SENSORY EVALUATION OF GROUND BEEF PATTIES IRRADIATED BY GAMMA RAYS VERSUS ELECTRON BEAM UNDER VARIOUS PACKAGING CONDITIONS

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ABSTRACT

Ground beef patties were packaged in air with: nylon/polyethylene, Saran/polyester/polyethylene, or Saran film overwrap plus a styrofoam tray. Samples were irradiated at 2 kGy by either gamma rays or electron beam, and evaluated for 7 flavor, 3 mouthfeel, and 7 taste attributes by a trained sensory panel. The only difference observed between irradiated and unirradiated samples was that the latter had a more pronounced beef/brothy flavor than irradiated patties. No differences were detected according to packaging material used. Comparing the two sources of irradiation, patties irradiated by gamma rays had more intense cardboardy and soured flavors, and salty and sour tastes than patties irradiated by electron beam.

INTRODUCTION

Food irradiation is a technology that has been endorsed by several health agencies and organizations for its ability to improve the safety of fresh products (Steele 1992). Recently, the Food and Drug Administration approved the use of this process for the decontamination of red meats, including ground beef (FDA 1997). One of the concerns of the food industry is that irradiation may affect the quality of such products, imparting off-flavors that would be unacceptable to consumers. Sensory evaluation of irradiated meats has revealed that dose, atmosphere, and temperature are the three factors that can affect the sensory quality of these products the most (Andrews *et al.* 1998).

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It has been speculated that the type of material used to package fresh foods may also play a role in the development of off-flavors, through the formation of free radicals during irradiation (Buchalla *et al.* 1993). Coupled with an oxygen-rich environment, such radicals can induce lipid oxidation, the precursor to development of rancid odors and flavors (Ahn *et al.* 1998). Low-density polyethylene and high-density polyethylene packaging materials have been suspected of causing the production of intense off-odors in foods as a result of irradiation, with the intensity of such odors increasing with oxygen concentration (Azuma *et al.* 1984a). In sensory tests, polyvinyl chloride and polystyrene have been reported to taint the odor of packaged water after irradiation (Kilcast 1990).

Gamma rays and accelerated electrons are two forms of electromagnetic radiation used for food irradiation (Diehl 1995). Compton scattering of this energy converts gamma rays into fast electrons as they pass through a medium, thus reactions caused by gamma rays and an electron beam from a linear accelerator are considered to be essentially the same (Hayashi 1991). However, one important difference is that gamma rays deliver radiation at a much slower dose rate (10^{-3} to 10^{-1} kGy/min) than electron beams (10^{1} to 10^{3} kGy/s) (Diehl 1995). Extremely high dose rates can result in the development of an anoxic environment, because oxygen molecules are used up in the production of free radicals at a faster rate than that of oxygen diffusion into the package (Thomas *et al.* 1981). It is also speculated that at higher dose rates, any such free radicals will react with each other preferentially instead of with food components, due to their fast formation rate (Taub 1979).

In order for the beef industry to be able to apply food irradiation to improve meat safety, it must be confident that product treated in this way will not be compromised in quality, regardless of packaging material and irradiation source. The objectives of this study were (1) to determine whether packaging materials currently used by the beef industry would affect the quality of ground beef patties, and (2) to determine the effect of irradiation source on the sensory quality of the product.

MATERIALS AND METHODS

Sample Preparation

Ground beef containing 20% fat was obtained from the Rosenthal Meat Science and Technology Center at Texas A&M University. The product was stored at -70C until needed, at which time the meat was defrosted at 4C inside a cooler (Frigitemp, Bally Case and Cooler, Inc., Philadelphia, PA). The meat was mixed in a KitchenAid bowl mixer (KitchenAid, Inc., St. Joseph, MO) with a flat beater attachment for 2 min. Portions of meat (25 g) were then packed into sterile 60 × 15 mm polystyrene petri dishes (Fisher Scientific Col, Pittsburgh, PA) in order to form the beef into patties of uniform shape. The patties were then aseptically removed from the plates and carefully packaged in one of three types of packaging material.

Packaging

We selected three types of packaging material (PM) on the basis of their current use in the food industry. These were: PM1: nylon/polyethylene bags (Koch Supplies, Inc., Kansas City, MO), consisting of 0.75 mil nylon and 2.25 mil polyethylene, with a moisture transmission rate of 0.73 g/100 in ^{2}/24 h/atm and oxygen permeability of 3.9 cc/100 in ^{2}/24 h/atm; PM2: Saran/polyester/polyethylene bags (Koch Supplies, Inc., Kansas City, MO), consisting of a top layer of 0.48 mil Saran + 2 mil polyethylene, and a bottom layer of 2 mil polyethylene + 0.48 metallized polyester, with a moisture transmission rate of 0.22 g/100 in ^{2}/24 h/atm and oxygen permeability of 0.49 cc/100 in ^{2}/24 h/atm; and PM3: Saran film overwrap (Dow Brands, Indianapolis, IN) plus a styrofoam tray (Albertson's, College Station, TX) on the bottom, with Saran having a moisture transmission rate of 0.45 g/100 in ^{2}/24 h/atm and an oxygen permeability of 1.0 cc/100 in ^{2}/24 h/atm. Thus, in terms of moisture and oxygen permeabilities, the materials can be ranked from highest to lowest as follows: nylon/polyethylene (PM1) > Saran overwrap (PM3) > Saran/polyester/polyethylene (PM2). Bags were sealed in air using a model CE95 modified atmosphere packaging machine (Koch Supplies, Inc., Kansas City, MO).

Ground beef samples were equilibrated to 5C inside a cooler for 16 h. They were then placed inside an insulated shipping box containing frozen cold packs, and then shipped by overnight courier to either Iowa State University (for irradiation by electron beam), or to Sterigenics, Inc. in Tustin, California (for irradiation by gamma rays). Upon arrival in California or Iowa, sample temperature was measured by a thermocouple. If temperature was found to be higher or lower than 5C of the target temperature, samples were deemed unacceptable and were not irradiated. Samples found acceptable by this criterion were irradiated within 1 h, and shipped the same day back to Texas A&M University by overnight courier. The rationale behind packaging in air and at refrigeration temperature only was to provide sensory panelists with patties irradiated under conditions that would be most likely to cause formation of free radicals, and thus result in off-odors and off-flavors.

Irradiation

Samples were irradiated by electron beam at the Iowa State University Linear Accelerator Facility in Ames, Iowa, which is equipped with an MeV CIRCE III Linear Electron Accelerator (MeV Industrie S.A., Jouy-en-Josas, France). Half of the samples were irradiated at the target average dose of 2.0 kGy, and the other half were left unirradiated. The dose was applied in electron beam mode at an energy level of 10 MeV and dose rate of 17 kGy/min. The target average dose represents an arithmetic average of the top and bottom surface doses received by the samples. The actual absorbed radiation dose was determined by the use of alanine dosimeter pellets (Bruker Analytische Messtechnik, Rheinstetten, Germany), placed on the top and bottom surfaces of one of the samples. Immediately following irradiation, the absorbed dose was determined by electron paramagnetic resonance on a Bruker EMS 104 EPR Analyzer or at Sterigenics, Inc. in Tustin, California.

Samples were irradiated by gamma rays at Sterigenics, Inc., in Tustin, California, which is equipped with a radioisotope Cobalt-60 source consisting of 3.4 M Ci. Samples were placed 20 ft from the source, and irradiated at a dose rate of 1.0 kGy/h to achieve a target dose of 2.0 kGy. The dosimetry was measured by Harwell Gammachrome dosimeters, with an effective dose range of 0.1-3.0 kGy (A.E.A. International, Harwell, United Kingdom). Three replications were carried out by irradiating samples on three different days. After irradiation, samples were shipped back to Texas A&M University by overnight courier the same day they were received.

Preparation of Samples for Sensory Evaluation

Immediately upon arrival, all patties were stored at 5C. One day later (2 days after being irradiated), the samples were prepared for sensory evaluation. Patties were cooked on electric skillets (West Bend Col, West Bend, WI; 176C cooking temperature) to an internal temperature of 71C. This was determined using a model HH21 microprocessor thermometer with a type T copper/constantan thermocouple probe (Omega Engineering, Inc., Stamford, CT) inserted into the center of each patty. A separate skillet was used for each treatment (3 for the unirradiated controls packaged in each of the three packaging materials, and 3 for the irradiated samples packaged in each of the three packaging materials). Once cooked, the patties were allowed to cool down to room temperature before serving to the panelists. Four sections, measuring 1.27 cm^2 of each sample were served to each panelist, with each of the six treatments evaluated twice for each of the three treatment replications. Samples were served in random order to minimize position bias.

Sensory Evaluation

The experimental design followed a 3×3 factorial treatment (3 packaging materials, 3 irradiation sources including control). This yielded 9 treatment combinations, which were evaluated two-at-a-time at random. There were two observations made per sample, with the entire sensory experiment replicated 3 times.

The five-member Texas A&M Meat Science Trained Flavor Profile Panel was used for evaluation of the cooked samples. Panel members were selected and trained using the procedures of Meilgaard *et al.* (1991). Samples were evaluated for aromatics, mouthfeel, taste, and aftertastes using the Spectrum® Universal Intensity Scale (Meilgaard *et al.* 1991). A score of 0 indicated absence of the attribute and a score of 15 indicated an extremely intense level of the attribute. Ballot development sessions were conducted prior to the study to select attributes to be evaluated. Aromatic attributes evaluated were: cooked beef/brothy, cooked beef fat, grainy, cardboard, liver, browned, and soured. Mouthfeel attributes were: metallic, astringent, and greasy. Taste attributes were: salty, sour, bitter, and sweet. Aftertaste attributes were: bitter, sweet, and soured. Panelists were provided with individual booths with red-filtered incandescent lighting, separated from the sample preparation area. They were supplied with double-distilled, deionized water, unsalted crackers and low-salt ricotta cheese to clear the palate between samples. The samples were randomly presented to each panelist, two samples at a time, with a rest period in between presentations to minimize sensory fatigue.

Statistical analysis of the data from three replications was performed using Statistical Analysis System, version 6.07 (SAS Institute, Inc., Cary, NC). Analysis of variance (ANOVA) was performed to detect significant differences according to packaging material and irradiation source. Comparisons of mean sensory values was performed using Duncan's multiple range test.

RESULTS AND DISCUSSION

No difference was detected between patties irradiated by gamma rays and unirradiated controls in terms of flavor attributes (Table 1). However, a difference was detected between patties irradiated by electron beam and controls, with the latter being deemed to have a stronger cooked beef/brothy flavor than the irradiated samples ($p<0.05$) (Table 1). Niemand *et al.* (1981) evaluated beef irradiated at 2.0 kGy for sensory quality. They found that irradiated samples ranked higher (were deemed closer to "excellent") for appearance and odor, compared with unirradiated controls. They ranked controls as possessing more intense flavors than unirradiated samples. Similarly, in terms of mouthfeel and taste, we found no differences between irradiated and unirradiated samples (Table 2).

TABLE 1.
MEAN RANGE OF FLAVOR ATTRIBUTES FOR GROUND BEEF PATTIES AFTER GAMMA VERSUS E-BEAM IRRADIATION IN THREE PACKAGING MATERIALS

Flavor Attribute	Treatment[1]	Mean Range (Gamma)[2]	Mean Range (E-beam)[3]
Cooked Beef/ Brothy Flavor	Control	5.75-5.84	5.67-5.93
	Irradiated	5.33-5.46	5.50-5.83
Cooked Beef Fat Flavor	Control	2.96-3.00	2.79-2.96
	Irradiated	2.67-2.96	2.75-3.04
Grainy Flavor	Control	1.00-1.33	1.21-1.67
	Irradiated	1.21-1.25	1.20-1.29
Cardboard Flavor	Control	1.87-1.88	0.46-0.64
	Irradiated	1.83-2.04	0.50-0.83
Liver-like Flavor	Control	0.00-0.25	0.00-0.00
	Irradiated	0.00-0.17	0.00-0.00
Browned Flavor	Control	0.25-0.67	0.88-1.33
	Irradiated	0.54-0.75	0.92-1.06
Soured Flavor	Control	1.04-1.50	0.00-0.00
	Irradiated	0.67-1.21	0.00-0.00

[1]Controls = not irradiated; Irradiated = 2.0 kGy
[2]Mean Range = mean range of values for all three packaging materials after gamma irradiation.
[3]Mean Range = mean range of values for all three packaging materials after irradiation by electron beam.

TABLE 2.
MEAN RANGE OF MOUTHFEEL ATTRIBUTES FOR GROUND BEEF PATTIES AFTER GAMMA VERSUS E-BEAM IRRADIATION IN THREE PACKAGING MATERIALS

Mouthfeel Attributes	Treatment[1]	Mean Range (Gamma)[2]	Mean Range (E-beam)[3]
Metallic Feeling	Control	1.46-1.50	1.29-1.54
	Irradiated	1.46-1.55	1.33-1.58
Astringent Feeling	Control	1.42-1.58	1.50-1.75
	Irradiated	1.38-1.55	1.50-1.88
Greasy Mouthfeel	Control	2.00-2.17	2.21-2.50
	Irradiated	1.88-2.13	2.33-2.46

[1]Controls = not irradiated; Irradiated = 2.0 kGy
[2]Mean range of values for all three packaging materials after gamma irradiation.
[3]Mean range of values for all three packaging materials after irradiation by electron beam.

All samples in our study were irradiated while packaged in air and at 5C, conditions that result in radical formation. Even so, no detrimental effects in terms of flavor, mouthfeel, or taste were observed between irradiated patties and controls (Tables 1-3). Luchsinger *et al.* (1996) reported that irradiation of frozen ground beef patties in air had a negative effect on oxidative rancidity of the product, while packaging under vacuum allowed the patties to be displayed up to 21 days with minimal changes in quality. However, in a previous study, Murano *et al.* (1995) found that serving irradiated patties 7 days after irradiation resulted in no differences in sensory quality when compared with patties served 1 day after irradiation, suggesting a quenching effect or inactivation of off-flavor notes within the product during the period between irradiation and cooking. Since we cooked and served the patties for the present study 2 days after irradiation, it is possible that this quenching effect may have taken place here as well, rendering the product indistinguishable from controls in terms of sensory quality.

TABLE 3.
TASTE ATTRIBUTES OF GROUND BEEF PATTIES AFTER GAMMA VERSUS E-BEAM IRRADIATION IN THREE PACKAGING MATERIALS

Taste Attributes	Treatment[1]	Mean Range (Gamma)[2]	Mean Range (E-beam)[3]
Salty Taste	Control	2.58-2.71	2.29-2.42
	Irradiated	2.59-2.75	2.14-2.42
Sour Taste	Control	1.84-2.04	1.29-1.46
	Irradiated	1.80-1.92	1.38-1.58
Bitter Taste	Control	1.96-2.05	1.54-1.83
	Irradiated	1.84-2.05	1.83-1.92
Sweet Taste	Control	1.83-2.00	1.83-1.96
	Irradiated	1.84-2.04	1.88-1.96
Bitter Aftertaste	Control	1.67-2.00	1.30-1.33
	Irradiated	1.67-1.92	1.25-1.50
Sweet Aftertaste	Control	1.25-1.38	1.33-1.42
	Irradiated	1.13-1.42	1.25-1.38
Sour Aftertaste	Control	0.58-1.08	0.08-0.25
	Irradiated	0.75-1.13	0.17-0.46

[1]Controls = not irradiated; Irradiated = 2.0 kGy
[2]Mean range of values for all three packaging materials after gamma irradiation.
[3]Mean range of values for all three packaging materials after irradiation by electron beam.

We found no difference between irradiated patties regardless of packaging material used (Tables 1-3). Rojas de Gante and Pascat (1990) conducted a study on the migration of volatile compounds from polyethylene and polypropylene into water, alcohol, and acetic acid during irradiation. No difference in migration was seen even after irradiation at 25 kGy, with all values being below 1 mg/dm^2. Similarly, Senior (1992) observed no differences in migration from polyethylene and polypropylene into aqueous simulants, as well as olive oil, even after irradiation at 15 kGy. In the case of multicomponent laminates, however, off odors and taint transfer problems have been observed with polyester/polyethylene, but only if irradiated at 10 kGy or higher (Keay 1968). Given the fact that we found no differences in sensory attributes between the materials tested, or between the irradiated and unirradiated controls, production of volatile compounds under the conditions used in this study must have been present at such low levels that no detectable change in the product resulted.

It is important to understand that although ANOVA identified differences between gamma- and electron-beam-irradiated samples (Table 4), no differences existed when comparing samples treated by either form of irradiation and unirradiated controls. Degradation of polyethylene film has been shown to be dependent upon dose rate, with the formation of carboxylic acids increasing as the dose rate decreases (Azuma *et al.* 1984b). Irradiation by gamma rays delivers doses at a slow dose rate, compared with electron beam. Irradiation by cobalt-60 should result in more volatiles being produced. This phenomenon may have caused the development of flavor notes such as "cardboardy" and "soured aftertaste" in gamma-irradiated patties which we observed (Table 4). However, it must be noted that such changes did not detrimentally affect the quality of the product, since no difference was detected in these attributes between irradiated and unirradiated controls.

TABLE 4.
COMPARISON OF SIGNIFICANT SENSORY ATTRIBUTES BETWEEN GAMMA-IRRADIATED AND ELECTRON-BEAM-IRRADIATED GROUND BEEF PATTIES

Sensory Attribute	Gamma	Electron Beam	P value[1]
Cardboardy	1.91	0.59	0.0001
Soured Flavor	1.06	0.00	0.0001
Salty Taste	2.66	2.34	0.0182
Sour Taste	1.89	1.42	0.0001

[1] Denotes significant differences between mean scores for each attribute if $p < 0.05$ by analysis of variance.

Other studies have shown that the difference between gamma-irradiated and electron-irradiated foods cannot be organoleptically detected. Josephson *et al.* (1973) showed no significant difference in consumer acceptability of roast beef between unirradiated controls and samples irradiated at 47-71 kGy, regardless of whether the samples were irradiated by gamma rays or electron beam. Heiligman and Rice (1972) compared gamma-irradiated and electron-beam-irradiated codfish. They found no detectable differences in consumer acceptability of the samples by sensory evaluation. Highly trained panels, as used in our study, cannot address the issue of consumer acceptability. However, they are better able to detect differences in flavor notes compared with the average consumer.

In conclusion, irradiation of ground beef patties at medium doses can result in product that is sensorially identical to controls, even if irradiation is carried out in the presence of oxygen and under refrigeration versus frozen conditions. Packaging material did not affect the quality, nor did the source of irradiation used, since no difference was observed between irradiated and unirradiated patties.

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