents, in an attempt either to stall FDA approval or irradiation or even more dramatic, ban the sale and distribution of irradiated foods nationwide or within individual states (Pszczola, 1990).

Endorsements. The government largely controls the quality and safety of foods available to consumers and is often responsible for the provision of nutrition and food safety information to consumers (Satin, 1993). However, government and industry approval of irradiation does not result in an automatic acceptance of irradiation by the consumer. Despite comprehensive research and endorsement by major health organizations, international expert committees, and scientific societies, it is believed that there is reluctance among consumers to accept irradiated food (Resurreccion et al., 1995).

J. Consumer concerns about food irradiation

Consumers express concern about the safety of irradiated foods, but concern is greater for chemical sprays and pesticide residues, use of preservatives, and foodborne illnesses than for irradiation. When asked about irradiation, people have questions about induced radioactivity, product safety, nutritional quality, potential harm to employees and potential danger from living near an irradiation facility (Resurreccion et al., 1995; Bruhn, 1998). These concerns appear to be derived from the association of irradiation with radioactivity, nuclear power plants, and atomic power (Bruhn and Schutz, 1989). However, consumers in several studies have expressed more concern for pesticide and animal residues, growth hormones, food additives, bacteria and naturally occurring toxins than irradiation (Wiese, 1984; Bruhn et al., 1986; Schutz et al., 1989; Resurreccion et al., 1995).

Induced radioactivity in food. All foods are to some extent radioactive, generally at extremely low levels (WHO, 1994). The energy used (approximately 5 to 10 MeV) in food irradiation is not great enough to cause food to become radioactive. Research demonstrates that foods irradiated with Cobalt-60 or Cesium137, X-ray sources of 5.0 MeV or less energy, and accelerated electrons with energies of less than 10 MeV, will not induce radioactivity in foods. As long as these thresholds are not exceeded, the radioactivity is essentially zero (Becker, 1983). Above approximately 10 to 15 MeV, it is possible for significant amounts of radioactivity to be created. Therefore, only lower-energy ionizing radiations are used in the irradiation of food (Webb and Lang, 1987). Even if new radioactive materials may be produced by accelerated electrons with high energies, the half-life of the generated isotopes are so short that radioactivity is not present in measurable amounts if the energy of the electron is kept below 10 MeV (Hayashi, 1991).

Production of radiolytic products. Radiolytic changes in irradiated foods are minimal and are predictable from the radiation chemistry of the principal components of the food (Thayer, 1994). Considerable evidence has shown to support the view that similar radiolytic reactions occur with the same constituents of different foods (protein, fat, carbohydrates, water, etc.) and that common radiolytic products are formed in approximately predictable yields on irradiation of these foods (Elias, 1989).

The irradiation process produces highly reactive free hydroxyl radicals, hydrated electrons, and hydrogen atoms (Thayer et al., 1991). The radiolytic products formed are essentially the same whether the food is exposed to large or small amounts of radiation (WHO, 1994).

Nutrient losses in irradiated food. Kilcast (1993) studied the literature extensively to examine the effect of irradiation on vitamins. The water-soluble vitamins, vitamin C (ascorbic acid) and B_1 (thiamine) and the fat-soluble vitamins, vitamins E and A, are the most sensitive to irradiation. Antioxidant vitamins can combine with free radicals and lose their vitamin activity or free radicals and their products can attack and destroy vitamin structure or activity (Murano, 1995b). The more complex the food, the less it suffers vitamin losses during irradiation (Webb and Lang, 1987). Since most foods contain a large proportion of water, the most probable reaction of the ionizing radiation will be with water; and as vitamins are present in very small amounts compared with other substances in the food, they will be affected indirectly by the radiation (Thayer et al., 1991).

Lakritz et al. (1995) found that beef, pork, lamb and turkey meats irradiated in air (0 and 9.4 kGy) resulted in a significant decrease in α-tocopherol levels, with turkey having the greater rate of loss of α-tocopherol. They also found that the rate of tocopherols loss by irradiation was greater in breast muscle than in leg meat. Bagorogoza et al. (2001) found greater losses in α-tocopherol levels compared with γ-tocopherol in irradiated turkey breasts and this reduction was significantly lower as compared to non-irradiated samples. Similar results were obtained in fresh chicken breast muscle when the effect of gamma irradiation (3 kGy) decreased α-tocopherol levels by 6% (Lakritz and Thayer, 1994). Dietary tocopherol of levels greater than 200 IU/kg improved storage stability and reduced the production of total volatiles in irradiated and unirradiated turkey breast and leg meat patties irradiated at 2.5 kGy (Ahn et al., 1997).

Thayer (1990) reported no loss of folic acid activity in chicken meat sterilized at an absorbed dose of 45 to 60 kGy with either gamma or electron-beam irradiation. The assays actually showed an increase of folate activity in the electron-beam irradiated meat. Muller and

Diehl (1996) found that at a radiation dose of 2.5 kGy, radiation only caused about 10% loss of total folates in spinach, green cabbage and Brussels sprouts. They also found that radiation stability was higher in dehydrated vegetables than in fresh vegetables and that folate stability did not appear to be much affected by the greatly differing fat content of the samples.

Quality and safety of irradiated foods. In evaluating the quality and the safety of meat and meat products, microbiology and shelf-life are important parameters (Silla and Simonsen, 1985). The quality of fresh chicken irradiated at 5 to 10 kGy was similar to that of fresh chicken for about 15 days though it deteriorated slightly after 20 days, however the irradiated chicken were still acceptable for consumption after 27 days of storage (Lee et al., 1985).

II. Sensory evaluation methods for irradiated foods

Sensory evaluation is a scientific discipline used to evoke, measure, analyze and interpret reactions to those characteristics of foods and materials as they are perceived by the senses of sight, smell, taste, touch and hearing (Stone and Sidel, 1993). There is no better judge of flavor quality than the human being, however, panelists may suffer from fatigue, indifference, time constraints, and/or variability (Reineccius, 1991). The need for control and standardization is obvious in sensory evaluation since it is based on psychological evaluation of physiological sensations (Larmond, 1979).

1. Consumer Sensory Evaluation.

Acceptance Test. Consumer acceptance tests are affective tests based on measurement of preference, or a measure from which relative preference can be determined by the panelist's personal feeling toward the product (Larmond, 1979). Acceptance tests are conducted to: (1)

determine overall liking or preference for a product or products by a sample of consumers who represent the population for whom the product is intended, (2) measure liking or preference for a product's sensory properties, including appearance, flavor and texture, and (3) quantify consumer responses and relating these to descriptive analysis results or physical and chemical measurements (Resurreccion, 1998).

There are three primary categories of sensory acceptance tests classified according to the site of the test: (1) laboratory test, (2) central location test, and (3) home-use test. However, there are many other qualititative and quantitative sensory methods used to determine acceptance, such as focus groups and simulated supermarket-setting tests.

Laboratory test. The laboratory test is the most frequently among the various types of sensory acceptance tests. In laboratory testing, the panel usually consists of 25 to 50 consumers (Stone and Sidel, 1993). Advantages of conducting a consumer test in the sensory laboratory are: (1) convenience of the location to the researchers, (2) it allows for the greatest control over the sample preparation and testing conditions, including lighting and environmental conditions, (3) sample preparation steps can be standardized because the laboratory is usually adjacent to a fully equipped kitchen, and (4) the rapid-turn around time for results to be obtained because of the proximity to the data processing facilities (Resurreccion, 1998).

The panel size and scales used should be valid and reliable. Al-Bachir and Mehio (2001) utilized a 20 member consumer-type laboratory test to detect sensory differences between irradiated and non-irradiated luncheon meat samples. Each member independently evaluated a 2-mm thick slice of meat for taste and flavor on a 5-point scale (1=very bad, 2= bad, 3=accepted, 4=good and 5=very good). Their panel size was too small and scales used were not validated Nam et al. (2002) utilized a 72 member consumer panel to evaluate irradiated pork. Panelists were asked to assign a numerical value between 1 (dislike extremely) and 7 (like extremely), depending on their acceptance of odor and color of the meat. While panel size was adequate, the 7-point scale used is effectively a 5-point scale as panelist tend to avoid extremes of the scale.

Central location test (CLT). The central location test (CLT) is one of the most frequently used consumer tests, especially by marketing research (Stone and Sidel, 1993). In CLT tests, the panel usually consists of 100 or more volunteers (Stone and Sidel, 1993). Advantages of conducting a central location test are (1) the capability to recruit a large number of participants through intercepts and obtain a large number of responses, (2) the test will result in considerable impact and validity, because actual consumers are used, and (3) more products may be tested than would be advisable in a home-use test (Resurreccion, 1998).

Home-use test (HUT). In the home-use test (HUT), there is no control of environment or other test factors, therefore, panel size should be about twice the size (50-100 families) of that used in the laboratory test (Stone and Sidel, 1993). Advantages of conducting HUT are (1) the products are tested in the actual home environment under actual, normal home-use conditions, (2) more information is available from this test method because one may obtain the responses of the entire household on usage of the product, and (3) this test method can be used early in the product-formulation phase, where it is not only able to test a product for acceptance or preference, but also for product performance (Resurreccion, 1998).

Hashim et al. (1995a) conducted a HUT to determine consumer preferences for irradiated poultry. Seventy-three percent or more of consumers participating in the test gave the color, appearance, and aroma of the raw poultry products a minimum rating of 7 or like moderately. After consumers participated in the home-use test, the selection of irradiated thighs and breasts in simulated supermarket studies increased as compared to non-irradiated products.

Focus groups. The focus group is a method by which small groups of consumers are used to obtain information about their reaction to products and concepts, and to investigate various other aspects of respondent's perceptions and reactions (Resurreccion, 1998). Hashim et al. (1996) conducted a focus group to obtain detailed information about consumers' awareness, attitudes, opinions, behaviors, and concerns toward irradiated poultry and to investigate the effect of labeling information on consumers' willingness to purchase irradiated poultry products. The results of the study suggested that consumer's awareness and acceptance can be increased by educational programs, and informative labels or posters.

Simulated Supermarket-Setting (SSS) tests. The supermarket-setting tests (SSS) provide a means by which purchase behavior can be measured (Resurreccion, 1998). Hashim et al. (1995a) conducted a SSS test to determine whether consumers would purchase irradiated poultry products and to study the effects of marketing strategies on consumer purchase of irradiated poultry products. The results of the study found that a slide program was the most effective educational strategy in changing consumers' purchase behavior and that this program caused a significant increase in the purchase of irradiated breasts and thighs. Fifty-eight percent of the participants stated that they would always buy irradiated chicken if available and an additional 27% stated that they would buy it sometimes.

Hashim et al. (2001) also conducted another SSS test to determine consumer's willingness to purchase irradiated beef products when provided with information at the grocery store level and consumer's perceptions towards irradiated beef. The results of the study indicated that irradiation information displayed on a poster at the point of purchase was effective in causing significant changes in beef purchase behavior. The information caused some confusion in consumers who had bought traditional packages initially to buy irradiated packages subsequently while others who bought irradiated packages initially subsequently bought traditional packages. They concluded that more information is needed to present the negative effect of not providing enough information.

Panelist selection. A critical decision in setting up consumer acceptance or preference tests is in the choice of panelists (McDermott, 1990). Unlike the analytic sensory tests where some level of sensory function is usually of importance, acceptance testing involves selection on the basis of product usage. The main requirement is that the panel be representative of the target population, meaning the consumer who would actually purchase and use the product (Lawless and Heymann, 1999).

Hashim et al. (1995b) selected their panelists for the evaluation of irradiated frozen and refrigerated chicken based on their recruitment criteria which stated that panelists had to be between the ages of 18 and 55, not allergic to chicken, consumers of chicken at least twice per week, willing to evaluate irradiated chicken and available and willing to participate during training and testing dates. When Resurreccion and Galvez (1999) also conducted a focus group study on irradiated beef, panelists were selected based on the recruitment criteria that they would eat beef at least 3-4 times in their next 10 dinners.

Scales. Selection of a scale for use in a particular test is one of several tasks that need to be accomplished by the sensory professional before a test can be implemented (Stone and Sidel, 1993). To derive the most value from a response scale it should be meaningful to subjects, uncomplicated to use, unbiased, relevant, sensitive to differences and provides for a variety of statistical analyses (Stone and Sidel, 1993).

Hedonic Scale. The hedonic scale was invented in the 1940s at the Food Research Division of the Quartermaster Food and Container Institute in Chicago, Ill. The scale was named for the type of response that it seeks to elicit or one which derives mainly from feeling or affectivity—in general, the emotional aspects of mental life as opposed to the intellectual. The scale, which measures preference, which is measured for the purpose of predicting acceptance, was designed to measure human behavior potential, not the characteristics of food (Peryam and Pilgrim, 1957).

Of all scales and test methods, the nine-point hedonic scale occupies a unique niche in terms of its general applicability to the measurement of product acceptance-preference (Stone and Sidel, 1993). Certain essentials of the hedonic scale method, such as the single stimulus method of presentation, the establishment of a well-defined continuum, and the selection of phrases to make the intervals as clearly successive as possible are standard features of the rating scale methods (Peryam and Pilgrim, 1957).

Facial Scale. Facial scales are primarily intended for use with children and those with limited reading and/or comprehension skills. Chen et al. (1996) demonstrated that 3-point facial hedonic scales with Peryam & Kroll verbal descriptors (Kroll, 1990) could be used with 36- to 47-month old children; 5-point facial hedonic scales with Peryam and Kroll verbal descriptors could be used with 47- to 59-month old children and 7-point facial hedonic scales with Peryam & Kroll verbal descriptors could be used with 60- to 71-month old children.

Lawless and Heymann (1999) summarized that preference or acceptance testing with children can be done with a few modifications from the adult methods, such as (1) one-on-one testing in most cases, to ensure compliance, understanding, and to minimize social influences; (2) use of either verbal or pictorial scales; (3) scales may need to be truncated for use with younger children; and (4) paired preference testing is suitable for very young children in the ranges of about 4 to 5 years.

2. Descriptive Analysis

The "Descriptive Analysis" technique of sensory evaluation identifies, describes, and quantifies sensory (visual, textural, auditory, olfactory, and gustatory) qualities of a given product (Gillette, 1984). These techniques allow the sensory scientist to obtain complete sensory descriptions of products, help identify underlying ingredient and process variables, and/or to determine which sensory attributes are important to acceptance (Lawless and Heymann, 1999).

In the food and flavor industry, descriptive analysis can be applied to product development, shelf-life testing, process development, product improvement, quality control, quality assurance, and sensory-instrumental correlations (Gillette, 1984). It is very useful in helping to understand the sensory qualities of a product, but it is not the appropriate test to be used when preference or acceptability judgments are required. However, it can be used most satisfactorily in conjunction with hedonic tests to explain affective results (Gillette, 1984).

Descriptive analysis is the most sophisticated of the methodologies available to the sensory professional (when compared with discrimination and acceptance methods) (Stone and Sidel, 1993). There are several techniques for descriptive analysis, which include flavor profile (FP) method, quantitative descriptive analysis (QDA) method, texture profile (TP) method, Spectrum Descriptive Analysis method and Free-Choice Profiling (Meilgaard et al., 1991).

Flavor Profile (FP). The Flavor Profile (FP) is a qualitative descriptive test that was developed by Arthur D. Little and Co., in Cambridge Massachusetts. FP describes the overall flavor and the flavor notes and estimates the intensity and amplitude (overall impression) of these descriptors. The technique provides a tabulation of the perceived flavors, their intensities, their order of perception, their aftertastes, and their overall impression (amplitude) (Lawless and

Heymann, 1999). The FP method utilizes a panel of four to six screened and selected subjects who first examine and then discuss the product in an open session (Stone and Sidel, 1993).

Quantitative Descriptive Analysis (QDA). The Quantitative Descriptive Analysis (QDA) was developed during the 1970s to correct some of the perceived problems associated with the FP analysis (Stone and Sidel, 1993). QDA may be used to completely describe the sensory sensations associated with a product from initial visual assessment to aftertaste, or panelists may be instructed to focus on a narrow range of attributes such as texture descriptors (Lawless and Heymann, 1999). As a means of quantifying sensory perception, an unstructured line scale is used that approaches a continuous scale, an important property that permits the use of standard statistical procedures (Gacula, 1997).

Hashim et al. (1995b) used an experienced sensory panel to evaluate irradiated frozen and refrigerated chicken. Panelists rated their intensities using a 150 mm line scale with anchors at 12.5 and 137.5 on the scale. Panelists used standard references for basic tastes and warm up samples during test sessions. Murano et al. (1998) used an experienced sensory panel to evaluate irradiated ground beef. Panelists recorded their perceptions of each sensory attribute on scorecards containing 15 cm lines with anchor words and scores ranged from 1 to 15 for each attribute. They did not indicate the use of standard references or a warm up sample in their study.

Texture Profile Analysis (TPA). The texture profile analysis (TPA) was developed by a group at the General Food Corporation Technical Center developed a test that could compress a bite-size piece of food two times in a reciprocating motion that imitates the action of the jaw. The major breakthrough in texture profile analysis came with the development of the General Foods Texturometer (Szczesniak et al., 1963). The creators based the TP on the concepts pioneered by developers of the FP to devise a sensory technique that would allow the assessment of all the texture characteristics of a product, from first bite through complete mastication, using engineering principles (Lawless and Heymann, 1999). Deatherage and Gernatz (1952) found poor correlations between sensory measurements of meat tenderness using the Warner-Bratzler shear machine. Apparently, the panel was not evaluating the same properties as the instrument.

Gunes et al. (2001) used an Instron Universal Testing Machine to evaluate firmness of irradiated apple slices. Firmness was taken as the maximum force recorded and expressed in Newtons (N). They also analyzed the irradiated apples by performing a puncture test. The results of the texture analysis showed that firmness decreased as irradiation dose increased beyond a 0.34 kGy threshold.

Spectrum Descriptive Analysis. The Spectrum Descriptive Method was designed by Gail Civille while working at General Foods in the 1970's. The Spectrum technique uses many of the ideas inherent to the TP. The unique characteristic of the Spectrum approach is that panelists generate a panel-specific vocabulary to describe sensory attributes of products, but that they use a standardized lexicon of terms (Civille and Lyon, 1996).

Training. The panel is the analytical "tool" in sensory evaluation and the value of this tool depends on the objectivity, precision and reproducibility of the judgments of the panelists (Larmond, 1979). Therefore, training of a panel is vital to the accuracy of the panel's performance. An important aspect of training is to practice identifying and recording the perceptible attributes in the order in which they actually occur (Einstein, 1991). The training requires two weeks of training or approximately eight to ten hours organized into ninety-minute sessions (Resurreccion, 1998). When training of a descriptive panel is initiated, the subjects are given instructions that they can use any words to describe a product, they are encouraged to use words that they understand and can explain to their fellow panel members; and no restriction is placed on the number of words except that preference or preference-related judgments, such as good, bad and so on are discouraged (Stone and Sidel, 1983). Training is best conducted in a conference-style room (Resurreccion, 1998).

Line scales. Line scales are used in descriptive analysis because it provides the subject with an infinite number of places in which to indicate the relative intensity for an attribute (within the constraints of the actual length of the line); numbers are not used, thus avoiding number biases; and finally, each subject could mark at whatever location on the line (Stone and Sidel, 1993). Line scales with anchors are commonly used. The anchors help to avoid end effects associated with the reluctance of subjects to use the ends of the scale (Lawless and Heymann, 1999).

Reference standards. Reference standards are useful tools in the training of a sensory evaluation panel because they help panelists develop terminology to properly describe products, help determine intensities and anchor end points and shorten training time (Rainey, 1986). References have a value by helping subjects relate to a particular sensation or group of sensations that is not easily detected or not easily described (Stone and Sidel, 1993).

Warm-up samples. In descriptive testing, warm-up samples should be provided to panelists to achieve reliable results. O'Mahony et al. (1988), concluded that warm-up samples should be given before evaluation of the samples to maximize reliability of analysis ratings and improve performance.

III. Quality

Thiobarbituric acid reactive substances (TBARS). Although the 2-thiobarbituric acid (TBA) test has never been standardized as an approved method for estimating meat acceptability due to its lack of correlation between similar or varied meat products (Wu and Sheldon, 1988), it is still the most widely used method for assessing oxidative state of muscle foods (Tarladgis et al., 1960). It is an objective test that follows sensory deterioration in food products (Tarladgis et al., 1960) by measuring malonaldehyde. Malonaldehyde is a decomposition product of lipid peroxides formed in meats. Malonaldehyde is a relatively minor product of autoxidation of polyunsaturated fatty acids and it reacts with 2-thiobarbituric acid reagent to produce a pink-colored complex with an absorption maximum at approximately 532 nm (Shahidi and Pegg, 1994). The measurement of the intensity of the pink color is expressed as the TBA number. The "TBA number" is defined as mg. of malonaldehyde per 1,000 g of sample (Sinnhuber and Yu, 1958). The majority of the malonaldehyde that reacts with TBA is produced by the decomposition of hydroperoxides during the distillation stage of the TBA procedure (Ajuyah, et al., 1993).

Tarladgis et al. (1960) concluded that the distillation procedure offers several advantages over other methods in that (1) malonaldehyde is obtained in a clear aqueous solution so that its reaction products with thiobarbituric acid does not need to be extracted with solvents, (2) there is less likelihood of fat oxidation occurring during the test itself and (3) the relation of the rancid odor to thiobarbituric acid-reactive material and to other volatile compounds can be more rapidly studied in the clear distillates. However, higher TBA values may be obtained from the distillation procedure as compared to the extracted fat. The higher TBA values by the distillation procedure may be due to thermal decomposition of malonaldehyde precursors to malonaldehyde and also to liberation by heat of malonaldehyde from its bound state with proteins (Kwon et al., 1965). Also increased recoveries could be possibly obtained by increasing distillation times (Ajuyah et al., 1993).

TBA-reactive material is produced in substantial amounts only from polyunsaturated fatty acids containing three or more double bonds (Rhee, 1978). The rapid increase in TBA values for turkey and pork may be attributed to the greater ratio of unsaturated to saturated fatty acids normally associated with these species in comparison with beef (Allen and Foegeding, 1981). Fatty acids with less than three double bonds also appear to give rise to smaller amounts of malonaldehyde (Tarladgis et al., 1960).

Igene et al. (1985) claimed that TBA values provide a good estimate of WOF. They demonstrated a significant linear relationship between taste panel scores for WOF in cooked chicken meat and TBA numbers. However, Pearson et al. (1977) concluded that the TBARS measurement is relatively non-specific and does not measure volatile compounds that specifically contribute to WOF.

TBA values revealed that ground beef patties irradiated (2 kGy) under air and stored under air, and those irradiated under vacuum and stored under air, showed a higher degree of lipid oxidation, compared with products irradiated and stored under vacuum, or nonirradiated (Murano et al., 1998). Ahn et al. (1998b) found that after 3 and 7 days of storage, TBARS of irradiated cooked pork patties with vacuum packaging remained unchanged or increased slightly. However, the TBARS values of irradiated cooked pork patties with aerobic packaging increased by 6- to 9-fold from the 0-day values.

Cooking does not increase TBA values, however, structural damage by the cooking process enhances oxygen contact with membrane lipids and accelerates lipid oxidation (Ahn et al., 1998b). Tims and Watts (1958), found that TBA values consistently increased to high values within a few hours after cooking, but such increases were not observed in raw meat. Only slight changes in TBA values occurred in raw meat after one or two weeks of storage, whereas cooked samples consistently increased to high values which were maintained throughout the storage period. Greene and Cumuze (1981) found that the TBA number range in which an intensity of oxidized flavor was first noted in cooked beef was between 0.6 and 2.0. Zipser and Watts (1961) found that muscle lipids of mullet begin to oxidize very rapidly after cooking, as was shown by the increases in TBA number and rancid odors. The intensity of the reaction appeared to be greater in tissues containing large quantities of lipids and heme pigments than in tissues containing lesser amounts.

Hexanal. All foods have some linoleic acid, the fatty acid from which hexanal is derived (Frankel, et al., 1984). Hexanal is a major volatile aldehyde formed from the oxidation of n-6 fatty acids (Tamura et al., 1991). Hexanal, one of the major products of oxidation of fats (Frankel et al., 1981), has been used to follow the course of lipid oxidation and off-flavor development in cooked foods (Dupuy et al., 1987). Hexanal generation appears to be a sensitive and reliable indicator for evaluation of the oxidative state and flavor acceptability of meat and meat products (Shahidi and Pegg, 1994).

Although hexanal can be used as an index of lipid oxidation and meat flavor deterioration, it is not intended to imply that it is mainly responsible for the characteristic off-flavor of stored meat or that it should be used as an index of lipid oxidation at the expense of the TBA test (Shahidi and Pegg, 1994). Shahidi and Pegg (1994) caution when using hexanal as an indicator of lipid oxidation and meat flavor deterioration, that a given hexanal level may correspond with two different points, during the earlier and again at the later stages, of storage, of cooked meats and because hexanal can be present in appreciable quantities in uncured products, but are barely detectable in the volatiles of the cured meat (Cross and Ziegler, 1965).

Palamand and Dieckmann (1974) subjected hexanal to autoxidation and reported that it underwent oxidation, polymerization and degradation resulting in the production of a large number of flavor-active compounds, most notably of which was hexanoic acid. However a decrease in the concentration of hexanal may also be due to cross-linking reactions with various components.

Gas chromatography and mass spectrometry. The mass spectrometer can function to selectively monitor individual compounds, which are potentially unresolved by the gas chromatograph or may permit detection at concentrations below the gas chromatographic threshold (Reineccius, 1991). The headspace gas chromatography methods are capable of detecting numerous volatile constituents in their native proportions and thus would more closely approximate the human senses than analyzing for one compound, such as the case with the TBA value (Wu and Sheldon, 1988).

Headspace is often the method of choice, since there is virtually no sample preparation involved. One simply places the sample in a closed vessel, allows the headspace to equilibrate, and then samples the headspace with a gas tight syringe or an automated sampling system (Reineccius, 1991). The primary limitation of headspace sampling is a lack of sensitivity, in which one may not isolate sufficient quantities of indicator compounds to permit accurate and precise quantification (Reineccius, 1991).

Gas chromatography/mass spectroscopy (GC/MS) static headspace analysis with a gas-tight syringe is rapid and useful for the qualitative identification of chemicals responsible for off-flavors and malodors, however, the technique of using gas-tight syringes is not recommended for quantitative work because volatiles may condense in the syringe body or needle (Marsili, 1997).

Pippen and Nonaka (1962) used a GC to study the effects of temperature and oxygen on fresh and rancid chicken. The results of the study found that most of the peaks for fresh chicken are also present in rancid chicken, but the peaks for the rancid chicken are much larger. Qualitatively the same volatiles occur in both irradiated and control meat, but larger quantities are released from irradiated specimens (Merritt et al., 1975; Hansen et al., 1987).

Texture profile analysis. The texture of an object is perceived by the senses of sight (visual texture), touch (tactile texture), and sound (auditory texture) (Lawless and Heymann, 1999). Sensory evaluation is extremely valuable in the measurement of food texture because no instrument can perceive, analyze, integrate and interpret a large number of textural sensations at the same time (Larmond, 1979). Brandt et al. (1963) stated that the texture profile method is a means of helping the food researcher obtain descriptive and quantitative sensory data on the textural characteristics of food products by offering flexibility of application to any food product or textural characteristics and objectivity through rigidly defined points of reference and nomenclature.

Instrumental procedures quantify physical textural changes over time and measure different component characteristics of meat systems (Lyon and Wilson, 1986). The Instron Universal Testing machine was designed for studying the stress-strain properties of materials, but it can also be set up to perform conventional tests in tension, compression, or bending, as well as a variety of more sophisticated tests such as hysteresis, stress relaxation, stress recovery, strain rate sensitivity, energy of deformation and rupture (Bourne, 1982).

Multivariate analysis

Multivariate analysis of variance (MANOVA) is clearly one of the multivariate procedures, which is insufficient by itself; therefore multivariate methods should be used in combination with univariate methods to provide more information than either type alone can (Powers, 1988). Nonetheless, it can provide guidance as to just how critically an array of ANOVA values should be examined (Powers, 1988). MANOVA tests for differences between two or more treatments; in contrast, ANOVA evaluates one dependent variable simultaneously (Lawless and Heymann, 1999).

Instrumental methods for the measurement of meat quality have many practical advantages over sensory panels and there needs to be continuing attempts to develop instrumental methods which imitate sensory panels (Toscas et al., 1999). Multivariate analysis can make use of instrumental data to predict consumer response. Unfortunately, there is no way around the initial measurement of the physical and chemical properties (Resurreccion, 1988) that are needed to help predict sensory data. Multivariate analysis can also help understand the underlying principles that are measured in evaluating the quality of food and establish which variables are determinants of food quality (Resurreccion, 1988). Not only does it indicate the underlying dimensions of food products, but it also indicates the degree of interdependency (Syarief et al., 1985).

Byrne et al. (2002) used multivariate analysis to study the effects of cooking on warmed-over flavor (WOF) development in non-irradiated chicken meat. Descriptive analysis indicated that the WOF development was described by an increase of rancid and sulfur sensory notes and a concurrent decrease of chicken meaty characteristics. They also found that increasing cooking temperature resulted in meat samples with a more roasted, toasted, and bitter sensory nature.

Grigioni et al. (2000) also studied WOF in vacuum cook-in-bag/tray technology (VCT) stored beef using an electronic nose. A WOF odor standard sample was presented to an electronic nose to determine the similarities of the aroma patterns between the samples and those corresponding to different storage times (0, 2, 4, 6, 13, 20, 34, 42, and 45 days). PCA analysis showed a match between the WOF odor standard and the VCT beef samples with 34 days or more of refrigerated storage.

Santos et al. (2003) used multivariate analysis to characterize three varieties of *Morcilla de Burgos,* a traditional Spanish blood sausage. *Morcillas* in group I were characterized by a notable blood smell and blood and pepper flavor, a high pH and water activity and a high protein content. *Morcillas* in group II were characterized by strong cumin smell and flavor and a high softness. *Morcillas* in group III had a high onion odor, high presence of onion and high contents of fat, total sugar and fiber.

Optimization

Optimization is defined as a series of steps for obtaining the best result under a given set of circumstances (Gacula, 1993). The optimization of all aspects of a product is the goal in product development. Sensory evaluation is often called upon to determine whether or not the optimum product has been developed (Giovanni, 1983) and descriptive analysis is the most appropriate sensory tool for optimization because there is no *a priori* knowledge concerning the important sensory characteristic (Stone and Sidel, 1993).

The most common models encountered in optimization studies to describe such a relationship are the so-called first-order and second-order models. The first-order model is given by a simple linear regression relationship, whereas a second-order model is described by a quadratic regression relationship (Gacula, 1993). First-order models may not be able to adequately predict the response if there is a complex relationship between the dependent variables and the independent variables, in which second-order models are required for these situations (Meilgaard, 1991).

Response surface methodology (RSM). Response surface methodology (RSM) is a statistical procedure used to predict the value of a response variable, or dependent variable, based on observed responses to experimental factors, or independent variables (Meilgaard, 1991). These equations can be graphically represented as response surfaces which can be used in three ways: (1) to describe how the test variables affect the response; (2) to determine the effect of interrelations among two test variables on the response; and (3) to determine the optimum combinations of test variables that will yield a desired response for a given measurement (Giovanni, 1983).

Pappa et al. (2000) used response surface methodology to determine the optimum salt level (1.3-21%) and pectin level (0.25-1.0%) when olive oil replaced pork backfat (0-100%) for the production of highly acceptable low-fat non-irradiated frankfurters (9% fat, 13% protein). The frankfurters receiving the highest overall acceptability were composed of 1.8-2.1% salt, 0-35% olive oil and 0.25-0.45% pectin.

Lemos et al. (1999) optimized the still-marinating process to increase weight gain, reduce loss of weight during storage and reduce cooking loss of non-irradiated chicken breast meat. The optimum marinating times for the chicken breast ranged from 8-12 hours, salt concentrations ranged from 3-4% and polyphosphates concentrations ranged from 2-3%.

VI. Summary

Irradiation by electron-beam is one of the newest technologies, which offers advantages to the poultry industry, as well as to consumers. Irradiation inhibits sprouting; destroys insect and parasites in food; delays ripening and senescence of fruits and vegetables; extends the shelf-life of perishable products; and eliminates disease-causing microorganisms in food. However, irradiation does cause some concerns among consumers. These concerns include the fate of pathogens that survive radiation; destruction of vitamins; induction of lipid oxides and off-flavors; possible toxicity of radiolytic products in irradiated foods; and the effects of irradiation on packaging materials. Although some concerns still remain, irradiation is becoming more accepted when educational information is provided to inform consumers about the technology.

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CHAPTER 3

CONSUMER ACCEPTANCE OF ELECTRON-BEAM IRRADIATED READY-TO-EAT POULTRY MEATS[1]

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ABSTRACT

Sensory characteristics and consumer acceptance of electron-beam irradiated commercial samples of ready-to-eat meats (frankfurters and diced chicken) were evaluated. Samples were removed from their original packaging, repackaged in irradiation-approved packaging, vacuum-sealed, irradiated by electron-beam at 1, 2 and 3 kGy and stored at 4°C for up to 32 days. Non-irradiated controls were held under similar conditions. A consumer panel (n=50) evaluated the effects of irradiation on the samples throughout the expected shelf-life of 32 days after irradiation. Overall acceptance, acceptance of flavor, juiciness, tenderness and mouthfeel of the non-irradiated samples were significantly lower ($P<0.05$) than most irradiated samples. Although the quality of the irradiated samples decreased with increasing storage time, consumers perceived that the irradiated frankfurters and diced chicken maintained their acceptability for up to 32 and 18 days, respectively, after irradiation.

INTRODUCTION

The steadily increasing number and volume of refrigerated, precooked, further processed poultry products and ready-to-eat meats offered to consumers emphasizes the expanded use of these products (MacNeil and Dimick, 1970). This can be attributed to convenience, time efficiency, minimal packaging, improved handling and enhanced quality. However, a high standard of safety is not always maintained. In more recent years, a variety of foods, such as refrigerated ready-to-eat meats, prepared sandwiches, frankfurters, meat spreads and meat salads have been recalled from the marketplace because of contamination with *L. monocytogenes* (Ryser and Marth, 1999). Consequently, preventive measures have been enforced due to a moral obligation to the public. In 1989, the FDA adopted and has continued to uphold the policy of "zero tolerance" regarding the presence of *L. monocytogenes* in ready-to-eat foods (Ryser and Marth, 1999). Also, in 1992, the U.S. Department of Agriculture Food Safety and Inspection Service (FSIS) finalized proposed regulations to permit the maximum irradiation dosage of 3.0 kGy to treat fresh or frozen "uncooked" poultry to prevent the onset of food-borne illnesses (USDA, 1992). There are currently no approved regulations for the use of food irradiation to inactivate food-borne pathogens on ready-to-eat meats.

Maintaining the quality and safety of refrigerated, ready-to-eat meats is of no use if consumers do not accept irradiation as a processing technology. Consumer acceptance is critical to the application of this technology and the realization of the advantages it offers (Schutz *et al.*, 1989). Previously, irradiated foods had not yet made a significant impact on the United States marketplace (Derr, 1996). However, more consumers are now more willing to purchase irradiated food in order to have a safer product (Hunter, 2000), although some concerns related to the irradiation of food remains, which may cause anxiety among consumers. These concerns include the fate of pathogens that survive radiation; destruction of vitamins; induction of lipid oxides and off-flavors; possible toxicity of radiolytic products in irradiated foods; and the effects of irradiation on packaging materials (Doyle, 1999).

Although years of research have proven the efficacy and safety of the food irradiation process to increase food safety, extend shelf life, reduce common food-spoilage organisms and reduce the chances of illness due to post-processing contamination, as with any technology, there are some disadvantages associated with the process. The problem with food irradiation is that most meats develop detectable off-odors when irradiated at ambient temperature. For chicken irradiated at 5-10°C, there is a threshold dose of 2.5 kGy resulting in a slight irradiation flavor with an intensity of 2.0 on a 5 point irradiation flavor scale: with 1 = no irradiation flavor, and 5 = very strong irradiation flavor (Sudarmadji and Urbain, 1972). Doses from 2.5 to 5.0 kGy were observed to produce a slight irradiation odor that dissipated during 4 days of storage, after which a fresh chicken odor reappeared on the 5^{th} day of storage (Kahan and Howker, 1977). However, sensory quality of high moisture foods, such as meat, can be protected by irradiating these in the frozen state (Farkas, 1987).

Some poultry products are currently packaged under modified atmosphere in order that a longer shelf life can be obtained (Thayer and Boyd, 1999). By irradiating poultry products under anaerobic conditions, off-flavors and odors are somewhat curtailed due to the absence of oxygen necessary to form peroxides (van Laack, 1994). However, to maintain the safety of irradiated poultry products from *Clostridium botulinum*, these products are allowed to undergo irradiation only in oxygen-permeable packaging (USDA, 1997). There is insufficient sensory research done on ready-to-eat foods to determine the quality and consumer acceptance of foods treated with irradiation at dosages needed to assure safety (Doyle, 2000).

The objective of this study was to evaluate the effect of electron-beam irradiation on fully cooked, ready-to-eat poultry meats. The specific objectives were (1) to evaluate consumer acceptance of irradiated chicken frankfurters and diced chicken meat up to 32 days of refrigerated storage after irradiation and (2) to develop prediction equations for overall acceptance from the independent variables, irradiation dose and storage time.

MATERIALS AND METHODS

Experimental Design

Two ready-to-eat poultry meat products were studied. Chicken frankfurters and diced chicken meat were irradiated by electron beam irradiation at 1, 2 and 3 kGy. Samples that were not irradiated (0 kGy) served as the controls for this study. The experiment was replicated three times resulting in a total of 12 samples for each day of sensory testing.

Samples

Irradiation of the frankfurters and the diced chicken meat was conducted in two separate studies three months apart.

Frankfurters

Commercial frankfurter samples were obtained from D. L. Lee & Sons, Inc., Alma, GA and transported to the Department of Food Science and Technology in Griffin, GA in coolers packed with ice. The frankfurter samples were held for 48 hours at 4°C in a walk-in refrigerator (Model W06430-1, Nor-lake, Inc., Hudson, Wisconsin) until ready for packaging. Five frankfurters were removed from their original packages and transferred into irradiation approved, oxygen-permeable 16.5 cm x 20.3 cm ethylene-vinyl acetate and polyvinylidene chloride bags formed from 16.5 cm x 40.6 cm bags (B-540, Cryovac, Saddle Brook, NJ) cut in half and heat-sealed. The frankfurters were vacuum-packaged (29 in Hg) within five min of removal from the refrigerator using a single chamber packaging machine (Model UV250, Koch Packaging Systems, Kansas City, MO) then heat-sealed to form a vacuum seal closure. Label information containing the desired irradiation dose and replication number was inserted in a 2.54 cm space between the vacuum seal closure and the final heat seal of the package to prevent the label from being detached from the sample. The samples were returned to the refrigerator (4°C) for overnight storage.

The following morning, all frankfurter packages were packed in polyfoam mailing boxes (35.5 cm x 35.5 cm x 38.7 cm Fisher Scientific, Pittsburgh, PA) and packed with sufficient ice packs (Fisher Scientific, Pittsburgh, PA), as determined in preliminary studies, to maintain refrigeration temperatures. Samples were shipped by air overnight to the Ion Beam Applications (IBA) irradiation facility (San Diego, CA).

Diced chicken meat

Frozen fully-cooked, seasoned diced chicken meat (1 inch cubes of skinless, boneless chicken breast pieces) were obtained from Wayne Farms, Gainesville, GA and transported to the Department of Food Science and Technology in Griffin, GA in coolers packed with sufficient dry ice to maintain the meat in the frozen state. The diced chicken was held for 24 to 48 hours at -15°C in a walk-in freezer (Model UDS-4, W.A. Brown & Son, Inc., Salisbury, North Carolina) until ready for packaging. Five ounces of frozen chicken meat was transferred into irradiation approved, oxygen-permeable 16.5 cm x 20.3 cm ethylene-vinyl acetate and polyvinylidene chloride bags formed from 16.5 cm x 40.6 cm bags (B-540, Cryovac, Saddle Brook, NJ) which were cut in half and heat-sealed. The samples were vacuum-packaged (29 in Hg) within five minutes of removal from the freezer as described for the frankfurters. The samples were returned to the freezer (-15°C) for overnight storage.

The following morning, all diced chicken packages were packed in polyfoam mailing boxes (61 cm x 45.7 cm x 45.4 cm, Fisher Scientific, Pittsburgh, PA) together with dry ice (Atlanta Dry Ice, Atlanta, GA), shielded from the samples by newsprint. Samples were shipped by air, overnight, under frozen conditions to the IBA irradiation facility (San Diego, CA).

Dose mapping

Dose mapping was conducted by Ion Beam Applications (IBA) (San Diego, CA) to: find the minimum and maximum absorbed dose points within the products and use this to determine the relation of the dose measured by an external dosimeter to dose absorbed by the product. From this relation, a dose range (adjusted minimum to the maximum dose) as measured by the external dosimeter, was determined to assure the minimum required irradiation dose and the maximum dose requirements were met throughout the product.

Radiochromic film dosimeters (Far West Technology, Inc., Goleta, CA) were placed at two locations on the frankfurter/diced chicken package, one on top and another on the bottom of each frankfurter/diced chicken package. Samples were placed in stainless steel trays, transported onto the conveyor belt and exposed to the ambient temperature of the irradiation chamber containing the electron beam source (RF linac linear accelerator Applied Radiation Company, San Jose, CA) with an energy level of 9.5 MeV and a dose rate of 45 kGy/ft/min using a single sided pass.

Irradiation processing

Upon the arrival of the samples at the IBA irradiation facility, the frankfurter samples were held overnight in a refrigerator at 3°C (Model B1031-2, Kool Star, Los Angeles, CA) and the diced chicken meat samples were held overnight in a freezer that ranged approximately from -15° C to approximately -23°C (Kelvinator, Model CB220D, R.I.E. Developments, Melbourne, Australia).

Samples were irradiated by exposing them to the ambient temperature of the electron beam irradiation source using a single-sided pass to achieve a 1.0, 2.0 or 3.0 kGy dose, which was verified with radiochromic film dosimeters attached on the top and bottom surfaces of representative samples to determine dose rate and uniformity of irradiation. Irradiated samples were held overnight in a refrigerator at 4°C for frankfurters and in a freezer at -15°C for diced chicken meat. Non-irradiated samples of each product were held under conditions similar to that of the product, including the receiving, packaging and shipping steps, except for exposure to the irradiation process. The following day, samples were packaged under conditions identical to their shipment to the irradiation facility, then transported by air to the sensory laboratory at the Department of Food Science and Technology (Griffin, GA).

Sample preparation

Frankfurters

Upon arrival at Griffin, non-irradiated and irradiated frankfurters samples were removed from the shipping boxes and were held in a refrigerator at 4°C until ready for sensory evaluation. The samples were stored for up to an expected shelf life of 32 days after irradiation. The samples were withdrawn from the walk-in refrigerator at 4, 18 and 32 days, corresponding to 0, 50 and 100% of shelf life, for the test.

Frankfurter samples were prepared according to preliminary testing procedures. Five frankfurter samples, directly from the refrigerator, were placed in 3-quart stainless steel pans (Revere Ware, Clinton, IL) with 800 ml of cold double-deionized water. The frankfurters and water were heated to boiling at a medium high setting and held for a total of approximately 7 min from the time samples started boiling. A total of 12 frankfurter samples were prepared in 3 sets of 4 for each session. During the preparation, within each set of 4, frankfurters were cooked approximately 3 min apart so that the consumers would receive warm samples in between each set. After the frankfurters boiled for the recommended time, they were removed from the stove and the water was drained and discarded. Frankfurters were placed on cutting boards, cut in half crosswise and each frankfurter half was placed in 8 oz squat cups (Stock No. 8SJ20, Dart, Mason, MI) coded with three digit random numbers. Samples were served immediately for sensory evaluation by a consumer panel.

Diced chicken meat

Upon arrival at Griffin, non-irradiated and irradiated diced chicken samples were transferred into individual gallon Ziploc® storage bags (S.C. Johnson, Inc., Racine,WI) and thawed under refrigeration overnight in a walk-in refrigerator to simulate food service retail and home use conditions. The samples were stored at 4°C for up to an expected shelf life of 32 days after irradiation. The samples were withdrawn from the walk-in refrigerator at 4, 18 and 32 days, corresponding to 0, 50 and 100% of expected shelf life, for the test.

On each sampling day, approximately 6 cubes of the diced chicken meat were placed in 4 oz squat cups (Stock No. 4J6, Dart, Mason, Mich.) coded with three digit random numbers for sensory evaluation by a consumer panel. Samples were served immediately without heating.

Sensory evaluation

A consumer sensory laboratory acceptance test was conducted (Resurreccion, 1998). Consumers were recruited from a list of consumers who had previously participated in consumer tests at the University. During recruitment, consumers were screened by using questions from a recruitment screener about their age, food allergies, and how frequently they consumed frankfurters/chicken to determine if they qualified for the test. Sixty consumers, from seven cities in the metro-Atlanta area, between the ages of 18–70 were recruited, allowing a 20% overage for "no-shows", who were not allergic to frankfurters or chicken, and consumed frankfurters at least four times a year and chicken at least twice a week. Among the sixty recruits, fifty participated in the test.

All tests were performed at the Consumer and Sensory Laboratories, Department of Food Science and Technology, University of Georgia, Griffin, Ga. Upon panelists' arrival, they were directed to a conference room and were met by a greeter who asked them to sign-in, given a brief explanation of the evaluation procedure and were required to complete and sign consent forms approved by the University of Georgia Institutional Review Board. After completion of the consent forms and a brief demographic questionnaire, consumers were escorted to the sensory booths for evaluation of the frankfurters or diced chicken meat samples.

Samples were evaluated in environmentally controlled partition booths illuminated with two 50-watt indoor reflector flood lamps, which provided 738 lux of light. Double-deionized water and unsalted crackers were provided so that consumers might cleanse their palates in between samples. Consumers rated their overall acceptance of the sample and acceptance of aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel/texture of each sample using a 9-point hedonic scale (Peryam and Pilgrim, 1957) with 1=dislike extremely and 9=like extremely using computer ballots (Compusense® five, version 3.8, Compusense, Inc., Guelph, Ontario, Canada). Compusense allowed panelists to return to previous questions regarding a sample, but did not allow panelists to return to previously evaluated samples.

On each sampling day, a randomized, balanced block design was used to serve all samples monadically. Each consumer evaluated four samples in each of three tests, separated by a compulsory break of five minutes between each test. Samples were randomized within each session for the frankfurter study, whereas the samples for the diced chicken meat were randomized by all panelists in the entire study. The order of presentation was balanced across the panel. At the conclusion of the frankfurters and diced chicken meat studies, consumers received an honorarium of 10 dollars for each day of participation.

Statistical Analysis

Statistical Analysis Software System (Version 8.0, SAS Institute, Cary, NC) was used to analyze all data results. Analysis of variance, using the general linear model (PROC GLM), was conducted on each attribute to determine the means and standard deviations among samples for all days and irradiation doses. Fisher's Least Significant Difference (LSD) test was performed to determine which sample means were significantly different (α=0.05).

Regression analysis (PROC REG) was performed using each sensory attribute as dependent variables and irradiation dose and storage time as independent variables to determine parameter estimates and the coefficient of determination, R^2. Equations with R^2 values ≤ 0.75 were not considered acceptable (Meilgaard, 1991) for predicting each sensory attribute rating from the independent variables of dose and day. Regression analysis was performed on data from two irradiation processing replications for consumer acceptance of frankfurters (3 days x 4 doses x 2 reps = 24 data points). The quadratic model for the consumer acceptance attributes included the linear terms, irradiation dose and storage time; the squared terms, dose x dose and day x day; and the interaction dose x day.

Data from the third replication was used for verification. Snee (1977) concluded that a portion of the data can be used to estimate the model coefficients and the remainder of the data is used to verify the prediction accuracy of the model. Means of overall acceptance ratings, obtained in the third replication, were compared to predicted ratings from the prediction equations developed using t-test. The t-test was performed between the means of the observed and predicted values to determine the probability that paired scores are significantly different from each other at $\alpha=0.05$.

RESULTS

Demographics

The demographic characteristics of consumers who participated in acceptance tests on irradiated frankfurters and diced chicken meat are shown in Table 3.1. Sixty-four percent and seventy-four percent of respondents in the frankfurter and diced chicken meat studies, respectively, were females. A wide range of participants from each age group participated, with 94% of respondents under the age of 65 for frankfurters and 88% of respondents under the age of 65 for diced chicken meat. The median age range of respondents participating in both studies

Table 3.1. Demographic characteristics and consumption patterns of consumers participating in sensory consumer test on irradiated ready-to-eat poultry meats

	% responding	
Demographics	**Frankfurters**	**Diced chicken**
Gender		
Female	64.0	74.0
Male	36.0	26.0
Age		
18-24	2.0	2.0
25-34	12.0	6.0
35-44	18.0	22.0
45-54	26.0	26.0
55-64	36.0	32.0
65-70	6.0	12.0
Race		
White	60.0	76.0
Black	38.0	20.0
Other	2.0	4.0
Education		
Less than seven years of school	0.0	0.0
Junior high school	2.0	2.0
Some high school	12.0	10.0
Complete high school or equivalent	34.0	38.0
Some college	32.0	26.0
Completed college	8.0	10.0
Graduate or professional school	12.0	14.0
Annual household income		
under $15,000	4.3	12.0
$15,000-24,999	19.1	22.0
$25,000-34,999	21.3	10.0
$35,000-44,999	8.5	18.0
$45,000-54,999	17.0	10.0
$55,000-64,999	17.0	4.0
$65,000-74,999	2.1	6.0
$75,000-84,999	4.3	10.0
$85,000-94,999	4.3	0.0
$95,000-104,999	0.0	2.0
$105,000+	2.1	6.0

Table 3.1. Continued

Consumption of ready-to-eat meats		
2-3 times/week	18.0	76.0
Once a week	30.0	18.0
Thrice a month	10.0	4.0
Twice a month	18.0	2.0
Once a month	18.0	0.0
Less than once a month	6.0	0.0

was 45-54 years of age. However, the largest age group category represented in the study was 55-64 years of age. The majority of the respondents were white (60% for frankfurters; 76% for diced chicken meat) and their median household income ranged from \$35,000-\$45,000 per year. Fifty-two percent and 50% of respondents in the frankfurter and diced chicken meat studies, respectively, had some college education or higher. The median consumption of frankfurters was three times a month and two to three times a week for diced chicken meat.

Frankfurters

The mean consumer ratings and significant differences for overall acceptance, aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel/texture for the irradiated frankfurters are shown in Table 3.2. At days 4 and 18, samples at a dosage of 1, 2 and 3 kGy and non-irradiated samples received a rating of 5.28 (neither like nor dislike) to 6.21 (like slightly). No significant differences ($P<0.05$) were found between any of the attributes for the non-irradiated and irradiated samples. At day 32, all flavor attributes for both the irradiated and non-irradiated samples were rated acceptable (≥5) by the consumers. Consumer acceptance of aroma, appearance and color were not significantly different in all irradiated samples. However, the non-irradiated samples received significantly lower consumer ratings for overall acceptance and acceptance of flavor, juiciness, tenderness and mouthfeel compared to all irradiated samples. The ratings of non-irradiated samples for juiciness, tenderness and mouthfeel were rated unacceptable and were below neither like nor dislike (≤5). No differences in consumer acceptance between the irradiated samples were found over the 32 day shelf life of the product.

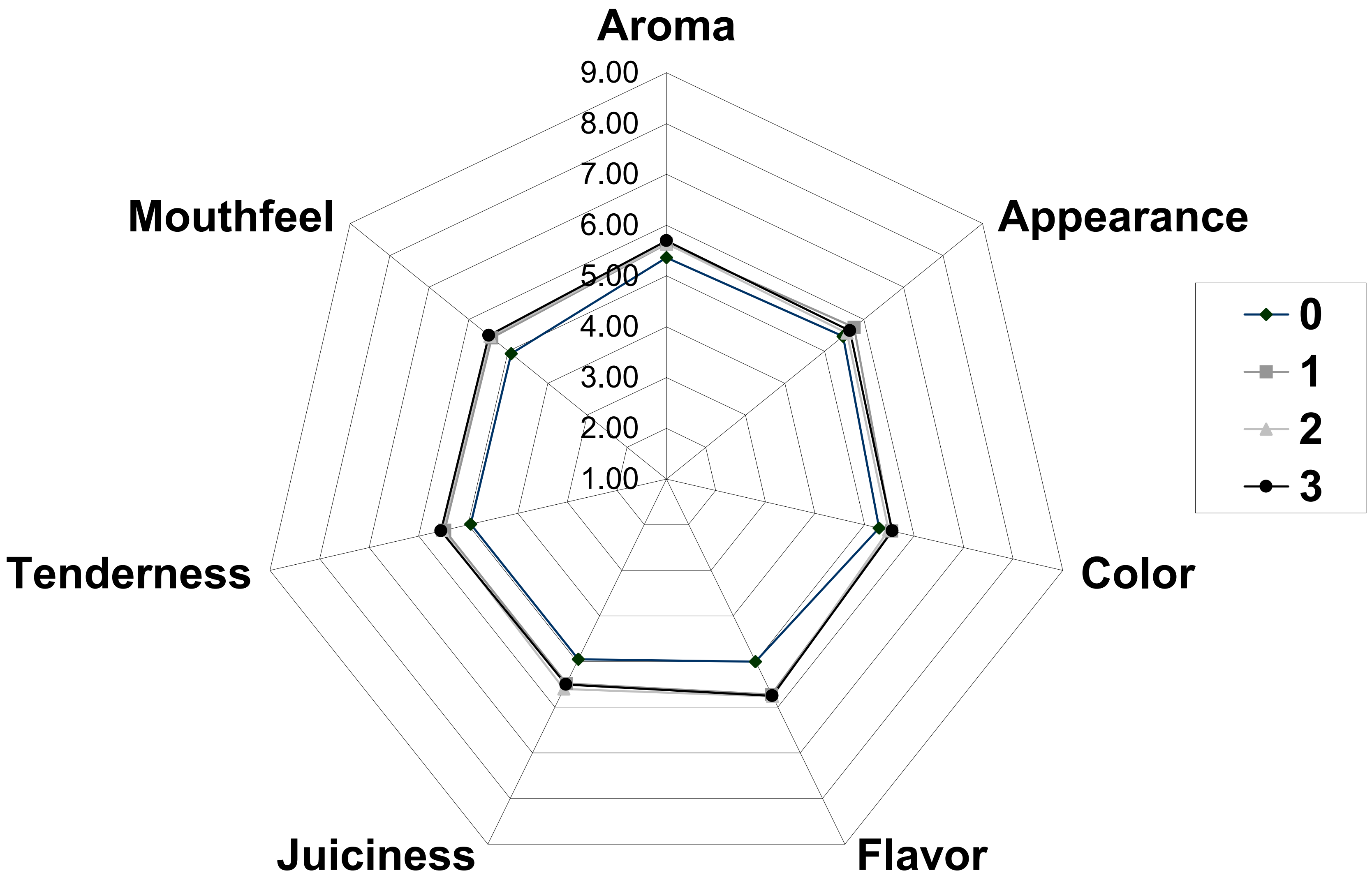
Consumer ratings for attributes of frankfurters stored at 32 days are plotted in Figure 3.1. The radar plot shows how samples irradiated at all doses for 32 days of storage were similar, as

Table 3.2. Means[a] and standard deviation, in parenthesis, of consumer ratings for frankfurters irradiated by electron-beam at 0, 1, 2 and 3 kGy after storage for 4, 18 and 32 days

Irradiation Dose (kGy) / Storage time (Days)	0	1	2	3
Day 4				
Overall Acceptance	5.89 (1.71) a	5.91 (1.74) a	6.21 (1.80) a	6.07 (1.77) a
Aroma	5.83 (1.55) a	5.83 (1.48) a	5.99 (1.53) a	5.79 (1.65) a
Appearance	5.68 (1.68) a	5.74 (1.63) a	5.67 (1.70) a	5.79 (1.70) a
Color	5.53 (1.83) a	5.56 (1.82) a	5.56 (1.84) a	5.66 (1.77) a
Flavor	5.91 (1.76) a	5.91 (1.71) a	6.13 (1.70) a	5.95 (1.83) a
Juiciness	5.85 (1.54) a	5.85 (1.65) a	5.92 (1.74) a	5.93 (1.63) a
Tenderness	5.95 (1.49) a	5.82 (1.61) a	5.99 (1.73) a	5.91 (1.59) a
Mouthfeel	5.83 (1.59) a	5.69 (1.67) a	5.88 (1.75) a	5.73 (1.71) a
Day 18				
Overall Acceptance	5.69 (1.78) a	5.95 (1.74) a	5.99 (1.78) a	6.09 (1.53) a
Aroma	5.69 (1.55) a	5.79 (1.65) a	5.87 (1.65) a	5.85 (1.51) a
Appearance	5.45 (1.60) a	5.63 (1.67) a	5.72 (1.65) a	5.70 (1.63) a
Color	5.28 (1.71) a	5.39 (1.79) a	5.45 (1.86) a	5.57 (1.75) a
Flavor	5.65 (1.92) a	5.82 (1.92) a	6.01 (1.85) a	6.01 (1.70) a
Juiciness	5.62 (1.76) a	5.71 (1.71) a	5.83 (1.63) a	6.00 (1.56) a
Tenderness	5.63 (1.76) a	5.66 (1.66) a	5.66 (1.75) a	5.82 (1.76) a
Mouthfeel	5.49 (1.76) a	5.59 (1.71) a	5.61 (1.78) a	5.85 (1.73) a
Day 32				
Overall Acceptance	5.18 (2.21) b	5.82 (1.86) a	5.72 (2.00) a	5.80 (1.91) a
Aroma	5.36 (1.83) a	5.63 (1.80) a	5.64 (1.87) a	5.69 (1.80) a
Appearance	5.47 (1.82) a	5.75 (1.67) a	5.57 (1.78) a	5.64 (1.84) a
Color	5.29 (1.92) a	5.55 (1.85) a	5.48 (1.83) a	5.56 (1.87) a
Flavor	5.00 (2.14) b	5.72 (1.95) a	5.76 (2.15) a	5.75 (1.98) a
Juiciness	4.95 (2.08) b	5.48 (1.89) a	5.60 (2.04) a	5.50 (1.94) a
Tenderness	4.95 (1.96) b	5.47 (1.95) a	5.51 (2.00) a	5.55 (1.95) a
Mouthfeel	4.92 (2.05) b	5.42 (1.92) a	5.46 (2.07) a	5.49 (2.02) a

[a]Means in the same row for each storage period not followed by the same letter are significantly different at $\alpha=0.05$ as determined by Fisher's Least Significance Difference (LSD) mean comparison test.

Figure 3.1. Mean hedonic ratings for acceptance of aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel/texture of frankfurters irradiated by e-beam and stored for 32 days at 4°C. Diamonds represent non-irradiated frankfurters (0 kGy), squares represent frankfurters irradiated at 1 kGy, triangles represent frankfurter samples irradiated at 2 kGy and circles represent frankfurters irradiated at 3 kGy. Ratings are based on a 9-point hedonic scale (1=dislike extremely; 9=like extremely). Fifty consumers rated twelve samples (4 doses x 3 replications).


Aroma
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
Appearance
Color
Flavor
Juiciness
Tenderness
Mouthfeel
0
1
2
3

shown in the overlap for each attribute. Comparison with the control samples demonstrated the difference in quality profiles, wherein the non-irradiated frankfurters were rated lower for each attribute and significantly lower for flavor, juiciness, tenderness and mouthfeel.

Overall acceptance of frankfurters for irradiated and non-irradiated samples for each day is shown in Figure 3.2. At each day of storage, overall acceptance of the non-irradiated samples was always rated lower than frankfurters receiving a dosage of 1, 2 and 3 kGy. Frankfurters at day 32 were always rated lower than frankfurters at day 4 or 18. However, the non-irradiated samples were always lower than the irradiated samples for any given day studied. The non-irradiated samples and the samples irradiated at 2 kGy showed a trend that the consumers perceived the quality of these samples to decrease with storage time. The samples irradiated at 1 kGy and 3 kGy showed little variation between days 4 and 18, but by day 32, the consumers perceived that the quality of these samples decreased with storage also.

Diced chicken meat

The mean consumer ratings and significant differences for overall acceptance, aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel/texture of the irradiated diced chicken meat are shown in Table 3.3. At day 4, no differences were found between the non-irradiated and irradiated samples for overall acceptance, appearance, color, flavor, juiciness, tenderness or mouthfeel/texture. However, the aroma of the non-irradiated samples, which received a rating of 5.37 was less acceptable (α=0.05) than the irradiated samples and significantly lower than the samples irradiated at 3 kGy, which received a rating of 5.85. No significant differences were found between the aromas of samples irradiated at different doses.

Figure 3.2. Mean hedonic ratings for overall acceptance of frankfurters irradiated by e-beam and stored for 4, 18 and 32 days at 4°C. Black bars represent all frankfurters at day 4, gray bars represent all frankfurters at day 18 and white bars represent all frankfurters at day 32. Ratings are based on a 9-point hedonic scale (1=dislike extremely; 9=like extremely). Fifty consumers rated twelve samples (4 doses x 3 replications).

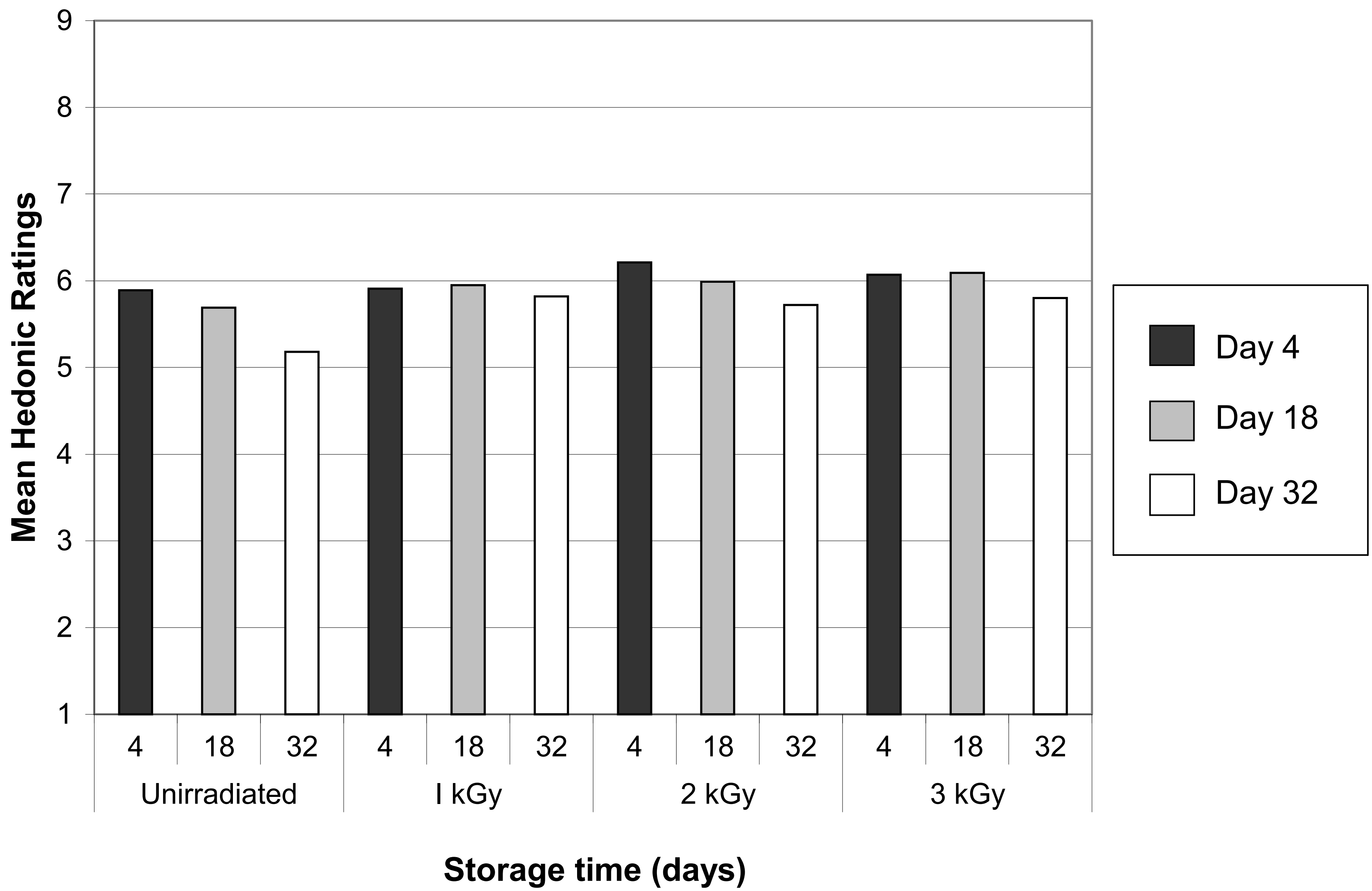

9
8
7
6
5
4
3
2
1
Mean Hedonic Ratings
4
18
32
4
18
32
4
18
32
4
18
32
Unirradiated
I kGy
2 kGy
3 kGy
Storage time (days)
Day 4
Day 18
Day 32

Table 3.3. Means[a] and standard deviation, in parenthesis, of consumer ratings for diced chicken irradiated by electron-beam at 0, 1, 2 and 3 kGy after storage at 4, 18 and 32 days

Irradiation Dose (kGy)	0	1	2	3
Storage time (Days)				
Day 4				
Overall Acceptance	5.70 (1.90) a	5.89 (2.01) a	5.63 (2.11) a	5.97 (2.11) a
Aroma	5.37 (1.69) b	5.61 (1.82) ab	5.51 (1.95) ab	5.85 (1.90) a
Appearance	5.32 (2.02) a	5.53 (2.03) a	5.47 (2.00) a	5.56 (2.04) a
Color	5.39 (2.02) a	5.51 (1.99) a	5.51 (2.01) a	5.49 (2.07) a
Flavor	5.90 (1.91) a	5.87 (1.99) a	5.79 (1.99) a	6.12 (1.97) a
Juiciness	6.61 (1.53) a	6.74 (1.50) a	6.50 (1.71) a	6.37 (1.85) a
Tenderness	6.69 (1.61) a	6.82 (1.58) a	6.61 (1.79) a	6.57 (1.79) a
Mouthfeel	6.19 (1.87) a	6.17 (1.83) a	6.20 (1.95) a	6.21 (1.90) a
Day 18				
Overall Acceptance	3.97 (2.26) b	5.22 (1.83) a	5.54 (1.85) a	5.33 (1.92) a
Aroma	3.62 (2.33) c	5.00 (1.83) b	5.49 (1.76) a	5.37 (1.83) ab
Appearance	4.72 (2.22) b	5.58 (1.84) a	5.59 (1.81) a	5.61 (1.72) a
Color	4.89 (2.16) b	5.67 (1.77) a	5.73 (1.70) a	5.75 (1.71) a
Flavor	1.00 (0.00) c	5.02 (2.01) b	5.44 (1.92) ab	5.47 (1.96) a
Juiciness	1.00 (0.00) b	5.82 (1.84) a	6.12 (1.81) a	5.89 (1.82) a
Tenderness	1.00 (0.00) b	5.88 (1.88) a	6.20 (1.82) a	5.99 (1.86) a
Mouthfeel	1.00 (0.00) b	5.47 (1.92) a	5.84 (1.86) a	5.68 (1.93) a
Day 32[b]				
Overall Acceptance	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Aroma	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Appearance	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Color	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Flavor	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Juiciness	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Tenderness	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a
Mouthfeel	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a	1.00 (0.00) a

[a]Means in the same row for each storage period not followed by the same letter are significantly different at α=0.05 as determined by Fisher's Least Significance Difference (LSD) mean comparison test.

[b]All inedible food samples were given a rating of 1.00 (dislike extremely).

On day 18, all non-irradiated samples (0 kGy) were rated less acceptable and were significantly different from all irradiated samples for each attribute. The overall acceptance, aroma, appearance and color of controls were unacceptable and were rated below 5 (neither like nor dislike). Flavor, juiciness, tenderness and mouthfeel/texture of the non-irradiated samples could not be evaluated due to deterioration and had developed a greenish color, slimy appearance and strong off-odor and these samples were discarded. In comparison, all samples irradiated at 1, 2 and 3 kGy were either rated neither like nor dislike or remained acceptable (5.00 to 6.20). Acceptance of aroma and flavor of samples irradiated at 1 kGy were marginal at 5.00 to 5.02, respectively. Significant differences were found between the non-irradiated samples that received different doses of irradiation for aroma and flavor. Although ratings for all irradiated diced chicken were slightly lower on day 18 than day 4, the samples were fit for consumption. At day 32, all samples (irradiated and non-irradiated) were deteriorated and could not be evaluated by the consumer panel.

Consumer ratings for attributes of diced chicken meat stored at 18 days are shown in Figure 3.3. The non-irradiated samples received the lowest ratings for all attributes. Samples irradiated at 1 kGy received the lowest ratings for acceptance of aroma and flavor. Samples irradiated at 2 kGy received the highest ratings for juiciness, tenderness and mouthfeel. Samples irradiated at 2 kGy and 3 kGy received similar ratings for aroma, appearance, color and flavor.

Overall acceptance of diced chicken meat for irradiated and non-irradiated samples for each day is shown in Figure 3.4. As the storage period progressed, ratings for overall acceptance of all treatments decreased with time from 4 to 18 days. The overall acceptance of the control was significantly lower than irradiated samples at 18 days regardless of dose and was

Figure 3.3. Mean hedonic ratings for acceptance of aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel/texture of diced chicken meat irradiated by e-beam and stored for 18 days at 4°C. Diamonds represent non-irradiated frankfurters (0 kGy), squares represent diced chicken meat irradiated at 1 kGy, triangles represent frankfurter samples irradiated at 2 kGy and circles represent diced chicken meat irradiated at 3 kGy. Ratings are based on a 9-point hedonic scale (1=dislike extremely; 9=like extremely). Fifty consumers rated twelve samples (4 doses x 3 replications).

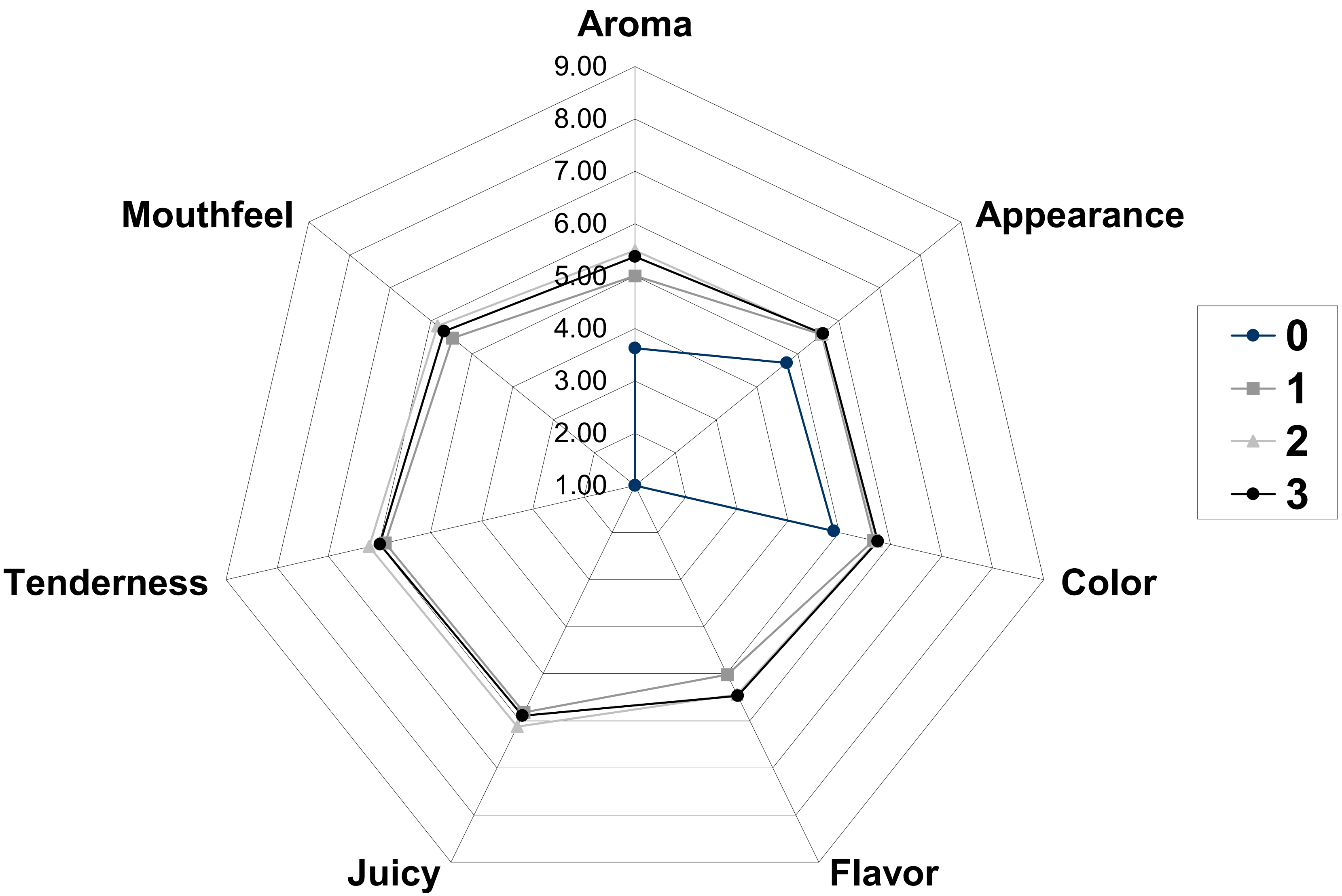
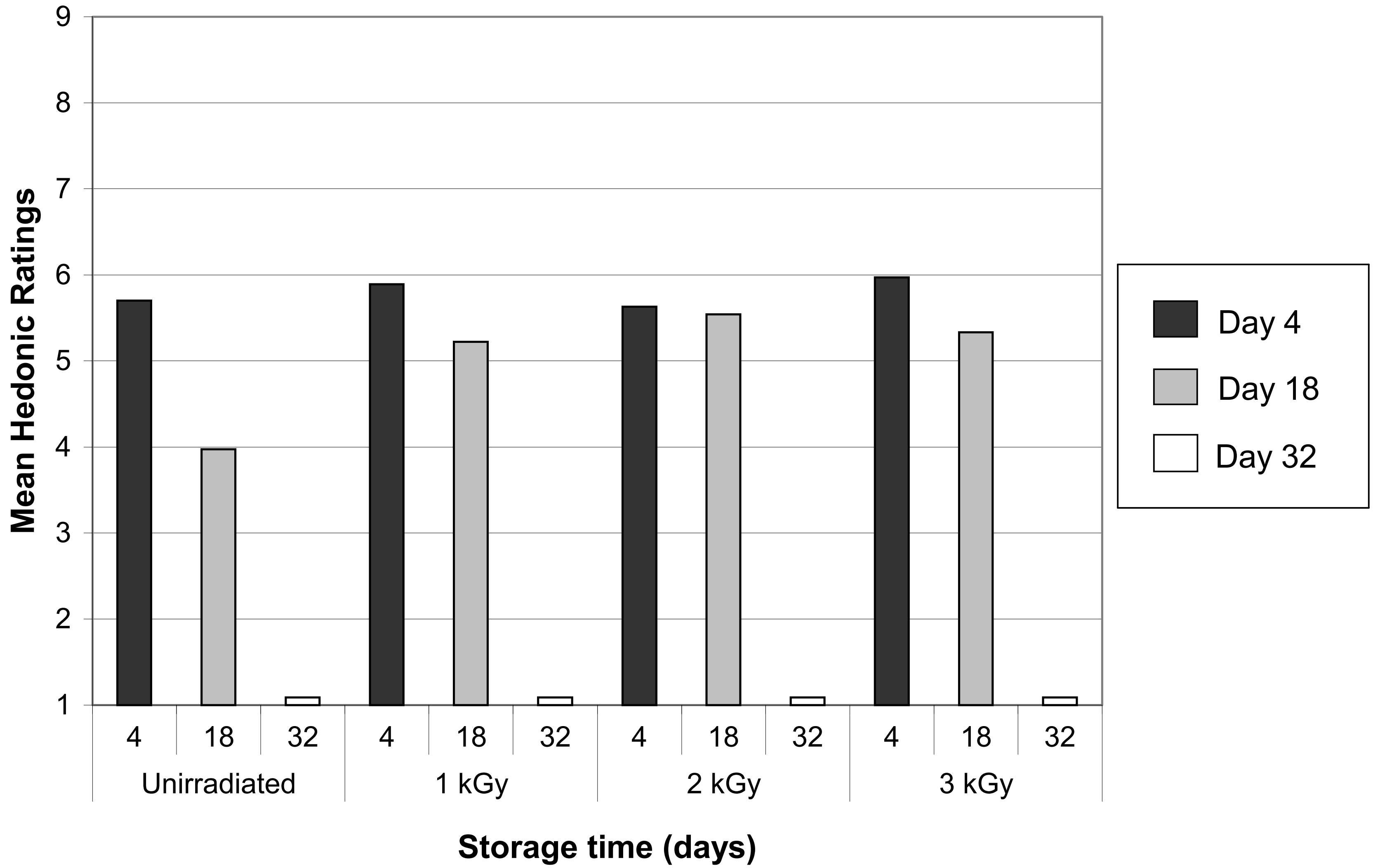

Aroma
Appearance
Color
Flavor
Juicy
Tenderness
Mouthfeel
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
1
2
3

Figure 3.4. Mean hedonic ratings for overall acceptance of diced chicken meat irradiated by e-beam and stored for 4, 18 and 32 days at 4°C. Black bars represent all diced chicken meat at day 4, gray bars represent all diced chicken meat at day 18 and white bars represent all diced chicken meat at day 32. Ratings are based on a 9-point hedonic scale (1=dislike extremely; 9=like extremely). Fifty consumers rated twelve samples (4 doses x 3 replications).


9
8
7
6
5
4
3
2
1
Mean Hedonic Ratings
4
18
32
4
18
32
4
18
32
4
18
32
Unirradiated
1 kGy
2 kGy
3 kGy
Storage time (days)
Day 4
Day 18
Day 32

rated dislike slightly (≤4). No differences occurred between overall acceptance of irradiated samples receiving different doses at day 18.

Regression analysis of frankfurters

Regression equations for the prediction of attributes for overall acceptance and acceptance of aroma, flavor, juiciness, tenderness and mouthfeel of electron beam irradiated frankfurters are shown in Table 3.4. Appearance and color were the only attributes that were not significant; therefore these attributes could not be modeled ($R^2<0.75$). Increasing irradiation dose had a positive effect on all attributes. Based on the parameter estimates, dose had the largest effect on overall acceptability and flavor. Storage time only had a positive effect on juiciness and a negative effect on all other attributes. The observed and predicted mean values for consumer overall acceptance of electron beam irradiated frankfurters are shown in Table 3.5. No significant differences were found between the observed and predicted mean values for the irradiated frankfurters. Regression analysis of the diced chicken meat could not be conducted to predict the rating from irradiation dose and storage time, because only two of the three days of sensory evaluations were evaluated by mouth and samples during the 3rd day could not be evaluated by mouth.

DISCUSSION

Demographics

The large percentage of females participating in both studies is typical for many consumer studies (Chambers *et al*., 1996). The demographics for gender are skewed to females because females are the primary purchasers of food products. According to the U.S. Census

Table 3.4. Intercepts and parameter estimates for regression equations of attributes, overall acceptance and acceptance of aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel of irradiated frankfurters[1] using electron-beam irradiation

Attribute	Prediction equation[2]	R-square[3]
Overall Acceptability	$5.8431 + 0.2530\ X_1 - 0.0007\ X_2 - 0.0449\ X_1^2 - 0.0004\ X_2^2 - 0.0003\ X_1{*}X_2$	0.7842
Aroma	$5.8502 + 0.0981\ X_1 - 0.0014\ X_2 - 0.0363\ X_1^2 - 0.0003\ X_2^2 + 0.0022\ X_1{*}X_2$	0.7880
Appearance	$5.6336 + 0.1901\ X_1 - 0.0092\ X_2 - 0.0213\ X_1^2 + 0.0002\ X_2^2 - 0.0044\ X_1{*}X_2$	NS
Color	$5.5809 + 0.0999\ X_1 - 0.0220\ X_2 + 0.0018\ X_1^2 + 0.0005\ X_2^2 - 0.0021\ X_1{*}X_2$	NS
Flavor	$5.8934 + 0.2215\ X_1 - 0.0044\ X_2 - 0.0648\ X_1^2 - 0.0005\ X_2^2 + 0.0044\ X_1{*}X_2$	0.8264
Juiciness	$5.7469 + 0.1216\ X_1 + 0.0110\ X_2 - 0.0225\ X_1^2 - 0.0009\ X_2^2 + 0.0020\ X_1{*}X_2$	0.8310
Tenderness	$5.9078 + 0.0288\ X_1 - 0.0151\ X_2 + 0.0014\ X_1^2 - 0.0002\ X_2^2 + 0.0021\ X_1{*}X_2$	0.7730
Mouthfeel	$5.8337 + 0.0160\ X_1 - 0.0092\ X_2 - 0.0029\ X_1^2 - 0.0004\ X_2^2 + 0.0034\ X_1{*}X_2$	0.7906

[1]50 panelists evaluated samples of e-beam irradiated frankfurters using a 9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely. Equations were obtained by using two replications.

[2]Variables in models are:

x_1=dose

x_2=day

x_1^2=dose*dose

x_2^2=day*day

x_1*x_2=dose*day

[3]R-square = 0.75

Table 3.5. T-test results of observed and predicted mean values for consumer overall acceptance of electron-beam irradiated frankfurters[1]

		Overall Acceptance Scores		
Storage Time (Days)	**Irradiation Dose (kGy)**	**Observed[2]**	**Predicted[3]**	**Probability[4]**
4	**0**	5.82	5.83	0.6912
4	**1**	5.84	6.04	0.3734
4	**2**	6.24	6.15	0.7003
4	**3**	5.92	6.18	0.4373
18	**0**	5.80	5.70	0.9635
18	**1**	6.00	5.90	0.7078
18	**2**	6.08	6.01	0.8729
18	**3**	6.20	6.04	0.6667
32	**0**	5.10	5.41	0.2039
32	**1**	5.52	5.61	0.1699
32	**2**	5.90	5.72	0.9999
32	**3**	5.90	5.73	0.6543

[1]Scores are based on a 9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely.

[2]Observed values=mean of third replication.

[3]Predicted values=predicted from two replications.

[4]Probability that paired scores are significantly different from each other at α=0.05.

Bureau (2000), the median age category is between 35-44 years of age, whereas in both studies, the median age category of respondents that participated was higher (45-54 years of age). This is expected because the age categories in this study begin at 18 years of age, whereas the U.S. Census begins under the age of five. The U.S. population is comprised of 75% whites and the remaining 25% accounts for African Americans and other races (U.S. Census Bureau, 2000). The race breakdown is similar to the U.S. Census in the diced chicken study. In the frankfurter study, there was a smaller number of white respondents (60%) compared to the U.S. Census. At least half of the respondents in our study and in the U.S. census had some college education or higher and the median annual household income reflects that of the U.S., which is equivalent to $42,000 (U.S. Census Bureau, 2000). Even though there has been a large increase in the consumption of ready-to-eat meat products, especially frankfurters due to changing lifestyles and eating habits (Ordonez *et al*., 2001), we found that consumers in the diced chicken study consumed chicken more frequently than consumers in the frankfurter study consumed frankfurters. This was expected because respondents who participated in each study were screened to consume chicken at least two times a week and frankfurters at least four times a year.

Frankfurters

An irradiation dose of 3 kGy is recommended to inactivate pathogens in poultry and poultry products (USDA, 1992). At this dosage, the sensory characteristics were not altered due to irradiation and throughout the 32 day shelf life of the product. Shelf life, based on consumer acceptance, of the frankfurters was extended by the irradiation process. The recommended unopened shelf life of packaged frankfurters is 14 days and its opened shelf life is 7 days (USDA, 2002). Consumers perceived the irradiated frankfurters to be acceptable after 14 to 32 days of storage in unopened packages. Frankfurters irradiated up to 3 kGy were as acceptable as frankfurters irradiated at 1 or 2 kGy for up to 32 days under refrigeration. It is possible considering the low rate of change of sensory qualities in irradiated products, that the frankfurters can have a shelf life longer than 32 days. The consumers did not detect any off-flavor among the irradiated samples, although reports by Kirn *et al*. (1956) concluded that cured meat exhibited an extremely bitter flavor in addition to those flavors usually attributable to irradiation. However they canned their products prior to irradiation and the dosage used was higher. Moreover, our findings support the conclusion that irradiation had no detrimental effects on the color, flavor or odor of cured meat (Shahidi *et al*., 1991). Therefore, irradiation from 1 to 3 kGy is recommended to increase the shelf life of frankfurters up to double the expected shelf life of non-irradiated frankfurters.

Diced chicken meat

The recommended irradiation dose of 3.0 kGy has been considered as optimal for the extension of refrigerated shelf life of prepackaged chicken (Mercuri *et al*., 1967). After the maximum shelf-life of approximately 6 days at 4.4°C for chicken carcasses (Kahan and Howker, 1977), consumers perceived the irradiated diced chicken meat to be acceptable up to 18 days, which is three times the recommended shelf life. However, non-irradiated samples spoiled within 18 days of refrigerated storage and were not fit for consumption.

One of the major concerns in irradiating meat is its effect on the generation of irradiation off-odor, which can impact negatively upon acceptance (Ahn *et al*., 2000). The conclusions deduced about the production of off-odors from the irradiation process are inconsistent. We found that at day 4, differences were found between only the aroma of the non-irradiated and the irradiated samples. Kahan and Howker (1977) found that the odor of non-irradiated chicken carcasses stored at 1.6°C deteriorated from a fresh chicken odor at 4 days to no odor after 8 days, a slight off-odor at 11 days and increasing putridity after 15 days. In this study, the consumers rated the irradiated samples as having a more pleasing aroma than the non-irradiated samples immediately after irradiation (4 days) and throughout the storage period. Hansen *et al.* (1987) also found that after 14 days, irradiated chicken still had acceptable odor, while the control had severely deteriorated. In a later study, Hanis *et al.* (1989) showed that irradiation off-odor of raw chicken meat sealed in polyethylene bags increased with doses equal to and above 1 kGy and temperature during irradiation. However, in this study, wherein we used ethylene-vinyl acetate and polyvinylidene chloride packaging, we did not find a deleterious effect on the acceptance of aroma (≤ 5) of the cooked chicken meat with increasing dosages up to 3 kGy after 4 days of refrigerated storage.

At day 18 after irradiation, the consumers found the non-irradiated samples to be unacceptable and rated all attributes of the non-irradiated samples significantly lower than that of irradiated samples. Poultry meat, stored over time, begins to decompose due to the degradation of the muscle tissue, which results in decreased sensory quality. The decrease of the sensory characteristics of the non-irradiated samples at day 18 was ascertained by observing changes in color, odor and surface sliminess. The primary mode of deterioration, for refrigerated fresh poultry, is the development of undesirable microorganisms, which cause slime and odors to develop (Hotchkiss, 1989). This deterioration was possibly caused by *Pseudomonas sp.*, one of the more dominating species responsible for the aerobic spoilage of meats stored at refrigeration temperatures (Gill and Newton, 1977) or one of the many other microorganisms, such as *Listeria,* that may be present due to cross-contamination and growth at refrigeration temperatures. It is believed that the survival and multiplication rate of *Listeria monocytogenes* after irradiation is greater on cooked meats than on raw meats during refrigerated storage (Thayer *et al*., 1998). In this study, there was no indication of the slime or green discoloration in the irradiated samples, whereas it was present in the controls, indicating that irradiation was sufficient to prevent the growth of some microorganisms. Lescano *et al.* (1991) found that chicken irradiated with doses of 2.5 to 3.8 kGy were considered acceptable (7.1-7.7 on a 12-point scale) up to 22 days of storage, although flavor ratings were lower (6.7-7.5). In contrast, Lewis *et al*. (2002) found that the texture and flavor attributes were lower for the irradiated (1.0 to 1.8 kGy) raw chicken breast samples after cooking and storing for 14 days as compared to non-irradiated samples. They found at day 28, irradiated samples were less desirable with decreased texture, flavor and overall acceptability.

Heat treatment prior to irradiation appears to be the best method for the prevention of undesirable enzyme-induced changes in flavor of irradiated foods (van Laack, 1994); therefore, ready-to-eat meats would seem to be the ideal candidate for irradiation. Kirn *et al*. (1956) found irradiated chicken to have a small flavor change, which resembled a slight irradiation flavor, but this was considered not too "objectionable" by a taste panel. This was not observed in this study when comparing irradiated chicken to non-irradiated chicken after 4 days. After 18 days of refrigerated storage, however flavor intensity was decreased in irradiated samples and controls had a putrid off-odor. Shamsuzzaman *et al*. (1992) found that irradiation doses of up to 3 kGy had very little effect on either the flavor or odor of sous-vide raw, skinless chicken breast up to 55 days and only received the worst ratings of 2 (1=no off-odor, 4=extreme off-odor), which indicates that only slight off-odors or off-flavors occurred. This is expected because the sous-vide product were vacuum-packaged, irradiated and stored in the same package. Samples in this study were not rated unacceptable (<5 where 1=dislike extremely, 9=like extremely) despite their removal from packaging used during irradiation into clean, but not sterile bags, to simulate institutional and home use conditions. Irradiation odors and flavors were less readily detected in chickens irradiated while frozen than in chickens irradiated at ambient temperature (Hanson *et al*. 1964), whereas Hashim *et al.* (1995) found no differences in sensory ratings of chicken irradiated in the frozen or refrigerated state.

The color in cooked irradiated poultry is important because they determine the ultimate consumer acceptance of irradiated meat (Du *et al*., 2002). The color of the irradiated diced chicken meat in this study was always rated higher than the color of the non-irradiated samples. Nanke *et al.* (1998) found that a pink color develops in irradiated turkey and that this might be perceived by consumers as fresher. Hashim *et al.* (1995) found that there were no significant differences between the color of the non-irradiated and irradiated chicken in the frozen or refrigerated state. Baker *et al.* (1986) found that sliced chicken and turkey breast meat (non-irradiated) developed a light brown surface discoloration. We observed similar color changes in the irradiated samples, but not in the non-irradiated controls.

Regression analysis of frankfurters

Overall acceptability, aroma, flavor, juiciness, tenderness and mouthfeel can be predicted using prediction equations developed in this study. Dose had a greater effect on irradiated frankfurter samples than storage time in this study. Patterson *et al*. (1993) found that dose had a greater effect on irradiated cooked poultry meat inoculated with *Listeria monocytogenes* than storage time. They reported that the lag phase of Listeria monocytogenes was most affected and increased significantly after an irradiation dose of 2.5 kGy, depending on the storage temperature. Other studies also found that irradiation dose had a greater effect than storage time, however, regression equations were not considered in these studies. From this study, we found that for up to 32 days of storage and up to an irradiation dose of 3 kGy, overall acceptance can be predicted using the prediction equations, developed in this study, for overall acceptability.

CONCLUSION

Irradiation of ready-to-eat poultry products at doses as high as 3 kGy did not have a detrimental effect on the consumer acceptance and on other sensory characteristics. In fact, the irradiated frankfurters and diced chicken meats were more acceptable to consumers throughout their refrigerated shelf life for up to 32 and 18 days, respectively, whereas the non-irradiated samples had either lower ratings or were unacceptable, respectively. Overall acceptance can be predicted using equations developed in this paper.

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CHAPTER 4

CONSUMER-BASED OPTIMIZATION OF THE ELECTRON-BEAM PROCESS FOR IRRADIATING READY-TO-EAT POULTRY FRANKFURTERS[1]

[1]Johnson, A.M., Reynolds, A.E., Chen, J. and A.V.A Resurreccion. To be submitted to the *International Journal of Food Science and Technology*.

ABSTRACT

Ready-to-eat poultry frankfurters were electron-beam irradiated at 0, 1, 2 and 3 kGy and stored under refrigeration for 32 days of storage. Consumer acceptance tests and descriptive analysis were conducted to evaluate the effect of irradiation dose and storage time. The consumer overall acceptance and acceptance of flavor, tenderness and juiciness ratings of 6 or like slightly were used to develop an optimum region of quality for the irradiated frankfurters. The descriptive attributes of chickeny, cured meat, wet dog aroma; off-flavor, meaty and cured meat flavors; and sour taste established a range of predicted values that characterized the optimum region. An irradiation dose of 2.5 to 3.0 kGy is recommended to process frankfurters and should not be stored for more than 11 days after irradiation when a 3 kGy dose is used and 8 days after irradiation when a 2.5 kGy dose is used. The attributes and values obtained in this study for the electron-beam process can be used to irradiate ready-to-eat poultry frankfurters that will be acceptable to consumers.

INTRODUCTION

High dose levels of irradiation (8 kGy to 32 kGy) have been known to affect texture, flavor and palatability of frankfurters made from pork and beef (Terrell et al., 1981a; 1981b) and chicken or turkey (Terrell et al., 1982). Due to consumer concerns regarding high salt consumption, the meat industry is searching for ways to reduce the sodium content of processed meat products, such as frankfurters. However, any reduction in salt may have adverse effects, such as undesirable texture, decreased flavor and support the growth of pathogens on meat products (Barbut et al., 1988b). Mechanically deboned poultry meat (MDPM) with its fine paste-like consistency, lower salt content and low cost, is an ideal raw material in comminuted meat products (Jantawat and Carpenter, 1989).

Important factors determining the storage stability of comminuted meat products are microbial quality, physicochemical changes, such as lipid oxidation and deterioration in color, texture, and flavor (Van Zyl and Setser, 2001). However, some poultry frankfurters lack acceptable texture (Meullenet et al., 1994) due to the reduction of salt content (Barbut et al., 1988b). Consequently, phosphates and sodium erythorbate have been incorporated into comminuted meats to enhance storage stability. Phosphates are used to compensate for loss of texture, meat bind, water holding capacity and flavor caused by salt reduction (Sofos, 1983). Sodium erythorbate is used to stabilize color, to speed curing and to make the cure more uniform (Jay, 2000). The free radicals generated by irradiation can destroy antioxidants in muscle, reduce storage stability and increase off-flavor production in meat (Lakritz et al., 1995).

Nitrites also serve to stabilize red meat color, contribute to cured meat flavor, retard rancidity, prevent the germination of clostridial spores (Jay, 2000), prevent warmed-over flavor in cured meats (Bailey, 1988), and cause a significant effect on the lag phase and growth rate of

Lactobacilli (Silia and Simonsen, 1985). However, nitrites can react with secondary amines to form carcinogenic nitrosamines (Jay, 2000). A high dose of irradiation (> 10 kGy) was found to reduce carcinogenic nitrosamines and nitrite levels in model systems for pork sausage during storage (Ahn et al., 2002). Irradiation has been proposed as a possible means of replacing or reducing some chemical preservatives such as nitrite in cured meat products (Barbut et al., 1988a). It has been suggested that irradiation might preserve frankfurters made without the use of nitrite in order to avoid formation of nitrosamines, however the addition of some nitrite may be necessary to produce a palatable cured meat product (Terrell et al., 1981a; Terrell et al., 1981b). Irradiated bacon with reduced levels of nitrite (20 to 40 mg/kg of nitrite) in evacuated packages and stored at 4°C, results in a product with good sensory quality, extends the shelf life of more than 90 days, as opposed to approximately 30 days for conventionally treated bacon and reduced preformed nitrosamines (Singh, 1988).

The objective of this study was to determine the effect of electron-beam irradiation on sensory characteristics of ready-to-eat poultry frankfurters. Specific objectives of this study are to: (1) optimize the irradiation dose and storage conditions using consumer acceptance and descriptive attributes for irradiated poultry frankfurters, and (2) establish a range of values for significant descriptive sensory attributes of irradiated poultry frankfurters that are acceptable to consumers.

MATERIALS AND METHODS

Experimental Design

Descriptive analysis of frankfurter samples were conducted at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, corresponding to 0, 25, 50, 75 and 100% of shelf life, for the descriptive analysis test. Consumer acceptance of frankfurter samples was evaluated at 4, 18 and 32 days of refrigerated storage after irradiation, corresponding to 0, 50 and 100% of shelf life for the consumer acceptance test. Four samples, consisting of non-irradiated frankfurters (0 kGy), which served as the non-irradiated control, and frankfurters irradiated 1, 2 and 3 kGy, were given. On each sampling day, a randomized, balanced block design was used to serve all frankfurters monadically. After each storage time, 12 samples representing the control and 3 doses of irradiation with 3 replications were assigned to 3 sets. Presentation order of the 4 samples within a set was randomized over the panelists.

Samples

Frankfurters (D. L. Lee & Sons, Inc., Alma, GA) were transported to the Department of Food Science and Technology in Griffin, GA in 48 quart insulated coolers (Igloo, Shelton, CT) packed with ice. The frankfurters were held for 48 hours at 4°C in a walk-in refrigerator (Model W06430-1, Nor-lake, Inc., Hudson, Wisconsin) until ready for packaging. Frankfurters were removed from their original packages. Five frankfurters were transferred into each irradiation approved 16.5 cm x 20.3 cm ethylene-vinyl acetate and polyvinylidene chloride bags formed from 16.5 cm x 40.6 cm bags (B-540, Cryovac, Saddle Brook, NJ) cut in half and heat-sealed. Within five minutes of removal from the refrigerator, the frankfurters were vacuum-packaged

(29 in Hg) using a single chamber packaging machine (Model UV250, Koch Packaging Systems, Kansas City, MO) and then heat-sealed, leaving approximately 2.54 cm space for the label to be inserted after the vacuum seal. Label information containing the desired irradiation doses were heat-sealed in the remaining portion of the bag to prevent the label from separating from the frankfurter samples. The samples were returned to the refrigerator (4°C) and held for overnight storage.

All samples were packed in polyfoam mailing boxes (35.5 cm x 35.5 cm x 38.7 cm Fisher Scientific, Pittsburgh, PA) and packed with ample ice packs (Fisher Scientific, Pittsburgh, PA) to maintain refrigeration temperatures determined in preliminary studies. Samples were shipped by air overnight to the Ion Beam Applications (IBA) irradiation facility (San Diego, CA).

Dose mapping

Dose mapping was conducted by IBA (San Diego, CA) to: (1) find the minimum and maximum absorbed dose points within the products, and (2) determine the relation of the dose measured by an external dosimeter to doses absorbed by the product (results from objective 1). From this relation, a dose range from the adjusted minimum and maximum doses as measured by the external dosimeter, was determined to assure the minimum required irradiation of the sample. Radiochromic film dosimeters (Far West Technology, Inc., Goleta, CA) were placed on the top and the bottom of each package. Samples were positioned in a single layer in stainless steel trays, transported onto the conveyor belt and exposed to the ambient temperature of the electron beam source (RF linac linear accelerator, Applied Radiation Company, San Jose, CA) with an energy level of 9.5 MeV and a dose rate of 45 kGy/ft/min using a single-sided pass.

Irradiation processing

Upon the arrival of the samples at the IBA irradiation facility, the frankfurter samples were held overnight in a refrigerator at 3°C (Model B1031-2, Kool Star, Los Angeles, CA). Samples were irradiated to achieve a 1.0, 2.0 or 3.0 kGy dose, which was verified with radiochromic film dosimeters attached on the top and bottom surfaces of representative samples to monitor dose rate and uniformity of irradiation. Irradiated samples were held overnight in a refrigerator at 3°C. Non-irradiated samples were held under similar conditions. On the following day, samples were repackaged under conditions similar to the shipment of the samples to the irradiation facility. Samples were then transported by air overnight to the sensory laboratory at the Department of Food Science and Technology (Griffin, GA).

Sample preparation

Upon arrival at Griffin, non-irradiated and irradiated frankfurter samples were removed from the shipping boxes and were held in a refrigerator at 4°C until ready for sensory evaluation. The samples were stored for up to an expected shelf life of 32 days after irradiation. The samples were withdrawn from the walk-in refrigerator at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, corresponding to 0, 25, 50, 75 and 100% shelf life, for the descriptive analysis and at 4, 18 and 32 days corresponding to 0, 50 and 100% of shelf life for the test for the consumer test.

Frankfurter samples were prepared according to preliminary testing procedures. Five frankfurter samples from one package, directly from the refrigerator, were placed in 3-quart stainless steel pans (Revere Ware, Clinton, IL) with 800 ml of cold double-deionized water. The frankfurters and water were heated to boiling at a medium high setting and held for a total of approximately 7 minutes from the time samples started boiling. Frankfurter samples were prepared in 3 sets of 4 for each session. During the preparation, within each set of 4, frankfurters were cooked approximately 3 minutes apart so that panelists could receive warm samples in between each set. After the frankfurters boiled for the recommended time, they were removed from the stove and the water was drained and discarded. Frankfurters were removed from the pans and placed on cutting boards, cut in half crosswise and each frankfurter half was placed in 8 oz squat cups (Stock No. 8SJ20, Dart, Mason, MI) coded with three digit random numbers. Samples were served immediately for sensory evaluation by a consumer panel or the descriptive panel.

Consumer acceptance test

A consumer sensory laboratory acceptance test (Resurreccion, 1998) was conducted. Consumers were recruited from a database of consumers who had previously participated in consumer tests at the University. During recruitment, consumers were screened with a recruitment screener inquiring about their age, food allergies, and how frequently they consumed frankfurters to determine if they qualified for the test. Sixty consumers between the ages of 18–70 were recruited, allowing a 20% overage for "no-shows", who were not allergic to frankfurter ingredients (corn syrup solids, salt, dextrose, hickory smoke flavoring, sodium erythorbate, sodium nitrate) and consumed frankfurters at least four times a year. Among the sixty recruits, fifty participated in the test.

All tests were performed at the Consumer and Sensory Laboratories, Department of Food Science and Technology, University of Georgia, Griffin, Ga. Upon panelists' arrival, a greeter escorted them to a conference room. They signed in and completed consent forms approved by the University of Georgia Institutional Review Board and a demographic questionnaire. A PowerPoint presentation of the evaluation procedure was given. Consumers were escorted to the sensory booths to evaluate the frankfurters. Samples were evaluated in environmentally-controlled partitioned booths illuminated with two 50-watt indoor reflector flood lamps, which provided 738 lux of light. Consumers rated their overall acceptance of the sample and acceptance of aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel / texture of each sample using a 9-point hedonic scale (Peryam and Pilgrim, 1957) with 1=dislike extremely and 9=like extremely using computer ballots (Compusense® five, version 3.8, Compusense, Inc., Guelph, Ontario, Canada). Compusense allowed panelists to return to previous questions regarding a sample, but did not allow panelists to return to previously evaluated samples. Each consumer evaluated four samples in each of three tests, separated with a compulsory break of five minutes between each test. At the conclusion of the study, consumers received an honorarium of 10 dollars for each day of participation.

Descriptive Analysis

Recruitment. Prospective members of the descriptive panel were recruited from a list of previously trained panelists, who had previously participated in descriptive analysis tests at the sensory laboratory, as well as sensory evaluation students from the University. All panelists were recruited on the basis of the following criteria: between 18 and 70 years of age, did not smoke, not allergic to frankfurters, consumers of frankfurters at least four times a year, willing to evaluate irradiated frankfurters, available and willing to participate during training and testing dates and able to verbally communicate about the product. Panelists were required to complete and sign consent forms approved by the University of Georgia Institutional Review Board.

Training. Ten panelists, 1 male and 9 females, were selected. Each panelist was trained and calibrated for 3 days. Each training session was 2 hours each day for a total of 6 hours. During the first day of training, panelists were presented with several frankfurter samples. Descriptive terms that characterized the sensory properties of samples were developed by the panel while evaluating samples. Panelists then decided on a final list of flavor and texture terms that was comprehensive with definitions understood by all panelists. Panelists did not necessarily define an attribute as indicated in existing literature. The final list of attributes with definitions and reference standards was decided upon by panel consensus (Table 4.1).

During the second day of training, panelists determined references that would best help them to rate the descriptive terms developed. Reference standards were evaluated as a group to assure that judgments of each panelist were in the same range as those of the other panelists. Panelists were calibrated to rate intensity of stimuli by presenting them with standard references for basic tastes (Meilgaard et al., 1987). Panelists evaluated samples using a "hybrid" descriptive analysis method (Einstein, 1991), a combination of the Quantitative Descriptive Analysis (QDA®) (Tragon Corp., Redwood City, Ca, USA) and Spectrum™ Analysis (Sensory Spectrum, Inc., Chatham, NJ, USA) Methods. Each panelist rated the attribute intensity of each reference for a particular attribute and gave it an intensity rating between 0 and 150 using flashcards. Calibration of the panel was conducted by first obtaining an average rating and those panelists not rating within 10% of the average rating were asked to re-evaluate the sample and adjust their rating until consensus was reached.

During the third day of training, panelists evaluated frankfurter samples frankfurters by refreshing themselves with the computerized ballot (Compusense, Version 4.0, Compusense Inc., Guelph, Ontario, Canada), with 31 attributes listed vertically in their order of appearance, five

Table 4.1. Attributes, definitions, references and intensity ratings used to evaluate electron-beam irradiated frankfurters

ATTRIBUTE[1]	DEFINITION	REFERENCE	INTENSITY
APPEARANCE			
Glossy [2,3]	The amount of light reflected from the skin surface	Vegetable oil (Crisco, Procter & Gamble, Cincinnati, OH)	137
Red color [2]	The intensity or strength of red color from white to dark red	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Red paper (L*=51.84, a*=51.92, b*=26.29)	75
Brown color [2]	The intensity or strength of brown color from white to dark brown	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Brown cardboard (L*=59.05, a*=5.25, b*=17.50)	66
		Chocolate syrup (Hershey Foods Corp., Hershey, PA) (L*=24.35, a*=2.00, b*=1.76)	150
Evenness of surface	The evenness of the surface texture	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	120
		Crisco (Crisco, Procter & Gamble, Cincinnati, OH)	150
AROMA:			
Smell the sample and evaluate for aroma			
Total aroma	The total aroma intensity of sample	Standard taste references at varying concentrations	

Table 4.1. Continued

Meaty [4,5,6]	Aromatic associated with cooked or roasted meat	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	25
Chickeny [3,4,5,6]	Aromatic associated with cooked chicken	Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	57
Cured meat [4]	Aromatic/taste sensation associated with processed products that contain curing agents (nitrites, sugars, salts)	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	21
Spice blend [4]	Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified	Standard taste references at varying concentrations	
Wet dog [4]	Aromatic associated with wet dog hair	Standard taste references at varying concentrations	
Off-flavor [4]	A general, non-specific term, related usually to characteristics that are inappropriated in a food system	Standard taste references at varying concentrations	
FLAVOR:			
Place 2 to 3 pieces of sample in mouth and evaluate for flavor			
Total flavor	The total flavor intensity of sample	Standard taste references at varying concentrations	
Meaty [4,5,6,7]	Aromatic associated with cooked or roasted meat	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	39

Table 4.1. Continued

Chickeny[3,4,6]	Aromatic associated with cooked chicken	Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	72
Oily[5,6]	An overall term for the aroma and flavor notes reminiscent of vegetable oil or mineral oil products	Vegetable oil (Crisco, Procter & Gamble, Cincinnati, OH)	55
Cured meat[4]	Aromatic/taste sensation associated with processed products that contain curing agents (nitrites, sugars, salts)	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	32
Spice blend[4]	Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified	Standard taste references at varying concentrations	
Pepper[4]	Aromatic associated with pepper	Ground black pepper (Kroger Co., Cincinnati, OH)	93
Liver/organy[4,5,7]	Aromatic associated with cooked liver, organ meat, serum and/or blood salts	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	12
		Hearts, gizzards, and livers (reference not supplied)[4]	75
Taste			
Salty[2,4,5]	The taste on the tongue associated with sodium chloride solutions	0.2% sodium chloride in deionized water (Fisher Scientific, Fair Lawn, NJ)	25
		0.35% sodium chloride in deionized water	50
		0.5% sodium chloride in deionized water	85

Table 4.1. Continued

Sour [2,4,5]	The taste on the tongue associated with citric acid solutions	0.05% citric acid in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		0.08% citric acid in deionized water	50
		0.15% citric acid in deionized water	100
Bitter [2,4,5]	The taste on the tongue associated with caffeine solutions	0.05% caffeine in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		0.08% caffeine in deionized water	50
		0.15% caffeine in deionized water	100
Sweet [2,4,5,6]	The taste on the tongue associated with sucrose solutions	2.0% sucrose in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		5.0% sucrose in deionized water	50
		10.0% sucrose in deionized water	100
		16.0% sucrose in deionized water	150
Umami [4]	Specific taste on the tongue stimulated by MSG (monosodium glutamate) and certain other nucleotides	0.2% MSG solution (Ajinomoto U.S.A., Inc., Teaneck, NJ)	36
		Standard taste references at varying concentrations	

Table 4.1. Continued

Feeling factors			
Tongue sting	Degree of a sharp, stinging sensation on the tongue or throat	Chili powder (Private Selection, Inter-American Products, Inc., Cincinnati, OH)	40
TEXTURE			
Springiness [2,8]	Degree to which sample returns to original shape	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	70
		Marshmallow[2] (Kraft, Nabisco, Inc., East Hanover, NJ)	95
First bite: Bite through 1 cm of sample with incisors before you rate			
Overall hardness [2,8]	Force required to bite through sample	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	50
		Peanuts[2] (Planter's, Nabisco Foods, Inc., East Hanover, NJ)	95
5 Chews: Chew sample five times before you rate			
Chewy [8]	Total amount of work necessary to chew a sample to a state ready for swallowing	Tootsie Roll midgees (Tootsie Roll Industries, Inc., Chicago, IL)	75
Cohesiveness of mass [2,8]	Degree to which sample holds together in a mass after five chews	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	75
10 Chews: Chew sample ten times before you rate			
Grainy [2,3,4]	The amount of particles in the mouth	Grits[3] (Kroger Instant Country Grits, The Kroger Co., Cincinnati, OH) prepared according to package instructions	90

Table 4.1. Continued

Residual: Evaluate sample after expectorating			
Oily mouthcoat [2]	Amount of oil left on mouth surfaces	Water (Deionized)	0
		Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	36

[1] Attribute listed in order as perceived by panelists.

[2] Meilgaard et al. (1991)

[3] Hashim et al. (1995)

[4] Civille and Lyon (1996)

[5] Lyon (1987)

[6] Landes (1972)

[7] Jacobson and Koehler (1970)

[8] Meullenet and Gross (1999)

attributes per display. Using a computer mouse, panelists clicked on each attribute on a 150-mm unstructured line scale, with anchors at 12.5 and 137.5 mm that appeared on the computer screen with a heading consisting of that particular attribute and definition. Panelists made a vertical mark on the line scale indicating the intensity of that attribute. The numerical rating for that attribute would then appear next to it indicating that the attribute had been rated and panelists could proceed to rate the next attribute. All attributes of one sample were rated for intensity before a panelist could proceed to the next sample.

Testing. All tests were performed at the Department of Food Science and Technology, University of Georgia in Griffin, Ga. Panelists evaluated samples in environmentally-controlled partitioned booths illuminated with two 50-watt indoor reflector flood lamps, which provided 738 lux of light. Samples were presented to the panelists monadically. After each storage time, 12 samples representing the control and 3 doses of irradiation with 3 replications were assigned to 3 sets. Presentation order of the 4 samples within a set was randomized over the panelists. Prior to each evaluation session, each panelist was presented with standard references for basic tastes, reference standards, warm-up sample and a control sample (non-irradiated frankfurters) in a one hour calibration session around a table in a sensory laboratory. Panelists were instructed to calibrate their judgments using standard references, then to evaluate the control sample and compare individual responses for outlying ratings, if any. Outliers were calibrated by reevaluating the sample and adjusting their ratings toward consensus. Panelists then evaluated their samples in individual partitioned booths. Water and unsalted crackers were provided for panelists to cleanse their palates between samples.

Unstructured line scales were used to rate samples for intensities of each attribute. Panelists recorded responses onto a computer utilizing an interactive program, described above, designed to prompt them to rate one attribute per sample at a time. The line scales consisted of 150 mm lines with a marker that could be moved from end to end with a mouse. Line scales were anchored with descriptors at 12.5 mm from each end. Panelists marked each scale to indicate ratings of intensities of attributes. Frankfurter samples were evaluated once each day during the 5 testing sessions. Descriptive panelists received an honorarium of 10 or 12 dollars for their participation based on experience.

Statistical Analysis

Statistical Analysis Software System (Version 8.0, SAS Institute, Cary, NC) was used to analyze all data results. Analysis of variance, using the general linear model (PROC GLM), was conducted on each attribute to identify the significant differences in sensory ratings on frankfurter samples for all storage times and irradiation doses.

Regression analysis (PROC REG) was used to calculate the coeffecient of determination (R^2) and to develop prediction models using each sensory attribute as dependent variables and irradiation dose and storage time as independent variables. Equations for consumer attributes with R^2 values less than 0.75 were not considered acceptable (Meilgaard, 1991) for predicting each sensory attribute rating from the independent variables of irradiation dose and storage time. Regression analysis was performed on data from two irradiation processing replications of frankfurters (3 days x 4 doses x 2 reps = 24 data points). The quadratic model for the attributes included the linear terms, irradiation dose and storage time; the squared terms, dose x dose and day x day; and the interaction dose x day.

Significant full models ($\alpha < 0.05$) from descriptive attributes with $R^2 \geq 0.50$ were selected to test if reduced models could be used to predict the response variables. All reduced models with $R^2 \geq 0.50$ were compared to full models by calculating the F-statistic. Model significance at $\alpha = 0.05$ level was determined using the F-ratio calculated from the following equation (Cornell, 1982):

$$F = \frac{\text{Sum of Squares Full Model} - \text{Sum of Squares Reduced Model}}{\text{Number of terms in Full Model} - \text{Number of terms in Reduced Model}} \times \frac{1}{\text{Residual Mean Square of Full Model}}$$

If the F-ratio exceeded the appropriate tabular value obtained from degress of freedom and the number of terms in the full model, then the reduced model is significantly different from the full model and could not be used. Otherwise, if the reduced model with the least amount of variables was not significantly different from the full model at $\alpha = 0.05$, then the model was used to predict a particular response variable. Contour maps were plotted using Statistca® (Statistica ® 2001) Version 6.0 (Statsoft, Inc., Tulsa OK) from final prediction models, calculated from mean data, to determine effects of irradiation dose and storage time on each sensory attribute.

Verification

Data from the third replication was used for verification. Snee (1977) concluded that a portion of the data could be used to estimate the model coefficients and the remainder of the data is used to verify the prediction accuracy of the model. Paired t-tests (PROC T-TEST) was performed to determine the probability that ratings of samples given the same irradiation dose and storage time were not significantly different from each other at $\alpha=0.05$.

RESULTS

Consumer Attributes

The consumer attribute regression equations that had coefficient of determination (R^2) greater than or equal to 0.75 and with a probability of less than 0.05 are overall acceptance, and acceptance of flavor, tenderness and juiciness. The full and reduced models for significant consumer attributes are shown in Table 4.2. Contour plots of significant descriptive attributes for irradiated frankfurters were superimposed onto the optimum region. The non-irradiated frankfurters were not acceptable (≤6 or like slightly) from the first day after irradiation throughout the 32 day shelf life, and therefore will not be discussed further.

Overall Acceptance. Throughout the 32 day shelf life of the irradiated frankfurters, overall acceptance (Fig. 4.1A) decreased with decreasing dose and increasing storage time. Overall acceptance ranged from 5.6 to 6.2 in the irradiated samples. Throughout the storage time, non-irradiated samples were rated 5 or neither like nor dislike for overall acceptance. The criteria of acceptability was ≥ 6 or like slightly. The overall quality of electron-beam irradiated frankfurters will remain acceptable for up to 21 days for samples irradiated at 3 kGy, 13 days for samples irradiated at 2 kGy, 5 days for samples irradiated at 1 kGy and non-irradiated frankfurters were predicted to be unacceptable throughout the 32 day storage time.

Flavor. Throughout the 32 day shelf life of the irradiated frankfurters, the ratings for acceptance of flavor (Fig. 4.1B) ranged from 5.4 to 6.2 and decreased throughout the storage time. The frankfurters irradiated at 3 kGy were predicted to receive a rating of 6 or like slightly for up to 12 days, 14 days for frankfurters irradiated at 2 kGy, 7 days for frankfurters irradiated at 1 kGy, and the non-irradiated frankfurters are predicted to have a rating of < 6 or like slightly throughout the storage time. Maximum shelf life will occur at 15 days of refrigerated storage after irradiation with a dose of 2.5 kGy.

Juiciness. Throughout the 32 days of shelf life of the non-irradiated and irradiated frankfurters, the consumer acceptance ratings for juiciness (Fig. 4.1C) decreased with decreasing dose and throughout the 32 day storage time. The acceptance ratings for juiciness ranged from

Table 4.2. Regression equations for full and reduced models for the prediction of consumer[1] attributes for electron-beam irradiated ready-to-eat poultry frankfurters[2]

Attribute		Prediction equation[3]						Adjusted R-square
Overall Acceptability								
	Full	5.8431 +	$0.2530\ X_1$	$-\ 0.0007\ X_2$	$-\ 0.0449\ X_1^2$	$-\ 0.0004\ X_2^2$	$-\ 0.0003\ X_1{*}X_2$	0.78
	Reduced	5.9661 +	$0.1131\ X_1$	$-\ 0.0142\ X_2$	——[4]	——	——	0.78
Flavor								
	Full	5.8934 +	$0.2215\ X_1$	$-\ 0.0044\ X_2$	$-\ 0.0648\ X_1^2$	$-\ 0.0005\ X_2^2$	$+\ 0.0044\ X_1{*}X_2$	0.83
	Reduced	5.8678 +	$0.3003\ X_1$	$-\ 0.0151\ X_2$	$-\ 0.0648\ X_1^2$	——	——	0.75
Juiciness								
	Full	5.7469 +	$0.1216\ X_1$	$+\ 0.0110\ X_2$	$-\ 0.0225\ X_1^2$	$-\ 0.0009\ X_2^2$	$+\ 0.0020\ X_1{*}X_2$	0.83
	Reduced	5.7159 +	$0.0897\ X_1$	$+\ 0.0140\ X_2$	——	$-\ 0.0009\ X_2^2$	——	0.85
Tenderness								
	Full	5.9078 +	$0.0288\ X_1$	$-\ 0.0151\ X_2$	$+\ 0.0014\ X_1^2$	$-\ 0.0002\ X_2^2$	$+\ 0.0021\ X_1{*}X_2$	0.77
	Reduced	5.8879 +	$0.0707\ X_1$	$-\ 0.0190\ X_2$	——	——	——	0.83

[1]50 panelists evaluated samples of e-beam irradiated frankfurters using a 9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely. Equations were obtained by using two replications.

[2]Full models of consumer attributes with adjusted coefficient of determination, R^2 = 0.75 were used to develop reduced models.

[3]Variables in models are:

x_1=dose

x_2=day

x_1^2=dose*dose

x_2^2=day*day

$x_1{*}x_2$=dose*day

[4]Blanks indicate that the variable of the full model above it was removed from the reduced model.

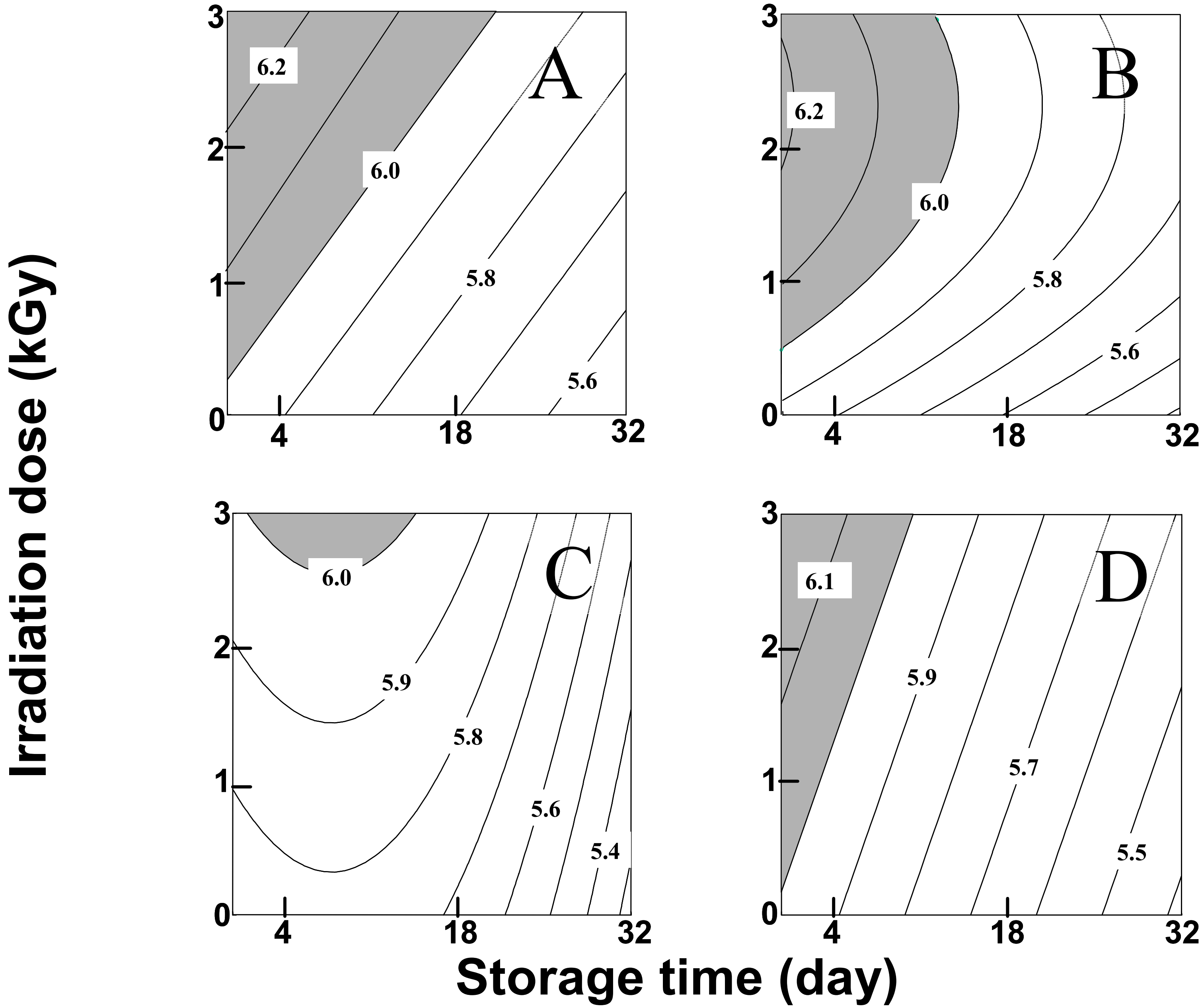
5.3 to 6.0. During any given time from 0 to 32 days, the frankfurters were rated higher with increasing irradiation doses. The frankfurters irradiated at 3 kGy are predicted to have a rating of 6 or like slightly from day 1 for up to 15 days after irradiation, whereas the remaining samples irradiated at 0 to 2.5 kGy would never receive ratings of 6, and were only marginally acceptable throughout their shelf life. At any given dose, the juiciness of the irradiated frankfurters is predicted to increase immediately after irradiation and continue to increase until 10 days after irradiation and then decrease throughout the storage time.

Tenderness. Throughout the 32 day shelf life of the irradiated frankfurters, the acceptance of tenderness (Fig. 4.1D) decreased throughout the storage time. Acceptance of tenderness is predicted to increase with irradiation dose, but decrease with storage time. The ratings for acceptance of tenderness range from 5.4 to 6.1. The acceptance of tenderness of the frankfurters would receive a rating of 6 or like slightly for up to 8 days for frankfurters irradiated at 3 kGy, 6 days for frankfurters irradiated at 2 kGy, 2 days for frankfurters irradiated at 1 kGy and non-irradiated frankfurters are predicted to have ratings below 6 or like slightly throughout the 32 day storage time and receive only marginally acceptable ratings.

The consumer attributes of aroma, color and appearance did not receive ratings of ≥ 6 or like slightly or higher and the mouthfeel attribute only received a rating of 6 for frankfurters irradiated at 3 kGy one day after irradiation. The red color of the frankfurters may have affected the color and appearance ratings, resulting in their lower acceptance. Aroma ratings (by sniffing) were low and disregarded in lieu of flavor acceptance (by tasting the samples) ratings, which were higher.

Optimum Region. The region of overlap of contour plots for overall acceptance, flavor, juiciness and tenderness representing irradiation dose and storage time treatment combination at

Figure 4.1. Contour plots illustrating the effects of irradiation dose and storage time (days) on overall acceptance (A), and acceptance of flavor (B), juiciness (C) and tenderness (D) of electron-beam irradiated frankfurters. The shaded area indicates a rating of ≥ 6 for all combinations of irradiation dose and storage period.



Irradiation dose (kGy)
Storage time (day)
A
6.2
6.0
5.8
5.6
B
6.2
6.0
5.8
5.6
C
6.0
5.9
5.8
5.6
5.4
D
6.1
5.9
5.7
5.5
0
1
2
3
4
18
32

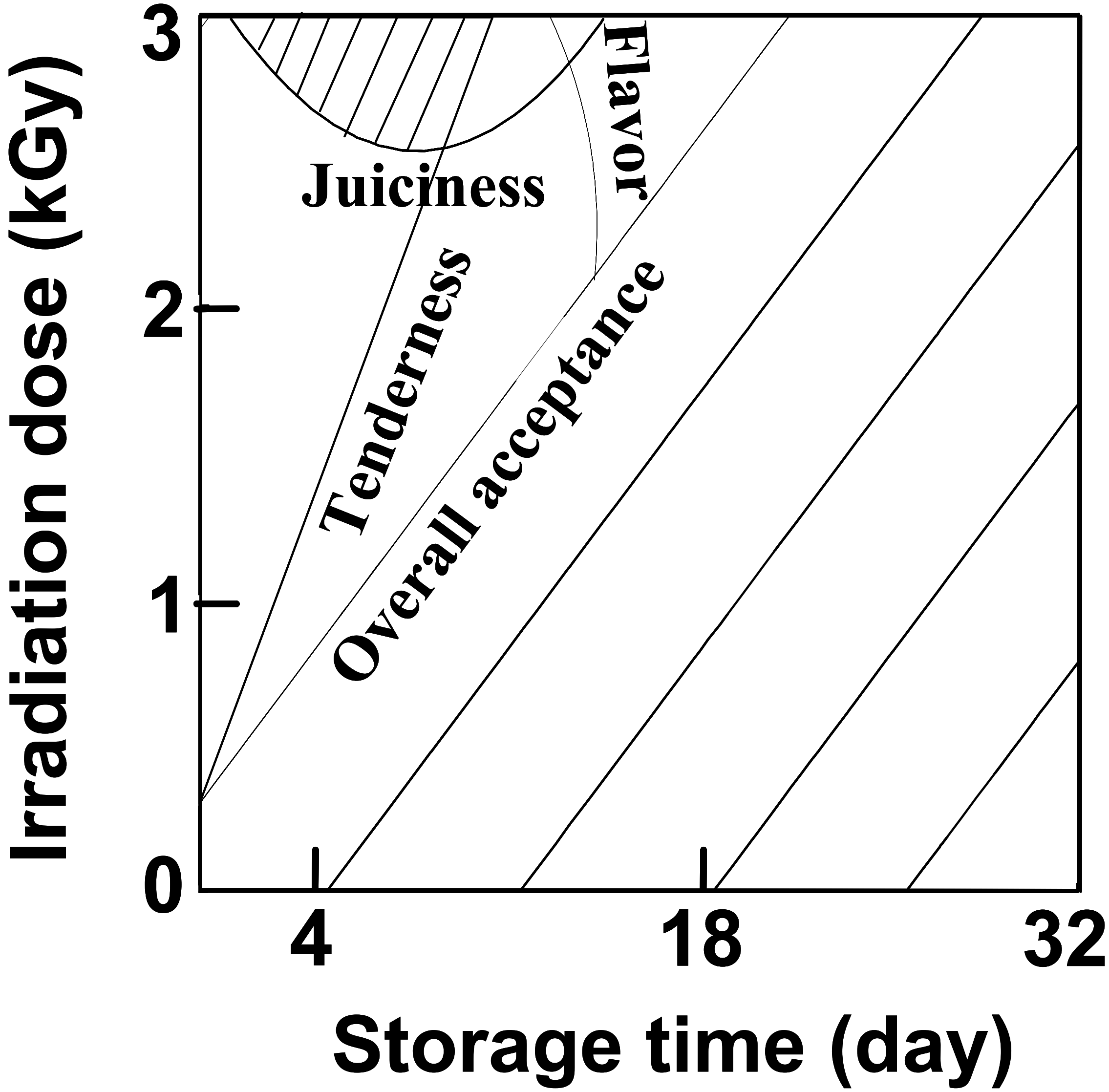
any dose up to 3 kGy and storage time up to 32 days resulting in ratings ≥ 6 or like slightly are presented in Fig. 4.2. Overall acceptance with ratings of 6 or greater resulted in the largest number of treatment combinations. Fewer treatment combinations met the criteria for the acceptance of flavor, followed by tenderness. Juiciness resulted in the least number of treatment combinations. The number of treatment combinations is lessened that meet acceptance criteria for juiciness, flavor, and overall acceptance. Then it is least when acceptance of juiciness, flavor, tenderness and overall acceptance are met. The optimum was found to be that region representing a 3 kGy dose and 2 to 11 days after storage; 2.5 kGy dose for 8 days after irradiation and all dose and day storage treatments between these boundaries.

Descriptive Attributes

Significant ($P< 0.05$) descriptive attributes with a coefficient of determination (R^2) greater than or equal to 0.50 are chickeny, cured meat, wet dog aromas; off-flavor meaty and cured meat flavors; and sour taste. Their full models are shown in Table 4.3, as are the reduced models used to prepare contour plots for irradiated frankfurters and superimposed onto the regions for consumer acceptance and the optimum region.

Chickeny. The chickeny aroma (Fig. 4.3A) of the irradiated frankfurters was affected by storage time. At any day during the 32 day storage time, the ratings for chickeny aroma would be identical, regardless of irradiation dose. The ratings for chickeny ranged from 27 to 28.8. One day after irradiation, the chickeny aroma would be rated at 28.3 and peaked to 28.8 by 11 through 15 days after storage. After 15 days of irradiation, the chickeny aroma decreased throughout the remaining storage time.

Figure 4.2. A contour plot illustrating the effect of irradiation dose and storage time (days) on the optimum region composed by the overlap of consumer overall acceptance, and acceptance of flavor, juiciness and tenderness of electron-beam irradiated frankfurters. The optimum region is identified by the hatched area, the area of overlap which indicates all combinations of irradiation dose and storage period that would receive a rating of ≥ 6 for all consumer acceptance attributes.



Irradiation dose (kGy)
3
2
1
0
Juiciness
Flavor
Tenderness
Overall acceptance
4
18
32
Storage time (day)

Table 4.3. Regression equations for full and reduced models for the prediction of descriptive[1] attributes for electron-beam irradiated ready-to-eat poultry frankfurters[2]

ATTRIBUTE	PREDICTION EQUATION[3]						ADJUSTED R-SQUARE
Chickeny							
Full	28.2809	- 0.0389 X_1	+ 0.0773 X_2	- 0.0137 X_1^2	- 0.0037 X_2^2	+ 0.0108 $X_1{*}X_2$	0.55
Reduced	28.1748	——[4]	+ 0.0936 X_2	——	- 0.0037 X_2^2	——	0.55
Cured meat							
Full	25.1496	- 0.2414 X_1	+ 0.0777 X_2	+ 0.0755 X_1^2	- 0.0033 X_2^2	+ 0.0046 $X_1{*}X_2$	0.59
Reduced	25.0519	——	+ 0.0846 X_2	——	- 0.0033 X_2^2	——	0.61
Wet dog							
Full	0.9203	+ 0.2524 X_1	- 0.2615 X_2	+ 0.1334 X_1^2	+ 0.0131 X_2^2	- 0.0498 $X_1{*}X_2$	0.57
Reduced	1.7656	——	- 0.3362 X_2	——	+ 0.0131 X_2^2	——	0.56
Off-flavor							
Full	0.3011	+ 0.7264 X_1	- 0.1880 X_2	+ 0.0026 X_1^2	+ 0.0110 X_2^2	- 0.0709 $X_1{*}X_2$	0.54
Reduced	0.2984	+ 0.7343 X_1	- 0.1880 X_2	——	+ 0.0110 X_2^2	- 0.0709 $X_1{*}X_2$	0.53
Meaty							
Full	28.8412	- 0.1633 X_1	+ 0.0519 X_2	+ 0.0366 X_1^2	- 0.0031 X_2^2	+ 0.0067 $X_1{*}X_2$	0.59
Reduced	29.4316	——	+ 0.0507 X_2	——	——	——	0.51
Cured meat							
Full	31.6123	- 0.2802 X_1	- 0.0819 X_2	+ 0.1070 X_1^2	+ 0.0007 X_2^2	+ 0.0010 $X_1{*}X_2$	0.51
Reduced	31.3973	——	- 0.0535 X_2	——	——	——	0.57

Table 4.3. Continued

Sour							
Full	1.3013 +	0.8070 X_1	- 0.4857 X_2 +	0.1154 X_1^2	+ 0.0248 X_2^2	- 0.1069 X_1*X_2	0.65
Reduced	2.9158	———	- 0.6460 X_2	———	+ 0.0248 X_2^2	———	0.56

[1]Descriptive panelists evaluated samples of e-beam irradiated frankfurters using 150 mm line scales. Equations were obtained by using two replications.

[2]Full models of descriptive attributes with adjusted coefficient of determination, R^2 = 0.50 were used to develop reduced models.

[3]Variables in models are:

x_1=dose

x_2=day

x_1^2=dose*dose

x_2^2=day*day

x_1*x_2=dose*day

[4]Blanks indicate that the variable of the full model above it was removed from the reduced model.

Overall acceptance and acceptance of flavor of samples irradiated up to a maximum of 2 kGy have similar ratings. From doses of 2 kGy to 3 kGy, these lines diverged. The chickeny aroma of the frankfurters irradiated at 1 kGy should receive a rating of 28.5. This occurred up to 5 days of refrigerated storage after irradiation. Frankfurters irradiated at 2 kGy should receive a rating of 28.8. This occurred for up to 14 days, after which consumers would rate it no longer acceptable. Frankfurters irradiated at 3 kGy should receive chickeny ratings of 28.3 or higher for up to 20 days for overall acceptance and 11 days for the acceptance of flavor. For optimum acceptance or a rating of ≥ 6 for overall acceptance and acceptance of flavor, juiciness and tenderness, the chickeny aroma intensity rating of the irradiated frankfurters should be from 28.3 or higher. This rating is obtained between 2 and 11 days after irradiation at a dose of 3 kGy and 8 days after irradiation at 2.5 kGy.

Cured meat. The cured meat aroma (Fig. 4.3B) of the irradiated frankfurters was only affected by storage time. At any day during the 32 day storage period, the ratings for cured meat aroma would be the same, regardless of irradiation dose. The ratings for cured meat ranged from 24.5 to 25.5. At 3 days after irradiation, the cured meat aroma was rated at 25.3. The cured meat aroma of the irradiated frankfurters was rated 25.5 at day 8 and remained constant from day 8 to day 19. After 19 days of irradiation, the cured meat aroma decreased throughout the remaining storage time.

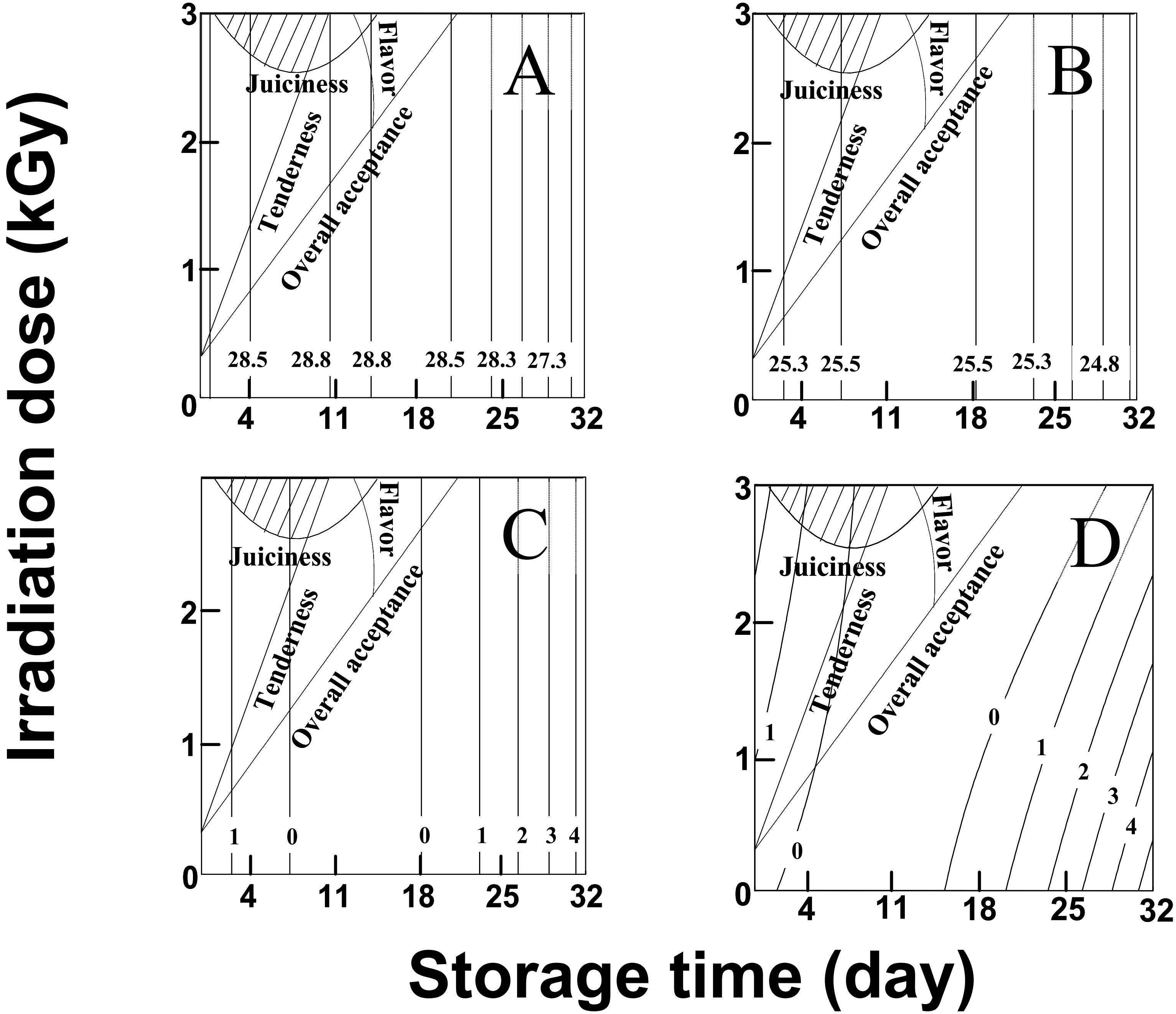
For overall acceptance and the acceptance of flavor, the cured meat aroma of the frankfurters irradiated from 0.25 kGy increased with increasing dose up to 2 kGy. Frankfurters irradiated at 1 kGy should receive an intensity rating of 25.4. This occurred at 5 days after irradiation, and frankfurters irradiated at 2 kGy should receive a rating of 25.5 at 14 days. Frankfurters irradiated at 3 kGy should receive ratings of 25.2 or higher for overall acceptance and flavor acceptance. This occurs at 20 and 12 days, respectively. For optimum acceptance of the cured meat aroma for the irradiated frankfurters, ratings should be from 25.2 to 25.6. After irradiation at a dose of 3 kGy, the storage time for these frankfurters is between 2 and 11 days and 8 days after irradiation at 2.5 kGy.

Wet dog. The wet dog aroma (Fig. 4.3C) of the irradiated frankfurters was low and ranged from 0 to 4. The intensity of wet dog aroma was only affected by storage time. At any day during the storage time, the ratings for wet dog would be the same, regardless of irradiation dose. The wet dog aroma was slightly detected immediately after irradiation, however the flavor disappeared around 8 days after irradiation and was not detected again until 23 days after irradiation. After 23 days of storage, the wet dog aroma increased.

For overall acceptance, the wet dog aroma rating should be 0-1 for the frankfurters irradiated up to 3 kGy. Frankfurters irradiated at 3 kGy would receive a wet dog intensity rating of approximately 0.5 after 20 days of storage for overall acceptance. For acceptance of flavor, the frankfurters irradiated at 1 kGy would receive a rating of 1 for up to 5 days of storage, 2 kGy would receive a rating of 0 for up to 14 days and 3 kGy would receive a rating of 0 for up to 12 days after irradiation. For optimum acceptance, the wet dog aroma for the irradiated frankfurters, ratings should be no more than 0 to 1 corresponding to 2 through 11 days after irradiation at a dose of 3 kGy and 8 days for frankfurters irradiated at 2.5 kGy.

Off-flavor. The intensity of off-flavor (Fig. 4.3D) of the irradiated frankfurters was affected by both irradiation dose and storage time. The ratings for off-flavor remained low throughout the storage time and ranged from 0 to 5. Initially after irradiation, a slight off-flavor was detected among irradiated frankfurters that were not present in non-irradiated samples. This

Figure 4.3. Contour plots illustrating the effects of irradiation dose and storage time (days) on descriptive attributes chickeny aroma (A), cured meat aroma (B), wet dog aroma (C) and off-flavor (D) intensity of electron-beam irradiated frankfurters. The hatched area indicates all combinations of irradiation dose and storage period that would receive a rating of ≥ 6 for all consumer acceptance attributes.


Irradiation dose (kGy)
Storage time (day)
A
Juiciness
Flavor
Tenderness
Overall acceptance
28.5
28.8
28.8
28.5
28.3
27.3
B
25.3
25.5
25.5
25.3
24.8
C
D
0
1
2
3
4
11
18
25
32

flavor increased with increasing dose from 0 to 7 days of storage. This flavor disappeared at day 5 and 13 for the frankfurters irradiated at 1 and 3 kGy, respectively. This off-flavor was not detected in non-irradiated frankfurters until 20 days after irradiation. The off-flavor reappeared at 23, 27 and 32 days after irradiation for the 1, 2 and 3 kGy frankfurters, respectively. Approximately 20 days after irradiation, the off-flavor increased with decreasing dose.

The intensity ratings for off-flavor of the irradiated frankfurters would be 0 to 1 for 20 days after irradiation. Regardless of dose, the intensity ratings for flavor would be 0 for 5 and 14 days after irradiation for frankfurters irradiated at 1 and 2 kGy and receive a rating of 0 for 20 days after irradiation for frankfurters irradiated at 3 kGy. For optimum acceptance, at 2 days after irradiation, the frankfurters irradiated at 2.5 to 3.0 kGy would receive a rating of 1.

Meaty. The meaty flavor (Fig. 4.4A) ranged from 28 to 29.3. The meaty flavor of the irradiated frankfurters was only affected by storage time. At any day during the storage time, the ratings for meaty flavor would be identical, regardless of irradiation dose. The meaty flavor decreased throughout the 32 day storage period.

For overall acceptance, meaty intensity ratings should be 29.2 for 1 kGy corresponding to storage for up to 5 days after irradiation and 28.8 for 2 kGy corresponding to up to 14 days after irradiation. Results for acceptance of flavor are identical to that of overall acceptance up to 2 kGy. For overall acceptance and acceptance of flavor for frankfurters irradiated at 3 kGy, they should receive a rating for meaty intensity of 28.4 up to 20 days after irradiation and 28.9 up to 11 days, respectively. For optimum acceptance, frankfurters irradiated at 3.0 kGy, would receive ratings of 29.4 to 29.9 from 2 through 11 days after irradiation and for samples irradiated at 2.5 kGy and held for 8 days after storage.

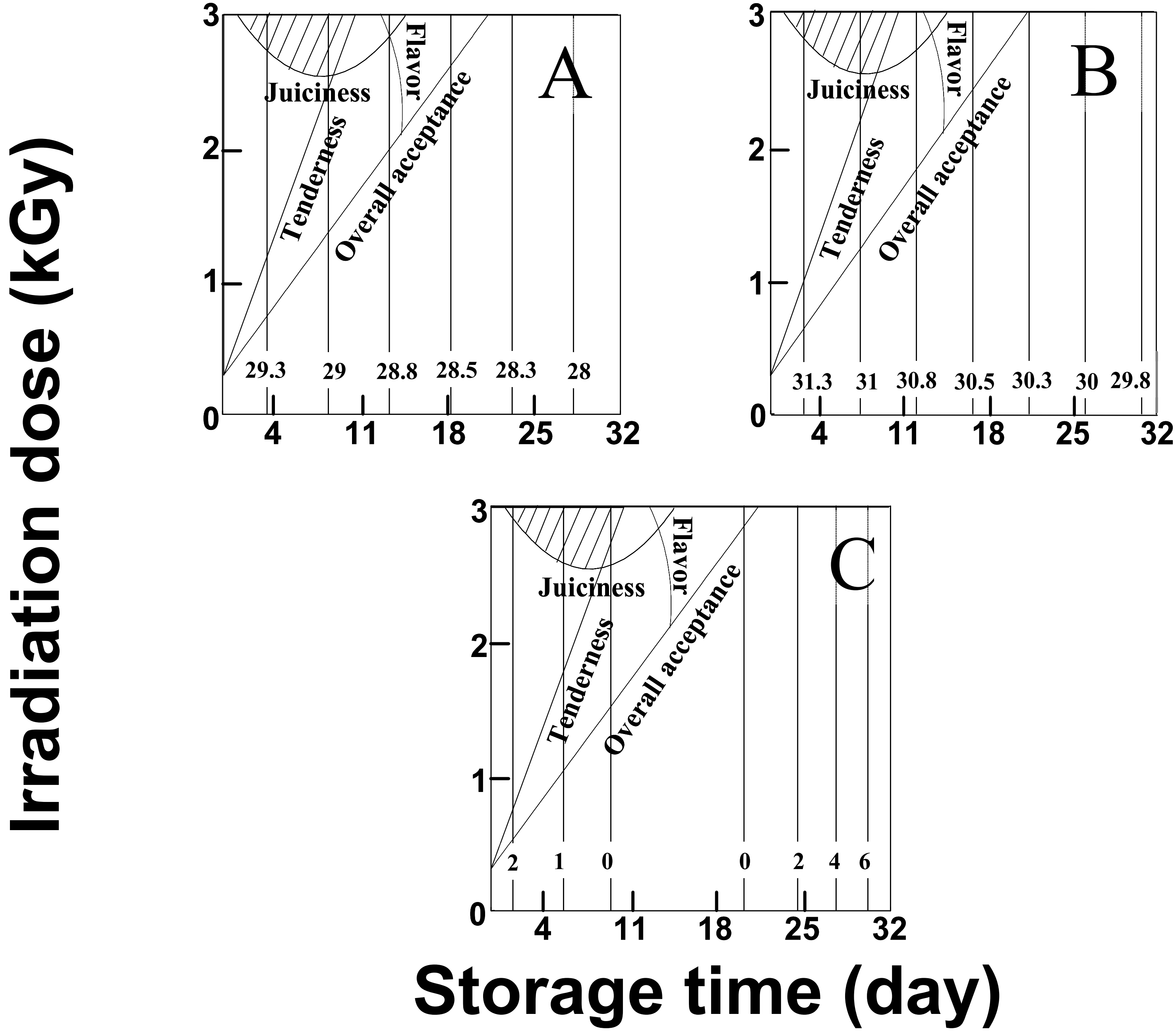
Cured Meat. The cured meat flavor (Fig. 4.4B) ranged from 29.8 to 31.3 and decreased throughout the storage time. The cured meat flavor of the irradiated frankfurters was only affected by storage time. At any day during the storage time, the ratings for cured meat flavor would be the identical, regardless of irradiation dose.

The frankfurters irradiated at 1 and 2 kGy should receive ratings of 31.2 corresponding to storage of up to 5 days and 30.7 to 14 days after irradiation, respectively. For overall acceptance and acceptance of flavor of frankfurters irradiated at 3 kGy, the cured meat intensity rating would be 30.3 corresponding to 20 and 30.8 for up to 12 days after irradiation, respectively. For optimum acceptance, the frankfurters irradiated at 3.0 kGy would receive ratings of 31.4 and 30.9 corresponding to storage of 2 through 11 days after irradiation.

Sour. The ratings for sour taste (Fig. 4.4C) ranged from 0 to 7 throughout the storage time. A sour flavor was detected in all frankfurters as early as 2 days after irradiation and decreased in intensity so that sourness was not detected (rating = 0) between 9 and 20 days after irradiation. The sour taste reappeared (rating > 0) 22 days after irradiation and increased to an intensity rating of 7 toward the end of storage. The sour taste of the irradiated frankfurters was only affected by storage time. At any day during the storage time, the ratings for sour taste would be the same, regardless of irradiation dose.

The frankfurters irradiated at 1 and 2 kGy received sour intensity ratings of 0 corresponding to 9 and 20 days after irradiation, respectively. The overall acceptance and the acceptance of flavor of the frankfurters irradiated at 3 kGy received sour intensity ratings of 0 corresponding to up to 20 days after irradiation for overall acceptance and up

Figure 4.4. Contour plots illustrating the effects of irradiation dose and storage time (days) on descriptive attributes meaty flavor (A), cured meat flavor (B) and sour taste (C) intensity of electron-beam irradiated frankfurters. The hatched area indicates all combinations of irradiation dose and storage period that would receive a rating of ≥ 6 for all consumer acceptance attributes.



Irradiation dose (kGy)
Storage time (day)
A
Juiciness
Flavor
Tenderness
Overall acceptance
29.3
29
28.8
28.5
28.3
28
B
Juiciness
Flavor
Tenderness
Overall acceptance
31.3
31
30.8
30.5
30.3
30
29.8
C
Juiciness
Flavor
Tenderness
Overall acceptance
2
1
0
0
2
4
6
0
1
2
3
4
11
18
25
32

to 11 days after irradiation for acceptance of flavor. The optimum acceptance of the frankfurters irradiated 3.0 kGy should receive sour intensity ratings no more than 2, corresponding to 2 through 11 days after irradiation.

Verification of prediction models

The observed and predicted mean values for consumer overall acceptance and acceptance of flavor and descriptive attributes for aroma, flavor and taste of electron-beam irradiated frankfurters are shown in Tables 4.4 through 4.7. No significant differences were found among all attributes between the observed and predicted mean values for each of the consumer acceptance or descriptive analysis attributes of irradiated frankfurters. This validates the prediction equations developed in this study.

DISCUSSION

Consumer Attributes

Overall Acceptance. Overall acceptance of all frankfurters decreased throughout the 32 day shelf life with the higher irradiation doses receiving the highest ratings for overall acceptance. Candogan and Kolsarici (2003) also found that scores for all sensory attributes of non-irradiated frankfurters decreased significantly ($P<0.05$) over time having the lowest values at the end of shelf life (day 49) due to increased microbial growth and deterioration of some quality characteristics of frankfurters during storage. Sofos (1983) found overall acceptability scores of non-irradiated beef-pork frankfurters formulated with 2.5% salt were high and remained in the acceptable range through long periods of storage (24-65 days), whereas in this study we found that non-irradiated poultry frankfurters were not acceptable, and received a hedonic rating

Table 4.4. T-test results of observed and predicted mean values for consumer acceptance attributes of electron-beam irradiated frankfurters[1]

		Overall Acceptance			Acceptance of flavor		
Storage Time (Day)	**Irradiation Dose (kGy)**	**Obs[2]**	**Pred[3]**	**Prob[4]**	**Obs[2]**	**Pred[3]**	**Prob[4]**
4	**0**	5.89	5.91	0.4782	5.78	5.81	0.5960
4	**1**	5.91	6.02	0.8213	5.58	6.04	0.2458
4	**2**	6.21	6.14	0.9523	6.06	6.15	0.2598
4	**3**	6.07	6.25	0.6148	5.64	6.13	0.7892
18	**0**	5.69	5.71	0.7029	5.66	5.60	0.6254
18	**1**	5.95	5.82	0.3364	5.82	5.83	0.7814
18	**2**	5.99	5.94	0.5197	6.12	5.94	0.3629
18	**3**	6.09	6.05	0.8145	6.00	5.91	0.4592
32	**0**	5.18	5.51	0.2418	4.86	5.38	0.1298
32	**1**	5.82	5.62	0.5961	5.45	5.62	0.8536
32	**2**	5.72	5.74	0.6346	5.96	5.73	0.4781
32	**3**	5.80	5.85	0.9120	5.86	5.70	0.2695

[1]Acceptance ratings are based on a 9-point hedonic scale where 1=dislike extremely, 5=neither like nor dislike, 9=like extremely.

[2]Obs=observed values, which are the means of third replication.

[3]Pred=predicted values, which are predicted from two replications.

[4]Prob=probability that paired scores are significantly different from each other at α=0.05.

Table 4.5. T-test results of observed and predicted mean values for descriptive aroma attributes of electron-beam irradiated frankfurters[1]

		Chickeny			Cured meat		
Storage Time (Day)	**Irradiation Dose (kGy)**	**Obs[2]**	**Pred[3]**	**Prob[4]**	**Obs[2]**	**Pred[3]**	**Prob[4]**
4	**0**	28.35	28.49	0.5984	25.57	25.34	0.9623
4	**1**	28.57	28.49	0.2395	25.72	25.34	0.5284
4	**2**	28.29	28.49	0.4177	24.52	25.34	0.9258
4	**3**	28.66	28.49	0.1295	26.17	25.34	0.1654
11	**0**	29.24	28.75	0.8741	26.41	25.59	0.2361
11	**1**	29.48	28.75	0.9635	26.10	25.59	0.5470
11	**2**	29.85	28.75	0.2398	26.33	25.59	0.9526
11	**3**	28.34	28.75	0.2142	25.73	25.59	0.3216
18	**0**	28.72	28.65	0.9526	26.03	25.52	0.1478
18	**1**	28.42	28.65	0.1754	25.72	25.52	0.5263
18	**2**	28.36	28.65	0.2601	25.42	25.52	0.8497
18	**3**	28.87	28.65	0.5819	25.07	25.52	0.4962
25	**0**	27.76	28.18	0.5368	24.26	25.14	0.1594
25	**1**	28.69	28.18	0.4218	25.42	25.14	0.6258
25	**2**	28.10	28.18	0.9566	24.67	25.14	0.3579
25	**3**	28.40	28.18	0.7953	25.26	25.14	0.2685
32	**0**	27.40	27.35	0.8417	24.76	24.43	0.9687
32	**1**	27.41	27.35	0.3541	24.50	24.43	0.6158
32	**2**	27.60	27.35	0.9522	25.09	24.43	0.2542
32	**3**	27.27	27.35	0.6145	24.57	24.43	0.3687

Table 4.5. Continued

Storage Time (Day)	Irradiation Dose (kGy)	Wet dog			Off-flavor		
		Obs[2]	Pred[3]	Prob[4]	Obs[2]	Pred[3]	Prob[4]
4	**0**	0.00	0.63	0.9528	0.00	-0.28	0.6325
4	**1**	0.00	0.63	0.6321	0.00	0.17	0.4126
4	**2**	0.00	0.63	0.4623	0.00	0.62	0.6982
4	**3**	0.00	0.63	0.2954	0.00	1.08	0.1635
11	**0**	0.00	-0.35	0.3215	0.00	-0.44	0.8534
11	**1**	1.28	-0.35	0.4752	0.00	-0.48	0.6498
11	**2**	0.00	-0.35	0.6251	0.00	-0.53	0.1321
11	**3**	0.00	-0.35	0.9853	0.00	-0.57	0.7548
18	**0**	0.00	-0.05	0.2478	0.00	0.49	0.9659
18	**1**	0.00	-0.05	0.6235	0.00	-0.05	0.2687
18	**2**	0.00	-0.05	0.1985	0.00	-0.59	0.5431
18	**3**	0.00	-0.05	0.7684	0.00	-1.14	0.3163
25	**0**	0.00	1.54	0.5336	0.00	2.49	0.9852
25	**1**	0.00	1.54	0.8561	0.00	1.45	0.5874
25	**2**	1.58	1.54	0.2941	0.00	0.42	0.6312
25	**3**	0.00	1.54	0.8799	0.00	-0.62	0.9850
32	**0**	9.67	4.40	0.2637	4.33	5.58	0.4891
32	**1**	3.42	4.40	0.1526	0.00	4.04	0.6532
32	**2**	1.91	4.40	0.3652	0.00	2.51	0.7875
32	**3**	4.33	4.40	0.9587	0.00	0.98	0.9450

[1]Intensity ratings are based on 150 mm line scale.

[2]Obs=observed values, which are the means of third replication.

[3]Pred=predicted values, which are predicted from two replications.

[4]Prob=probability that paired scores are significantly different from each other at α=0.05.

Table 4.6. T-test results of observed and predicted mean values for descriptive flavor attributes of electron-beam irradiated frankfurters[1]

Storage Time (Day)	Irradiation Dose (kGy)	Meaty			Cured meat		
		Obs[2]	Pred[3]	Prob[4]	Obs[2]	Pred[3]	Prob[4]
4	**0**	28.36	29.23	0.5982	30.45	31.18	0.1694
4	**1**	29.62	29.23	0.6231	30.98	31.18	0.9641
4	**2**	28.73	29.23	0.1847	30.82	31.18	0.8632
4	**3**	28.81	29.23	0.2691	31.95	31.18	0.4978
11	**0**	28.94	28.87	0.3699	32.03	30.81	0.5166
11	**1**	28.20	28.87	0.4368	31.13	30.81	0.3942
11	**2**	29.33	28.87	0.8531	31.34	30.81	0.2986
11	**3**	29.84	28.87	0.9785	31.72	30.81	0.6435
18	**0**	28.94	28.52	0.6197	30.33	30.43	0.7642
18	**1**	29.10	28.52	0.4873	29.99	30.43	0.6517
18	**2**	28.37	28.52	0.9831	30.07	30.43	0.7667
18	**3**	29.33	28.52	0.7984	30.23	30.43	0.4985
25	**0**	28.42	28.16	0.5617	30.67	30.06	0.1864
25	**1**	28.34	28.16	0.3964	29.99	30.06	0.3618
25	**2**	27.83	28.16	0.1976	29.23	30.06	0.8449
25	**3**	28.10	28.16	0.3325	29.81	30.06	0.7310
32	**0**	28.73	27.81	0.9460	30.17	29.69	0.9489
32	**1**	38.50	27.81	0.7643	30.90	29.69	0.6823
32	**2**	27.91	27.81	0.5978	29.50	29.69	0.3481
32	**3**	27.90	27.81	0.2260	30.58	29.69	0.8620

[1]Intensity ratings are based on 150 mm line scale.

[2]Obs=observed values, which are the means of third replication.

[3]Pred=predicted values, which are predicted from two replications.

[4]Prob=probability that paired scores are significantly different from each other at $\alpha=0.05$.

Table 4.7. T-test results of observed and predicted mean values for descriptive taste attribute of electron-beam irradiated frankfurters[1]

Storage Time (Day)	Irradiation Dose (kGy)	Sour		
		Obs[2]	Pred[3]	Prob[4]
4	**0**	0.00	0.73	0.9568
4	**1**	0.00	0.73	0.1687
4	**2**	0.00	0.73	0.2645
4	**3**	0.00	0.73	0.3816
11	**0**	0.00	-1.19	0.4621
11	**1**	0.00	-1.19	0.9762
11	**2**	0.00	-1.19	0.8720
11	**3**	0.00	-1.19	0.6158
18	**0**	0.00	-0.69	0.5984
18	**1**	0.00	-0.69	0.6153
18	**2**	0.00	-0.69	0.7948
18	**3**	0.00	-0.69	0.6159
25	**0**	0.00	2.24	0.1976
25	**1**	0.00	2.24	0.6155
25	**2**	0.00	2.24	0.7984
25	**3**	0.00	2.24	0.6481
32	**0**	11.17	7.60	0.9460
32	**1**	4.17	7.60	0.1912
32	**2**	1.91	7.60	0.3367
32	**3**	6.26	7.60	0.9423

[1]Intensity ratings are based on 150 mm line scale.

[2]Obs=observed values, which are the means of third replication.

[3]Pred=predicted values, which are predicted from two replications.

[4]Prob=probability that paired scores are significantly different from each other at $\alpha=0.05$.

of 5.6-5.9 (=neither like nor dislike) throughout the 32 day storage period. Terrell et al. (1982) found significant differences between control frankfurters and frankfurters irradiated at 32 kGy, however the frankfurters irradiated at 32 kGy were less palatable. The higher irradiation dose used may have resulted in off-flavor. However, we used a maximum of 3 kGy and these frankfurters were rated high in consumer acceptance (=6.2).

Flavor. Frankfurters irradiated at 2.5 kGy would receive the highest ratings for flavor acceptance throughout the storage time, however the acceptance of flavor would decrease with storage time. Similarly, Johnson et al. (2000) found that pepperoni irradiated at doses as high as 3.0 kGy did not affect the intensity of flavor. In contrast to our study, they did not store their product.

Montgomery et al. (2003) studied the effects of storage and packaging on the flavor of irradiated (2 kGy) ground beef patties. They found that at 6 days of storage, the flavor intensity of the non-irradiated and irradiated ground beef patties was not significantly different. However, the irradiated ground beef patties were found to have a more intense flavor than the non-irradiated patties. The patties received ratings of 5 corresponding to an extremely intense flavor on a 5-point scale. The difference in intensity of flavor between irradiated and non-irradiated controls was only 0.2 points (5.2 vs. 5.4) and was not significantly different. Sofos (1983) found that the flavor acceptability of non-irradiated frankfurters with 2.5 and 5.0% salt were comparable, and in most cases approached the unacceptable zone (<5) only toward the end of the storage period (31-65 days), whereas in this study we found that flavor acceptability approached unacceptable levels as early as 0 days for non-irradiated frankfurters and 6 days after irradiation for frankfurters irradiated at 1 kGy and as early as 15 days for frankfurters irradiated at 2 kGy.

None of the non-irradiated or irradiated frankfurters remained acceptable (<6) after 15 days of storage.

Juiciness. Juiciness is an important textural attribute in determining acceptability in sausages (Meullenet et al., 1994) and it was the limiting factor in determining the acceptability of irradiated frankfurters in this study. The juiciness of frankfurters at the higher irradiation doses of 2.5 kGy to 3.0 kGy was only acceptable a few days after irradiation. Montgomery et al. (2003) found no significant differences between the juiciness of non-irradiated and irradiated ground beef patties, however the irradiated patties were rated higher than the non-irradiated patties. In this study, we also found that the juiciness of the irradiated frankfurters was rated higher than the non-irradiated frankfurters.

Tenderness. Tenderness of muscle foods strongly influences and drives consumer's perception of acceptability and quality of muscle foods (Miller, 1994). The tenderness of the irradiated frankfurters was higher for the frankfurters irradiated at the higher irradiation doses. Montgomery et al. (2003) found no significant differences between the tenderness of non-irradiated and irradiated ground beef patties, however the non-irradiated patties received higher ratings than the irradiated patties.

Descriptive Attributes

Chickeny. Raw, white chicken irradiated (1.66 to 2.86 kGy) at a refrigerated or frozen state and dark chicken irradiated at a refrigerated state had higher "fresh chickeny" aroma intensity than controls, whereas cooked dark chicken meat irradiated while frozen had more chickeny flavor than the control (Hashim et al., 1995). In our study, chickeny ratings of non-irradiated and irradiated frankfurters were not significantly different (P<0.05) and ranged from 27-28.8 regardless of dose.

Cured meat. Cured meat flavor is commonly associated with products that have added nitrites. Nitrites are essential for enhancing sensory traits, such as less off-flavor, more desirable internal color and more palatability (Terrell et al., 1982). Cured meat is a descriptive attribute that is associated positively with overall consumer acceptance (Munoz and Chambers, 1993). Beggs et al. (1997) found that cured impression in reduced-fat turkey frankfurters was greatest at extremely low (3.5) and high (3.9) levels of starch, although the scoring range was relatively narrow. The range of cured meat aroma for our frankfurters was rated 29.8-31.3 over the storage period regardless of dose. Our ratings are within the range found by Beggs et. al (1997). Matulis et al. (1995) found that flavor intensity of cured/smoked meat includes salty flavor and the contribution of cooked lean and fat may contribute less to overall flavor intensity because of the high contribution of saltiness.

Wet dog. Wet dog aroma is a descriptor that was attributed to Huber et al. (1953) by Nam et al. (2001) and close examination of the Huber et al. (1953) paper, failed to find this descriptor associated with irradiated products. In this study, a wet dog aroma was detected in all frankfurters, but ratings were extremely low (0 - 4) considering the 150 mm point scale used.

Off-flavor. Johnson et al. (2000) found that the off-flavor intensity of pepperoni was not affected by irradiation. However, off-flavor was less intense in pepperoni irradiated at 3.0 kGy than in pepperoni irradiated at 1.25 kGy. In this study, we also found irradiation did not have much of an effect on the frankfurters, which is indicated by the low intensity ratings. At the higher irradiation doses, during the later storage times, the intensity ratings for off-flavor were lower. In contrast, Montgomery et al. (2003) found that with increasing dose, a significant increase in off-flavor occurred.

Terrell et al. (1982) studied the effects of sodium nitrite, sodium acid pyrophosphate and meat formulation on properties of irradiated (0, 8 and 32 kGy) frankfurters. The frankfurters irradiated at 0 and 8 kGy were not significantly different from each other, but they were significantly different from the frankfurters irradiated at 32 kGy. The frankfurters irradiated at 0 and 8 kGy had weak off-flavors, whereas the frankfurters irradiated at 32 kGy had a much stronger off-flavor. Doses used by these investigators were higher than those used in this study.

Desmond and Kenny (1998) used an eight-member panel to evaluate other flavors of commercial non-irradiated frankfurters using surimi-like material. The frankfurters comprised of 15% surimi was rated the highest for 'other flavors', however these ratings were low and scored as 'just detectable'. We also found in this study that only threshold intensities of off-flavor were detected in the frankfurters.

Yetim et al. (2001) studied the sensory effects of non-irradiated frankfurters using fluid whey to replace ice in the formulations. They found no statistically significant differences in off-flavor in the control frankfurters and the liquid whey frankfurters. They stated that "hypothetically a potential existed for off-flavor development in the products containing higher liquid whey, but the experienced panelists did not detect a difference in off-flavor". Matulis et al. (1995) found that fat content had more of an influence than salt concentration on off-flavor intensity of non-irradiated frankfurters as affected by fat, salt and pH. They found that as fat increased, less off-flavor was perceived at constant salt levels.

Meaty. Van Zyl and Setser (2001) found that when the meaty aroma of frankfurters extended with sorghum flour was analyzed for the effect of day of storage, no significant differences were found. However, in our study we found that the day of storage had a significant effect on the meaty aroma of all frankfurters, whereas irradiation dose did not. Throughout the shelf-life, the meaty flavor decreased. Beggs et al. (1997) found that the ranges of scores for meaty flavor of non-irradiated turkey frankfurters with modified corn starch and water were narrow. We also found in this study that the meaty flavor intensity did not show a big change throughout the storage life. Beggs et al. (1997) also stated that sulfur-based compounds give meat its "meaty flavor."

Sour. The sour taste of the frankfurters was barely detectable throughout the storage time. The sourness of the frankfurters is associated as being an off-flavor, in which both attributes received low ratings.

CONCLUSION

An irradiation dose of 2.5 to 3.0 kGy is recommended to process frankfurters by electron-beam irradiation to receive the optimum acceptance by consumers. Frankfurters should be evaluated for overall acceptability and acceptability of flavor, juiciness and tenderness for optimum quality and should be stored for no more than 11 days after irradiation when a 3 kGy dose is used and should be used after 8 days of storage when 2.5 kGy is used.

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CHAPTER 5

SENSORY PROFILING OF ELECTRON-BEAM IRRADIATED READY-TO-EAT POULTRY FRANKFURTERS[1]

[1]Johnson, A.M. and A.V.A. Resurreccion. To be submitted to the *Journal of Sensory Studies*.

ABSTRACT

Ready-to-eat poultry frankfurters were irradiated by electron-beam at medium doses of 0, 1, 2 and 3 kGy and evaluated for sensory characteristics over a 32 day refrigerated storage period. A descriptive panel identified and rated 31 attributes describing the effects of irradiation dose on the appearance, aroma, flavor and texture of the frankfurters throughout the shelf-life. It was found that storage time had a more significant effect on frankfurters than irradiation dose. Irradiation affected the aroma attributes of chicken, cured meat, spice blend, and wet dog; the flavor attributes of meaty, chickeny, and off-flavor; and the taste attributes of sour and sweet. The texture of the poultry frankfurters was not significantly affected by irradiation.

INTRODUCTION

The trend toward convenience foods has resulted in an increase in the production of precooked and ready-to-eat meat products. When contaminated with foodborne pathogens, these convenience foods provide a suitable environment for microbial growth. Consequently, irradiation is a highly recommended alternative to inactivate microorganisms to help maintain the quality and safety of these products. However, irradiation can accelerate the onset of lipid oxidation in cooked ready-to-eat meats and result in off-flavor that decreases their consumer acceptance.

Any development of lipid oxidation in irradiated cooked meat may be influenced by packaging, storage, and other processing conditions before and after irradiation (Ahn et al., 1998). Cooked meats are more susceptible to lipid peroxidation than raw meats during refrigerated and frozen storage due to the heating process resulting in acceleration of oxidative reactions with the lipids in meat (Kingston et al., 1998). To prevent these meats from undergoing further oxidation, the addition of antioxidants and phosphates, subfreezing temperatures and/or vacuum packaging are used to prevent oxidative rancidity from occurring. Although, vacuum packaging may minimize oxygen contact, the residual oxygen inside the bag and transferred oxygen from outside through the packaging film could be responsible for the development of a certain degree of lipid oxidation and odor changes (Ahn et al., 2000).

Further oxidation of precooked and ready-to-eat meats can lead to the development of warmed-over flavors (WOF). Although the general problem of WOF is recognized by the meat and poultry industries as a major problem in marketing new precooked, ready-to-eat, and ready-to-heat and serve products, the specific mechanisms of WOF development are not clearly defined (Lyon, 1988). Sensory profiles have been used to study the effects WOF in chicken (Ang and

Lyon, 1990; Byrne et al., 2002; Igene et al., 1985; Lyon, 1987) and turkey (Bruun-Jensen, et al., 1996; Wu and Sheldon, 1988). Although some studies report sensory scores for intensity of warmed-over flavor or rancidity as a single attribute (Byrne et al., 2002), most studies have included descriptive terms such as warmed-over, oxidized, rancid, painty, stale, old and reheated (Ang and Lyon, 1990; Lyon, 1987; Wu and Sheldon, 1998) to illustrate various flavor character notes present in precooked, ready-to-eat, stored and reheated meats (Lyon, 1988).

Instrumental tests should accompany the sensory tests to study the problem of off-flavor development in precooked and ready-to-eat meats to validate the relationships of the instrumental tests to the sensory perceptions (Igene et al., 1985). The measurement of malonaldehyde by the 2-thiobarbituric acid (TBA) test and hexanal are the two most commonly used methods to monitor secondary lipid oxidation of meats. Although primary lipid oxidation measurements of fatty acids and peroxide values are valuable, they are limited by only monitoring the initial stages of lipid oxidation (Melton, 1983).

The objective of this study was to profile sensory attributes for electron-beam irradiated ready-to-eat poultry frankfurters. The specific objectives were to: 1) determine appearance, flavor and texture attributes and their respective intensities using descriptive analysis, 2) model sensory properties of frankfurters irradiated at 0, 1, 2 and 3 kGy and stored at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, and 3) use regression models to determine the effects of irradiation dose and storage time and their interactions on the sensory properties of irradiated frankfurters.

MATERIALS AND METHODS

Experimental Design

Four treatments, consisting of non-irradiated frankfurters (0 kGy), which served as the control, and frankfurters irradiated 1, 2 and 3 kGy, were studied. Descriptive analysis of frankfurter samples was conducted at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, corresponding to 0, 25, 50, 75 and 100% of shelf life for the product. After each storage period, a total of 12 samples representing the control and the 3 irradiation doses for each of 3 replications were evaluated by trained panelists. On each sampling day, the 12 samples were randomly assigned to 3 sets of 4 samples and served monadically. The 3 sets of samples were served in each session and 1 session was conducted per day for five testing sessions. Presentation order of the 4 samples within a set was randomized over panelists, making sure not to have more than two replications of one treatment in the same set.

Samples

Frankfurters (D. L. Lee & Sons, Inc., Alma, GA) were transported to the Department of Food Science and Technology in Griffin, GA in three 48 quart insulated coolers (Igloo, Shelton, CT) packed with ice. The frankfurters were held for 48 hours at 4°C in a walk-in refrigerator (Model W06430-1, Nor-lake, Inc., Hudson, Wisconsin) until ready for packaging in irradiation approved materials. Frankfurters were removed from their original packages. Five frankfurters were transferred into each irradiation approved 16.5 cm x 20.3 cm ethylene-vinyl acetate and polyvinylidene chloride bags formed from 16.5 cm x 40.6 cm bags (B-540, Cryovac, Saddle Brook, NJ) cut in half and heat-sealed. Within five minutes of removal from the refrigerator, the frankfurters were vacuum-packaged (29 in Hg) using a single chamber packaging machine

(Model UV250, Koch Packaging Systems, Kansas City, MO) and then heat-sealed, leaving approximately 2.54 cm space for the label to be inserted after the vacuum seal. Label information containing the desired irradiation doses were heat-sealed in the remaining portion of the bag to prevent the label from separating from the frankfurter samples. The samples were returned to the refrigerator (4°C) and held overnight.

All samples were packed in polyfoam mailing boxes (35.5 cm x 35.5 cm x 38.7 cm Fisher Scientific, Pittsburgh, PA) and packed with ample ice packs (Fisher Scientific, Pittsburgh, PA) to maintain refrigeration temperatures determined in preliminary studies. Samples were shipped by air overnight to the Ion Beam Applications (IBA) irradiation facility (San Diego, CA).

Dose mapping

Dose mapping was conducted by IBA (San Diego, CA) to: (1) find the minimum and maximum absorbed dose points within the products and (2) determine the relation of the dose measured by an external dosimeter to doses absorbed by the product (results from objective 1). From this relation, a dose range from the adjusted minimum and maximum doses as measured by the external dosimeter, was determined to assure the minimum required irradiation of the sample. Radiochromic film dosimeters (Far West Technology, Inc., Goleta, CA) were placed on the top and the bottom of each frankfurter package. Samples were positioned in a single layer in stainless steel trays, transported onto a conveyor belt, and then exposed to the ambient temperature of the electron beam source (RF linac linear accelerator, Applied Radiation Company, San Jose, CA) with an energy level of 9.5 MeV and a dose rate of 45 kGy/ft/min using a single-sided pass.

Irradiation processing

Upon the arrival of the samples at the IBA irradiation facility, the frankfurter samples were held overnight in a refrigerator at 3°C (Model B1031-2, Kool Star, Los Angeles, CA). Samples were irradiated to achieve a 1.0, 2.0 or 3.0 kGy dose, which was verified with radiochromic film dosimeters attached on the top and bottom surfaces of representative samples to monitor dose rate and uniformity of irradiation. Irradiated samples were held overnight in a refrigerator at 3°C. Control, non-irradiated samples were held under similar conditions. On the following day, samples were repackaged under conditions similar to the shipment of the samples to the irradiation facility. Samples were then transported by air overnight to the sensory laboratory at the Department of Food Science and Technology (Griffin, GA).

Sample preparation

Upon arrival at Griffin, non-irradiated and irradiated frankfurter samples were removed from the shipping boxes and were held, unopened, in a refrigerator at 4°C until ready for sensory evaluation. The samples were stored for up to an expected shelf life of 32 days after irradiation. The samples were withdrawn from the walk-in refrigerator at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, corresponding to 0, 25, 50, 75 and 100% shelf life, for the descriptive analysis.

Frankfurter samples were cooked according to preliminary testing procedures. Five frankfurter samples from one package, directly from the refrigerator, were placed in 3-quart stainless steel pans (Revere Ware, Clinton, IL) with 800 ml of cold double-deionized water. The frankfurters and water were heated to boiling at a medium high setting and held for a total of approximately 7 minutes from the time samples started boiling. Frankfurter samples were prepared in 3 sets of 4 for each session. During the preparation, within each set of 4, frankfurters were cooked approximately 3 minutes apart so that panelists could receive warm samples in between each set without using a heat lamp. After the frankfurters boiled for the recommended time, they were removed from the stove and the water was drained and discarded. Frankfurters were removed from the pans and placed on cutting boards, cut in half crosswise and each frankfurter half was placed in 8 oz squat cups (Stock No. 8SJ20, Dart, Mason, MI) coded with three digit random numbers. Samples were served immediately for sensory evaluation by the descriptive panel.

Descriptive Analysis

Recruitment. Prospective members of the descriptive panel were recruited from a list of previously trained panelists, who had previously participated in descriptive analysis tests at the sensory laboratory, as well as sensory evaluation students from the University. All panelists were recruited on the basis of the following criteria: between 18 and 70 years of age, did not smoke, not allergic to ingredients in frankfurters, consumed frankfurters at least four times a year, were willing to evaluate irradiated frankfurters, were available and willing to participate during training and testing dates and were able to verbally communicate about the product. Panelists were required to complete and sign consent forms approved by the University of Georgia Institutional Review Board.

Training. Ten panelists, 1 male and 9 females, were selected. Each panelist was trained and calibrated for 3 days. Each training session was 2 hours each day for a total of 6 hours. During the first day of training, panelists were presented with frankfurter samples, representing each irradiation dose and storage period. Descriptive terms that characterized the sensory properties of samples were developed by the panel while evaluating samples. Panelists then decided on a final list of flavor and texture terms that was comprehensive with definitions understood by all panelists. Panelists did not necessarily define an attribute as indicated in existing literature. The final list of attributes with definitions, reference standards and procedures for evaluating the attribute was decided upon by panel consensus (Table 5.1).

During the second day of training, panelists determined references that would best help them to rate the descriptive terms developed. Reference standards were evaluated as a group to assure that judgments of each panelist were in the same range as those of the other panelists. Panelists were calibrated to rate intensity of stimuli by presenting them with standard references for basic tastes (Meilgaard et al., 1991).

Panelists evaluated samples using a "hybrid" descriptive analysis method (Einstein, 1991), a combination of the Quantitative Descriptive Analysis (QDA®) (Tragon Corp., Redwood City, CA) and Spectrum™ Analysis (Sensory Spectrum, Inc., Chatham, NJ) Methods. Each panelist rated the attribute intensity of each reference for a particular attribute and then gave it an intensity rating between 0 and 150 using flashcards shown to the panelists at the same time. Calibration of the panel was conducted by asking panelists not rating within 10% of the consensus rating to re-evaluate the sample and adjust their rating. An average rating was obtained based on final intensity ratings. During the third day of training, panelists evaluated frankfurter samples with the computerized ballot (Compusense, Version 4.0, Compusense Inc., Guelph, Ontario, Canada).

Ballot. A computerized ballot with 31 attributes listed vertically in their order of appearance, five attributes per display. Using a computer mouse, panelists clicked on each attribute on a 150-mm unstructured line scale, with anchors at 12.5 and 137.5 mm that appeared

Table 5.1. Attributes, definitions, references and intensity ratings used to evaluate electron-beam irradiated frankfurters

ATTRIBUTE[1]	DEFINITION	REFERENCE	INTENSITY
APPEARANCE			
Glossy [2,3]	The amount of light reflected from the skin surface	Vegetable oil (Crisco, Procter & Gamble, Cincinnati, OH)	137
Red color [2]	The intensity or strength of red color from white to dark red	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Red paper (L*=51.84, a*=51.92, b*=26.29)	75
Brown color [2]	The intensity or strength of brown color from white to dark brown	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Brown cardboard (L*=59.05, a*=5.25, b*=17.50)	66
		Chocolate syrup (Hershey Foods Corp., Hershey, PA) (L*=24.35, a*=2.00, b*=1.76)	150
Evenness of surface	The evenness of the surface texture	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	120
		Crisco (Crisco, Procter & Gamble, Cincinnati, OH)	150
AROMA:			
Smell the sample and evaluate for aroma			
Total aroma	The total aroma intensity of sample	Standard taste references at varying concentrations	

Table 5.1. Continued

Meaty [4,5,6]	Aromatic associated with cooked or roasted meat	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	25
Chickeny [3,4,5,6]	Aromatic associated with cooked chicken	Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	57
Cured meat [4]	Aromatic/taste sensation associated with processed products that contain curing agents (nitrites, sugars, salts)	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	21
Spice blend [4]	Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified	Standard taste references at varying concentrations	
Wet dog [4]	Aromatic associated with wet dog hair	Standard taste references at varying concentrations	
Off-flavor [4]	A general, non-specific term, related usually to characteristics that are inappropriated in a food system	Standard taste references at varying concentrations	
FLAVOR:			
Place 2 to 3 pieces of sample in mouth and evaluate for flavor			
Total flavor	The total flavor intensity of sample	Standard taste references at varying concentrations	
Meaty [4,5,6,7]	Aromatic associated with cooked or roasted meat	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	39

Table 5.1. Continued

Chickeny [3,4,6]	Aromatic associated with cooked chicken	Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	72
Oily [5,6]	An overall term for the aroma and flavor notes reminiscent of vegetable oil or mineral oil products	Vegetable oil (Crisco, Procter & Gamble, Cincinnati, OH)	55
Cured meat [4]	Aromatic/taste sensation associated with processed products that contain curing agents (nitrites, sugars, salts)	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	32
Spice blend [4]	Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified	Standard taste references at varying concentrations	
Pepper [4]	Aromatic associated with pepper	Ground black pepper (Kroger Co., Cincinnati, OH)	93
Liver/organy [4,5,7]	Aromatic associated with cooked liver, organ meat, serum and/or blood salts	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	12
		Hearts, gizzards, and livers (reference not supplied)[4]	75
Taste			
Salty [2,4,5]	The taste on the tongue associated with sodium chloride solutions	0.2% sodium chloride in deionized water (Fisher Scientific, Fair Lawn, NJ)	25
		0.35% sodium chloride in deionized water	50
		0.5% sodium chloride in deionized water	85

Table 5.1. Continued

Sour [2,4,5]	The taste on the tongue associated with citric acid solutions	0.05% citric acid in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		0.08% citric acid in deionized water	50
		0.15% citric acid in deionized water	100
Bitter [2,4,5]	The taste on the tongue associated with caffeine solutions	0.05% caffeine in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		0.08% caffeine in deionized water	50
		0.15% caffeine in deionized water	100
Sweet [2,4,5,6]	The taste on the tongue associated with sucrose solutions	2.0% sucrose in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		5.0% sucrose in deionized water	50
		10.0% sucrose in deionized water	100
		16.0% sucrose in deionized water	150
Umami [4]	Specific taste on the tongue stimulated by MSG (monosodium glutamate) and certain other nucleotides	0.2% MSG solution (Ajinomoto U.S.A., Inc., Teaneck, NJ)	36
		Standard taste references at varying concentrations	

Table 5.1. Continued

Feeling factors			
Tongue sting	Degree of a sharp, stinging sensation on the tongue or throat	Chili powder (Private Selection, Inter-American Products, Inc., Cincinnati, OH)	40
TEXTURE			
Springiness [2,8]	Degree to which sample returns to original shape	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	70
		Marshmallow[2] (Kraft, Nabisco, Inc., East Hanover, NJ)	95
First bite: Bite through 1 cm of sample with incisors before you rate			
Overall hardness [2,8]	Force required to bite through sample	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	50
		Peanuts[2] (Planter's, Nabisco Foods, Inc., East Hanover, NJ)	95
5 Chews: Chew sample five times before you rate			
Chewy [8]	Total amount of work necessary to chew a sample to a state ready for swallowing	Tootsie Roll midgees (Tootsie Roll Industries, Inc., Chicago, IL)	75
Cohesiveness of mass [2,8]	Degree to which sample holds together in a mass after five chews	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	75
10 Chews: Chew sample ten times before you rate			
Grainy [2,3,4]	The amount of particles in the mouth	Grits[3] (Kroger Instant Country Grits, The Kroger Co., Cincinnati, OH) prepared according to package instructions	90

Table 5.1. Continued

Residual: Evaluate sample after expectorating			
Oily mouthcoat [2]	Amount of oil left on mouth surfaces	Water (Deionized)	0
		Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	36

[1] Attribute listed in order as perceived by panelists.

[2] Meilgaard et al. (1991)

[3] Hashim et al. (1995)

[4] Civille and Lyon (1996)

[5] Lyon (1987)

[6] Landes (1972)

[7] Jacobson and Koehler (1970)

[8] Meullenet and Gross (1999)

on the computer screen with a heading consisting of that particular attribute and definition. Panelists made a vertical mark on the line scale indicating the intensity of that attribute. The numerical rating for that attribute would then appear next to it indicating that the attribute had been rated and panelists could proceed to rate the next attribute. All attributes of one sample were rated for intensity before a panelist could proceed to the next sample.

Environmental conditions. All tests were performed at the Department of Food Science and Technology, University of Georgia in Griffin, Ga. Panelists evaluated samples in environmentally-controlled partitioned booths illuminated with two 50-watt indoor reflector flood lamps, which provided 738 lux of light.

Evaluation Procedures. Each panelist was presented with standard references for basic tastes, reference standards, a warm-up sample (a non-irradiated control or irradiated sample) and a control sample in a one hour calibration session around a table in a sensory laboratory. Panelists were instructed to calibrate their judgments using standard references, then to evaluate the control sample and compare individual responses for outlying ratings, if any. Outliers were calibrated by reevaluating the sample and adjusting their ratings toward consensus. Panelists then evaluated their samples in individual partitioned booths. Water and unsalted crackers were provided for panelists to cleanse their palates between samples. Descriptive panelists received an honorarium of 10 or 12 dollars, based on experience, for their participation in each session.

Statistical Analysis

Statistical Analysis Software System (Version 8.0, SAS Institute, Cary, NC) was used to analyze all data results. Results of the descriptive analysis were first analyzed by cluster analysis (PROC VARCLUS) to identify any outlier panelists for each sampling time (Malundo and

Resurreccion, 1992). Results from the cluster analysis (PROC VARCLUS) showed that none of the panelists were outliers. Therefore, data from all ten panelists were included in the data analysis.

Analysis of variance, using the general linear model (PROC GLM), was conducted on each attribute to identify the significant differences in sensory ratings on frankfurter samples for all storage times and irradiation doses. Regression analysis (PROC REG) was used to calculate the coeffecient of determination (R^2) and to develop prediction models using each sensory attribute as dependent variables and irradiation dose and storage time as independent variables. Regression analysis was performed on data from all three irradiation processing replications of frankfurters (5 days x 4 doses x 3 reps = 60 data points). The quadratic model for the attributes included the linear terms, irradiation dose and storage time; the squared terms, dose x dose and day x day; and the interaction dose x day.

Significant full models ($\alpha < 0.05$) from descriptive attributes with R^2 greater or equal to 0.50 were selected to test if reduced models could be used to predict the response variables. All reduced models with $R^2 \geq 0.50$ were compared to full models by calculating the F-statistic. Model significance at $\alpha = 0.05$ level was determined using the F-ratio calculated from the following equation (Cornell, 1982):

$$F = \frac{\dfrac{\text{Sum of Squares Full Model}}{\text{Number of terms in in Full Model}} - \dfrac{\text{Sum of Square Reduced Model}}{\text{Number of terms in Reduced Model}}}{} \times \frac{1}{\text{Residual Mean Square of Full Model}}$$

If the F-ratio exceeded the appropriate tabular value obtained from degress of freedom and the number of terms in the full model, then the reduced model is significantly different from the full model and could not be used. Otherwise, if the reduced model with the least amount of variables was not significantly different from the full model at $\alpha = 0.05$, then the model was used to predict a particular response variable. Contour maps were plotted from final prediction models, calculated from mean data,using Statistica® (Version 6.0, Statsoft, Inc., Tulsa, OK) to determine effects of irradiation dose and storage time on each sensory attribute.

RESULTS AND DISCUSSION

Descriptive Analysis

Prediction models for attributes glossy, red color, brown color, evenness of surface, total aroma, meaty (aroma), total flavor, oily, cured meat flavor, spice blend flavor, pepper, liver/organy, salty, bitter, umami, tongue sting, overall hardness, springiness, chewy, cohesiveness of mass, grainy and oily mouthcoat were not developed because their R^2 values were less then 0.50. These attributes were unable to profile the effect of irradiation dosage and storage time on poultry frankfurters. Mean intensity ratings for these attributes are shown in Tables 5.2 through 5.5.

Appearance. The appearance attributes of glossy, red color, brown color and evenness of surface were not found to be significant attributes in determining the effect of irradiation dose and storage time on poultry frankfurters. The glossiness of the non-irradiated and irradiated frankfurters ranged from 38.80 to 40.48, red color ranged from 40.76 to 44.21 and brown color ranged from 67.60 to 71.87. In a study by Johnson et al. (2000), panelists perceived that irradiated pepperoni more closely resembled the color of unheated controls and that irradiation did not have an effect on the color of pepperoni. Nitrites are added to poultry frankfurters to provide palatability and helped to maintain the sensory characteristics, such as color, of the irradiated frankfurters throughout the shelf-life. The evenness of surface for the frankfurter samples ranged from 95.35 to 101.60.

Table 5.2. Mean intensity ratings for appearance and aroma attributes of electron-beam irradiated poultry frankfurters[1]

	APPEARANCE				AROMA	
	Glossy	**Red color**	**Brown color**	**Evenness of surface**	**Total aroma**	**Meaty**
Day 4						
0 kGy	40.28	43.06	70.50	97.80	44.87	20.92
1 kGy	40.05	41.85	70.19	100.18	43.84	21.07
2 kGy	39.57	42.13	70.24	96.57	43.91	20.65
3 kGy	39.65	41.61	70.65	97.70	44.88	20.73
Day 11						
0 kGy	39.23	43.94a	67.60	96.95	44.94	21.32
1 kGy	38.80	44.21	68.71	95.35	44.62	21.48
2 kGy	39.03	43.61	71.17	95.78	44.94	21.61
3 kGy	38.84	43.33	70.57	95.50	44.70	20.63
Day 18						
0 kGy	39.73	43.12	70.06	97.32	44.57	20.43
1 kGy	40.40	43.12	71.87	98.05	44.07	20.44
2 kGy	39.68	41.63	71.30	99.71	44.45	20.61
3 kGy	39.30	41.83	71.57	98.92	44.44	27.57
Day 25						
0 kGy	40.01	43.13	70.19	99.17	44.11	20.03
1 kGy	39.45	40.76	71.09	98.07	44.62	20.70
2 kGy	40.48	42.55	70.89	101.60	44.49	20.62
3 kGy	38.81	40.83	71.06	96.73	44.69	20.53
Day 32						
0 kGy	39.75	43.52	70.61	99.24	43.77	20.34
1 kGy	40.15	43.48	70.94	100.12	44.70	19.92
2 kGy	39.73	41.62	71.28	98.78	44.46	20.48
3 kGy	39.83	42.53	71.23	100.12	44.09	20.41

[1]Ratings are based on 150-mm unstructured line scales with anchors at 12.5 and 137.5. Means are from 3 replications of processing by irradiation. The descriptive panel was composed of 10 trained assessors.

Table 5.3. Mean intensity ratings for flavor attributes of electron-beam irradiated poultry frankfurters[1]

	FLAVOR					
	Total flavor	**Oily**	**Cured meat**	**Spiceblend**	**Pepper**	**Liver/ organy**
Day 4						
0 kGy	63.23	19.82	30.14	49.28	29.79	0.55
1 kGy	61.98	19.93	30.97	48.24	30.31	0.48
2 kGy	63.13	19.82	30.92	48.43	29.93	1.20
3 kGy	63.51	20.18	31.33	49.74	30.00	1.02
Day 11						
0 kGy	64.08	20.20	31.16	49.87	30.22	1.38
1 kGy	63.81	20.12	31.15	50.63	31.10	1.32
2 kGy	63.31	20.13	31.25	50.16	29.80	1.78
3 kGy	64.24	20.34	31.09	50.39	30.21	1.64
Day 18						
0 kGy	62.68	19.79	30.41	49.12	32.34	1.80
1 kGy	63.58	20.18	30.32	49.80	29.63	2.10
2 kGy	63.20	19.79	30.33	49.27	29.48	1.75
3 kGy	61.75	19.96	30.01	49.30	29.86	1.83
Day 25						
0 kGy	63.12	20.16	29.55	49.36	30.33	0.47
1 kGy	63.18	20.23	30.28	50.02	30.29	0.83
2 kGy	62.97	20.29	29.52	49.44	29.47	0.78
3 kGy	62.71	20.38	30.02	49.45	30.23	1.61
Day 32						
0 kGy	62.49	20.05	30.00	48.70	29.75	2.55
1 kGy	61.55	20.07	29.44	47.44	29.28	2.74
2 kGy	63.45	20.10	30.17	48.72	29.77	1.11
3 kGy	61.29	20.07	30.58	49.01	29.63	0.72

[1]Ratings are based on 150-mm unstructured line scales with anchors at 12.5 and 137.5. Means are from 3 replications of processing by irradiation. The descriptive panel was composed of 10 trained assessors.

Table 5.4. Mean intensity ratings for taste and feeling factor of electron-beam irradiated poultry frankfurters[1]

	TASTE			FEELING FACTOR
	Salty	**Bitter**	**Umami**	**Tongue Sting**
Day 4				
0 kGy	77.35	0.07	13.77	17.53
1 kGy	76.20	0.00	13.79	18.18
2 kGy	76.91	0.00	13.93	18.69
3 kGy	76.94	0.00	13.73	18.64
Day 11				
0 kGy	80.28	0.00	14.36	18.96
1 kGy	79.57	0.00	14.19	19.08
2 kGy	79.55	0.00	14.09	19.01
3 kGy	79.02	0.00	14.14	18.87
Day 18				
0 kGy	77.92	0.00	13.69	19.31
1 kGy	77.60	0.00	13.69	18.60
2 kGy	77.36	0.00	14.24	19.02
3 kGy	76.42	0.00	13.32	18.34
Day 25				
0 kGy	76.80	0.00	13.71	18.51
1 kGy	77.00	0.00	13.87	18.65
2 kGy	77.59	0.17	13.81	18.65
3 kGy	76.86	0.00	14.21	18.59
Day 32				
0 kGy	76.77	0.00	13.56	19.02
1 kGy	76.67	0.00	13.70	19.30
2 kGy	76.55	0.00	13.23	18.88
3 kGy	76.72	0.00	13.59	17.03

[1]Ratings are based on 150-mm unstructured line scales with anchors at 12.5 and 137.5. Means are from 3 replications of processing by irradiation. The descriptive panel was composed of 10 trained assessors.

Table 5.5. Mean intensity ratings for texture attributes of electron-beam irradiated poultry frankfurters[1]

	TEXTURE					
	Springiness	**Overall hardness**	**Chewy**	**Cohesiveness of mass**	**Grainy**	**Oily Mouthcoat**
Day 4						
0 kGy	73.50	54.06	35.79	75.19	36.55	20.45
1 kGy	74.55	53.59	36.56	75.25	36.23	20.35
2 kGy	72.47	54.64	35.47	75.23	37.48	19.97
3 kGy	73.16	53.82	35.10	74.31	36.98	20.01
Day 11						
0 kGy	74.45	53.54	35.07	74.69	36.82	20.27
1 kGy	73.50	52.91	35.32	74.92	37.78	20.08
2 kGy	73.68	54.16	35.73	74.70	37.79	20.16
3 kGy	74.14	52.89	34.89	74.98	37.05	20.03
Day 18						
0 kGy	73.90	53.77	34.97	74.71	36.85	20.11
1 kGy	73.46	44.00	35.07	74.53	37.60	19.96
2 kGy	74.05	52.80	35.20	74.22	36.62	19.93
3 kGy	73.64	53.99	34.88	74.53	36.92	19.88
Day 25						
0 kGy	74.23	54.38	35.89	75.04	37.05	20.48
1 kGy	73.87	54.44	36.66	74.78	37.43	20.35
2 kGy	74.54	52.88	35.17	74.20	36.04	19.90
3 kGy	73.53	52.90	34.82	74.29	37.43	19.73
Day 32						
0 kGy	73.91	54.22	35.62	75.02	37.31	20.25
1 kGy	73.83	54.16	35.41	74.44	36.65	19.73
2 kGy	73.66	53.68	35.34	74.58	37.40	20.08
3 kGy	73.34	52.74	34.75	74.00	37.28	20.31

[1]Ratings are based on 150-mm unstructured line scales with anchors at 12.5 and 137.5. Means are from 3 replications of processing by irradiation. The descriptive panel was composed of 10 trained assessors.

Total aroma. The different levels of irradiation or the storage time did not affect the total aroma of the non-irradiated and irradiated frankfurters. The total aroma of the frankfurters ranged from 43.77 to 44.94. Wheeler et al. (1999) found that control patties had a more intense ground beef aroma and less of an off aroma than irradiated (3.0 and 4.5 kGy) patties, whereas, Luchsinger et al. (1996) found that raw and cooked pork aroma attributes were not influenced by irradiation dose levels.

Meaty. The different levels of irradiation or the storage time did not affect the meaty aroma. The intensity of the meaty aroma ranged from 19.92 to 21.61. Montgomery et al. (2003) found that irradiated ground beef patties were not significantly different from control patties for cooked aroma intensity. Similarly, Ahn et al. (2000) found that no irradiation dose effect was found on the odor preference of pork patties with vacuum packaging.

Total flavor. Storage time and irradiation dosage did not have a significant effect on the intensity of total flavor for the non-irradiated and irradiated frankfurters. The means for total flavor ranged from 61.29 to 64.24. Previous studies have found that as irradiation dosage increased, the intensity of flavor increased, however this increase was not found to be significant (Johnson et al., 2000; Montgomery et al., 2003). Wheeler et al. (1999) found that non-irradiated ground beef patties had a more intense ground beef flavor than irradiated (3.4 and 4.5 kGy).

Oily. The oily flavor of the non-irradiated and irradiated frankfurters was not affected by storage time and irradiation dose. The mean intensity ratings ranged from 19.79 to 20.38.

Cured meat, spice blend and pepper. These flavor attributes were not significantly affected by irradiation dosage throughout the storage period. The ratings for cured meat ranged from 29.44 to 31.33, from 47.44 to 50.63 for spiceblend and from 29.28 to 32.34 for pepper.

Liver/organy. The liver/organy flavor of the irradiated frankfurters was not affected by irradiation dose and storage time. The intensity ratings were low and ranged from 0.47 to 2.74. Beggs et al. (1997) found that organ meat/metallic flavor was the only flavor attribute for which a significant starch and water interaction occurred in reduced-fat turkey frankfurters, however in this study, we did not find liver/organy to be a significant flavor attribute affected by irradiation dosage and storage time. Although Beggs et al. (1997) perceived this attribute to be negative; they stated that organ meat/metallic is a naturally occurring attribute in turkey meat. Sulfur-based compounds give meat its "meaty flavor," and such compounds may be entrapped in the starch matrix. If this occurs, undesirable flavor notes such as organ meat/metallic may become apparent (Beggs et al., 1997).

Salty. The salty taste of the irradiated frankfurters was not affected due to irradiation dosage and storage time. The range of salty taste was from 76.20 to 80.28. Matulis et al. (1995) found that the flavor intensity of non-irradiated frankfurters was influenced by salt concentration. As salt increased, flavor intensity increased.

Bitter. Irradiation dose and storage time did not have a significant effect on the intensity of bitter taste. The bitter taste of the frankfurters was low and ranged from 0 to 0.17. Yackel and Cox (1992) found that increased moisture levels increase the perception of bitterness, however only a slight increase in bitterness was detected only after 32 days of refrigerated storage after irradiation. Ang and Lyon (1990) also found that bitterness increased throughout 5 days of storage for non-irradiated cooked broiler breast, thigh and skin. Luchsinger et al. (1996) found that bitterness increased in aerobically packaged, irradiated chilled pork chops when dose increased from 1.5 to 2.5 kGy and was greater in aerobically packaged than in vacuum packaged, irradiated chops at 2.5 kGy. However, in frozen, irradiated boneless pork chops, irradiation dose levels did not affect bitterness.

Umami. The effect of irradiation dose and storage time did not have a significant effect on the intensity of umami taste. The umami taste of the frankfurters ranged from 13.23 to 14.36. These ratings were rated slightly higher than threshold levels, but the intensity of the taste was relatively low.

Texture attributes. The texture attributes of tongue sting, springiness, overall hardness, chewy, cohesiveness of mass, grainy and oily mouthcoat for the irradiated frankfurters were not significantly affected the irradiation dose throughout the storage time. Luchsinger et al. (1996) found that the textural attributes of chilled boneless pork chops were not affected by irradiation dose levels of 1.5 kGy and 2.5 kGy. Beggs et al. (1997) found that springiness is affected by the level of added water. Beggs et al. (1997) believes that starch used in turkey frankfurters may produce grain-like notes in comminuted meat products. They also found that high levels of starch produced frankfurters that were more cohesive than those with low levels of starch and water, whereas, Matulis et al. (1995) found that as salt levels increase, frankfurter cohesiveness increases and that the most cohesive frankfurters resulted from reducing fat and increasing salt. It was concluded that this may be due to the increased protein extraction resulting in more protein-protein interactions at higher salt levels. Lyon (1980) did not find significant differences among canned boned chicken products for all attributes except mouthcoating.

Effect of irradiation dose and storage time on poultry frankfurters

Regression equations of full and reduced models and their corresponding adjusted R^2 values for the significant descriptive attributes of irradiated frankfurters are chickeny, cured meat, spice blend, wet dog, off-flavor aromas; meaty and chickeny flavors; and sour and sweet taste are shown in Table 5.6. The results of the F-test (data not shown) showed that the reduced models were not significantly different from the full models. Therefore the reduced models were used to predict the significant attributes for non-irradiated and irradiated frankfurters.

Chickeny aroma. Both irradiation dosage and storage time had a significant effect on the intensity of chickeny aroma (Fig. 5.1A). The intensity of chickeny aroma decreased throughout the storage time. The ratings of the chickeny aroma were from 29.5 to 27.3. Until 15 days after irradiation, the intensity of the chickeny aroma decreased with increasing irradiation doses, whereas throughout the remaining storage time, the intensity of the chickeny aroma decreased with decreasing irradiation dose. Ang and Lyon (1990) found that the chicken intensity of non-irradiated cooked broiler breast, thigh and skin decreased during storage. These findings were also found in this study.

Cured meat. The cured meat aroma (Fig. 5.1B) was affected by storage time; irradiation dose did not have an effect on the aroma. No matter the dose, the rating for cured meat will remain the same. The ratings of cured meat ranged from 24.5 to 25.5. The intensity of cured meat increased from 25.3 at 2 days after irradiation to 25.5 at 7 days after irradiation. The cured meat aroma remained constant until 16 days after irradiation. After 17 days of irradiation, the intensity of cured meat aroma decreased throughout the remaining storage time. However, at day 23, the intensity of the cured meat was rated the same as it was rated at 2 days after

Table 5.6. Regression equations for full and reduced models for the prediction of descriptive[1] attributes for electron-beam irradiated ready-to-eat poultry frankfuters[2]

ATTRIBUTE	PREDICTION EQUATIONS[3]						ADJUSTED RSQUARE
Chickeny							
Full	29.2874	- 0.2649 X_1	- 0.0112 X_2	- 0.0408 X_1^2	- 0.0020 X_2^2	+ 0.0233 $X_1 * X_2$	0.61
Reduced	29.7693	- 0.3873 X_1	- 0.0815 X_2	———[4] X_1^2	——— X_2^2	+ 0.0233 $X_1 * X_2$	0.58
Cured meat							
Full	25.4311	- 0.3467 X_1	+ 0.0525 X_2	+ 0.0781 X_1^2	- 0.00278 X_2^2	+ 0.0079 $X_1 * X_2$	0.53
Reduced	25.1845	——— X_1	+ 0.0643 X_2	——— X_1^2	- 0.00278 X_2^2	——— $X_1 * X_2$	0.55
Spice blend							
Full	30.6272	+ 0.3569 X_1	- 0.0059 X_2	- 0.15035 X_1^2	- 0.0013 X_2^2	+ 0.0110 $X_1 * X_2$	0.56
Reduced	30.9102	+ 0.3569 X_1	- 0.0509 X_2	- 0.15035 X_1^2	——— X_2^2	+ 0.0110 $X_1 * X_2$	0.53
Wet dog							
Full	0.7099	+ 0.0320 X_1	- 0.2086 X_2	+ 0.2251 X_1^2	+ 0.0111 X_2^2	- 0.0466 $X_1 * X_2$	0.68
Reduced	1.5458	——— X_1	- 0.2785 X_2	——— X_1^2	+ 0.0111 X_2^2	——— $X_1 * X_2$	0.62
Off-flavor							
Full	0.1101	- 0.1802 X_1	- 0.0522 X_2	+ 0.2216 X_1^2	+ 0.0062 X_2^2	- 0.0587 $X_1 * X_2$	0.65
Reduced	-1.52075	+ 0.4845 X_1	+ 0.0172 X_2	——— X_1^2	——— X_2^2	- 0.0587 $X_1 * X_2$	0.55
Meaty							
Full	28.9824	+ 0.1726 X_1	+ 0.0150 X_2	- 0.0503 X_1^2	- 0.0020 X_2^2	+ 0.0040 $X_1 * X_2$	0.70
Reduced	29.5221	——— X_1	- 0.0518 X_2	——— X_1^2	——— X_2^2	——— $X_1 * X_2$	0.65

Table 5.6. Continued

Chickeny							
Full	36.6570	- 0.4923 X_1	+ 0.0524 X_2	+ 0.1133 X_1^2	- 0.0037 X_2^2	+ 0.0151 X_1*X_2	0.65
Reduced	36.3151	—— X_1	+ 0.0751 X_2	—— X_1^2	- 0.0037 X_2^2	—— X_1*X_2	0.61
Sour							
Full	1.2414	+ 0.3874 X_1	- 0.3924 X_2	+ 0.1230 X_1^2	+ 0.0197 X_2^2	- 0.0744 X_1*X_2	0.74
Reduced	2.2528	—— X_1	- 0.5040 X_2	—— X_1^2	+ 0.0197 X_2^2	—— X_1*X_2	0.66
Sweet							
Full	8.8188	- 0.0159 X_1	+ 0.0670 X_2	- 0.0175 X_1^2	- 0.0032 X_2^2	+ 0.0059 X_1*X_2	0.56
Reduced	8.7336	—— X_1	+ 0.0759 X_2	—— X_1^2	- 0.0032 X_2^2	—— X_1*X_2	0.62

[1]Descriptive panelists (n=10) evaluated samples of e-beam irradiated frankfurters using 150 mm line scales. Equations were obtained by using three replications.

[2]Full models of descriptive attributes with adjusted coefficient of determination, R^2 = 0.50 were used to develop reduced models.

[3]Variables in models are:

x_1=dose

x_2=day

x_1^2=dose*dose

x_2^2=day*day

x_1*x_2=dose*day

[4]Blanks indicate that the variable of the full model above it was removed from the reduced model.

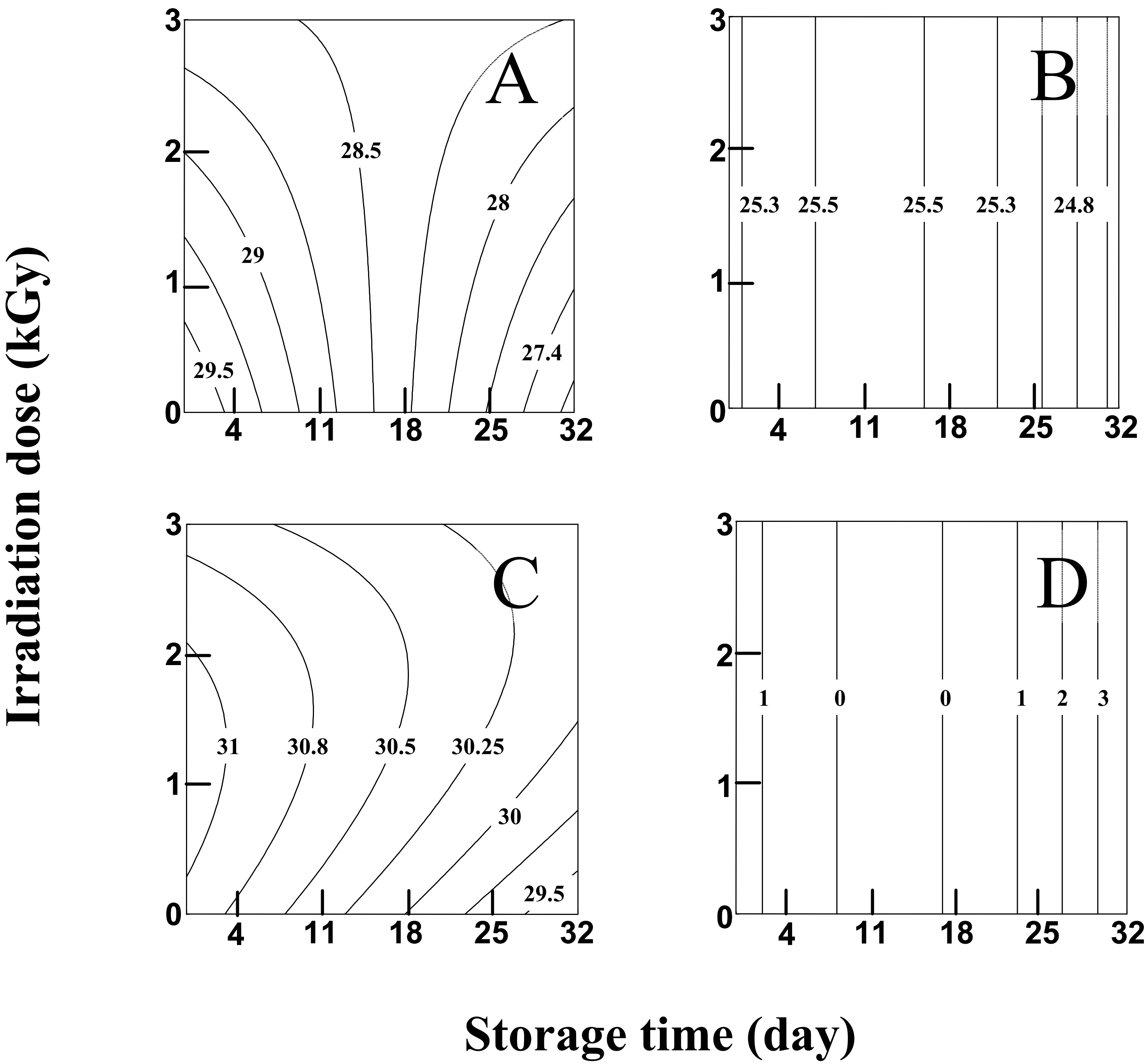
irradiation. Matulis et al. (1995) found that flavor intensity of cured/smoked meat includes salty flavor and the contribution of cooked lean and fat may contribute less to overall flavor intensity because of the high contribution of saltiness.

Spice blend. The intensity of spiceblend (Fig. 5.1C) aroma was affected by storage time and irradiation dose. The intensity ratings for the aroma of spiceblend ranged from 29.5 to 31. For up to 17 days of refrigerated storage after irradiation, as irradiation doses increased the intensity of spice blend decreased. Throughout the remaining storage time, the spiceblend intensity decreased with decreasing irradiation dose. Munoz and Chambers (1993) found that high intensities of spice complex (green herbs and pepper) were a descriptive attribute that is negatively associated with consumer acceptance.

Wet dog. Storage time had a significant effect on the intensity of the wet dog aroma (Fig. 5.1D), regardless of irradiation doses. The intensity ratings for wet dog aroma were extremely low, and received ratings of 0 to 3. Immediately after irradiation, the wet dog aroma was detected. However, this aroma decreased and was not present at 9 days after irradiation through 17 days after irradiation. At 23 days after irradiation, the wet dog aroma reappeared and received the same low rating as 2 days after irradiation. From 23 days throughout the remaining storage period, the intensity of the wet dog aroma increased to a maximum of 3.75.

Off-flavor. The off-flavor (Fig. 5.2A) of the frankfurters was affected by irradiation dose and storage time. The intensity ratings for off-flavor were low and ranged from 1 to 7. Immediately after irradiation, an off-flavor was detected and increased with increasing irradiation dose. However, the intensity ratings were low, indicating that this flavor was barely detectable. A slight (2.5-3.0) off-flavor was detected in frankfurters irradiated at 3 kGy

Figure 5.1. Contour plots illustrating the effects of irradiation dose and storage time (days) on chickeny aroma (A), cured meat aroma (B), spiceblend aroma (C) and wet dog aroma (D) intensity of electron-beam irradiated frankfurters

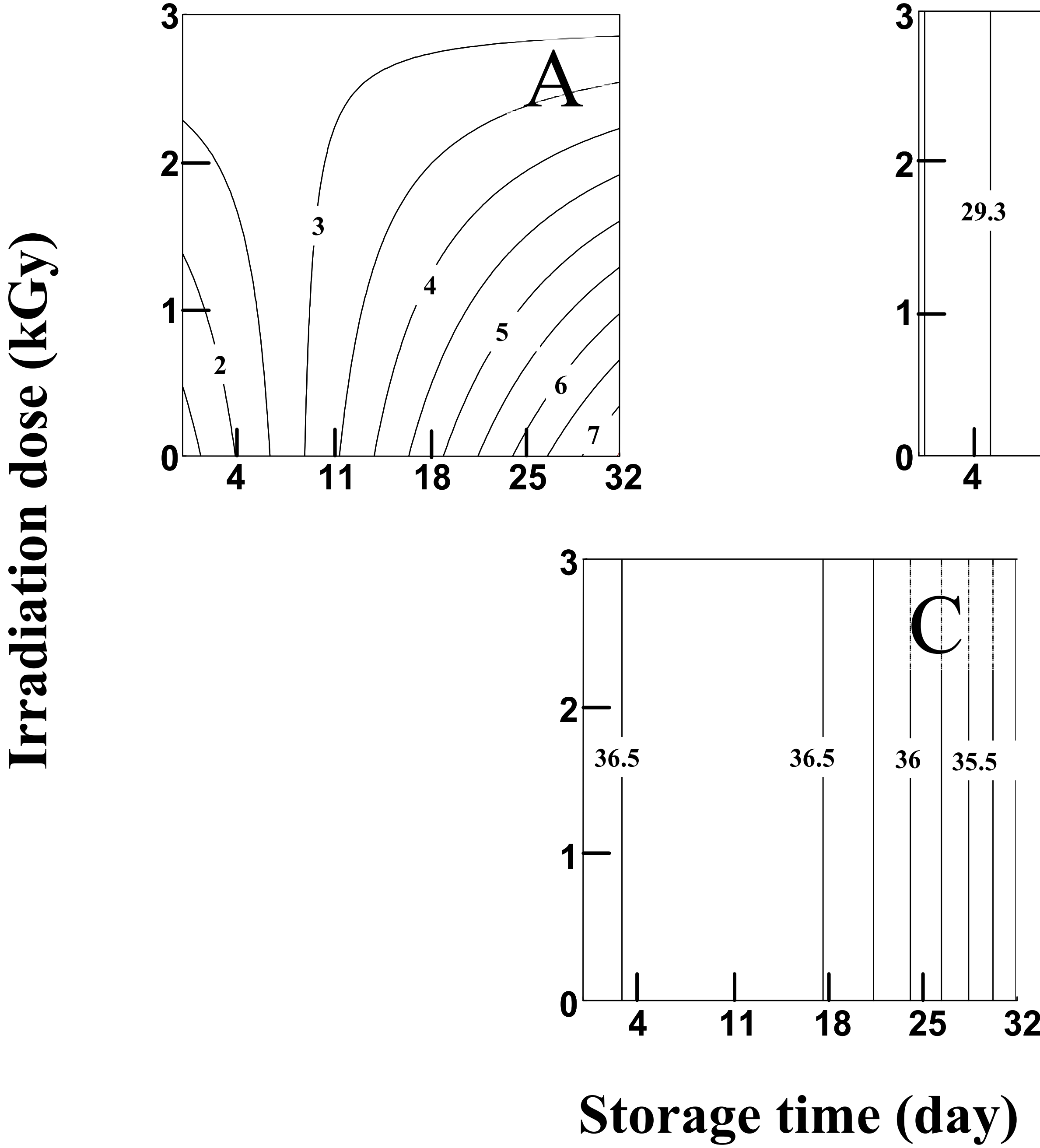

A
B
C
D
28.5
28
29
27.4
29.5
25.3
25.5
25.5
25.3
24.8
31
30.8
30.5
30.25
30
29.5
1
0
0
1
2
3
Irradiation dose (kGy)
Storage time (day)
0
1
2
3
4
11
18
25
32

throughout the storage time. At 9 days after irradiation, the intensity of off-flavor increased with decreasing dose. By the end of the storage time, non-irradiated frankfurters had the highest off-flavor, even though it was rated low, indicating that panelists were sensitive to off-flavor. Ang and Lyon (1990) found that off-flavor increased throughout their 5 days of storage for non-irradiated cooked broiler breast, thigh and skin. They also stated that cardboard, warmed over and rancid were associated with the development of off-flavor. Bagorogoza et al. (2001) found that the stale flavor of cooked samples, both irradiated and non-irradiated , were very low, but increased during the 3rd day of storage. They found that slight staleness, but not rancidity, was detected in all, irradiated and non-irradiated cooked turkey samples during storage.

Meaty. Storage time had a significant effect on the intensity of the meaty flavor (Fig. 5.2B) for non-irradiated and irradiated frankfurters, whereas irradiation dose did not. No matter the dose, the rating for meaty will be rated as having the same intensity. The ratings for the meaty flavor ranged from 29.5 to 28. The intensity of meaty flavor decreased throughout the storage time. Van Zyl and Setser, (2001) found that when the meaty aroma of non-irradiated frankfurters extended with sorghum flour were analyzed for the effect of day of storage, no significant differences were found. Ang and Lyon (1990) found that the meaty intensity of non-irradiated cooked broiler breast, thigh and skin decreased during storage. We also found this to be true for non-irradiated and irradiated samples in our study.

Chickeny. The chickeny flavor (Fig. 5.2C) of the non-irradiated and irradiated frankfurters was affected by storage time and not irradiation dose. The intensity of the chickeny flavor ranged from 36.5 to 35.3. From days 3 to 18, the intensity of chicken flavor remained constant. At 18 days after irradiation, the chickeny flavor decreased

Figure 5.2. Contour plots illustrating the effects of irradiation dose and storage time (days) on off-flavor (A), meaty flavor (B) and chickeny flavor (C) intensity of electron-beam irradiated frankfurters

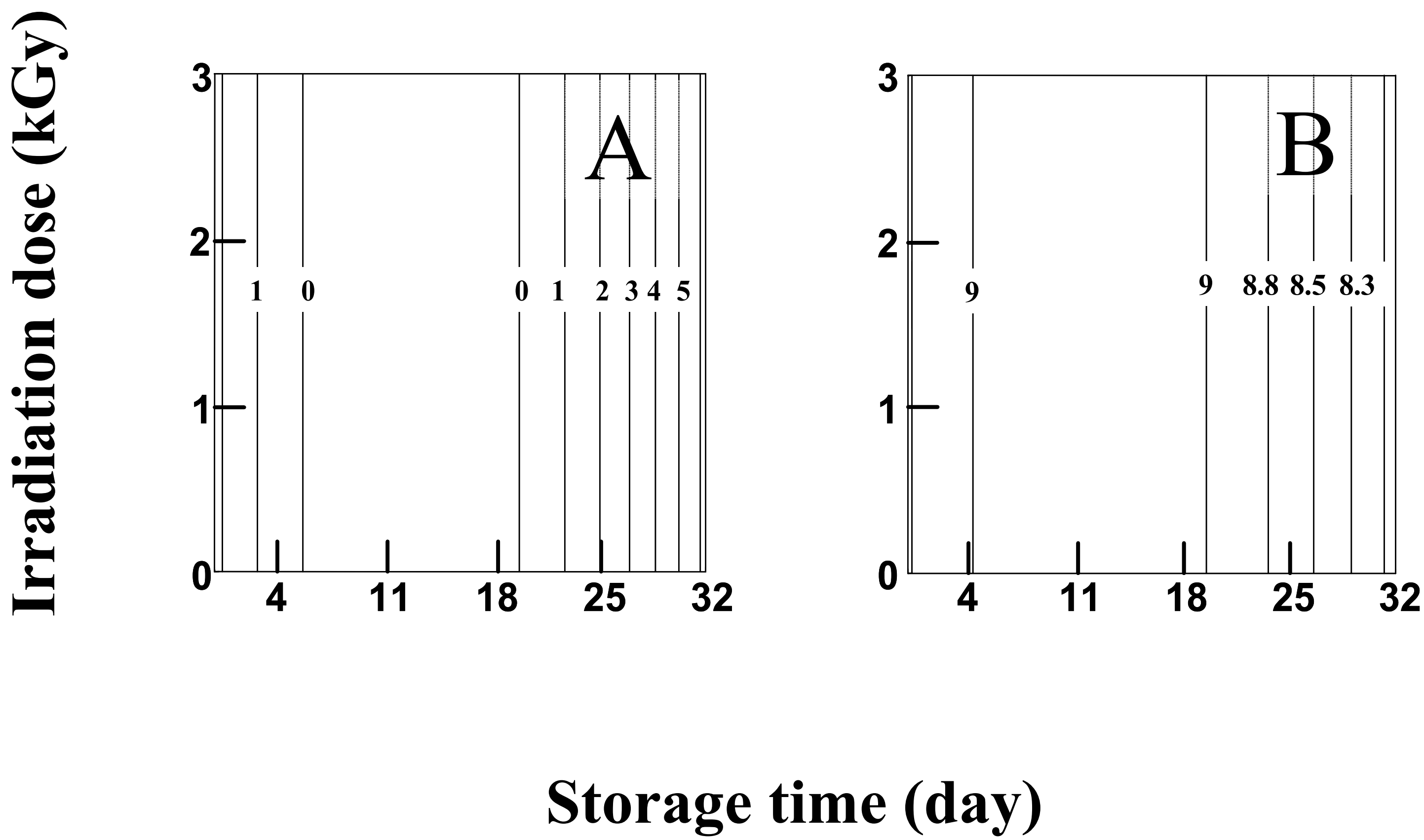

Irradiation dose (kGy)
Storage time (day)
A
B
C
0
1
2
3
4
11
18
25
32
2
3
4
5
6
7
29.3
29
28.8
28.5
28.3
28
36.5
36.5
36
35.5

throughout the storage time. However after 23 days, the chickeny flavor disappeared rapidly, at a much faster rate. Cooked chicken has been found to have a more chickeny flavor than raw meat, and no other sensory attributes of cooked chicken meat were affected by irradiation (Hashim et al., 1995). Bagorogoza et al. (2001) found that the turkey flavor in irradiated samples increased during storage, whereas it stayed the same in non-irradiated samples.

Sour. Storage time had a significant effect on the intensity of sour taste (Fig. 5.3A), regardless of irradiation doses. The intensity ratings for sour were extremely low, and received ratings of 0 to 6. Immediately after irradiation, the sour taste was detected. However, this aroma decreased and was not present at 6 – 19 days after irradiation. At 23 days after irradiation, sour taste reappeared and received the same low rating (=1) as 3 days after irradiation. From days 20 to 27, the intensity of sour taste increased to a rating of 3. From days 27 to 31, the rating for sour increased and the rating doubled to 6. However, this increase occurred at a faster rate in half the time. Electron-beam irradiated vacuum packaged chops had stronger sour notes than cobalt-irradiated vacuum packaged samples (Luchsinger et al., 1996).

Sweet. The sweet taste (Fig. 5.3B) of the irradiated and non-irradiated frankfurters was only affected by storage time and not irradiation dose. The intensity ratings for sweet were low and ranged from 8 to 9. The intensity ratings of sweet remained constant from 4 to 20 days after irradiation and decreased throughout the remaining storage period. Ahn et al. (2000) found that panelists characterized vacuum-packaged, irradiated and frozen meat odor as sweet, along with other descriptors. It has also been reported that increased moisture levels increased the perception of sweetness (Yackel and Cox, 1992). Ang and Lyon (1990) found that the meaty intensity of non-irradiated cooked broiler breast, thigh and skin decreased during storage. We

Figure 5.3. Contour plots illustrating the effects of irradiation dose and storage time (days) on sour (A) and sweet (B) taste intensity of electron-beam irradiated frankfurters


Irradiation dose (kGy)
3
2
1
0
A
1
0
0
1
2
3
4
5
4
11
18
25
32
B
9
9
8.8
8.5
8.3
Storage time (day)

also found this in our study. Sweet notes were lower in aerobic chops treated at 2.5 kGy with Cobalt irradiation than in those treated with electron beam irradiation (Luchsinger et al., 1996).

CONCLUSION

Mean ratings for appearance, aroma, flavor and texture attributes were found for the electron-beam irradiated poultry frankfurters. Regression models for significant attributes ($R^2 \geq 0.50$) were developed and the effects of irradiation dose and storage time were described. Storage time had a more significant effect on the frankfurters than irradiation dose. Irradiation had a significant effect on some aroma and flavor attributes, however it did not have a significant effect on texture attributes of the electron-beam irradiated frankfurters.

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CHAPTER 6

MULTIVARIATE ANALYSIS OF SENSORY AND INSTRUMENTAL MEASUREMENTS OF ELECTRON-BEAM IRRADIATED READY-TO-EAT POULTRY MEATS[1]

[1]Johnson, A.M. and A.V.A. Resurreccion. To be submitted to the *Journal of Sensory Studies*.

ABSTRACT

Ready-to-eat poultry meats (frankfurters and diced chicken) were electron-beam irradiated and stored for their expected shelf life. Refrigerated frankfurters and diced chicken irradiated at 1, 2 and 3 kGy were stored under refrigeration at 4°C for 32 days. Frozen diced chicken meat irradiated at 3 kGy was stored at -15°C for 90 days. Descriptive analysis, consumer acceptance and instrumental measurements (texture, moisture, fat, color, thiobarbituric acid reactive substances and hexanal) were performed to evaluate the effect of irradiation on these products throughout the shelf life. The non-irradiated and irradiated frankfurters at 18 and 32 days after irradiation, respectively, developed a sour taste, wet dog aroma and off-flavors. The non-irradiated and irradiated refrigerated diced chicken at 18 and 25 days after irradiation, respectively, became oxidized and developed off-flavors, whereas the irradiated frozen diced chicken remained similar to frozen non-irradiated diced chicken and of a high quality > 90 days after irradiation.

INTRODUCTION

Quality of irradiated meats is determined by many factors including the state of the meat, atmosphere around the meat at all times, packaging material, temperature of the meat at irradiation and during storage, and the irradiation dose absorbed (Bagorogoza *et al.* 2001). However, consumers are the final judges of quality and this can become costly when a consumer panel is used to determine product quality. Therefore, instrumental methods for the measurement of meat quality have many practical advantages over sensory panels and there needs to be continuing attempts to develop instrumental methods which imitate sensory panels (Toscas *et al.* 1999). Multivariate analysis can make use of instrumental data to predict consumer response. Unfortunately, there is no way around the initial measurement of the physical and chemical properties (Resurreccion 1988) that are needed to help predict sensory data. Multivariate analysis helps understand the underlying principles that are measured in evaluating the quality of food and establish which variables are determinants of food quality (Resurreccion 1988). Not only does it indicate the underlying dimensions of food products, but it also indicates the degree of interdependency among sensory characteristics (Syarief *et al.* 1985).

Multivariate analysis has been performed to determine descriptive characteristics of meat. Ruiz *et al.* (2002) used partial least squares regression to predict acceptability of dry-cured ham from descriptive analysis data. The analysis explained 63% of the total variation and showed that juiciness and several flavor traits were the major attributes positively influencing acceptability, whereas yellowness of the fat, dryness and fibrousness showed a negative influence. Lyon (1987) developed descriptive attributes for chicken flavor using multivariate analysis. In the study, factor analysis was used to reduce 45 descriptive terms to 12 sensory descriptors that would describe flavor changes in cooked and reheated chicken patties.

Syrarief *et al.* (1985) used factor analysis to profile the flavor of beefsteaks and frankfurters among other products. For the beefsteaks, a close relation between sour and astringent notes were found from factor 1 and factor 2 indicated a close relationship among cooked beef, beef and browned notes. For the frankfurters, the smoke flavor and the dairy notes of the frankfurters were negatively affected by the perception of smoke aroma, whereas pork notes were positively associated with fat notes. However, the seasoning complex made it more difficult to sense the pork fat notes.

Byrne *et al.* (2002) studied the effects of cooking on warmed-over flavor (WOF) development in chicken meat using multivariate analysis of variance-partial least squares regression (APLSR). Descriptive analysis indicated that the WOF development was described by an increase of rancid and sulfur sensory notes and a concurrent decrease of chicken meaty characteristics. They also found that increasing cooking temperature resulted in meat samples with a more roasted, toasted, and bitter sensory nature.

The objective of this study was to use multivariate analysis to describe relations between sensory and instrumental measurements of electron-beam irradiated ready-to-eat poultry meats. The specific objectives were to: 1) conduct principal component analysis (PCA) on descriptive attributes, consumer acceptance attributes, instrumental texture and physicochemical measurements for irradiated frankfurters and diced chicken to describe the data, 2) determine relations of consumer acceptance data with all measurements obtained in this study to identify determinants of acceptance for electron-beam irradiated frankfurters and diced chicken meat, and

3) use instrumental texture and physicochemical measurements to observe the effect of storage on irradiated ready-to-eat poultry meats.

MATERIALS AND METHODS

Two ready-to-eat poultry meat products, chicken frankfurters and diced chicken meat, were studied. The irradiation of the frankfurters and the diced chicken meat was conducted in two separate studies three months apart.

Experimental Design

For the refrigerated frankfurters and diced chicken samples, descriptive analysis and instrumental measurements were conducted at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, corresponding to 0, 25, 50, 75 and 100% of refrigerated shelf life. Consumer acceptance tests were conducted at 4, 18 and 32 days of refrigerated storage after irradiation, corresponding to 0, 50 and 100% of shelf life. Samples were evaluated on the same days, but at different testing sessions.

In addition, frozen diced chicken samples, descriptive analysis and instrumental measurements were conducted at 4, 32, 49 and 94 days of frozen storage after irradiation, corresponding to 0, 35, 50 and 100% of shelf life. Consumer sensory testing was not conducted on the frozen diced chicken meat.

After each storage period, a total of 12 samples, representing a non-irradiated control and three irradiation doses (1, 2, and 3 kGy) for each of three replications, were evaluated by trained panelists. On each sampling day, the 12 samples were randomly assigned to three sets of four samples and served monadically. The three sets of samples were served in each session and one session was conducted per day for five testing days for the descriptive analysis and one set of 12 served in three sets of four samples per day for three testing days for consumer acceptance tests. A total of five sessions were held in order to accommodate 50 consumers for testing. Presentation order of the 4 samples within a set was randomized over panelists, making sure not to have more than two replications of one treatment in the same set. Instrumental measurements were also done for each day of testing.

Samples

Frankfurters

Frankfurters (D. L. Lee & Sons, Inc., Alma, GA) were transported to the Department of Food Science and Technology in Griffin, GA in 48 quart insulated coolers (Igloo, Shelton, CT) packed with ice. The frankfurters were held for 48 hours at 4°C in a walk-in refrigerator (Model W06430-1, Nor-lake, Inc., Hudson, Wisconsin) until ready for packaging. Frankfurters were removed from their original packages. Five frankfurters were transferred into each irradiation approved 16.5 cm x 20.3 cm ethylene-vinyl acetate and polyvinylidene chloride bags (EVA/PVC) formed from 16.5 cm x 40.6 cm bags (B-540, Cryovac, Saddle Brook, NJ) cut in half and heat-sealed. Within five minutes of removal from the refrigerator, the frankfurters were vacuum-packaged (29 in Hg) using a single chamber packaging machine (Model UV250, Koch Packaging Systems, Kansas City, MO) and then heat-sealed, leaving approximately 2.54 cm space for the label to be inserted after the vacuum seal. Label information containing the desired irradiation doses were heat-sealed in the remaining portion of the bag to prevent the label from separating from the frankfurter samples. The samples were returned to the refrigerator (4°C) and held for overnight storage.

All samples were packed in polyfoam mailing boxes (35.5 cm x 35.5 cm x 38.7 cm Fisher Scientific, Pittsburgh, PA) and packed with ample ice packs (Fisher Scientific, Pittsburgh, PA) to maintain refrigeration temperatures determined in preliminary studies. Samples were shipped by air overnight to the Ion Beam Applications (IBA) irradiation facility (San Diego, CA).

Diced chicken meat

Frozen fully-cooked, seasoned diced chicken meat (1 in cubes of skinless, boneless chicken breast pieces) were obtained from Wayne Farms, Gainesville, GA and transported to the Department of Food Science and Technology in Griffin, GA in coolers packed with sufficient dry ice to maintain the meat in the frozen state. The diced chicken was held for 24 to 48 hours at -15°C in a walk-in freezer (Model UDS-4, W.A. Brown & Son, Inc., Salisbury, North Carolina) until ready for packaging. Five ounces of frozen chicken meat was transferred into irradiation approved 16.5 cm x 20.3 cm ethylene-vinyl acetate and polyvinylidene chloride bags formed from 16.5 cm x 40.6 cm bags (B-540, Cryovac, Saddle Brook, NJ) which were cut in half and heat-sealed. The samples were vacuum-packaged (29 in Hg) within five minutes of removal from the freezer as described for the frankfurters. The samples were returned to the freezer (-15°C) for overnight storage.

All samples were packed in polyfoam mailing boxes (61 cm x 45.7 cm x 45.4 cm, Fisher Scientific, Pittsburgh, PA) and packed with dry ice (Atlanta Dry Ice, Atlanta, GA), shielded from the samples by newsprint. Samples were shipped by air overnight under frozen conditions to Ion Beam Applications (IBA) irradiation facility (San Diego, CA).

Dose mapping

Dose mapping was conducted by Ion Beam Applications (IBA) (San Diego, CA) to: find the minimum and maximum absorbed dose points within the products and use this to determine the relation of the dose measured by an external dosimeter to dose absorbed by the product. From this relation, a dose range (adjusted minimum to the maximum dose) as measured by the external dosimeter, is determined to assure the minimum required irradiation dose and the maximum dose requirements are met throughout the product.

Radiochromic film dosimeters (Far West Technology, Inc., Goleta, CA) were placed at two locations on the package, one on top and another on the bottom of each frankfurter/diced chicken package. Samples were placed in stainless steel trays, transported onto the conveyor belt and exposed to the ambient temperature of the electron beam source (RF linear accelerator Applied Radiation Company, San Jose, CA) with an energy level of 9.5 MeV and a dose rate of 45 kGy/ft/min using a single sided pass.

Irradiation processing

Upon the arrival of the samples at the IBA irradiation facility, the frankfurter samples were held overnight in a refrigerator at 3°C (Model B1031-2, Kool Star, Los Angeles, CA) and the diced chicken meat samples were held overnight in a freezer that ranged approximately from -15° C to approximately -23°C (Kelvinator, Model CB220D, R.I.E. Developments, Melbourne, Australia).

Samples were irradiated by exposing them to the ambient temperature of the electron beam irradiation source using a single-sided pass to achieve a 1.0, 2.0 or 3.0 kGy dose, which was verified with radiochromic film dosimeters attached on the top and bottom surfaces of representative samples to determine dose rate and uniformity of irradiation. Irradiated samples were held overnight in a refrigerator at 4°C for frankfurters and in a freezer at -15°C for diced chicken meat. Non-irradiated samples of each product were held under conditions similar to that of the product, including the receiving, packaging and shipping steps, except the irradiation process. The following day, samples were packaged under conditions identical to their shipment to the irradiation facility, then transported by air to the sensory laboratory at the Department of Food Science and Technology (Griffin, GA).

Sample preparation

Frankfurters

Upon arrival at Griffin, non-irradiated and irradiated frankfurter samples were removed from the shipping boxes and were held in a refrigerator at 4°C until ready for sensory evaluation. The samples were stored for up to an expected shelf life of 32 days after irradiation. The samples were withdrawn from the walk-in refrigerator at 4, 11, 18, 25 and 32 days of refrigerated storage after irradiation, corresponding to 0, 25, 50, 75 and 100% shelf life, for the descriptive analysis and at 4, 18 and 32 days corresponding to 0, 50 and 100% of shelf life for the test for the consumer test.

Frankfurter samples were prepared for the sensory test according to preliminary testing procedures. Five frankfurter samples were removed from one package, directly from the refrigerator, and placed in 3-quart stainless steel pans (Revere Ware, Clinton, IL) with 800 ml of cold double-deionized water. The frankfurters and water were heated to boiling at a medium high setting and held for a total of approximately 7 minutes from the time samples started boiling. Frankfurter samples were prepared in 3 sets of 4 for each session. During the preparation, within each set of 4, frankfurters were cooked approximately 3 minutes apart so that panelists could receive warm samples in between each set. After the frankfurters boiled for the recommended time, the pans were removed from the stove and the water was drained and discarded. Frankfurters were removed from the pans and placed on cutting boards, cut in half crosswise and each frankfurter half was placed in 8 oz squat cups (Stock No. 8SJ20, Dart, Mason, MI) coded with three digit random numbers. Samples were served immediately for sensory evaluation by a descriptive panel or consumer panel.

Refrigerated diced chicken

Upon arrival at Griffin, frozen, non-irradiated and irradiated diced chicken samples were transferred into individual gallon Ziploc® storage bags (S.C. Johnson, Inc., Racine,WI) and thawed under refrigeration overnight in a walk-in refrigerator to simulate food service retail and home use conditions. The samples were stored at 4°C for up to an expected shelf life of 32 days after irradiation. The samples were withdrawn from the walk-in refrigerator at day 4, 18 and 32.

On each sampling day, approximately 6 cubes of refrigerated diced chicken meat were placed in 4 oz squat cups (Stock No. 4J6, Dart, Mason, Mich.) coded with three digit random numbers for sensory evaluation by a descriptive panel or consumers. Samples were served immediately without heating.

Frozen diced chicken

Upon arrival at Griffin, frozen non-irradiated and irradiated diced chicken samples remained in their packaging and were placed directly in a walk-in freezer at -15°C. The samples were stored at -15°C for up to an expected shelf of 90 days after irradiation to determine whether irradiation would have an effect on frozen diced chicken. The samples were withdrawn from the walk-in freezer at day 4, 32, 49 and 94.

On each sampling day, approximately 6 cubes of frozen diced chicken meat samples were placed in 4 oz squat cups (Stock No. 4J6, Dart, Mason, Mich.) coded with three digit random numbers and refrigerated overnight to thaw for sensory evaluation by a descriptive panel. Samples were served immediately without heating.

Sensory evaluation

A consumer sensory laboratory acceptance test (Resurreccion 1998) was conducted. Consumers were recruited from a database of consumers who had previously participated in consumer tests at the University. During recruitment, consumers were screened by using questions from a recruitment screener about their age, food allergies, and how frequently they consumed frankfurters/diced chicken to determine if they qualified for the test. Sixty consumers, from seven cities in the metro-Atlanta area, between the ages of 18–70 were recruited, allowing a 20% overage for “no-shows”, who were not allergic to the ingredients in frankfurters/chicken and consumed frankfurters at least four times a year and/or chicken at least twice a week. Among the sixty recruits, fifty participated in the test.

All tests were performed at the Consumer and Sensory Laboratories, Department of Food Science and Technology, University of Georgia in Griffin, Ga. Upon panelists’ arrival, they were directed to a conference room and were met by a greeter who asked them to sign-in, given a brief explanation of the evaluation procedure and were required to complete and sign consent forms approved by the University of Georgia Institutional Review Board. After completion of the consent forms and a brief demographic questionnaire, consumers were escorted to the sensory booths for evaluation of the frankfurters or diced chicken meat samples.

Samples were evaluated in environmentally-controlled partition booths illuminated with two 50-watt indoor reflector flood lamps, which provided 738 lux of light. Double-deionized water and unsalted crackers were provided so that consumers may cleanse their palates in between samples. Consumers rated their overall acceptance of the sample and acceptance of aroma, appearance, color, flavor, juiciness, tenderness and mouthfeel/texture of each sample using a 9-point hedonic scale (Peryam and Pilgrim 1957) with 1=dislike extremely and 9=like extremely using computer ballots (Compusense® five, version 3.8, Compusense, Inc., Guelph, Ontario, Canada). Compusense allowed panelists to return to previous questions regarding a sample, but did not allow panelists to return to previously evaluated samples.

On each sampling day, all samples were served monadically. Each consumer evaluated four samples in each of three sets, separated with a compulsory break of five minutes between each set. Samples were randomized within each of the three sessions for the frankfurter study, whereas the 12 samples for the diced chicken meat were randomized by panelist in the entire study. The order of presentation was balanced across the panel. At the conclusion of the frankfurters and diced chicken meat studies, consumers received an honorarium of 10 dollars for each day of participation.

Descriptive Analysis

Recruitment. Prospective members of the descriptive panel were recruited from a list of previously trained panelists, who had previously participated in descriptive analysis tests at the sensory laboratory, as well as sensory evaluation students from the University. All panelists were recruited on the basis of the following criteria: between 18 and 70 years of age, did not smoke, not allergic to frankfurters/diced chicken, consumed frankfurters at least four times a year/chicken twice a week, were willing to evaluate irradiated frankfurters/diced chicken, were available and willing to participate during training and testing dates and were able to verbally communicate about the product. Panelists were required to complete and sign consent forms approved by the University of Georgia Institutional Review Board.

Training. Ten panelists, 1 male and 9 females, were selected. Each panelist was trained and calibrated for 3 days. Each training session was 2 hours each day for a total of 6 hours. During the first day of training, panelists were presented with frankfurter/diced chicken samples, representing each irradiation dose and storage period. Descriptive terms that characterized the sensory properties of samples were developed by the panel while evaluating samples. Panelists then decided on a final comprehensive list of flavor and texture terms with definitions understood by all panelists. Panelists did not necessarily define an attribute as indicated in existing literature. The final list of attributes with definitions, references and procedure for evaluating the attributes for frankfurters and diced chicken was decided upon by panel consensus (Tables 6.1 and 6.2, respectively).

During the second day of training, panelists determined references that would best help them to rate the descriptive terms developed. Reference standards for the frankfurters and diced chicken were evaluated as a group to assure that judgments of each panelist were in the same

Table 6.1. Attributes, definitions, references and intensity ratings used to evaluate electron-beam irradiated frankfurters

ATTRIBUTE[1]	DEFINITION	REFERENCE	INTENSITY
APPEARANCE			
Glossy[2,3]	The amount of light reflected from the skin surface	Vegetable oil (Crisco, Procter & Gamble, Cincinnati, OH)	137
Red color[2]	The intensity or strength of red color from white to dark red	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Red paper (L*=51.84, a*=51.92, b*=26.29)	75
Brown color[2]	The intensity or strength of brown color from white to dark brown	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Brown cardboard (L*=59.05, a*=5.25, b*=17.50)	66
		Chocolate syrup (Hershey Foods Corp., Hershey, PA) (L*=24.35, a*=2.00, b*=1.76)	150
Evenness of surface	The evenness of the surface texture	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	120
		Crisco (Crisco, Procter & Gamble, Cincinnati, OH)	150
AROMA:			
Smell the sample and evaluate for aroma			
Total aroma	The total aroma intensity of sample	Standard taste references at varying concentrations	

Table 6.1. Continued

Meaty [4,5,6]	Aromatic associated with cooked or roasted meat	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	25
Chickeny [3,4,5,6]	Aromatic associated with cooked chicken	Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	57
Cured meat [4]	Aromatic/taste sensation associated with processed products that contain curing agents (nitrites, sugars, salts)	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	21
Spice blend [4]	Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified	Standard taste references at varying concentrations	
Wet dog [4]	Aromatic associated with wet dog hair	Standard taste references at varying concentrations	
Off-flavor [4]	A general, non-specific term, related usually to characteristics that are inappropriated in a food system	Standard taste references at varying concentrations	
FLAVOR:			
Place 2 to 3 pieces of sample in mouth and evaluate for flavor			
Total flavor	The total flavor intensity of sample	Standard taste references at varying concentrations	
Meaty [4,5,6,7]	Aromatic associated with cooked or roasted meat	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	39

Table 6.1. Continued

Chickeny [3,4,6]	Aromatic associated with cooked chicken	Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	72
Oily [5,6]	An overall term for the aroma and flavor notes reminiscent of vegetable oil or mineral oil products	Vegetable oil (Crisco, Procter & Gamble, Cincinnati, OH)	55
Cured meat [4]	Aromatic/taste sensation associated with processed products that contain curing agents (nitrites, sugars, salts)	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	32
Spice blend [4]	Aromatics of a group of spices or herbs perceived in a product that cannot be individually identified	Standard taste references at varying concentrations	
Pepper [4]	Aromatic associated with pepper	Ground black pepper (Kroger Co., Cincinnati, OH)	93
Liver/organy [4,5,7]	Aromatic associated with cooked liver, organ meat, serum and/or blood salts	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	12
		Hearts, gizzards, and livers (reference not supplied)[4]	75
Taste			
Salty [2,4,5]	The taste on the tongue associated with sodium chloride solutions	0.2% sodium chloride in deionized water (Fisher Scientific, Fair Lawn, NJ)	25
		0.35% sodium chloride in deionized water	50
		0.5% sodium chloride in deionized water	85

Table 6.1. Continued

Sour [2,4,5]	The taste on the tongue associated with citric acid solutions	0.05% citric acid in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		0.08% citric acid in deionized water	50
		0.15% citric acid in deionized water	100
Bitter [2,4,5]	The taste on the tongue associated with caffeine solutions	0.05% caffeine in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		0.08% caffeine in deionized water	50
		0.15% caffeine in deionized water	100
Sweet [2,4,5,6]	The taste on the tongue associated with sucrose solutions	2.0% sucrose in deionized water (Fisher Scientific, Fair Lawn, NJ)	20
		5.0% sucrose in deionized water	50
		10.0% sucrose in deionized water	100
		16.0% sucrose in deionized water	150
Umami [4]	Specific taste on the tongue stimulated by MSG (monosodium glutamate) and certain other nucleotides	0.2% MSG solution (Ajinomoto U.S.A., Inc., Teaneck, NJ)	36
		Standard taste references at varying concentrations	

Table 6.1. Continued

Feeling factors			
Tongue sting	Degree of a sharp, stinging sensation on the tongue or throat	Chili powder (Private Selection, Inter-American Products, Inc., Cincinnati, OH)	40
TEXTURE			
Springiness [2,8]	Degree to which sample returns to original shape	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	70
		Marshmallow[2] (Kraft, Nabisco, Inc., East Hanover, NJ)	95
First bite: Bite through 1 cm of sample with incisors before you rate			
Overall hardness [2,8]	Force required to bite through sample	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	50
		Peanuts[2] (Planter's, Nabisco Foods, Inc., East Hanover, NJ)	95
5 Chews: Chew sample five times before you rate			
Chewy [8]	Total amount of work necessary to chew a sample to a state ready for swallowing	Tootsie Roll midgees (Tootsie Roll Industries, Inc., Chicago, IL)	75
Cohesiveness of mass [2,8]	Degree to which sample holds together in a mass after five chews	Hebrew National frankfurter[2] (ConAgra Foods, Eagle, ID) prepared according to package instructions	75
10 Chews: Chew sample ten times before you rate			
Grainy [2,3,4]	The amount of particles in the mouth	Grits[3] (Kroger Instant Country Grits, The Kroger Co., Cincinnati, OH) prepared according to package instructions	90

Table 6.1. Continued

Residual: Evaluate sample after expectorating			
Oily mouthcoat [2]	Amount of oil left on mouth surfaces	Water (Deionized)	0
		Cooked chicken thighs (Tyson Foods, Inc., Springdale, AR) cooked until fat was rendered	36

[1] Attribute listed in order as perceived by panelists.

[2] Meilgaard et al. (1991)

[3] Hashim et al. (1995)

[4] Civille and Lyon (1996)

[5] Lyon (1987)

[6] Landes (1972)

[7] Jacobson and Koehler (1970)

[8] Meullenet and Gross (1999)

Table 6.2. Attributes, definitions, references and intensity ratings used to evaluate electron-beam irradiated diced chicken meat

ATTRIBUTE[1]	DEFINITION	REFERENCES	INTENSITY
APPEARANCE			
Brown Color [2]	The intensity of color from white to dark brown	White paper (Georgia-Pacific Corp., Atlanta, GA) (L*=92.88, a*=1.54, b*=-1.01)	0
		Brown Cardboard (L*=59.05,a*=5.25,b*=17.50)	66
		Control (non-irradiated diced chicken meat)	16
Sharp edges	Corner retains its shape when cut with a knife	Sliced boiled eggs (Kroger Co., Cincinnati, OH) cooked approximately 20 minutes	130
		Control (non-irradiated diced chicken meat)	93
Moist (dry) [2]	Amount of wetness or oiliness on surface	Crackers (Kraft, Nabisco, Inc., East Hanover, NJ)	0
		Wet cardboard	85
		Pineapple (Kroger Co., Cincinnati, OH)	120
		Control (non-irradiated diced chicken meat)	87
Stringy	Coarse, tough or fibrous, as meat	Pineapple (Kroger Co., Cincinnati, OH)	113
		Control (non-irradiated diced chicken meat)	81

Table 6.2. Continued

TEXTURE			
Moist (dry) [2]	Amount of wetness or oiliness on surface as perceived by the tongue and mouth	Crackers[3] (Kraft, Nabisco, Inc., East Hanover, NJ)	0
		Pineapple (Kroger Co., Cincinnati, OH)	105
		Control (non-irradiated diced chicken meat)	68
2 chews: Chew sample two times before you rate			
Juiciness [3]	Amount of juice or moisture expressed from the sample after two chews	Crackers[3] (Kraft, Nabisco, Inc., East Hanover, NJ)	12
		Applesauce[3] (Mott's, Stamford, CT)	137
		Control (non-irradiated diced chicken meat)	77
Tenderness [3]	Lack of resistance to chewing	Cream cheese (Kraft, Nabisco, Inc., East Hanover, NJ)	137
		Control (non-irradiated diced chicken meat)	80
5 chews: Chew sample five times before you rate			
Chewy [4]	Force required to masticate the sample five times, at a constant rate of force application	Sunnyland Jumbo Franks (Sunnyland Inc., Plant City, FL) prepared according to package instructions	20

Table 6.2. Continued

		Tootsie Roll midgees (Tootsie Roll Industries, Inc., Chicago, IL)	75
Cohesiveness of mass [2,4]	Degree to which sample holds together in a mass after five chews	Sunnyland Jumbo Franks (Sunnyland Inc., Plant City, FL) prepared according to package instructions	75
		Control (non-irradiated diced chicken meat)	51
Adheres to molar	Particles that adhere to the molars after five chews	Water (Deionized)	0
		Tootsie Roll midgees (Tootsie Roll Industries, Inc., Chicago, IL)	62
		Spearming chewing gum stick(Wrigley's, Cincinnati, OH)	137
		Control (non-irradiated diced chicken meat)	27
Residual: Feel mouth surface and teeth with tongue after product is expectorated			
Mealy	Amount of particles remaining in the mouth after expectoration	Water (Deionized)	0
		Cornbread (Jiffy, Chelsea Milling Co., Chelsea, MI) prepared according to package instructions	137
		Control (non-irradiated diced chicken meat)	79
Oily [5,6]	Amount of oil left on the mouth surfaces after expectoration	Water (Deionized)	0

Table 6.2. Continued

		Chicken fat (Tyson Foods, Inc., Springdale, AR) rendered from cooked chicken thighs	70
		Control (non-irradiated diced chicken meat)	20
Tooth pack [2]	Amount of sample left in or on teeth after expectoration	Peanuts (Planter's, Nabisco Foods, Inc., East Hanover, NJ)	35
		Control (non-irradiated diced chicken meat)	17
FLAVOR			
Cooked chicken[6,7]	Aromatic associated with cooked chicken	Chicken bouillon (Maggi, Nestle, Glendale, CA) prepared according to package instructions	54
		Cooked chicken thighs[7] (Tyson, Springdale, AR) cooked until fat was rendered	72
		Control (non-irradiated diced chicken meat)	77
Chicken broth [3,7]	Aromatic associated with chicken stock	Chicken bouillon (Maggi, Nestle, Glendale, CA) prepared according to package instructions	96
		Control (non-irradiated diced chicken meat)	47
Sulfur [7]	Aromatic associated with overcooked eggs	Sliced, cooked eggs[7] (Kroger Co., Cincinnati, OH) cooked approximately 20 minutes	40
		Control (non-irradiated diced chicken meat)	11

Table 6.2. Continued

Sweet aromatic [3,7]	Aromatic associated with cooked chicken, but different from chickeny flavor	Vanilla[7] (Kroger Co., Cincinnati, OH)	42
		Control (non-irradiated diced chicken meat)	0
Ginger[7]	Aromatic associated with ginger	Ginger root[7] (Standard taste references at varying concentrations)	
		Control (non-irradiated diced chicken meat)	3
Pepper [7]	Aromatic associated with pepper	Black pepper[7] (Kroger Co., Cincinnati, OH)	93
		Control (non-irradiated diced chicken meat)	13
Chicken fat [7]	Aromatic associated with chicken fat	Chicken fat[2,7] (Tyson Foods, Inc., Springdale, AR) rendered from cooked chicken thighs	40
Oxidized [5,7]	The flavor associated with oxidized fats and oils	Water (Deionized)	0
		Old vegetable oil[7] (Crisco, Procter and Gamble, Cincinnati, OH)	48
Cardboard [5,7]	Aromatic associated with slightly oxidized fats and oils, reminiscent of wet cardboard	Dehydrated mashed potatoes (prepared according to package instructions)	34
		Wet cardboard[7]	85

Table 6.2. Continued

		Control (non-irradiated diced chicken meat)	3
Off-flavor [7]	Flavor generally regarded as uncharacteristic of cooked chicken.	Standard taste references at varying concentrations	
TASTE			
Salty [2,5,7]	The taste on the tongue associated with sodium chloride solutions	0.2% NaCl solution in deionized water[2](Fisher Chemical, Fair Lawn, NJ)	25
		0.35% Nacl solution in deionized water[2]	50
		0.5% NaCl solution in deionized water[2]	85
Sour [2,5,7]	The taste on the tongue associated with citric acid solutions	0.05% Citric acid in deionized water[2] (Fisher Chemical, Fair Lawn, NJ)	20
		0.08% Citric acid in deionized water[2]	50
		0.15% Citric acid in deionized water[2]	100
Bitter [2,5,7]	The taste on the tongue associated with caffeine solutions	0.05% Caffeine in deionized water[2](Fisher Chemical, Fair Lawn, NJ)	20
		0.08% Caffeine in deionized water[2]	50
		0.15% Caffeine in deionized water[2]	100

Table 6.2. Continued

Sweet [2,5,7,8]	The taste on the tongue associated with sucrose solutions	2.0% Sucrose in deionized water[2] (Fisher Chemical, Fair Lawn, NJ)	20
		5.0% Sucrose in deionized water[2]	50
		10.0% Sucrose in deionized water[2]	100
		16.0% Sucrose in deionized water[2]	150

[1]Attribute listed in order as perceived by panelists

[2]Meilgaard et al. (1991)

[3] Hashim et al. (1995)

[4] Meullenet and Gross (1999)

[5] Lyon (1987)

[6] Landes (1972)

[7]Civille and Lyon (1996)

[8] Jacobson and Koehler (1970)

range as those of the other panelists. Panelists were calibrated to rate intensity of stimuli by presenting them with standard references for basic tastes (Meilgaard *et al.* 1991).

Panelists evaluated samples using a "hybrid" descriptive analysis method (Einstein 1991), a combination of the Quantitative Descriptive Analysis (QDA®) (Tragon Corp., Redwood City, CA) and Spectrum™ Analysis (Sensory Spectrum, Inc., Chatham, NJ) Methods. Each panelist rated the attribute intensity of each reference for a particular attribute and then gave it an intensity rating between 0 and 150 using flashcards shown to the panelists at the same time. Calibration of the panel was conducted by asking panelists not rating within 10% of the consensus rating to re-evaluate the sample and adjust their rating. An average rating was obtained based on final intensity ratings. During the third day of training, panelists evaluated frankfurter/diced chicken samples with the computerized ballot (Compusense, Version 4.0, Compusense Inc., Guelph, Ontario, Canada).

Ballot. A computerized ballot with 31 attributes for frankfurters and 27 attributes for diced chicken were listed vertically in their order of appearance, five attributes per display. Using a computer mouse, panelists clicked on each attribute on a 150-mm unstructured line scale, with anchors at 12.5 and 137.5 mm that appeared on the computer display with a heading consisting of that particular attribute and definition. Panelists made a vertical mark on the line scale indicating the intensity of that attribute. The numerical rating for that attribute would then appear next to it briefly, indicating that the attribute had been rated and panelists could proceed to rate the next attribute. All attributes of one sample were rated for intensity. Compusense allowed panelists to return to previous questions regarding a sample, but did not allow panelists to return to previously evaluated samples.

Evaluation Procedures. All tests were performed at the Department of Food Science and Technology, University of Georgia, Griffin, GA. Before each evaluation session, panelists were presented with standard references for basic tastes, reference standards, a warm-up sample (a non-irradiated control or irradiated sample) and a control sample in a one hour calibration session around a table in a sensory laboratory. Panelists were instructed to calibrate their judgments using standard references, then to evaluate the control sample and compare individual responses for outlying ratings, if any. Outliers were calibrated by reevaluating the sample and adjusting their ratings toward consensus. Panelists then evaluated their samples in individual environmentally- controlled partition booths as described previously. Water and unsalted crackers were provided for panelists to cleanse their palates between samples. Descriptive panelists received an honorarium of 10 or 12 dollars, based on experience, for their participation in each session.

Physicochemical Measurements

Color. The instrumental Hunter color values were measured using a hand-held colorimeter (Minolta CR-200, Minolta Camera Co., Ltd., Osaka, Japan) to measure color lightness, L*, a*, and b* values of each sample. The colorimeter was calibrated with a standard red tile (L=48.76, a=36.79, b=14.46) due to the redness of the frankfurters and a brown tile (L=58.69, a=10.71, b=12.55) for the diced chicken. Frankfurter/diced chicken samples representing each treatment were a composite from several packages. Frankfurters were cut into 1 inch slices, placed on white paper and color was measured on the cross section of the slice. Diced chicken were placed on white paper and color was measured. Three slices/dices were obtained randomly from each treatment per rep. Three readings per slice/dice per sample were taken and averaged. Color measurements were means from the average of the 3 slices/dices. Subsequent color measurements on samples were measured once per week for the duration of the study. Chroma ($[a^2 + b^2]^{1/2}$) and hue angle ($\tan^{-1} b/a$) were calculated from the a* and b* values.

Moisture. AOAC official method (1998) No. 926.12 was used to determine moisture content. Approximately 5 grams of ground frankfurters/diced chicken were placed in an aluminum dish containing an aluminum liner and dried, uncovered, to a constant weight overnight for approximately 16 hours at 70°C in a vacuum oven (Model 281A, Fisher Scientific, Pittsburg, PA). After the sample was removed from the vacuum oven, it was covered with an aluminum lid to prevent moisture absorption and cooled in a desiccator for one hour. Samples were weighed and moisture content was calculated as follows:

$$\%\ \text{Moisture} = \frac{\text{Loss of Moisture X 100}}{\text{Weight of Sample}}$$

Fat. The fat content of freeze-dried frankfurter/diced chicken samples was determined using AACC official method (1999) No. 30-25. The fat content was measured for approximately 2 to 3 grams of freeze-dried frankfurter/diced chicken samples by oil extraction using reagent grade petroleum ether (b.p.=36-65°C, J.T. Baker Phillipsburg, NJ, USA) in a Goldfisch apparatus (Labconco, Kansas City, MO, USA) for approximately 24 hours. The extraction beakers containing oil were transferred into a vacuum oven (Model 281A, Fisher Scientific, Pittsburgh, PA, USA) preheated to 70°C and placed under vacuum for approximately 2 hours. The beakers were removed and placed in a desiccator to cool for at least one hour prior to weighing. The total oil content of the samples on a dry weight basis was calculated using the following equation:

$$\% \text{ Total oil} = \frac{\text{Weight of Fat x 100}}{\text{Weight of Sample}}$$

Thiobarbituric Acid Analysis (TBA). The 2-thiobarbituric acid (TBA) test and distillation method of Tarladgis *et al.* (1960) was used to determine the malonaldehyde content of the frankfurter/chicken samples. Slight modifications, such as the use of a sulfanilamide reagent, were used according to recommendations of Zipser and Watts (1962) to correct for interference of the nitrite level in the frankfurter samples and antioxidants, n-propyl gallate and ethylenediaminetetraacetic acid was used according to Rhee (1978) to prevent the occurrence of oxidation during the grinding process for the diced chicken samples. The constant value of K was calculated by using the following equation:

$$\text{K (distillation)} = \left(\frac{\text{conc. in moles / 5 ml. of distillate}}{\text{optical density}}\right) \text{ X } \left(\text{mol. wt. of malonaldehyde}\right) \text{ X } \left(\frac{10^7}{\text{wt. of sample}}\right) \text{ X } \left(\frac{100}{\text{\% recovery}}\right)$$

where molecular weight of malonaldehyde = 72.06 g, the weight of sample = 10 g and the percent recovery for this study = 84. The "TBA number", mg. of malonaldehyde per 1,000 g of sample, was calculated by using the following equation:

TBA number (mg malonaldehyde/1000 g of sample) = absorbancy X K (distillation)

Measurement of Hexanal in Headspace Volatile Compounds. Headspace volatile compounds were determined using a gas chromatographic (GC) method adapted from Young and Hovis (1990). Frankfurter/diced chicken (1.5 g) samples at ambient temperature were weighed directly into a 5.0-mL mini-vial, having heavy wall construction, a tapered cone and fitted with an open-hole screw cap with an 18 mm Teflon/rubber disc lining (Alltech Associates, Inc., Deerfield, IL). An internal standard, 50 ul of 4-heptanone (Sigma, St. Louis, MO) was added to the vial. The vials were heated for 15 minutes in a Multi-Blok heater (Lab-line

Instruments, Inc., Melrose Park, IL) set at 110ºC. Headspace volatile compounds (1.0 cc) were drawn out from the vial using a 2-ml pressure-lok gas syringe (Dynatech Precision Sampling Corp., Baton Rouge, LA) and injected into a gas chromatograph (Model 5890A, Hewlett Packard, Avondale, PA) fitted with a glass column (1.8 M x 2 mm i.d.) packed with 80-100 mesh Porapak P (Waters Chromatography Corp., Milford, MA). The gas chromatograph was equipped with a flame ionization detector coupled to an integrator (Model 3390A, Hewlett Packard, Avondale, PA). Helium was used as the carrier gas and flow rate was adjusted so that hexanal eluted after 5.0 min. Hexanal was tentatively identified by comparing sample retention time (approximately 5.00 ± 0.03 min) with that of an internal standard, 4-heptanone. The hexanal content was calculated using the following equation:

$$\mu g/g = \left(\frac{\text{abs response factor of hexanal}}{\text{abs response factor of 4-heptanone}}\right) \text{X} \left(\frac{\text{area hexanal}}{\text{area 4-heptanone}}\right) \text{X} \left(\frac{\text{amt of 4-heptanone}}{\text{amt of sample}}\right)$$

Instrumental Texture. A double compression test (Loup *et al.* 2001) was performed using the Instron Universal Testing machine (Model 1122, Instron Inc., Canton, MA) to determine springiness, cohesiveness, gumminess and chewiness of the frankfurter samples. Compression plates, 100 mm in diameter, were used to perform the instrumental Texture Profile Analysis (TPA). The sample was compressed to 90% of the frankfurters original height. One half-inch section of the frankfurter was placed on the skin side between the compression plates. The clearance between the top compression plate and the base was set at 30 mm. A 50-kg maximum-load cell was used. The cross-head speed was set at 5mm/s and the test speed was set at 10 mm/s. Two replications were performed for each sample. Instrumental texture was not conducted on the diced chicken samples due to the non-uniform shape of the samples. Data were collected using Merlin Software (Instron Corp., Canton, MA).

Statistical Analysis. Statistical Analysis Software System (Version 8.0, SAS Institute, Cary, NC) was used to analyze all data results. Analysis of variance, using the general linear model (PROC GLM), was conducted on each attribute to identify the significant differences in sensory ratings on frankfurter/diced chicken samples for all storage times and irradiation doses. This analysis was also performed on the instrumental texture and each physicochemical measurement to determine the means for each sample for all storage times and irradiation doses.

All PCA and PLSR analysis were conducted using the Unscrambler 7.6 (Camo ASA, Trondheim, Norway). PCA is a bilinear modeling method that gives an interpretable overview of the main information in a multidimensional data table. PCA was used to analyze descriptive analysis, consumer acceptance, and instrumental measurements to view the underlying structure of the data. Bi-plots of scores superimposed on PCA loadings were also used to describe the attributes related to the scores. Relations were determined between descriptive analysis, instrumental texture/physicochemical measurements using partial least squares regression (PLSR2) with all measurements obtained in this study to identify determinants of acceptance for electron-beam irradiated frankfurters and diced chicken meat. A final PLSR2 was conducted, where consumer acceptance was related to all data sets (descriptive analysis and instrumental texture/physicochemical variables). PLSR2 was conducted so that several dependent variables (Y-variables) were modeled simultaneously, whereas PLSR1 is based only on one dependent variable (Y-variable). Correlation coefficients for this model were also calculated by plotting predicted versus observed ratings or measurements. All data analysis was performed with standardized variables and full cross validation. Standardization of the variables was conducted so that all variables included in the analysis have an equal chance to influence the model, regardless of their original variances (Esbensen *et al.* 2000). For all analysis, mean data for the three replications was used in all plots.

RESULTS AND DISCUSSIONS

Descriptive analysis of irradiated frankfurters

In the principal component analysis (PCA) and partial least squares regression (PLSR) plots, all 20 frankfurter treatment means are the averages of 3 replication means, which are identified by treatment numbers. The numbers and the corresponding storage time and irradiation dose are listed in Table 6.3.

Loadings for descriptive data. PCA was conducted to view relations between the sensory attribute variables and identify sample groupings within the sensory data. From the loading plot (Fig. 6.1A), the first two principal components (PC) described 65% of the total variation in the sensory data. The first PC (PC1) explained 50% of the variation and the second PC (PC2) described 15% of the attributes. Attributes with positive loadings in PC1 were sour taste (0.725), wet dog odor (0.421), off-flavor (0.326) and evenness of surface (0.209), while attributes chickeny flavor (0.155), spiceblend (0.121), salty taste (0.120), sweet taste (0.117), chickeny flavor (0.112), total flavor (0.107), and meaty aroma (0.103) had negative effects in PC1. Attributes overall hardness (0.921) and meaty aroma (0.138) had positive loadings in PC2 while brown color (0.194), evenness of surface (0.185) and glossy (0.104) attributes had negative loadings in PC2.

Evenness of surface had significant loadings in both PC1 and PC2, however the higher loading was found in PC1. PC1 explains the sour taste, wet dog aroma and off-flavors due to

Table 6.3. Sample numbers corresponding to irradiation dose and storage time for electron-beam irradiated ready-to=eat poultry frankfurters[1]

Sample	Storage time (day)	Irradiation dose (kGy)
1	4	0
2	4	1
3	4	2
4	4	3
5	11	0
6	11	1
7	11	2
8	11	3
9	18	0
10	18	1
11	18	2
12	18	3
13	25	0
14	25	1
15	25	2
16	25	3
17	32	0
18	32	1
19	32	2
20	32	3

[1]Each frankfurter treatment mean of the average of 3 replication means are identified by the sample number

irradiation on the frankfurters. PC2 explains the appearance attributes of the frankfurters. The remaining attributes did not contribute much weight and were grouped in close proximity toward the center of the plot.

Scores and loadings for descriptive data. A biplot (Fig. 6.1B) showed the scores superimposed on the loading plot. Majority of the samples were grouped in close proximity toward the center of the plot. The non-irradiated frankfurters (no. 17) and frankfurters irradiated at 1 kGy at 32 days after irradiation (no. 18) were related to sour taste, wet dog aroma and off-flavor attributes. The frankfurter irradiated at 1kGy after 18 days after irradiation is negatively related to overall hardness and could have been perceived by the panelists to be soft (opposite of hardness) due to the irradiation process. Grigelmo-Miguel *et al.* (1999) found that when sensory results of non-irradiated frankfurters with added peach dietary fiber were compared, the only significant relationship was found between acceptability and hardness, which indicated the importance of this attribute in the acceptability of frankfurters. The correlation coefficient was negative, meaning that the consumer preferred the softer products.

Consumer acceptance of irradiated frankfurters

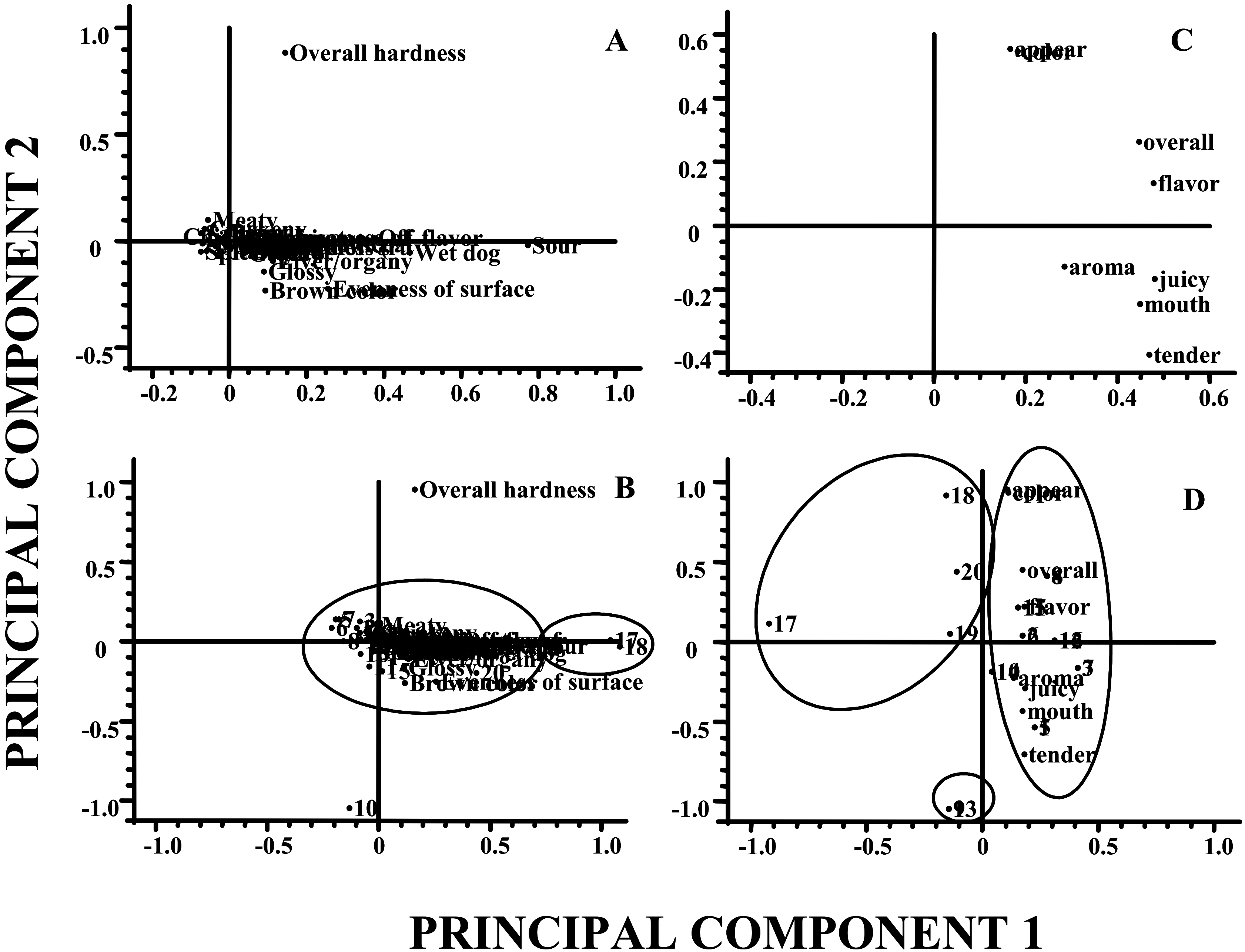
Loadings for consumer acceptance data. PCA on consumer acceptance data was conducted to view the underlying structure of the data. From the loading plot (Fig. 6.1C), the first two principal components described 94% of the variation for the consumer data. The first PC (PC1) explained 90% of the variation and the second PC (PC2) described 4% of the attributes. In PC1, all of the consumer attributes had positive loadings. The loadings are: juicy (0.442), flavor (0.438), tender (0.430), mouthfeel (0.409), overall (0.406), aroma (0.245), color (0.143) and appearance (0.126). In PC2, the positive attributes were appearance (0.581), color (0.573), overall (0.289) and flavor (0.158), whereas tenderness (0.381), mouthfeel (0.222), juiciness (0.141) and aroma (0.105) had negative loadings.

Scores and loading for consumer acceptance data. A biplot (Fig. 6.1D) showed the scores superimposed on the loading plots. At day 18 and 25 days after irradiation, the non-irradiated samples (no. 9 and 13, respectively) were away from the cluster, whereas the irradiated samples for these days remained inside the cluster, indicating that these samples were still perceived to be acceptable for these days. At day 32, the non-irradiated (no. 17) and irradiated frankfurters (no. 18, 19 and 20) were grouped away from the consumer acceptance attributes, indicating that these samples were not as acceptable as samples from previous days. However, the irradiated samples were closer to the cluster than the non-irradiated sample, indicating that these samples were more acceptable than the non-irradiated samples.

Instrumental measurements of irradiated frankfurters

Loadings for instrumental data. PCA on instrumental data was conducted to view the underlying structure of the data. From the loading plot (Fig. 6.2A), the first two principal components described 99% of the variation for the instrumental data. The first PC (PC1) explained 97% of the variation and the second PC (PC2) described 2% of the attributes. In PC1, only the hexanal (0.998) analysis had a positive loading. Attributes with positive loadings in PC2 are texture hardness (0.807), a* value (0.401), chroma (0.377) and chewiness (0.202).

Figure 6.1. (A) Loading plot of the first and second principal components on a PCA of descriptive data for electron-beam irradiated frankfurters, (B) bi-plot of loadings with scores superimposed for the first and second principal components on a PCA of descriptive data for electron-beam irradiated frankfurters (C) loading plot of the first and second principal components on a PCA of consumer data for electron-beam irradiated frankfurters and (D) bi-plot of loadings with scores superimposed for the first and second principal component on a PCA of consumer data for electron-beam irradiated frankfurters


PRINCIPAL COMPONENT 2
PRINCIPAL COMPONENT 1
A
•Overall hardness
•Meaty
•Off-flavor
•Sour
•Wet dog
•Liver/organy
•Glossy
•Brown color
•Evenness of surface
B
•Overall hardness
•10
C
•appear
•color
•overall
•flavor
•aroma
•juicy
•mouth
•tender
D
•18
•20
•17
•19
•13
•appear
•color
•overall
•flavor
•aroma
•juicy
•mouth
•tender

Descriptive analysis, instrumental measurements and their relation with consumer acceptance of irradiated frankfurters

Correlation coefficients for consumer acceptance attributes. The predicted versus observed plots indicated correlation coefficients were high for all attributes. Coefficients are enclosed in parenthesis for: overall acceptability (0.95), aroma (0.94), appearance (0.84), color (0.89), flavor (0.98), juicy (0.98), tender (0.98) and mouthfeel/texture (0.97).

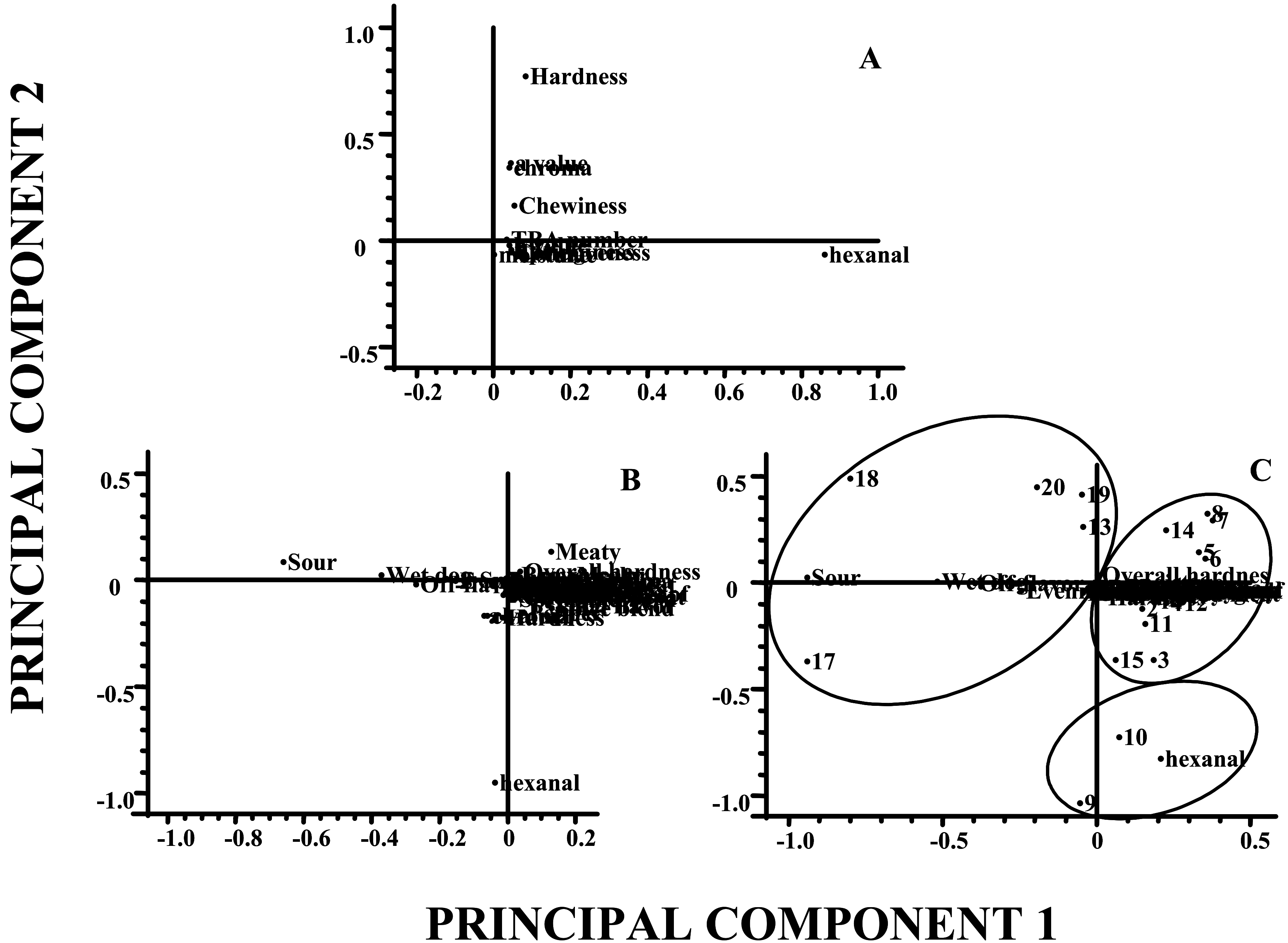
Prediction of consumer acceptance (y-matrix) by descriptive analysis and instrumental measurements (x-matrix). PLSR2 was used to investigate relations between 31 descriptive attributes, 12 instrumental measurements with 8 consumer acceptance attributes (Fig 6.2B). In total, 84% of the variance for descriptive analysis and instrumental measurements were explained by two factors. For consumer acceptance data, 69% of the total variance from two factors was explained. This analysis was conducted to view an overall relation between consumer acceptance and all other data sets discussed previously in this paper. All consumer acceptance attributes were grouped closely together in one quadrant.

Munoz and Chambers (1993) used a two-factor PLS to find relations between overall consumer acceptance and descriptive attributes. They found that overall consumer acceptance was loaded positively on the first factor together with the product's critical attributes of smoke, cured meat, sweetness, saltiness, moistness, moisture release, cohesiveness, cohesiveness of mass, oiliness and fat and that products with high intensities of these attributes were liked by consumers. Overall, the hot dogs that were springy, dense, firm, and mottled and had grain and poultry flavor notes and high intensities of spice complex, onion/garlic and speckles were disliked.

Scores of samples superimposed on loadings for consumer acceptance (y-matrix) and descriptive analysis and instrumental measurements (x-matrix). From the PLSR2 bi-plot (Fig. 6.2C), the first two factors described 84% of the variation for the instrumental data. The first factor explained 69% of the variation and the second factor described 15% of the attributes. In factor 1, the attributes with positive loadings are chickeny flavor (0.154), meaty aroma (0.142), chickeny aroma (0.125), and sweet (0.105) and salty taste (0.102), whereas sour taste (0.708), wet dog aroma (0.420), off-flavor (0.319), evenness of surface (0.201) and the a* value (0.117) had negative loadings. Attributes with positive loadings in PC2 were meaty flavor (0.170) and sour taste (0.120), whereas the pepper flavor (0.120), a* value (0.131) and chroma (0.131) were loaded negatively. Sour taste and the a* value measurement appeared in both PC1 and PC2. Sour taste was loaded more heavily in PC1, whereas the a* value measurement was loaded more heavily in the PC2.

At day 18 after irradiation, the non-irradiated frankfurters (no. 9) and the frankfurters irradiated at 1 kGy (no. 10) were away from the cluster of acceptance attributes and were closely related to hexanal. At 32 days after irradiation, all irradiated samples (no. 18, 19, 20) are grouped with the non-irradiated, 25 day old sample (no. 13) away from acceptance attributes and are related to the descriptive attributes of wet dog, off-flavor and sour. The non-irradiated sample at 32 days after irradiation (no. 17) was farthest away from the acceptance attributes. All samples at days 4 (no. 1, 2, 3, 4) and days 11(no. 5, 6, 7, 8) after irradiation and samples irradiated at 2 and 3 kGy (no. 11, 12) at 18 days after irradiation were directly related to the acceptance attributes.

Figure 6.2. (A) loading plot of the first and second principal components on a PCA of instrumental data for electron-beam irradiated frankfurters, (B) loading plot of PLSR2 analysis on descriptive attributes, instrumental texture/physicochemical measurements (x-matrix) versus consumer acceptance data (y-matrix) for electron-beam irradiated frankfurters, and (C) bi-plot of PLSR2 analysis on descriptive attributes, instrumental texture/physicochemical measurements (x-matrix) versus consumer acceptance data (y-matrix) for electron-beam irradiated frankfurters


A
•Hardness
•a value
•chroma
•Chewiness
•TBA number
•hexanal
B
•Sour
•Meaty
•Overall hardness
•hexanal
C
•18
•20
•19
•13
•14
•8
•7
•5
•6
•Sour
•Overall hardnes
•11
•15
•3
•17
•10
•hexanal
•9
PRINCIPAL COMPONENT 2
PRINCIPAL COMPONENT 1

Descriptive analysis of irradiated refrigerated and frozen diced chicken

In the PCA and PLSR plots, all refrigerated and frozen diced chicken treatment means are the average of 3 replication means, which are identified by treatment numbers. The numbers and the corresponding storage time and irradiation dose are listed in Table 6.4.

Loadings for descriptive data. PCA was conducted to view relations between the sensory attribute variables and identify sample groupings within the sensory data. From the loading plot (Fig. 6.3A), the first two principal components (PC) explained 99% of the total variation in the sensory data. The first PC (PC1) explained 97% of the variation and the second PC (PC2) explained 2% of the variation. Attributes with positive loadings in PC1 are tenderness (0.400), mealy (0.394), juiciness (0.381), moist (0.339), cooked chicken (0.305), cohesiveness of mass (0.260), chicken broth (0.252), chewy (0.150), salty (0.143), and adheres to molar (0.135), whereas other flavor (0.298) and oxidized (0.147) had negative loadings in PC1. In PC2, other flavor (0.847), moist (dry) (0.179), mealy (0.150), tenderness (0.133), and juiciness (0.131) had positive loadings, whereas sharp edges (0.213), bitter (0.206), sour (0.184), oxidized (0.163), and sulfur (0.104) had negative loadings in PC2.

The texture attributes of juiciness, tenderness and mealy and the flavor attributes oxidized and other flavor had positive loadings in both PC1 and PC2. However, the higher loadings for the texture attributes were found in PC1, whereas the higher loadings for the flavor attributes were found in PC2. The remaining attributes not mentioned above (brown color, stringy, moist, oily, toothpack, sweet aromatic, ginger, pepper, chicken fat, cardboardy, sweet) did not contribute much weight and were grouped toward the center of the plot.

Table 6.4. Sample numbers corresponding to irradiation dose and storage time for electron-beam irradiated ready-to-eat refrigerated and frozen chicken[1]

Sample	Storage time (day)	Irradiation dose (kGy)
Refrigerated chicken		
1	4	0
2	4	1
3	4	2
4	4	3
5	11	0
6	11	1
7	11	2
8	11	3
9	18	0
10	18	1
11	18	2
12	18	3
13	25	0
14	25	1
15	25	2
16	25	3
Frozen chicken		
17	4	0
18	4	3
19	32	0
20	32	3
21	49	0
22	49	3
23	94	0
24	94	3

[1]Each diced chicken treatment mean of the average of 3 replication means are identified by the sample number

Scores and loadings for descriptive data. A biplot (Fig. 6.3B) showed the scores superimposed on the loading plot. The non-irradiated diced chicken at 18 days after irradiation (no. 9) and diced chicken at 25 days after irradiation (no. 13, 14, 15, 16) were away from the cluster of descriptive attributes. These samples were related to the off-flavor attribute, indicating that these samples had developed an off-flavor and were not accepted.

Frozen chicken samples, non-irradiated or irradiated (no. 17-24) were grouped closer toward the center of the plot and related to all the descriptive attributes, except off-flavor. This freshness of the frozen samples could be attributed to the freezing and the vacuum packaging of the samples. It has been found that the state at which chicken had been irradiated (refrigerated or frozen) did not affect the sensory properties of the chicken (Hashim *et al.* 1995). They also found that white chicken irradiated at a refrigerated or frozen state had higher "fresh chickeny" aroma intensity than controls.

Consumer acceptance of irradiated diced chicken meat

Loadings for consumer acceptance data. PCA on consumer acceptance data was conducted to view the underlying structure of the data. From the loading plot (Fig. 6.3C), the first two principal components explained 99% of the variation for the consumer data. The first PC (PC1) explained 98% of the variation and the second PC (PC2) explained 1% of the attributes. In PC1, all of the consumer attributes had positive loadings. The loadings for the attributes are tender (0.512), juicy (0.501), mouth (0.467), flavor (0.445), aroma (0.186) and overall (0.173). In PC2, all of the attributes were significant except color and mouthfeel. The attributes with positive loadings are aroma (0.637), overall (0.441), flavor (0.356) and appearance (0.177), whereas, juicy (0.412) and tender (0.262) had negative loadings.

The attributes of overall acceptance, aroma, flavor, juicy and tender were found in both PC1 and PC2. However, the higher loadings for flavor, juiciness and tenderness were found in PC1, whereas overall acceptance and aroma had higher loadings in PC2.

Scores and loading for consumer acceptance data. A biplot (Fig. 6.3D) showed the scores superimposed on the loading plots. At 18 days after irradiation, the non-irradiated diced chicken (no. 9) and the chicken irradiated at 1 kGy (no. 10) were away from the cluster of consumer acceptance attributes, whereas the samples irradiated at higher doses remained inside the cluster, indicating that these samples were related to consumer acceptance attributes. The diced chicken samples at day 32 could not be evaluated due to spoilage and these samples would not be found in the plots.

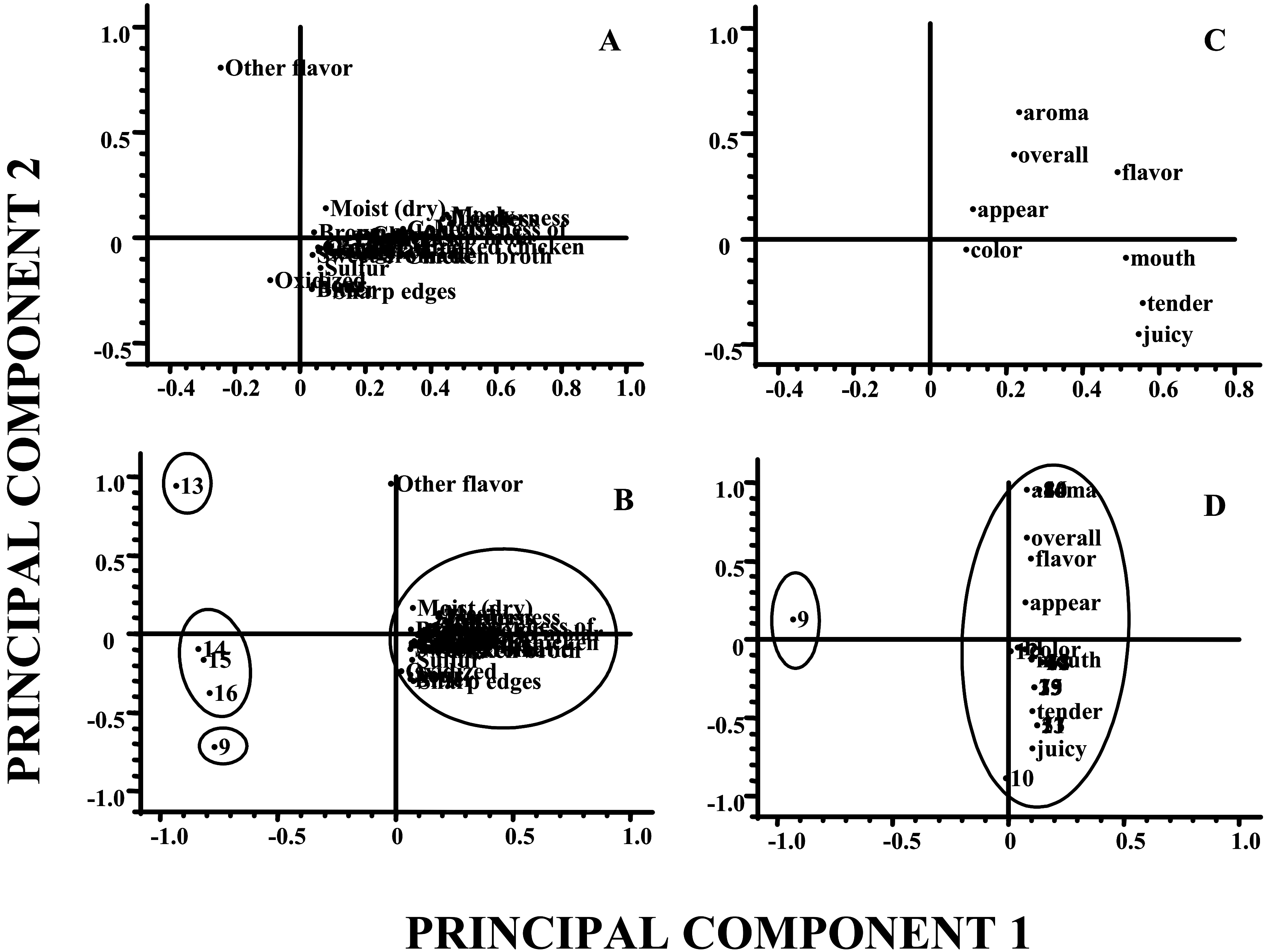
Instrumental measurements of irradiated chicken

Loadings for instrumental data. PCA on instrumental data was conducted to view the underlying structure of the data. From the loading plot (Fig. 6.4A), the first principal component explained 100% of the variation for the instrumental data. In PC1, only the hexanal (1.000) analysis had a positive loading. Attributes with positive loadings in PC2 are TBA (0.930) and moisture (0.106), whereas, the L* value has a negative loading (0.337).

Descriptive analysis, instrumental measurements and their relation with consumer acceptance of irradiated diced chicken

Correlation coefficients for consumer acceptance attributes. The predicted versus observed plots indicated correlation coefficients were high for all attributes. Coefficients are

Figure 6.3. (A) loading plot of the first and second principal components on a PCA of descriptive data for electron-beam irradiated refrigerated and frozen diced chicken meat (B) bi-plot of loadings with scores superimposed for the first and second principal components on a PCA of descriptive data for electron-beam irradiated refrigerated and frozen diced chicken meat (C) loading plot of the first and second principal components on a PCA of consumer data for electron-beam irradiated refrigerated and frozen diced chicken meat and (D) bi-plot of loadings with scores superimposed for the first and second principal component on a PCA of consumer data for electron-beam irradiated refrigerated and frozen diced chicken meat

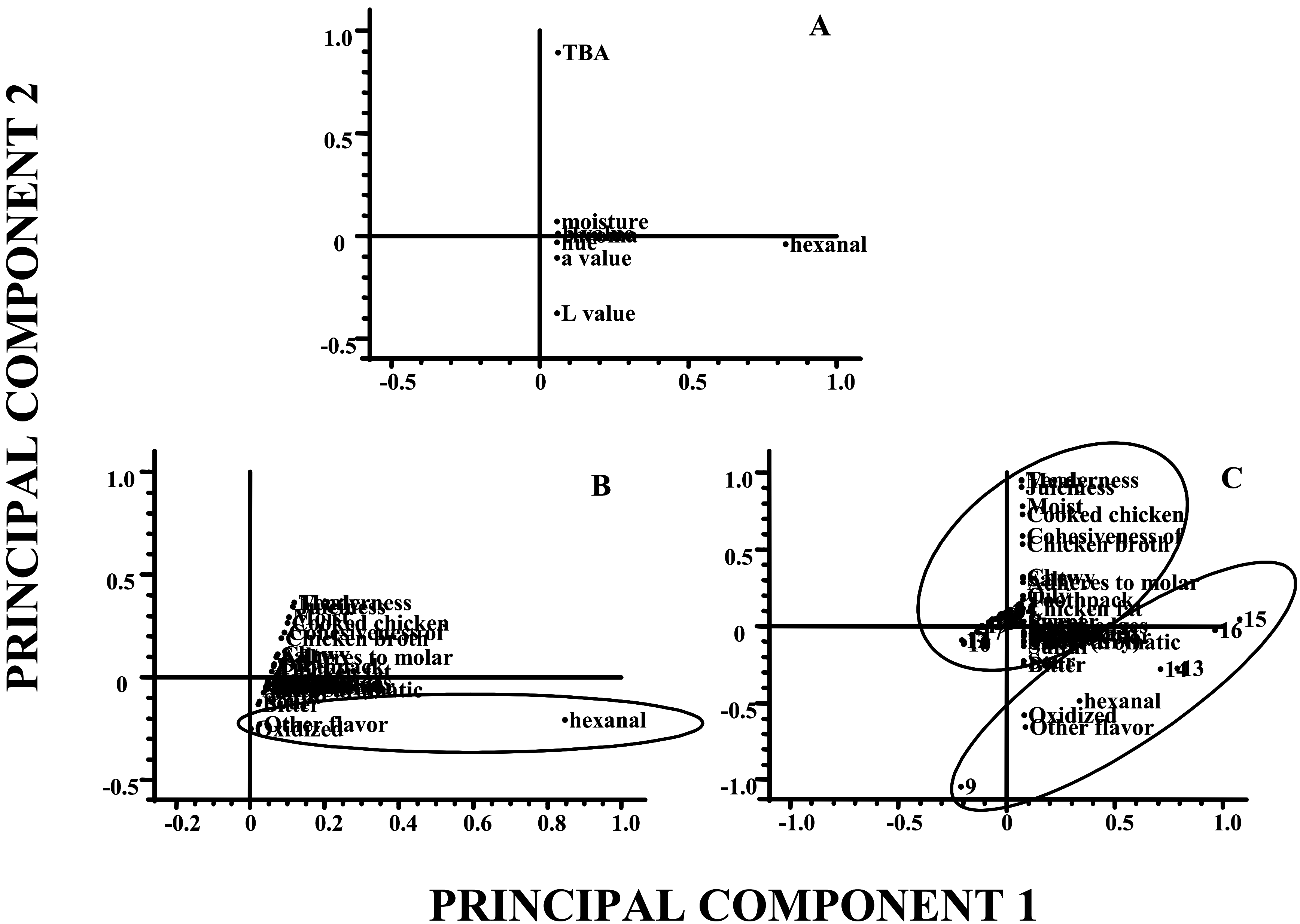

PRINCIPAL COMPONENT 2
PRINCIPAL COMPONENT 1
A
•Other flavor
•Moist (dry)
•Sulfur
•Oxidized
Sharp edges
C
•aroma
•overall
•flavor
•appear
•color
•mouth
•tender
•juicy
B
•13
•Other flavor
•14
•15
•16
•9
Sharp edges
D
•9
•overall
•flavor
•appear
•tender
•juicy
•10

enclosed in parenthesis for: overall acceptability (0.90), aroma (0.92), appearance (0.82), color (0.70), flavor (0.96), juiciness (0.95), tenderness (0.95) and mouthfeel/texture (0.96).

Relations of descriptive analysis, instrumental measurements (x-matrix) versus consumer acceptance (y-matrix). PLSR2 was used to investigate relations between 27 descriptive attributes, 8 instrumental measurements with 8 consumer acceptance attributes. In total, 100% of the variance for descriptive analysis and instrumental measurements were explained in one factor (Fig 6.4B). For consumer acceptance data, 85% of the total variance from two factors was explained. In factor 1, 80% of the variance is explained and 5% of the variance is explained in factor 2. This analysis was conducted to view an overall relation between consumer acceptance and all other data sets discussed previously in this paper. All consumer acceptance attributes were grouped closely together in one quadrant. The hexanal analysis was closely related to the descriptive attributes of oxidized and other flavor.

Scores of samples superimposed on loadings for consumer acceptance (y-matrix) and descriptive analysis and instrumental measurements (x-matrix). A biplot of descriptive analysis and instrumental measurements (x-matrix) versus consumer acceptance is shown in (Fig. 6.4C). The non-irradiated diced chicken at 18 days after irradiation (no. 9) and all refrigerated samples at 32 days after irradiation (no. 13, 14, 15, 16) were negatively related to the acceptance attributes. These samples were closely related to hexanal measurements and the oxidized and other flavor attributes. All remaining samples, irradiated and non-irradiated and stored for 4 and 11 days after irradiation and irradiated samples at 18 days after irradiation and all frozen samples were related to consumer acceptance attributes.

Figure 6.4. (A) loading plot of the first and second principal components on a PCA of instrumental data for irradiated electron-beam irradiated refrigerated and frozen diced chicken, (B) loading plot of PLSR2 analysis on descriptive attributes, instrumental texture/physicochemical measurements (x-matrix) versus consumer acceptance data (y-matrix) for electron-beam irradiated refrigerated and frozen diced chicken, and (C) bi-plot of PLSR2 analysis on descriptive attributes, instrumental texture/physicochemical measurements (x-matrix) versus consumer acceptance data (y-matrix) for electron beam irradiated refrigerated and frozen diced chicken



A
B
C
PRINCIPAL COMPONENT 2
PRINCIPAL COMPONENT 1
•TBA
•moisture
•hue
•a value
•L value
•hexanal
Tenderness
Juiciness
Moist
Cooked chicken
Chicken broth
Adheres to molar
Toothpack
Chicken fat
Butter
Other flavor
Oxidized
•15
•16
•13
•9

Instrumental Texture/Physicochemical measurements of irradiated frankfurters

Color. The color measurements (Table 6.5) of the electron-beam irradiated frankfurters varied inconsistently. The non-irradiated frankfurters at 4, 11 and 18 days after irradiation were not significantly different for the L*, a*, b* values, chroma and hue. The a* value for the non-irradiated frankfurters at 25 and 32 days after irradiation were not significantly different from each other, but they were significantly higher than the frankfurters at 4, 11, and 18 days after irradiation. At 25 days after irradiation, the b* value for the non-irradiated frankfurters was significantly higher than the non-irradiated frankfurters at 4, 11, 18 and 32 day after irradiation. For the chroma value, the non-irradiated frankfurters at day 25 were significantly higher than non-irradiated frankfurters at 32 days after irradiation. The frankfurters at 25 and 32 days after irradiation were significantly higher than the non-irradiated frankfurters at 4, 11, and 18 days after irradiation. The hue value of frankfurters at 25 days after irradiation were significantly higher than frankfurters at 32 days after irradiation, however the non-irradiated frankfurters at 4, 11, and 18 days after irradiation were similar to 25 and 32 day non-irradiated frankfurters.

The color measurements of the frankfurters irradiated at 1 kGy were not significantly different at 4, 11 and 18 days after irradiation. The L*value of the frankfurters at 25 and 32 after irradiation were significantly lower than at 4, 11, and 18 days after irradiation. The a* value and the chroma of the frankfurters at day 25 was significantly higher than the frankfurters at 4, 11, and 18 days after irradiation. The frankfurters at 32 days after irradiation were similar to all previous days. The b* value and the hue of all the frankfurters irradiated at 1 kGy remained constant throughout the storage time.

The color measurements of the frankfurters irradiated at 2 kGy were not significantly different at 4 and 11 days after irradiation. The L* value of the frankfurters at 4, 11 and 32 days

Table 6.5. Color measurements, L*,A*,B*, chroma and hue, of electron-beam irradiated ready-to-eat poultry frankfurters[1,2,3]

Irradiation Dose (kGy) / Storage time (Days)	0	1	2	3
L* value				
4	52.22 a	52.20 a	51.79 a	52.28 a
11	52.04 a	52.53 a	51.65 a	52.39 a
18	51.90 a	52.00 a	51.33 ab	52.21 a
25	51.37 a	51.22 b	51.18 b	51.62 b
32	51.39 a	50.96 b	51.50 a	51.82 ab
a* value				
4	27.56 b	27.56 b	27.12 b	26.84 a
11	27.83 b	27.56 b	27.12 b	26.84 a
18	27.83 b	27.56 b	27.12 b	26.84 a
25	28.96 a	28.10 a	27.57 ab	26.49 a
32	28.59 a	27.81 ab	27.92 a	27.01 a
b* value				
4	11.26 b	11.22 a	11.39 a	11.48 ab
11	11.35 b	11.22 a	11.39 a	11.48 ab
18	11.35 b	11.22 a	11.39 a	11.48 ab
25	12.15 a	11.75 a	11.80 a	11.66 a
32	11.32 b	11.27 a	11.67 a	11.16 b
Chroma				
4	29.77 c	29.76 b	29.41 b	29.20 a
11	30.06 c	29.76 b	29.41 b	29.20 a
18	29.65 c	29.76 b	29.41 b	29.20 a
25	31.42 a	30.47 a	29.99 ab	28.94 a
32	30.75 b	30.01 ab	30.27 a	29.22 a
Hue				
4	0.39 ab	0.38 a	0.40 a	0.41 a
11	0.39 ab	0.38 a	0.40 a	0.41 a
18	0.39 ab	0.38 a	0.40 a	0.41 a
25	0.40 a	0.40 a	0.40 a	0.42 a
32	0.38 b	0.38 a	0.40 a	0.39 b

[1]Means not followed by the same letter (a,b,c,d) within a column for each color measurement are significantly different at $\alpha=0.05$ by storage time (day).

[2]Chroma=$[a^2 + b^2]^{1/2}$

[3]Hue=$\tan^{-1} b/a$

after irradiation were not significantly different, whereas frankfurters at day 25 were significantly lower. The L* value for the frankfurters at 18 days after irradiation were similar to all days. For the a* value and the chroma of the frankfurters at 32 days after irradiation were significantly different from days 4, 11 and 18, whereas the a* value and chroma was similar to frankfurters at 25 days after irradiation. The b*value and the hue of the frankfurters at all days after irradiation remained constant.

The color measurements of the frankfurters irradiated at 3 kGy were not significantly different for 4, 11 and 18 days after irradiation. The L* value of the frankfurters at 25 days after irradiation was significantly lower than the frankfurters at days 4, 11 and 18, but not significantly different from frankfurters at 32 days after irradiation. The a* value and the chroma of the frankfurters irradiated at 3 kGy were not significantly different throughout the storage time. The b* value of the frankfurters at 25 days after irradiation were significantly higher than the frankfurters at day 32, but were similar to the frankfurters at day 4, 11 and 18. The hue value of the frankfurters at day 32 was significantly lower than the hue values at previous days of storage.

Moisture. The moisture (Table 6.6) of non-irradiated and irradiated frankfurters remained constant throughout the storage period, indicating that the storage of the frankfurters for the 32 day period did not have a significant effect on the moisture content of frankfurters. Wheeler *et al.* (1999) found that there were no significant effects of irradiation dose (3.0 and 4.5 kGy) on the moisture content for ground beef patties. We also found this to be true in this study.

Fat. The frankfurter samples in this study contained approximately 23% fat (data not presented), whereas current formulations of frankfurters have fat contents as high as 30% (Grigelmo-Miguel *et al.* 1999). Wheeler *et al.* (1999) found that there were no significant effects of irradiation dose (3.0 and 4.5 kGy) on the fat content for ground beef patties stored for up to 29 days after irradiation.

TBA. The TBA values (Table 6.6) of the non-irradiated and irradiated frankfurters were not significantly different at 4, 11, 18 and 25 days after irradiation. However the TBA values of the frankfurters at 32 days after irradiation were significantly higher than the previous days. The TBA values were low and below 1.00 for all samples, except for the frankfurter irradiated at 1 kGy and stored for 32 days, which had a TBA value of 1.25. Van Zyl and Setser (2001) found no significant differences in TBA values in non-irradiated frankfurters that were stored for 40 days. The frankfurters stored at 5 days had lower TBA values than those stored for 15, 30 and 40 days. Smith and Alvarez (1988) found TBA values to be generally low (< 1.0) in their precooked non-irradiated turkey slices and they attribute this to the vacuum packaging of the product. We found similar results in this study.

Tarladgis *et al.* (1960) found that TBA numbers at which rancid flavors were first perceived in meat have been reported to range between 0.5 to 2.0. We also found this to be true. Although our TBA values were low and within this range, an off-flavor was detected by the descriptive panelists. Shahidi *et al.* (1985) reported that, in the absence of residual nitrite in a sample, sulphanilamide may react with malonaldehyde resulting in underestimation of the TBA values, however, no statistical evidence for these claims were presented.

Hexanal. The hexanal values (Table 6.6) of the non-irradiated and irradiated frankfurters varied inconsistently throughout the storage period. The non-irradiated frankfurters were not significantly different from each other at 4, 11, 18 and 25 days after irradiation, however frankfurters at 4, 11 and 25 days after irradiation were significantly lower than the frankfurters at day 32. The non-irradiated frankfurters at day 18 were not significantly different

Table 6.6. Physicochemical measurements, moisture, TBA and hexanal, of electron-beam irradiated ready-to-eat poultry frankfurters[1]

Irradiation Dose (kGy) / Storage time (Days)	0	1	2	3
Moisture[2] (%)				
4	62.75 a	62.62 a	61.92 a	62.50 a
11	63.25 a	63.61 a	63.37 a	63.80 a
18	61.13 a	62.33 a	61.62 a	61.54 a
25	62.78 a	63.26 a	62.92 a	63.37 a
32	62.52 a	62.46 a	62.78 a	63.18 a
TBA[3] (mg/kg of sample)				
4	0.04 b	0.04 b	0.03 b	0.06 b
11	0.28 b	0.07 b	0.03 b	0.09 b
18	0.10 b	0.10 b	0.09 b	0.11 b
25	0.18 b	0.15 b	0.14 b	0.13 b
32	0.67 a	1.25 a	0.37 a	0.61 a
Hexanal[4] (μg/g)				
4	20.37 b	27.27 a	30.18 a	19.62 a
11	17.56 b	19.72 ab	13.71 b	12.36 a
18	26.00 ab	28.04 a	31.02 a	18.12 a
25	11.82 b	14.89 b	28.85 a	19.44 a
32	35.99 a	8.71 b	12.08 b	9.77 a

[1]Means not followed by the same letter(a,b,c,d) within a column for each physicochemical measurement are significantly different at α=0.05 by storage time (day).

[2]AOAC, 1998.

[3]Tarladgis, et al., 1960 and Zipser and Watts, 1962.

[4]Young,C.T. and Hovis,A.R. 1990.

for the frankfurters at 4, 11, 25 and 32 days after irradiation. The highest amount of hexanal (35 μg/g) was found in the non-irradiated frankfurter at day 32.

The hexanal value of frankfurters irradiated at 1 kGy was significantly lower at days 25 and 32 as compared to days 4 and 18. The frankfurters at day 11 were similar to all days of storage. The hexanal value of the frankfurters irradiated at 2 kGy at 4, 18 and 25 days after irradiation was significantly higher for frankfurters stored at 11 and 32 days after irradiation. The hexanal value of the frankfurters irradiated at 3 kGy was not significantly different throughout the storage period. At 32 days after irradiation, the hexanal value of the non-irradiated frankfurter was almost 3 times higher than the hexanal value of all irradiated frankfurters. At 4, 11, and 18 days after irradiation, the hexanal value of the frankfurters irradiated at 3 kGy were lower than non-irradiated frankfurters and frankfurters irradiated at 1 and 2 kGy.

Texture. The texture (Table 6.7) of the non-irradiated and irradiated frankfurters was not affected by irradiation dose or storage time. The hardness, cohesiveness of mass, springiness and chewiness of the frankfurters were not significantly different throughout the 32 day shelf life period. The hardness of all frankfurters ranged from 6.33 to 9.93, cohesiveness of mass ranged from 0.70 to 0.81, springiness ranged from 0.70 to 0.81, and chewiness ranged from 3.60 to 4.91 throughout the storage period.

Physicochemical measurements of irradiated refrigerated diced chicken meat

Color. For all days of storage, color (Table 6.8) of the diced chicken varied inconsistently. The L* value of the non-irradiated diced chicken at day 4 was significantly higher than the color of the diced chicken at day 18. The L* value of the diced chicken at 11 and

Table 6.7. Instrumental texture measurements of electron-beam irradiated ready-to-eat poultry frankfurters[1]

Irradiation Dose (kGy)	0	1	2	3
Storage time (Days)				
Hardness (N)				
4	9.40	9.58	7.30	7.73
11	9.30	8.30	7.94	6.52
18	9.20	9.93	7.31	6.84
25	9.44	8.64	7.12	7.54
32	8.62	8.27	6.33	7.13
Cohesiveness of mass				
4	0.72	0.71	0.72	0.78
11	0.70	0.73	0.72	0.81
18	0.70	0.71	0.72	0.81
25	0.72	0.71	0.74	0.79
32	0.73	0.72	0.76	0.79
Springiness (m)				
4	0.71	0.71	0.72	0.78
11	0.70	0.73	0.72	0.81
18	0.70	0.70	0.72	0.73
25	0.71	0.71	0.74	0.78
32	0.73	0.72	0.76	0.79
Chewiness (J)				
4	4.73	4.78	3.80	4.72
11	4.55	4.33	4.12	4.21
18	4.55	4.91	3.76	3.96
25	4.71	4.32	3.85	4.66
32	4.56	4.29	3.60	4.43

[1]Means not followed by the same letter (a,b,c,d) within a column for each texture measurement are significantly different at α=0.05 by storage time (day).

Table 6.8. Color measurements, L*,A*,B*, chroma and hue, of electron-beam irradiated ready-to-eat refrigerated diced chicken[1,2,3]

Irradiation Dose (kGy) / Storage time (Days)	0	1	2	3
L* value				
4	83.24 a	79.41 a	79.66 a	78.61 a
11	79.38 ab	79.72 a	79.24 a	78.13 a
18	78.00 b	79.74 a	78.55 a	79.11 a
25	80.80 ab	79.62 a	79.30 a	80.02 a
a* value				
4	2.09 a	1.78 a	1.99 a	1.61 a
11	1.66 a	1.63 a	1.25 b	1.79 a
18	1.83 a	1.56 a	1.29 ab	1.41 a
25	2.24 a	1.62 a	1.96 ab	1.13 a
b* value				
4	12.46 b	12.66 a	12.05 b	12.53 b
11	13.24 ab	12.36 a	12.37 b	12.81 ab
18	12.81 ab	13.62 a	12.34 b	12.56 b
25	13.87 a	13.90 a	14.95 a	14.56 a
Chroma				
4	12.65 b	12.79 a	12.23 b	12.66 b
11	13.35 ab	12.49 a	12.45 b	12.96 ab
18	12.95 ab	13.72 a	12.43 b	12.65 b
25	14.07 a	14.01 a	15.09 a	14.62 a
Hue				
4	1.40 a	1.43 a	1.41 b	1.44 ab
11	1.45 a	1.45 a	1.47 a	1.43 b
18	1.43 a	1.46 a	1.47 a	1.46 ab
25	1.41 a	1.46 a	1.44 a	1.49 a

[1]Means not followed by the same letter (a,b,c,d) within a column for each color measurement are significantly different at α=0.05 by storage time (day). Color measurements were made using a hand-held colorimeter (Minolta CR-200, Minolta Camera Co., Ltd., Osaka, Japan).

[2]Chroma=$[a^2 + b^2]^{1/2}$

[3]Hue=$\tan^{-1} b/a$

25 days after irradiation was similar to days 4 and 18. The a* value and the hue value of the non-irradiated diced chicken were not significantly different throughout the storage period. The b* value and the chroma of the non-irradiated diced chicken at day 4 was significantly lower than the diced chicken at day 25, whereas the diced chicken at day 11 and 18 were similar to days 4 and 25.

The color measurements of the diced chicken irradiated at 1 kGy were not significantly different throughout the storage time. The L* value of all irradiated diced chicken was not significantly different by day. The a* value of the diced chicken irradiated at 2 kGy at 4 days after irradiation was significantly higher than the diced chicken at day 11, but not different from day 18 and day 25. The b* value and the chroma of the diced chicken irradiated at 2 kGy at 411, and 18 days after irradiation were similar, but significantly lower than those at day 25. The hue of the diced chicken at day 4 was significantly lower than the diced chicken at the remaining days of storage.

The L* and a* values of the diced chicken irradiated at 3 kGy were not significantly different throughout the storage period. The b* value and the chroma of the diced chicken at days 4 and 18 were significantly lower than the diced chicken at day 25, whereas diced chicken at day 11 was similar to all days of storage. The hue of the diced chicken at day 4 was not significantly different from any days. At 11 days after irradiation, the hue value was significantly lower from day 25. The frankfurters at 18 days after irradiation were similar to all days.

Smith and Alvarez (1988) found that there were no significant ($p>0.05$) changes in Hunter L or b values in internal slices of non-irradiated turkey meat during refrigerated storage. However, the Hunter a* values of turkey slices varied inconsistently during storage (Smith and

Alvarez 1988). Bagorogoza *et al.* (2001) found that the color was more intense in the irradiated (2.4 to 2.9 kGy) raw and cooked turkey breast samples than in non-irradiated samples. They found that the a* values, but not the b* values or L* values of raw turkey breasts, were affected by irradiation and the irradiated samples had higher a* values (redder) than the non-irradiated samples.

Moisture. The moisture (Table 6.9) of all diced chicken did not differ significantly throughout the storage period. Ang and Lyon (1990) found that the water content of non-irradiated cooked chicken breast meat did not change during post-cooking storage.

Fat. The diced chicken meat used in this study contained approximately 7% fat (data not presented). If the fat content is low, the moisture content is likely to be high (Grigelmo-Miguel *et al.* 1999) and this is true for chicken breasts. Wheeler *et al.* (1999) found that there were no significant effects of irradiation dose (3.0 and 4.5 kGy) on the fat content for irradiated ground beef patties. Ang and Lyon (1990) found that the fat content of the non-irradiated cooked chicken breast meat did not change during post-cooking storage. We found similar results in this study.

TBA. The TBA (Table 6.9) of the diced chicken increased throughout the 32 day storage period. The TBA value of the non-irradiated diced chicken at day 4 was significantly lower than the diced chicken at day 18 and 25, whereas the TBA value at day 11 was similar to all days of storage. The TBA value of the diced chicken irradiated at 1 kGy for day 4 was significantly lower than the TBA value of the diced chicken at day 18, whereas the TBA values at day 11 and 25 were similar to all days throughout the storage period. The TBA value of the diced chicken irradiated at 2 kGy was significantly lower at day 4 than at days 11, 18 and 25. The TBA value of the diced chicken irradiated at 3 kGy was significantly lower at day 4 than the

TBA values of the diced chicken stored at days 18 and 25, whereas the diced chicken stored at 11 days after irradiation was similar to all days throughout the storage period.

Ang and Lyon (1990) found that non-irradiated freshly cooked breast meat exhibited significant changes over storage time. They found that TBA numbers increased from 0.97 at day 0 to 11.43 at day 5 of storage. They found that the TBA was associated with off-flavor development. We also found that our diced chicken exhibited significant increases throughout the storage time and peaked at 9.06 – 11.06 for irradiated samples at 18 days after irradiation.

Hexanal. The hexanal values (Table 6.9) of the diced chicken varied inconsistently throughout the 32 day storage period. The hexanal values of all diced chicken at day 18 were significantly lower than days 4, 11 and 25. The hexanal values at days 4 and 11 were not significantly different. The hexanal value for the diced chicken samples at 25 days after irradiation was significantly higher from previous days of storage. The irradiated diced chicken had higher (2.0 – 2.5 mg/g for irradiated samples) hexanal values than the non-irradiated diced chicken. The hexanal values of the irradiated diced chicken are more than double that for the non-irradiated diced chicken. Ang and Lyon (1990) identified the volatiles of non-irradiated chicken breasts, thigh and skin and found that hexanal increased greatest in the chicken breast throughout the 5 day storage period. They also found that cooked breast meat is most susceptible to oxidation during storage and that the headspace measurements were associated with off-flavor development.

Table 6.9. Physicochemical measurements, moisture, TBA and hexanal of electron-beam irradiated ready-to-eat refrigerated diced chicken[1]

Irradiation Dose (kGy) / Storage time (Days)	0	1	2	3
Moisture[2] (%)				
4	74.53 a	76.33 a	77.14 a	76.76 a
11	79.49 a	77.73 a	75.50 a	75.90 a
18	74.92 a	76.45 a	77.19 a	77.26 a
25	78.51 a	77.54 a	77.08 a	76.79 a
TBA[3] (mg/kg of sample)				
4	0.51 b	4.44 b	3.21 b	2.79 b
11	4.61 ab	7.29 ab	8.39 a	6.55 ab
18	8.43 a	11.06 a	9.06 a	10.25 a
25	7.07 a	9.27 ab	9.21 a	9.34 a
Hexanal[4] (μg/g)				
4	116.30 b	267.50 b	467.40 b	243.70 b
11	102.21 b	367.14 b	388.87 b	308.73 b
18	23.61 c	23.25 c	19.43 c	1.16 c
25	978.00 a	2009.00 a	2508.00 a	2390.00 a

[1]Means not followed by the same letter (a,b,c,d) within a column for each physicochemical measurement are significantly different at α=0.05 by storage time (day).

[2]AOAC, 1998.

[3]Tarladgis, et al., 1960 and Rhee, 1978.

[4]Young,C.T. and Hovis,A.R. 1990.

Physicochemical measurements of irradiated frozen diced chicken meat.

The color, moisture, TBA and hexanal measurements for the frozen chicken (shown in Table 6.10 and 6.11, respectively) were not significantly different throughout the storage time. This can be attributed to the freezing and vacuum packaging of the sample.

Table 6.10. Color measurements, L*,A*,B*, chroma and hue, of electron-beam irradiated ready-to-eat frozen diced chicken[1,2,3]

Irradiation Dose (kGy) / Storage time (Days)	0	3
L* value		
4	83.24	78.61
11	83.20	78.60
18	81.30	78.82
25	81.43	79.37
a* value		
4	2.09	1.61
11	2.09	1.62
18	2.48	1.81
25	2.38	1.72
b* value		
4	12.46	12.53
11	12.46	12.53
18	13.61	11.95
25	13.14	13.45
Chroma		
4	12.65	12.66
11	12.64	12.64
18	13.83	12.09
25	13.36	13.57
Hue		
4	1.40	1.44
11	1.40	1.44
18	1.39	1.42
25	1.39	1.45

[1]Means not followed by the same letter (a,b,c,d) within a column for each color measurement are significantly different at α=0.05 by storage time (day). Color measurements were made using a hand-held colorimeter (Minolta CR-200, Minolta Camera Co., Ltd., Osaka, Japan).

[2]Chroma=$[a^2 + b^2]^{1/2}$

[3]Hue=$\tan^{-1} b/a$

Table 6.11. Physicochemical measurements, moisture, TBA and hexanal of electron-beam irradiated ready-to-eat refrigerated diced chicken[1]

Irradiation Dose (kGy)	0	3
Storage time (Days)		
Moisture[2] (%)		
4	74.70	76.92
11	74.26	76.77
18	76.21	75.88
25	78.52	76.94
TBA[3] (mg/kg of sample)		
4	0.40	2.74
11	2.89	3.37
18	3.68	4.04
25	4.51	4.65
Hexanal[4] (µg/g)		
4	116.30	243.70
11	197.22	289.38
18	311.62	366.19
25	335.85	485.12

[1]Means not followed by the same letter (a,b,c,d) within a column for each physicochemical measurement are significantly different at α=0.05 by storage time (day).

[2]AOAC, 1998.

[3]Tarladgis, et al., 1960 and Rhee, 1978.

[4]Young,C.T. and Hovis,A.R. 1990.

CONCLUSION

Multivariate analysis of the descriptive and consumer data for the electron-beam irradiated ready-to-eat refrigerated frankfurters and diced chicken showed that storage time profoundly effects on the quality of these products. Irradiated frankfurters developed sour tastes, wet dog aromas and off-flavors at day 32 and diced chicken became oxidized and developed off-flavors at day 25, whereas the frozen diced chicken was not affected by storage time.

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CHAPTER 7

CONSUMER ATTITUDES TOWARD IRRADIATED FOOD: 2003 vs. 1993[1]

[1]Johnson, A.M., Reynolds, A.E., Chen, J., and A.V.A. Resurreccion. Submitted to the *Journal of Food Trends*, 7/28/2003.

ABSTRACT

A survey was conducted to determine current consumer attitudes toward irradiation after consuming irradiated ready-to-eat poultry meat products and evaluate differences in consumer acceptance, if any, over the past ten years. Surveys were completed by 50 consumers in the metro-Atlanta area. Although consumers were exposed to irradiated foods prior to the 2003 survey, consumer awareness did not increase in this study, compared to 1993 when consumers were not exposed to irradiated foods prior to the survey. The majority (66%) of the respondents were aware of irradiation, among these, 71% "have heard about irradiation, but do not know much about it". Consumers in both studies expressed more concern for pesticide and animal residues, growth hormones, food additives, bacteria and naturally occurring toxins than irradiation. Consumers expressed slight concern regarding irradiation, however, this has decreased significantly over the past ten years. Approximately 76% prefer to buy irradiated pork and 68% prefer to buy irradiated poultry to decrease the probability of illness from *Trichinella* and *Salmonella,* respectively. More consumers (69%) are willing to buy irradiated products in 2003 as compared to 29% in 1993.

INTRODUCTION

Many innovations, even ones with obvious advantages, require a lengthy period of time from when they become available to the time when they are widely accepted (*28*). Given that food irradiation is a process that has been proven to be both safe and effective in eliminating microorganisms and making food safer for human consumption, the only barrier to widespread commercial application of food irradiation is the food industry's perception of lack of consumer acceptance (*29*). Uncertain about the acceptance of irradiated commodities by consumers, the food industry, in general, has made little practical use of the irradiation process (*8*). Individual meat and poultry companies, although concerned about food safety, are reluctant to be among the first to launch irradiated products for fear of an adverse reaction (*17*). However, the government and food industry's interest in irradiation has peaked following approvals to irradiate meat and poultry and the anticipated approval for ready-to-eat foods (*2*).

For irradiation to be found acceptable, it must offer the consumer an advantage of having a higher quality, greater safety, longer shelf life, wide product availability and/or lower cost (*5*). Since most consumers in this country have not been presented with the option to purchase irradiated products, the deliberation about consumer acceptance has centered around the results of several market tests, consumer research polls, and the opinions of various special interest groups (*6*). A majority of these studies have based consumer acceptance on actual purchases, or their intent to purchase, irradiated products. In 1987, a consumer in-store study on irradiated papayas showed that 66% and 80% of participants from Anaheim and Irvine, California, respectively, stated that they would buy irradiated papaya (*4*). In 1990, an apple marketing study found that 56% of consumers purchased irradiated apples offered at roadside market stands, whereas only 44% purchased non-irradiated apples (*33*). In 1995, a supermarket simulated test showed that 58% of consumers would purchase irradiated chicken, if available (*15*). In 1995, a mail survey showed that 45% of consumers would buy irradiated foods (*24*). In the 1998-1999 FoodNet population telephone survey, 50% of consumers stated that they were willing to buy irradiated meat or poultry (*11*). In retail trials, of irradiated and non-irradiated chicken at the same price, conducted in 1995 and 1996, irradiated chicken accounted for 43% of total sales. In 1998, a market experiment on irradiated and non-irradiated chicken resulted in 80% of participants purchasing irradiated chicken. When irradiated chicken was offered at a 10% discount price, 84% of participants purchased irradiated chicken (*9*).

Consumer acceptance has also been obvious as irradiated products have entered the market. In January 1992, a Florida market sold approximately 600 pints of irradiated strawberries as compared to only 450 pints of non-irradiated strawberries, despite the lower cost for the non-irradiated strawberries (*19*). In March 1992, irradiated and non-irradiated strawberries, grapefruit and oranges were sold at retail stores in the Chicago area. Approximately 90-95% of 1,200 pints of strawberries, sold in one day, were irradiated. Ninety percent of total sales for grapefruits and oranges, sold over an unspecified time, were irradiated and 10% were unirradiated (*23*).

This study was conducted to investigate current consumer attitudes toward irradiation after consuming irradiated ready-to-eat poultry meat products and evaluate differences, if any, on consumer acceptance of irradiation over the past ten years.

MATERIALS AND METHODS

Questionnaire. The questionnaire used in this study was a duplicate of the questionnaire used in a previous irradiation study conducted in 1993 by Resurreccion *et al.* (*24*). The self-administered, eight-page questionnaire was designed to measure the extent of consumer knowledge, attitudes, concerns and feelings toward food irradiation and some food-safety issues over the past ten years since the first irradiation study was conducted. The first page of the questionnaire provided definitions to some of the terms frequently used throughout the questionnaire to make sure that the respondents understood the questions that were asked. The remaining pages of the questionnaire contained questions about respondents' demographic characteristics, eating habits/consumption patterns and their knowledge about irradiation and other food safety issues using scales suitable for each question.

Questionnaire distribution. In this study, a total of 50 questionnaires were evaluated by consumers who resided in a total of seven cities in the Metro-Atlanta area. These consumers had previously participated in consumer tests on irradiated ready-to-eat poultry meats at the University of Georgia, Griffin, GA. Most of the consumers (74%) were responsible for the purchasing and/or preparation of food in their household. Criteria for recruitment of participants included that they were between the ages of 18 and 70, they must like and consume poultry products, and they must not be allergic to poultry. The consumers completed the questionnaire at the Department of Food Science and Technology, University of Georgia, Griffin, GA. Upon panelists' arrival, they were directed to a conference room, asked to sign-in and given a brief explanation on how to complete the questionnaire.

In 1993, a total of 918 questionnaires were mailed out to consumers who resided in a total of 18 cities in the Metro-Atlanta area and who had previously participated in consumer tests at the University of Georgia. Consumers were provided with questionnaires that contained a cover letter, a statement of confidentiality, and a telephone number to call if questions arose. A self-addressed postage-paid envelope was included to facilitate mail-back. Reminders, in the form of a letter with a second copy of the questionnaire, were mailed after six weeks to consumers whose responses had not been received. A total of 446 completed questionnaires were received resulting in a 54% response rate. The consumers were not provided with the option to consume irradiated products prior to the completion of the questionnaire.

Statistical analysis. Statistical Analysis Software System (*30*) was used to analyze all data. Response frequencies, percentages and means were obtained on responses to all questions from participants. A chi-square test was used to compare the data from this study (n=50) and the previous study (n=446) conducted by Resurreccion *et al.* (*24*).

RESULTS AND DISCUSSION

Demographics. The demographic characteristics of the consumers that completed the questionnaire are shown in Table 7.1. The majority of the respondents in these studies were females. In this study, a wide range of participants from each age group participated, with 94% of respondents under the age of 65. In the previous study, an older sample resulted from responses to the mailed survey, with 70% under the age of 65. The median age range of respondents participating in this study was 45-54 years of age. However, the largest age group category represented in this study was 55-64 years of age. The majority of the respondents were white and married. The median household income ranged from \$30,000-\$40,000 per year. Although 49% of the participants and 40% of their spouses had some college education or higher, less than 50% were employed full time.

Consumer Awareness. Over the past 20 years, surveys and market studies have been conducted to evaluate consumer awareness and their acceptance of irradiation. Nevertheless, the surveys on consumer acceptance of irradiation have shown considerable uncertainties and

Table 7.1. Demographic characteristics of consumers participating in irradiation survey[a]

Demographics		% responding 1993	% responding 2003
Gender			
	Female	76	64
	Male	24	36
Age			
	18-24	2	2
	25-34	4	12
	35-44	11	18
	45-54	30	26
	55-64	23	36
	65-70	30	6
Race			
	White	91	60
	Black	7	38
	Other	2	2
Marital Status			
	Married	74	76
	Divorced/separated	8	12
	Widowed	14	6
	Never Married	4	6
Education			
	Some grade school	1	2
	Grade school graduate	1	2
	Some high school	7	12
	High school/technical school graduate	23	35
	Some college or vocational school	33	33
	College graduate	23	8
	Advanced college degree	13	8
Education of spouse			
	Some grade school	1	0
	Grade school graduate	2	5
	Some high school	8	16
	High school/technical school graduate	23	38
	Some college or vocational school	27	19
	College graduate	25	14
	Advanced college degree	15	8

Table 7.1. Continued

Employment			
	Full-time	36	46
	Part-time	14	10
	Retired/Disabled	38	38
	Unemployed	12	6
Employment of spouse			
	Full-time	52	49
	Part-time	6	15
	Retired/Disabled	35	36
	Unemployed	8	0
Annual household income			
	Under $10,000	4	8
	$10,000 to $19,999	13	4
	$20,000 to $29,999	16	18
	$30,000 to $39,999	18	20
	$40,000 to $49,999	14	10
	$50,000 to $59,999	13	18
	$60,000 to $69,999	8	8
	$70,000 and over	14	14

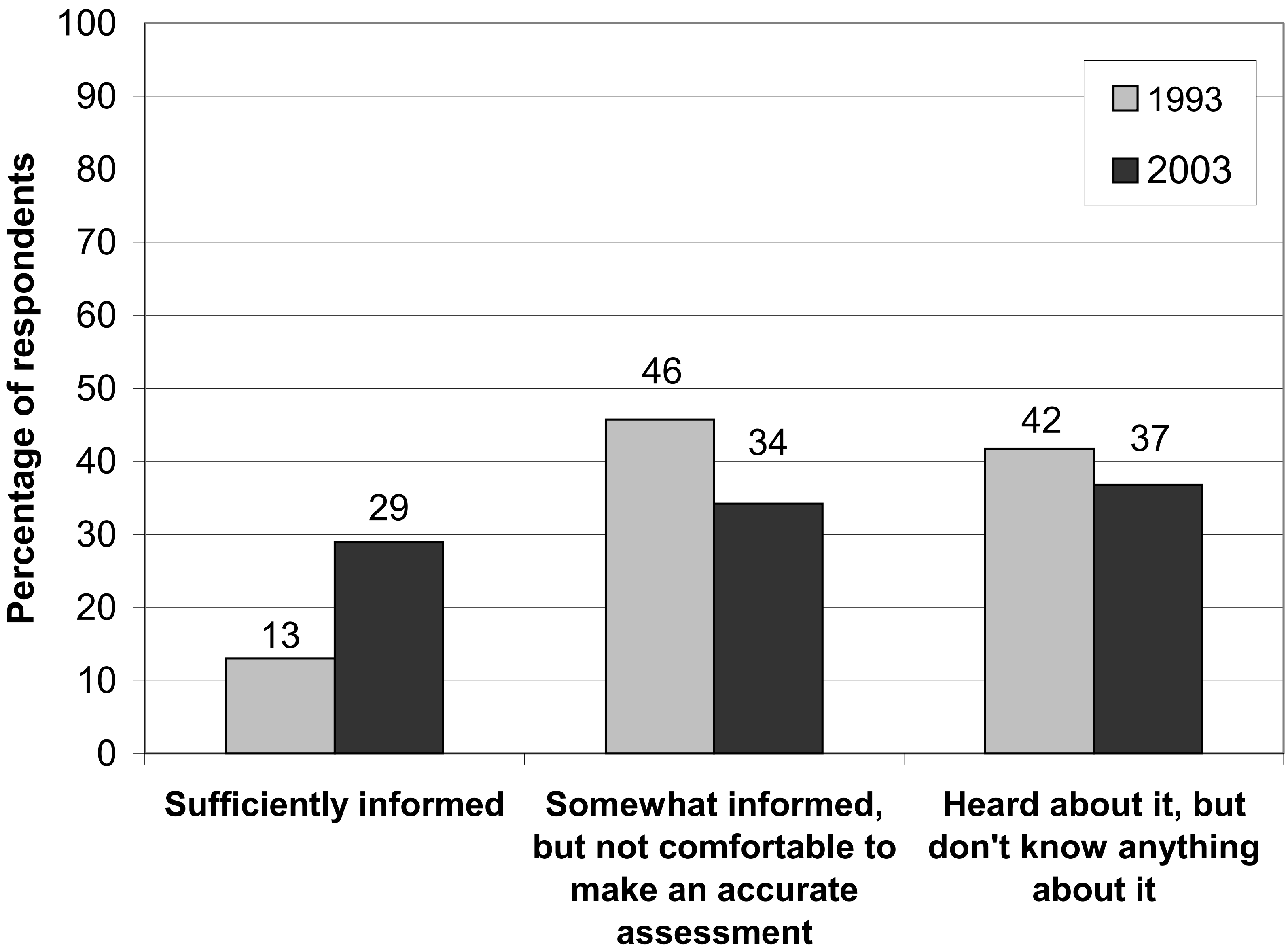
[a] Consumer participation in survey: 1993 mailed survey (*n* =446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

inconsistencies. In 1989, a mailed survey with 1,004 respondents showed that 60% of consumers were aware of the irradiation process (*31*). In 1993, a mailed survey with 446 respondents showed that consumer awareness increased to 72% (*24*). However in 1998, another mailed survey with 229 respondents showed that only 55% of consumers were aware of irradiation (*9*). The present study showed that 66% of 50 consumers were aware of the irradiation process. Although, a slight decline in consumer awareness since 1993 was observed, it was not statistically significant.

Seventy-one percent of the consumers in the present study compared to 88% in 1993 indicated that they were either "somewhat informed" about irradiation or only "heard, but did not know anything about it" (Figure. 7.1). This percentage reflects a significant decrease in consumers' perception of their lack of knowledge about irradiation because more of consumers in this study indicated that they were more sufficiently informed than those in the 1993 survey. Consumers indicated that they are informed about irradiation from several sources shown in Figure 7.2. Consumers in this study indicated that they acquired their information about irradiation from their participation in surveys, radio/television, newspapers, magazines, and peers. These results are similar to the findings of Gravani *et al.* (*14*) and Resurreccion *et al.* (*24*), which indicate that consumers became aware of the irradiation process through the radio or television, newspapers and magazines.

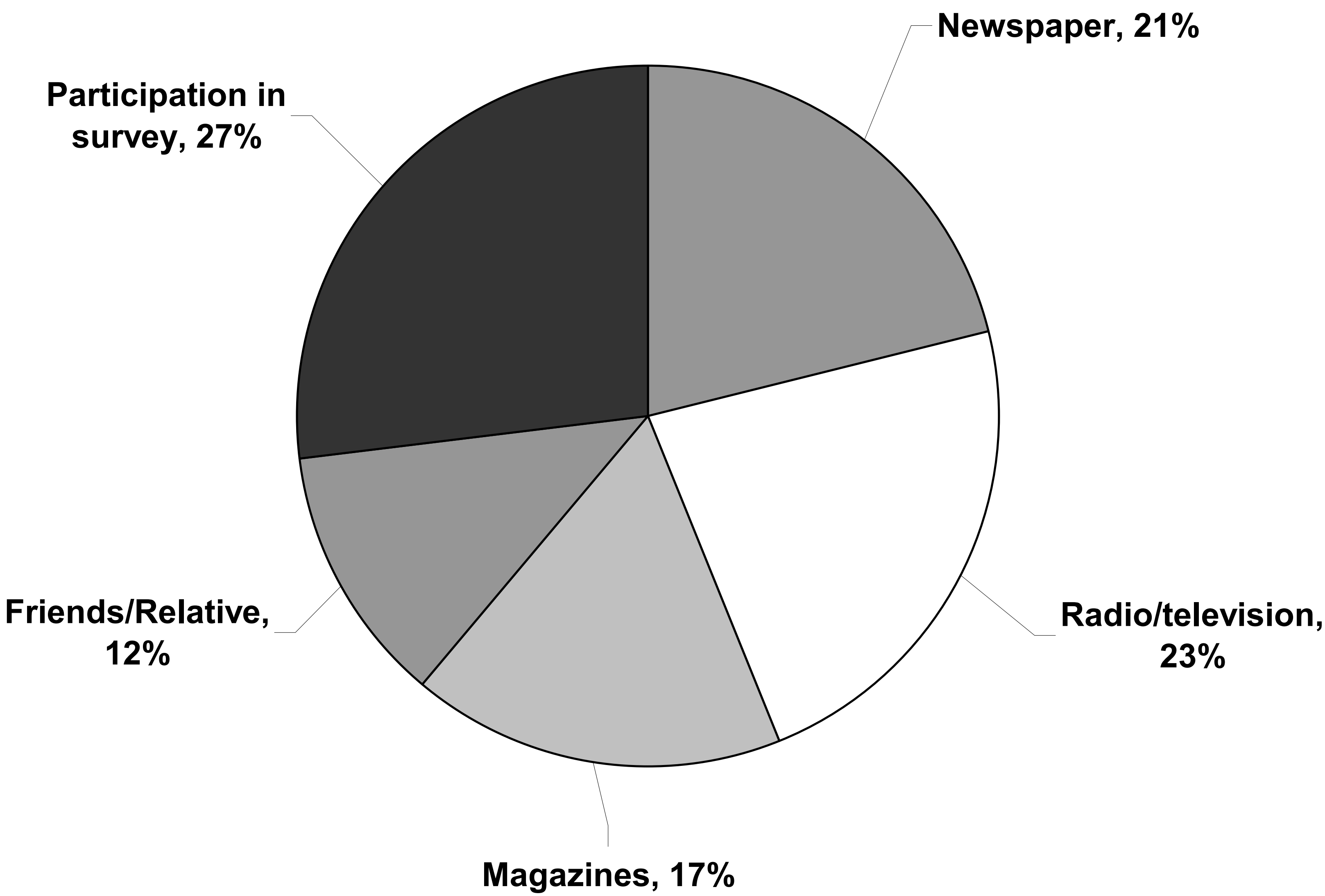
Consumer knowledge about irradiation. The lifestyles of the American public have changed significantly over the past 20 years, and these changes have influenced food choices and the way food is prepared in the home and/or consumed away from home (*36*). In this study, 38% of consumers indicated that either they or a member of their household became ill due to the presence of bacteria in the food. Most consumers who became ill, associated this illness with

Figure 7.1. Percentage of consumers that are informed about irradiation.



100
90
80
70
60
50
40
30
20
10
0
Percentage of respondents
1993
2003
13
29
46
34
42
37
Sufficiently informed
Somewhat informed, but not comfortable to make an accurate assessment
Heard about it, but don't know anything about it

Figure 7.2. Sources of consumer information regarding irradiation in 2003.


Newspaper, 21%
Participation in survey, 27%
Radio/television, 23%
Friends/Relative, 12%
Magazines, 17%

food eaten away from home (Figure. 7.3) and not to food consumed at home. This increase has prompted decisions by a number of food service companies to use irradiated meat and poultry.

In the 7,219 foodborne disease outbreaks between 1973 and 1987 where the site of mishandling was reported, 79% of the implicated food was prepared in commercial or institutional establishments, and 21% was prepared in the home (2). Gravani *et al.* (*14*) found that the home was ranked third out of six choices by consumers as the place where food safety risks are most likely to occur.

When consumers are questioned about their knowledge of irradiation, in-depth information and sufficient responses may not be provided when asked. When consumers were asked true or false questions, a larger number of respondents answered in the "don't know" category, indicating that they are still not sufficiently informed about the irradiation process (Table 7.2). However in this study, we found that more consumers answered the questions correctly as compared to responses in 1993.

In 1993, one-third of all consumers surveyed believed that irradiated foods were radioactive. This has decreased by half in the present study and was accompanied by an increase in respondents indicating that the statement is false or they did not know enough to answer the question (Table 7.2). These results are significantly different from those obtained in 1993. The remaining questions on consumer knowledge in 2003 were not significantly different from those in 1993.

From past research, it has been suggested that the acceptance of irradiation will increase by educating consumers and exposing them to irradiated products. Higher rates of acceptability are found in controlled retail studies, where more information can be provided (*10*). Schutz *et al.* (*31*) believed that identifying consumer benefits through label statements or descriptive

Figure 7.3. Percentage of consumers that attributed a foodborne illness to food consumed at home or away from home.

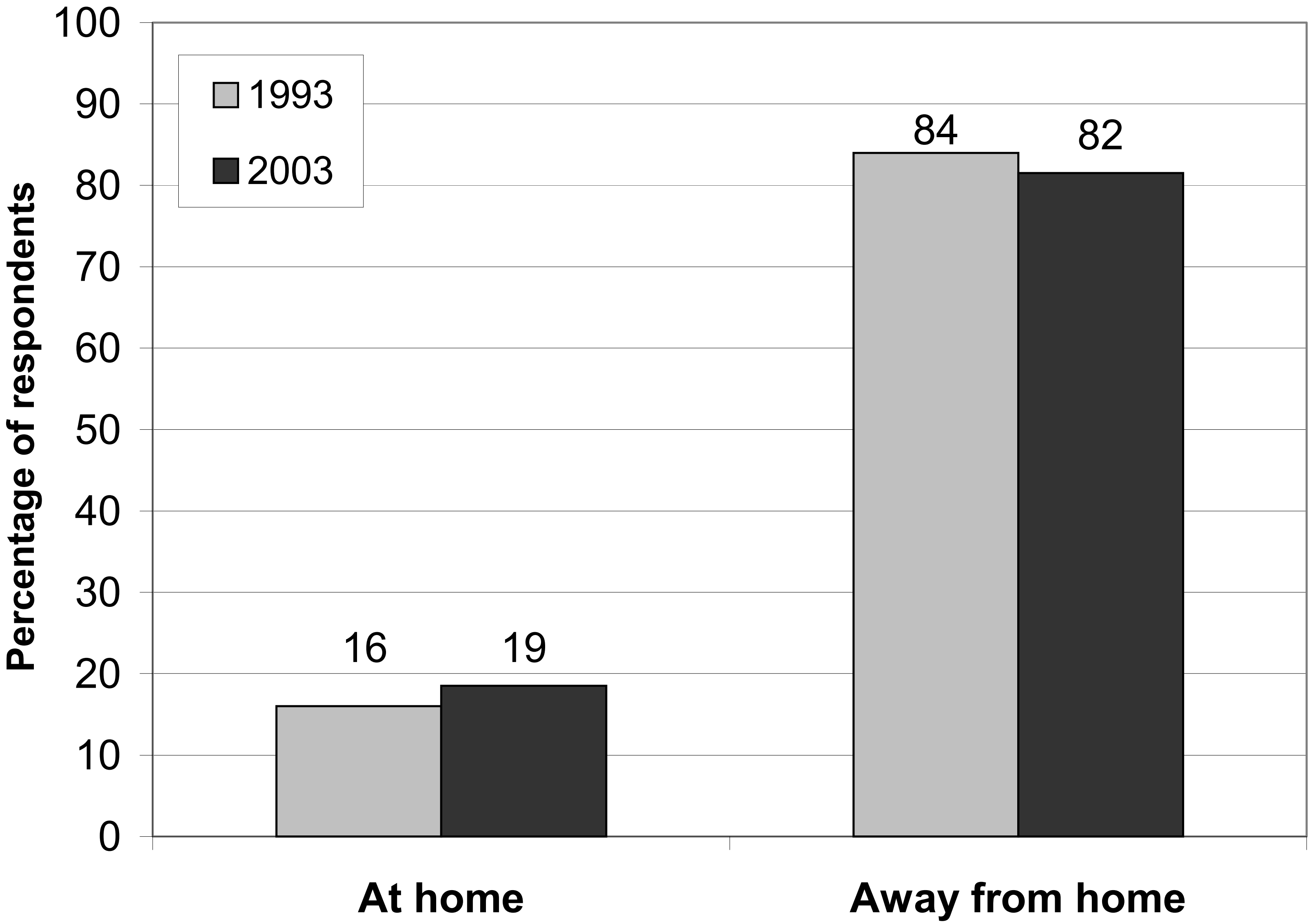

100
90
80
70
60
50
40
30
20
10
0
Percentage of respondents
1993
2003
16
19
84
82
At home
Away from home

Table 7.2. Consumer knowledge about irradiation

	% Responding[a]						
	True		False		Don't know		
Consumer knowledge questions	1993	2003	1993	2003	1993	2003	Level of significance[b]
Irradiated foods							
contain natural radioactivity	33	15	19	26	49	59	P<0.05
cannot be recontaminated	7	14	47	35	46	51	NS
retain quality characteristics and are almost indistinguishable from raw	54	57	9	16	37	27	NS
Spoilage cannot be recognized in irradiated foods	8	2	43	47	49	51	NS
It is legal to irradiate foods repeatedly	8	16	21	24	71	60	NS

[a] Consumer participation in survey: 1993 mailed survey (n =446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

[b] Level of significance from chi-square analysis; NS=not significant at α=0.05

information would have a definite influence on consumer perceptions. Pohlman *et al.* (*21*) reported that audiovisual presentation increased the consumers' knowledge and attitudes toward food irradiation. Loaharanu (*18*) expressed that the opinion of consumers on irradiated food would be quite different if they were given the opportunity to select and purchase the food. Hashim *et al.* (*15*) found that a slide program about irradiation and its benefits was effective in increasing consumer purchase of irradiated poultry compared to posters and label information. Hashim *et al.* (*16*) also suggested that consumers' awareness and acceptance can be increased by education programs, informative irradiation labels and/or posters, television shows, children interactions, pamphlets or brochures, and in-store sampling.

Although education would inform consumers and make them more aware of the advantages of irradiation, to be successful, it must stress the critical components of food safety, for both new-generation foods and/or traditional food items (*26*). However, Cramwinckel and van Mazijk-Bokslag (*7*) found that providing more information to concerned consumers increases their understanding of the goals of irradiation, but does not necessarily lessen their concern toward the technical means of irradiation. This may mean redefining education by finding new and more personal ways to present information, tailoring irradiation to make it meet the needs of the individual and consider the psychology or psyche of the consumer (*22*). In addition to information on irradiation, consumers could also benefit from home food safety education. These programs should be directed more toward consumers under 35 years of age, because many children and young adults may not be learning the basic principles of safe home food preparation (*36*).

Consumer concerns about food safety issues. Food safety is still foremost in the minds of American consumers (*20*). Although many consumers express concern about food safety, relatively few appear to be changing their food buying behavior in view of their concern (*1*). In this study, we found that consumers are more concerned with pesticide and animal drug residues, growth hormones, food additives, bacteria and naturally occurring toxins than with irradiation (Table 7.3). Our findings support the conclusions, found in previous studies (3, 24, *31, 35*). Although consumers expressed only slight concern for food additives and irradiation, this concern has decreased significantly over the past ten years from 1993 to 2003.

Consumers' concern about the irradiation process. In 1989, approximately 25% of the population showed major concern with regard to irradiation (*31*). From 1993 to 2003 (Table 7.4), consumers expressed specific concerns that irradiation may cause induced radioactivity in food; result in loss of nutrients; present a risk of workers becoming ill and increased food prices due to the cost of irradiation processing of food. The level of concern is > 3 or above "somewhat concerned". Although consumers are concerned with environmental pollution, this concern due to the irradiation process is significantly lower in 2003 as compared to 1993.

Attitudes toward labeling of irradiated food. In this study, consumers were asked, "How important is it that the irradiated products be clearly labeled?" Only 74% of consumers found the label to be important. This is a slight, but insignificant ($P<0.05$) decrease compared to 1993, where 81% of consumers found the label to be important. When consumers were also presented with the question, "Do you feel these labels are sufficient to inform consumers that the food in the package is irradiated?", 83% responded yes, whereas in 1993, only 50% of consumers felt that the labels were sufficient. This is a significant increase compared to 1993.

In 1994, Hashim *et al.* (*16*) found that in focus group discussions consumers were not familiar with the irradiation logo (Figure. 7.4) and that consumers felt that it was not enough to

Table 7.3. Concern of consumers about food safety issues[a]

Problems	Mean Response[b] 1993	2003	Level of Significance[c]
Pesticide residues	3.7	3.5	NS
Animal drug residues	3.6	3.5	NS
Bacteria	3.6	3.4	NS
Growth hormones	3.6	3.2	NS
Food additives	3.3	2.8	P<0.05
Irradiation	2.8	2.4	P<0.05
Naturally occurring toxins	2.7	2.4	NS

[a] A 5-point scale for concern was used, with 1=not concerned, 3=somewhat concerned and 5=extremely concerned.

[b] Consumer participation in survey: 1993 mailed survey (*n* =446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

[c] Level of significance from chi-square analysis; NS=not significant at α=0.05

Table 7.4. Concern of consumers regarding irradiation[a]

Concerns	Mean Response[b] 1993	2003	Level of Significance[c]
Increased food prices	3.8	3.8	NS
Risk of workers becoming ill	3.8	3.5	NS
Environmental pollution	3.8	3.4	$P<0.05$
Reduced levels of nutrients	3.7	3.4	NS
Food becoming radioactive	3.5	3.3	NS

[a] A 5-point scale for concern was used, with 1=not concerned, 3=somewhat concerned and 5=extremely concerned.

[b] Consumer participation in survey: 1993 mailed survey (*n* =446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

[c] Level of significance from chi-square analysis; NS=not significant at $\alpha=0.05$

Figure 7.4. FDA-approved labels required for irradiated foods.

TREATED WITH
RADIATION

TREATED BY
IRRADIATION

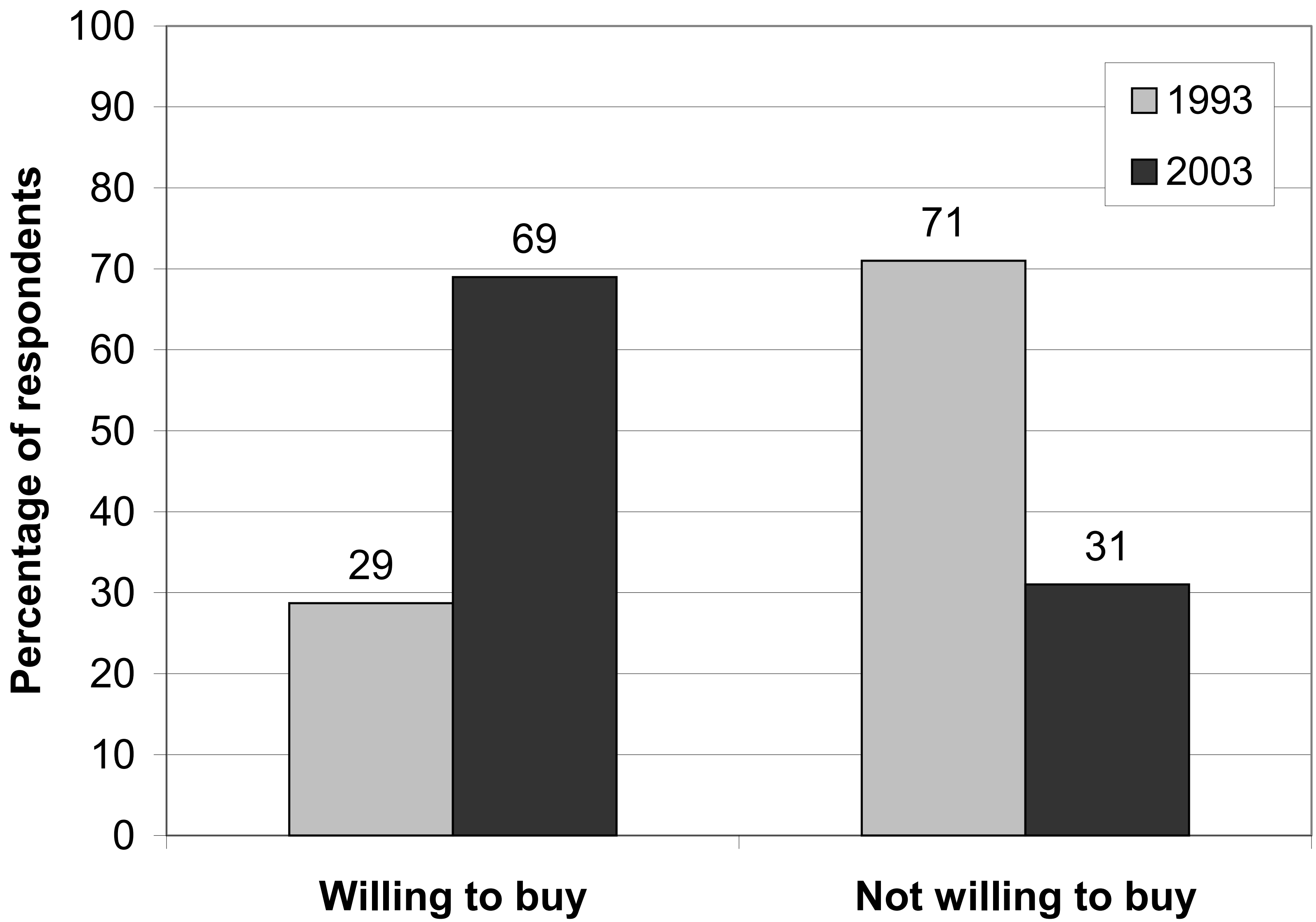
let them know the product had been irradiated. Consumers even stated that "the logo is misleading and that people might assume that the "flower" (radura symbol) is stating that the food was organically grown or is an all natural product rather than being irradiated". The 1993 survey by Resurreccion et al. (24) also found similar findings that the international logo and statement to be insufficient to inform consumers that the food is irradiated.

Due to the negative connotations associated with the words "radiation" and "irradiation," which are mandatory on the label, many in the food industry believe that an alternative wording on the label, such as "electronically pasteurized," would be helpful (*10*). However, this is an oxymoron when one considers that the definition of pasteurization implies heating (34).

Consumer purchase intent for irradiated foods. For the public to benefit fully from irradiation, irradiated foods must be widely available in the market for consumers to exercise their freedom of choice (*18*). Bruhn *et al.* (*3*) found that willingness to buy irradiated food was based on the safety of the process rather than the advantages for any specific food product. As the consumers' perception of safety increased, their willingness to buy increased. Acceptance will be greater if irradiated food is not much more expensive than nonirradiated food (*32*). However, purchase of irradiated foods is difficult due to the limited number of supermarkets willing to offer irradiated products for sale in their stores. There is reluctance, because supermarkets need to be assured of a steady, adequate supply of a product before introducing it (*13*). It is now possible to irradiate products in larger volumes due to the increase in food irradiation facilities nationwide.

More consumers in 2003 were willing to buy irradiated food (Figure. 7.5). The percentage of consumers in this study who were willing to buy irradiated food has more than

Figure 7.5. Percentage of consumers that are willing to buy irradiated food



100
90
80
70
60
50
40
30
20
10
0
Percentage of respondents
1993
2003
29
69
71
31
Willing to buy
Not willing to buy

doubled since 1993. Our findings indicate a considerable increase compared to that by Schutz *et al.* (*31*) who found in 1989 that 43% of consumers were likely to buy irradiated foods. The number of consumers who would not buy irradiated food, has decreased by 56% in 2003. Giamalva *et al.* (*12*) in a series of experiments found that 68% of consumers were willing to pay an average amount of $0.75 for an irradiated meat product.

When consumers were given brief statements about the benefits of irradiation on *Salmonella* and *Trichina*, a small of percentage of consumers indicated that they would prefer to buy non-irradiated meat (Table 7.5). In this study when presented with the benefit statement, most consumers would prefer to purchase irradiated poultry and pork. In 1993, only 47% and 48% of consumers were willing to purchase irradiated meat, poultry, and pork, respectively.

The amounts of produce, poultry, pork, beef and fish items consumers indicated they were willing to buy, if these foods were irradiated and properly labeled, remained unchanged from 1993 to 2003 (Table 7.6). Price was a big factor that was considered in decision making. More consumers stated that they would buy irradiated products if the price remained the same or if there was a 1-5% (Table 7.7). Only a few consumers were willing to pay 6-10% more. However, the difference in the percentages that consumers were willing to pay as compared to 1993 was insignificant. Fox and Olson (*9*) also found that consumers are more willing to buy irradiated products if they are offered at the same price or with a 10% discount than if they are offered at a 10% or 20% premium. Using a supermarket simulated test, a study by Resurreccion and Galvez (*25*) revealed the following inconsistency on irradiated ground beef. Of the 44% of participants who stated in a survey that they would buy irradiated food, only 27% actually purchased the products. Among 16% who stated they would not purchase irradiated food, 5% did and of the 41% who were undecided, almost half of them bought irradiated beef. In another

Table 7.5. Consumer responses to statements of benefits

Raw meats and poultry may contain bacteria, such as *Salmonella* , which can cause illness. Irradiation can kill these bacteria. Knowing this, which would you prefer to buy?

	% Responding[a]		Level of significance[b]
	1993	2003	
Irradiated meat and poultry	47	68	$P<0.05$
Non-irradiated meat and poultry	15	4	NS
Uncertain	34	26	NS
Neither	4	2	NS

Pork may contain a parasite, such as *Trichinella* , which is harmful to people when pork is not thoroughly cooked. Irradiation destroys *Trichinella* . Knowing this, which would you prefer to buy?

	% Responding[a]		Level of significance[b]
	1993	2003	
Irradiated pork	48	76	$P<0.01$
Non-irradiated pork	18	4	NS
Uncertain	27	18	NS
Neither	6	2	NS

[a] Consumer participation in survey: 1993 mailed survey (n =446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

[b] Level of significance from chi-square analysis; NS=not significant at $\alpha=0.05$

Table 7.6. Consumer purchase intent for irradiated foods

How much of the following would you buy relative to the present amount you buy if they are irradiated and properly labeled?

	% Responding[a]					
	Less		Same		More	
Food item	1993	2003	1993	2003	1993	2003
Produce	12.1	14.3	76.8	73.8	11.0	11.9
Poultry	4.8	5.0	81.3	70.0	13.9	25.0
Pork	7.0	4.9	75.1	70.7	17.8	24.4
Beef	7.6	7.5	78.9	67.5	13.5	25.0
Fish	8.0	9.8	68.6	70.7	23.4	19.5

[a] Consumer participation in survey: 1993 mailed survey (n=446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

Table 7.7. Consumer willingness to pay, relative to current prices[a]

How much of the following would you be willing to pay, relative to current prices for the following potential irradiated food products?

	Willingness to pay more (%)											
	None		1-5		6-10		11-15		16-20		>20	
Food item	1993	2003	1993	2003	1993	2003	1993	2003	1993	2003	1993	2003
Produce	50	62	38	29	8	7	2	2	1	0	1	0
Poultry	38	41	40	44	15	8	3	3	2	5	2	0
Pork	41	43	38	45	14	10	4	0	1	3	2	0
Beef	41	46	42	41	12	5	3	3	1	5	2	0
Fish	41	51	36	31	16	13	4	3	1	3	2	0

[a]Consumer participation in survey: 1993 mailed survey (n=446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

supermarket simulation test, Rimal et al. (*27*) found further evidence of inconsistency between actual and intended purchase behavior.

Consumer response on the necessity for irradiation in specific foods. Consumers' response to the necessity of irradiation is shown in Table 7.8. The majority of consumers indicated that irradiation is very necessary for fruits only, somewhat necessary for vegetables and not necessary for meats and seafood. In this study, a total of 94% of consumers indicated that irradiation of poultry was either somewhat necessary or not necessary. This indicates that a significant decrease has occurred in the past years from 59%. It is possible that educational programs have sufficiently informed consumers about the benefits of fully cooking poultry, pork and beef to where consumers view irradiation as not necessary. Results of this study also showed a slight increase from 1995 findings of Hashim *et al.* (*15*), that 84% of participants considered it somewhat or not necessary to irradiate raw chicken.

In conclusion, as in 1993, consumers are willing to purchase irradiated foods as long as its price does not increase. Consumers in 2003 are still more concerned with food safety issues, such as bacteria, food additives and pesticide/animal drug residues than irradiation. The 2003 study indicated consumers were less concerned with food irradiation then in 1993 when the previous study had been conducted. This also indicates that food irradiation presents a good alternative in maintaining food quality and safety as compared to recommendations for safe food handling such as thoroughly cooking poultry and meat products. Most consumers feel they are uninformed about the advantages of the irradiation process, thus with more education and greater exposure to irradiated products, most concerns should diminish.

Table 7.8. Consumer response on the necessity for irradiation in specific food products

	% Responding[a]						
	Very necessary		Somewhat necessary		Not necessary		Level of
Food item	1993	2003	1993	2003	1993	2003	significance[b]
Fruits	12	44	34	40	54	16	P<0.05
Vegetables	12	38	36	42	52	20	P<0.05
Poultry products	41	6	32	35	27	59	P<0.01
Pork products	40	4	33	38	27	58	P<0.01
Beef products	32	4	37	45	31	51	P<0.01
Seafoods	44	12	27	36	28	52	P<0.05

[a]Consumer participation in survey: 1993 mailed survey (n=446); 2003 survey of participants in a consumer acceptance sensory test (n=50)

[b] Level of significance from chi-square analysis; NS=not significant at α=0.05

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CHAPTER 8

SUMMARY AND CONCLUSIONS

The effect of medium dose (1, 2 and 3 kGy) electron-beam irradiation on ready-to-eat poultry meats (frankfurters and diced chicken) stored at refrigeration temperatures throughout a 32 day shelf life period was studied. Irradiation at doses as high as 3 kGy did not have a detrimental effect on consumer acceptance and other sensory characteristics. The irradiated frankfurters and diced chicken meats were more acceptable to consumers throughout their refrigerated shelf life for up to 32 and 18 days, respectively, whereas the non-irradiated controls had either lower ratings or were unacceptable, respectively.

For optimization of the electron-beam process, an irradiation dose of 2.5 to 3.0 kGy is recommended to process frankfurters by electron-beam irradiation, to receive the optimum acceptance by consumers. Frankfurters should be evaluated for overall acceptability and acceptability of flavor, juiciness and tenderness for optimum quality and should be stored for no more than 11 days after irradiation when a 3 kGy dose is used and no more than 8 days of storage when 2.5 kGy is used.

Mean ratings for appearance, aroma, flavor and texture attributes were used to profile the effect of irradiation dose and storage time on electron-beam irradiated ready-to-eat poultry frankfurters. Regression models for significant attributes ($R^2 \geq 0.50$) were developed and the effects of irradiation dose and storage time were described. Storage time had a more significant effect on the frankfurters than irradiation dose. Irradiation had a significant effect on some aroma and flavor attributes, however it did not have a significant effect on texture attributes of the electron-beam irradiated frankfurters.

Multivariate analysis of the descriptive and consumer data for the electron-beam irradiated ready-to-eat refrigerated frankfurters and refrigerated/frozen diced chicken showed that storage time profoundly effect on the quality of these products. Irradiated frankfurters developed sour tastes, wet dog aromas and off-flavors at day 32 and diced chicken became oxidized and developed off-flavors at day 25, whereas the frozen diced chicken was not affected by storage time.

After consumers were exposed to irradiated foods prior to a survey, consumer acceptance of the irradiation process did not increase in this study, compared to 1993 when consumers were not exposed to irradiated foods prior to the survey. As compared to 1993, consumers are willing to purchase irradiated foods as long as its price does not increase. However, consumers are still more concerned with food safety issues, such as bacteria, food additives and residues than irradiation. Their diminished concern regarding irradiation indicates that acceptance of the process by consumers presents a good alternative to maintain the quality and safety of food. Most consumers feel they are uninformed about the advantages of the irradiation process, thus with more education and greater exposure to irradiated products, these concerns should diminish.

CHAPTER 9

APPPENDICES

Appendix 1. Calculated F-ratio to determine significant differences between full and reduced models in Chapter 4

	Sum of squares		Degrees of freedom		Mean Square Error		Degrees of freedom			
Attribute	Full[a]	Red[b]	Full[c]	Red[d]	Full[e]	F-value (calc)[f]	Num[g]	Denom[h]	F-value[i]	Model comparison[j]
Overall	0.54606	0.5459	5	4	0.01214	0.01317957	1	5	6.61	similar
	0.54606	0.53231	5	3	0.01214	0.56630972	2	5	5.79	similar
	0.54606	0.50811	5	2	0.01214	1.04200988	3	5	5.41	similar
Flavor	0.63729	0.61376	5	4	0.01111	2.11791179	1	5	6.61	similar
	0.63729	0.57618	5	3	0.01111	2.75022502	2	5	5.79	similar
	0.63729	0.52586	5	2	0.01111	3.34323432	3	5	5.41	similar
Juicy	0.70407	0.698	5	4	0.01192	0.50922819	1	5	6.61	similar
	0.70407	0.69033	5	3	0.01192	0.57634228	2	5	5.79	similar
	0.70407	0.61112	5	2	0.01192	2.59927293	3	5	5.41	similar
Tender	0.65485	0.65483	5	4	0.01542	0.00129702	1	5	6.61	similar
	0.65485	0.65083	5	3	0.01542	0.13035019	2	5	5.79	similar
	0.65485	0.64218	5	2	0.01542	0.27388673	3	5	5.41	similar

[a]SSfull=Sum of squares from full model

[b]SSreduced=Sum of squares from reduced model

[c]DFfull=Degrees of freedom from full model

[d]DFreduced=Degrees of freedom from reduced model

[e]MSEfull=Mean of squares error from full model

[f]F-value calculated=(SSfull-Ssreduced)/(DFfull-Dfreduced)/MSEfull

[g]Degrees of freedom of the numerator

[h]Degrees of freedom of the denominator

[i]F-value is obtained from the critical value table at 0.05

[j]Full models and reduced models are compared for similarity or dissimilarity by comparing F-Values. If F-value calculated < F-value from table then the models are similar. If F-value calculated > F-value from table, then models are dissimilar.

Appendix 2. Calculated F-ratio to determine significant differences between full and reduced models of significant descriptive attributes in Chapter 5

	Sum of squares		Degrees of freedom		Mean Square Error		Degrees of freedom			
Attribute	Full[a]	Red[b]	Full[c]	Red[d]	Full[e]	F-value (calc)[f]	Num[g]	Denom[h]	F-value[i]	Model comparison[j]
Chickeny	6.14094	6.10765	5	4	0.17955	0.185407964	1	5	6.61	similar
	6.14094	5.59554	5	3	0.17955	1.518796992	2	5	5.79	similar
Cured meat	3.87678	3.7547	5	4	0.14844	0.822419833	1	5	6.61	similar
	3.87678	3.60245	5	3	0.14844	0.924043385	2	5	5.79	similar
	3.87678	3.58055	5	2	0.14844	0.665207042	3	5	5.41	similar
Spice blend	3.55422	3.34336	5	4	0.1238	1.703231018	1	5	6.61	similar
Wet dog	51.24273	50.2294	5	4	1.12327	0.902125046	1	5	6.61	similar
	51.24273	44.90666	5	3	1.12327	2.820368211	2	5	5.79	similar
	51.24273	44.47316	5	2	1.12327	2.008887741	3	5	5.41	similar
Off-flavor	36.7312	35.74929	5	4	0.90409	1.086075501	1	5	6.61	similar
	36.7312	30.5209	5	3	0.90409	3.434558506	2	5	5.79	similar
Meaty	6.12041	6.08136	5	4	0.12555	0.311031462	1	5	6.61	similar
	6.12041	6.03069	5	3	0.12555	0.357307845	2	5	5.79	similar
	6.12041	5.81208	5	2	0.12555	0.818611443	3	5	5.41	similar
	6.12041	5.2627	5	1	0.12555	1.707905217	4	5	5.19	similar
Chickeny	9.14883	8.89211	5	4	0.22475	1.142246941	1	5	6.61	similar
	9.14883	8.3302	5	3	0.22475	1.821201335	2	5	5.79	similar
	9.14883	7.96886	5	2	0.22475	1.750048202	3	5	5.41	similar
Sour	155.7187	155.4163	5	4	2.63934	0.114574098	1	5	6.61	similar
	155.7187	141.86547	5	3	2.63934	2.624373897	2	5	5.79	similar
	155.7187	133.38659	5	2	2.63934	2.820415963	3	5	5.41	similar

Appendix 2. Continued

Sweet	4.42773	4.42158	5	4	0.15025	0.04093178	1	5	6.61	similar
	4.42773	4.33571	5	3	0.15025	0.306222962	2	5	5.79	similar
	4.42773	4.29943	5	2	0.15025	0.284636717	3	5	5.41	similar

[a]SSfull=Sum of squares from full model

[b]SSreduced=Sum of squares from reduced model

[c]DFfull=Degrees of freedom from full model

[d]DFreduced=Degrees of freedom from reduced model

[e]MSEfull=Mean of squares error from full model

[f]F-value calculated=(SSfull-Ssreduced)/(DFfull-Dfreduced)/MSEfull

[g]Degrees of freedom of the numerator

[h]Degrees of freedom of the denominator

[i]F-value is obtained from the critical value table at 0.05

[j]Full models and reduced models are compared for similarity or dissimilarity by comparing F-Values. If F-value calculated < F-value from table then the models are similar. If F-value calculated > F-value from table, then models are dissimilar.

Appendix 3. Survey on consumer attitudes toward irradiation in Chapter 7

UNIVERSITY OF GEORGIA
(CONFIDENTIAL)

Your responses will be kept in strict confidence. Since many questions concern food shopping behavior, we suggest that the primary food shopper of the household answer the questions.

Definitions of some of the terms frequently used in the questionnaire:

PESTICIDE RESIDUES:

Any leftover of a substance intended for preventing, destroying, repelling, or mitigating any pest.

ANIMAL DRUG RESIDUES:

Any leftover of chemicals used on animals to maintain good health and increase growth rates and production.

GROWTH HORMONES:

Chemicals used in the livestock industry to increase the rate at which an animal gains weight and decrease the amount of feed required per pound of weight gained.

FOOD ADDITIVES:

Substances other than basic foodstuffs intentionally added to foods which become components of the foods or affect their quality characteristics.

BACTERIA:

A large group of microscopic organisms widely distributed in air, water, soil, the bodies of living animals and plants, and dead organic matter.

NATURALLY OCCURRING TOXINS:

Toxins that are inherently present in products in their natural state.

IRRADIATION:

Exposure of food to very high-energy, invisible lightwaves (radiation) to destroy bacteria that cause illness, kill parasites, control insect infestation, and extend shelf-life. It has been approved as safe by the U.S. Food and Drug Administration (FDA) for use in some foods.

Q-1. Prior to this survey, had you ever heard of the irradiation process for preserving and sterilizing foods? (Circle number)

1. YES 2. NO

(IF YES)
A. How would you rate your knowledge about the irradiation process? (Circle one number)

1. I AM SUFFICIENTLY INFORMED ABOUT THE IRRADIATION PROCESS
2. I AM SOMEWHAT INFORMED ABOUT IRRADIATION BUT DO NOT FEEL COMFORTABLE TO MAKE AN ACCURATE ASSESSMENT
3. I HAVE HEARD ABOUT THE IRRADIATION PROCESS BUT DO NOT KNOW ANYTHING ABOUT IT

B. What is the source of your information regarding food irradiation? (Circle all which apply)

1. NEWSPAPER
2. RADIO/TELEVISION
3. MAGAZINES
4. FRIENDS/RELATIVES
5. PREVIOUS PARTICIPATION TO A SIMILAR SURVEY LIKE THIS ONE
6. OTHER (please specify) ____________________

Q-2. Do you think that you or a member of your household has become ill due to the presence of bacteria in the food? (Circle number)

1. YES 2. NO

(IF YES)
A. Did you or a member of your household become ill within the last 12 months due to the presence of bacteria in the food? (Circle number)

1. YES 2. NO

B. Did you or a member of your household become ill due to the presence of bacteria in the food eaten at home or eaten away from home? (Circle number)

1. FOOD EATEN AT HOME 2. FOOD EATEN AWAY FROM HOME

Q-3. Do you think the approved (by FDA) process of irradiation is safe enough to be used on the food we eat? (Circle letter)

A. YES B. NO C. DON'T KNOW

Q-4. On a scale of 1 to 5, how do you perceive the following treatments, chemical residues and microbial contaminants in foods you eat, where 1=no problem, and 5=an extremely serious problem. (Circle number)

A. PESTICIDE RESIDUES	1	2	3	4	5
B. ANIMAL DRUG RESIDUES	1	2	3	4	5
C. GROWTH HORMONES	1	2	3	4	5
D. FOOD ADDITIVES	1	2	3	4	5
E. BACTERIA	1	2	3	4	5
F. IRRADIATION	1	2	3	4	5
G. NATURALLY OCCURRING TOXINS	1	2	3	4	5

Q-5. On a scale of 1 to 5, have you changed your food consumption habits due to the following food safety factors, where 1=no change, and 5=taking extreme precaution to only buy items that are guaranteed to be safe. (Circle number)

A. PESTICIDE RESIDUES	1	2	3	4	5
B. ANIMAL DRUG RESIDUES	1	2	3	4	5
C. GROWTH HORMONES	1	2	3	4	5
D. FOOD ADDITIVES	1	2	3	4	5
E. BACTERIA	1	2	3	4	5
F. IRRADIATION	1	2	3	4	5
G. NATURALLY OCCURRING TOXINS	1	2	3	4	5

Q-6. Please answer the following irradiation related questions by circling the number that you think to represent the correct answer, where 1=true, 2=false, and 3=don't know.

A. FOOD DELIBERATELY TREATED WITH RADIATION CAN AT PRESENT BE BOUGHT IN SOME COUNTRIES OF THE WORLD.
1 2 3

B. THE UNITED STATES LEADS THE WORLD IN THE NUMBER OF IRRADIATED FOODS AVAILABLE FOR RETAIL SALE.
1 2 3

C. FOODS CONTAIN NATURAL RADIOACTIVITY.
1 2 3

D. SCIENTISTS CAN EASILY ASCERTAIN FOOD THAT HAS BEEN IRRADIATED.
1 2 3

E. FOOD THAT HAS BEEN TREATED WITH RADIATION CAN NOT BE RECONTAMINATED.
1 2 3

F. IRRADIATED FOODS MAY RETAIN MOST OF THEIR APPEARANCE, TASTE, AND QUALITY, MAKING THEM ALMOST INDISTINGUISHABLE FROM FRESH RAW FOODS.
1 2 3

G. SPOILAGE CANNOT BE RECOGNIZED IN IRRADIATED FOOD.
1 2 3

H. IT IS LEGAL TO IRRADIATE FOOD REPEATEDLY.
1 2 3

Q-7. Please answer the following irradiation related questions by circling number that you think best represents your feeling, where 1=not concerned and 5=extremely concerned.

A. IF IRRADIATION WAS USED ON THE FOOD YOU EAT, WHAT WOULD BE YOUR REACTION?	1	2	3	4	5
B. IRRADIATION IS APPROVED AS SAFE BY THE U.S. FOOD AND DRUG ADMINISTRATION. HOW WOULD THIS AFFECT YOUR FEELING ABOUT IRRADIATED FOOD?	1	2	3	4	5

Q-8. On a scale of 1 to 5, how much concern do you have with the following, where 1=not concerned, and 5=extremely concerned? (Circle number)

A. THE POSSIBILITY OF FOOD BECOMING RADIOACTIVE DUE TO IRRADIATION	1	2	3	4	5
B. THE POSSIBILITY OF REDUCED LEVELS OF NUTRIENTS DUE TO IRRADIATION	1	2	3	4	5
C. THE RISK OF WORKERS AT IRRADIATION FACILITIES BECOMING ILL	1	2	3	4	5
D. THE RISK OF ENVIRONMENT POLLUTION DUE TO IRRADIATION FACILITIES	1	2	3	4	5
E. THE POSSIBILITY OF INCREASED FOOD PRICES DUE TO IRRADIATION	1	2	3	4	5

Q-9. Labeling Irradiated foods has been considered essential so that consumers will be adequately informed. The Food and Drug Administration approved initial labeling requirements in April 1986. At the retail level, the label must bear this international symbol and statement:

TREATED WITH RADIATION

or

TREATED BY IRRADIATION

A. How important is it that the irradiated products be clearly labeled? (Circle number)

1. VERY IMPORTANT
2. SOMEWHAT IMPORTANT
3. NOT IMPORTANT

B. Do you feel these labels are sufficient to inform consumers that the food in the package is irradiated? (Circle number)

1. YES
2. NO

Q-10. How would you feel about these product characteristics of an irradiated product labelled with the symbol and the following statement. (Circle number to reflect your answer where 1=higher or longer, 2=same, 3=lower or shorter, and 4=don't know.)

A. "Irradiated to control microorganisms."				
PRODUCT QUALITY	1	2	3	4
SHELF-LIFE OF PRODUCT	1	2	3	4
PRICE	1	2	3	4
PRODUCT SAFETY	1	2	3	4
B. "Irradiated to extend shelf life."				
PRODUCT QUALITY	1	2	3	4
SHELF-LIFE OF PRODUCT	1	2	3	4
PRICE	1	2	3	4
PRODUCT SAFETY	1	2	3	4
C. "Irradiated to retard spoilage."				
PRODUCT QUALITY	1	2	3	4
SHELF-LIFE OF PRODUCT	1	2	3	4
PRICE	1	2	3	4
PRODUCT SAFETY	1	2	3	4

Q-11. The process of irradiation can be used on various products. According to your opinion how necessary is irradiation for the following? (Circle number for each item)

	NOT NECESSARY	SOMEWHAT NECESSARY	VERY NECESSARY
A. FRUITS	1	2	3
B. VEGETABLES	1	2	3
C. POULTRY PRODUCTS	1	2	3
D. PORK PRODUCTS	1	2	3
E. BEEF PRODUCTS	1	2	3
F. SEAFOOD	1	2	3

Q-12. Raw meats and poultry may contain bacteria, such as Salmonella, which can cause illness. Irradiation can kill these bacteria. Knowing this, which would you prefer to buy? (Circle letter)

A. NON-IRRADIATED MEAT AND POULTRY
B. IRRADIATED MEAT AND POULTRY
C. UNCERTAIN
D. NEITHER

Q-13. Pork may contain a parasite, such as Trichina, which is harmful to people when pork is not thoroughly cooked. Irradiation destroys Trichina. Knowing this, which would you prefer to buy? (Circle letter)

A. NON-IRRADIATED MEAT AND PORK
B. IRRADIATED MEAT AND PORK
C. UNCERTAIN
D. NEITHER

Q-14. Would you buy food that was treated with approved doses of radiation and is properly labeled? (Circle one number)

1. YES 2. NO 3. UNDECIDED

(If YES, please circle one number for each question in 14.1 and 14.2. If NO or UNDECIDED, please answer questions 14.3 and 14.4)

Q-14.1. If irradiated and properly labeled, would you buy more, less, or about the same quantity of the following food groups, <u>relative to the present amount</u> you buy?

	LESS	SAME	MORE
A. IRRADIATED PRODUCE	1	2	3
B. IRRADIATED POULTRY	1	2	3
C. IRRADIATED PORK	1	2	3
D. IRRADIATED BEEF	1	2	3
E. IRRADIATED FISH	1	2	3
F. ALL IRRADIATED FOOD PRODUCTS	1	2	3

Q-14.2. How much more would you be willing to pay, <u>relative to current prices</u>, for the following potential irradiated food products?

	WILLINGNESS TO PAY MORE IN PERCENT					
	NONE	1-5	6-10	11-15	16-20	> 20
A. IRRADIATED PRODUCE	1	2	3	4	5	6
B. IRRADIATED POULTRY	1	2	3	4	5	6
C. IRRADIATED PORK	1	2	3	4	5	6
D. IRRADIATED BEEF	1	2	3	4	5	6
E. IRRADIATED FISH	1	2	3	4	5	6
F. ALL IRRADIATED FOOD PRODUCTS	1	2	3	4	5	6

(If NO or UNDECIDED, please answer questions 14.3 and 14.4)

Q-14.3. Why would you not buy it or why are you undecided? (Circle all which apply)

A. IS HARMFUL AND MAY LEAD TO HEALTH COMPLICATIONS
B. POSES OCCUPATIONAL HAZARDS FOR THOSE INVOLVED
C. POSES SERIOUS ENVIRONMENTAL HAZARDS
D. NOT SURE WHETHER THE PROCESS IS SAFE

Q-14.4. Would you be willing to buy food that was treated with irradiation if it was available at a lower price relative to current prices? (Circle one number)

1. YES 2. NO

Q-15. How many times per week, if ever, does your household eat the following, in meals eaten at home and away from home?

A. POULTRY _______ TIMES PER WEEK
B. PORK _______ TIMES PER WEEK
C. BEEF _______ TIMES PER WEEK
D. SEAFOOD _______ TIMES PER WEEK

Q-16. How would you describe your health? (Circle letter)

A. EXCELLENT B. GOOD C. FAIR D. POOR

Q-17. Do you live in a city? (Circle letter)

A. YES
B. NO

Q-18. What is your race? (Circle letter)

A. WHITE B. BLACK C. HISPANIC D. OTHER

Q-19. What is your marital status? (Circle letter)

A. MARRIED
B. DIVORCED/SEPARATED
C. WIDOWED
D. NEVER MARRIED

Q-20. What is the grade in school that you have completed? (Circle highest grade)

A. SOME GRADE SCHOOL: 1 2 3 4 5 6 7
B. GRADE SCHOOL GRADUATE: 8
C. SOME HIGH SCHOOL: 9 10 11
D. HIGH SCHOOL OR TECHNICAL SCHOOL GRADUATE: 12
E. SOME COLLEGE OR VOCATIONAL SCHOOL: 13 14 15
F. COLLEGE GRADUATE: 16
G. ADVANCED COLLEGE DEGREE: 17+

Q-21. If married, what is the highest grade in school that your spouse have completed? (Circle highest grade completed)

A. SOME GRADE SCHOOL: 1 2 3 4 5 6 7
B. GRADE SCHOOL GRADUATE: 8
C. SOME HIGH SCHOOL: 9 10 11
D. HIGH SCHOOL OR TECHNICAL SCHOOL GRADUATE: 12
E. SOME COLLEGE OR VOCATIONAL SCHOOL: 13 14 15
F. COLLEGE GRADUATE: 16
G. ADVANCED COLLEGE DEGREE: 17+

Q-22. What is your employment status? (Circle letter)

A. EMPLOYED FULL-TIME
B. EMPLOYED PART-TIME (Please specify hours/week) ______________
C. RETIRED/DISABLED
D. UNEMPLOYED

Q-23. (IF MARRIED) What is your spouse's employment status? (Circle letter)

A. EMPLOYED FULL-TIME
B. EMPLOYED PART-TIME (Please specify hours/week) ______________
C. RETIRED/DISABLED
D. UNEMPLOYED

Q-24. What was your household's total income for last year (1991) before taxes? This includes all members of the household and all sources of income (wages, rent, interest, dividends, retirement, social security, etc.). (Circle number)

1. UNDER $10,000
2. $10,000 TO 19,999
3. $20,000 TO 29,999
4. $30,000 TO 39,999
5. $40,000 TO 49,999
6. $50,000 TO 59,999
7. $60,000 TO 69,000
8. $70,000 AND OVER

A. What proportion of the total income is earned by you:______ percent
B. What proportion of the total income is earned by your spouse:______ percent

Q-25. Please describe all members of your household (including yourself) in terms of their relationships to you (e.g., spouse, children, father, mother, etc.), their ages and sex.

	FAMILY MEMBER (RELATIONSHIP)	AGE (YEARS)	SEX (M/F)
1.	YOURSELF		
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			

Your contribution to this consumer study is greatly appreciated.