Trained Sensory Panel and Consumer Evaluation of the Effects of Gamma Irradiation on Palatability of Vacuum-Packaged Frozen Ground Beef Patties[1,2,3]

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ABSTRACT: The objectives for this experiment were to determine the effects of gamma irradiation on 1) the palatability of vacuum-packaged frozen ground beef patties by trained sensory panel and 2) consumer evaluation of the taste of hamburgers made with those patties. Boxes (4.5 kg) of frozen (–28°C) ground beef patties (113.4 g/patty, 19% fat) from a commercial supplier were irradiated at a commercial gamma irradiation facility at one of three levels (0, 3.0, or 4.5 kGy). All boxes were stored at 28°C for 27 to 29 d after irradiation before evaluation by a trained descriptive attribute sensory panel and for 62 to 104 d after irradiation before consumer evaluation. The trained panel evaluated grilled patties for ground beef aroma intensity, off-aroma, and off-flavor on 4-point scales (4 = intense, none, and none; 1 = none, intense, and intense, respectively) and ground beef flavor intensity, tenderness, and juiciness on 8-point scales (8 = extremely intense, tender, or juicy; 1 = extremely bland, tough, or dry). Control patties had more intense ($P < .05$) ground beef aroma (3.1 vs 2.6), less off-aroma (3.3 vs 2.6), and more intense ground beef flavor (4.9 vs 4.3) than irradiated patties. However, there were no differences ($P > .05$) in any sensory trait between frozen ground beef patties treated with 3.0 or 4.5 kGy of gamma irradiation. There were no differences ($P > .05$) among treatments for tenderness (6.3, 6.6, and 6.7) or juiciness ratings (5.7, 5.9, and 5.9), respectively, for 0, 3.0, and 4.5 kGy. The consumers evaluated taste of a hamburger that included their choice of condiments on a 10-point scale (10 = excellent; 1 = terrible). Hamburgers made with patties treated with 4.5 kGy were rated lower ($P < .05$) in taste than hamburgers made with either control patties or those treated with 3.0 kGy (6.5, 6.6, and 6.2, respectively, for 0, 3.0, and 4.5 kGy); however, all doses were rated at some level of "fair." These results imply that hamburgers made from ground beef patties irradiated under the conditions of this experiment would encounter little, if any, consumer acceptance problems at the 3.0 kGy dose and only slightly greater problems at the 4.5 kGy dose.

Key Words: Beef, Consumers, Ground Beef, Irradiation, Quality, Sensory Evaluation

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Introduction

The efficacy of irradiation for eliminating pathogenic bacteria in food is well established (for review see Radomyski et al., 1994; Olson, 1998). The Food and Drug Administration (**FDA**) recently approved ionizing radiation for refrigerated and frozen uncooked meat to control foodborne pathogens and extend shelf-life (FDA, 1997). The Food Safety and Inspection Service (**FSIS**) has published proposed rules defining the use of irradiation for meat (FSIS, 1999), and final rules are expected later this year. The meat industries now are considering whether they should use this technology to improve the safety of their products and, if so, how they should apply it.

There are conflicting data regarding the effect of irradiation on the sensory properties of meat (Thayer, 1990). This likely results from the fact that the development of off-odors and off-flavors in irradiated meat can be affected by a number of factors, including temperature, environment within the package, packaging material, radiation dose, postirradiation storage time, and the condition of the meat before irradiation (Olson, 1998). In order to minimize the development of objectionable off-odors and flavors, it has been recommended to irradiate meat in the frozen state with reduced oxygen or oxygen-free atmosphere at the minimum re-

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[3]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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quired dose to meet safety goals (Olson, 1998). Based on current information, at –20°C, 3.0 and 4.5 kGy would be expected to provide a 5 D kill of *E. coli* 0157:H7 and *Salmonella* spp., respectively (Thayer and Boyd, 1993; Monk et al., 1994; Thayer, personal communication). However, the final rule from FSIS on use of irradiation on meat may contain slightly different D values than we have used. The objective of this experiment was to determine the effect of gamma irradiation at 3.0 or 4.5 kGy on trained sensory panel evaluation of vacuum-packaged frozen ground beef patties using commercially produced product and to determine consumer perception of the taste of hamburgers made from those patties.

Materials and Methods

Samples

Industry standard ground beef patties (113.4 g/patty, formulated to 19% fat) were produced from fed-beef and cow trimmings by a commercial processor. The patties were frozen by passing them through an IQF freezer (Frigoscandia, Sandusky, OH). After a dwell time of 99 s in the freezer, patty temperature was –18°C. Forty patties per box were packaged in a plastic-lined, corrugated cardboard box and stored at –20°C. On each of six consecutive Mondays, three boxes of patties were randomly selected from a single production lot. The boxes were shipped overnight on Dry Ice to Cryovac (Duncan, SC). The patties were vacuum-packaged using an Ultravac 2100D (Koch Supplies, Kansas City, MO) to 9 torr in B540 bags (Cryovac; oxygen transmission rate 3 to 6 cc [$m^2 \times 24$ h] at 4.4°C, 0% RH) approved for gamma irradiation by FDA. Four 10-patty stacks were vacuum-packaged, reboxed, and stored at –40°C overnight. The boxes were transported on Dry Ice to a commercial irradiation facility (SteriGenics, Charlotte, NC) for irradiation treatment.

Irradiation

Irradiation was accomplished with an ExCell irradiator (SteriGenics). The ExCell is a Category IV panoramic ^{60}Co gamma irradiator. Product moves through the source room (exposing all sides of the product) on an automated overhead conveyor system using aluminum carriers in a "shuffle and dwell" mode. The ExCell has a greater distance from product to source (91 to 182 cm) and a graded isotope arrangement that may contribute to lower minimum:maximum ratios than are achieved with standard commercial systems. Each week, one box of patties served as a nonirradiated control, and one box each was irradiated to obtain a minimum dose of 3.0 or 4.5 kGy. Based on available information at the time this experiment was designed, at –20°C, 3.0 and 4.5 kGy would be expected to provide a 5 D kill of *E. coli* 0157:H7 and *Salmonella* spp., respectively (Thayer and Boyd, 1993; Monk et al., 1994; Thayer, personal communication). However, the final rule on use of irradiation on meat from FSIS may contain slightly different D values than we have used. For irradiation, the patty boxes were placed into an inner box, which was placed into a foam-insulated outer box with 2.5 to 3.5 kg of Dry Ice pellets surrounding the inner box to maintain temperature. The dimensions of the outer box were 51 × 51 × 46 cm. The approximate bulk density of the boxes as irradiated was .38 g/cm^3. Patties remained in this packaging 8 to 10 h during preparation for and application of irradiation treatment. The irradiation dose rate was 1.8 kGy/h. Control boxes remained in a cooler, covered with Dry Ice. Immediately after irradiation, temperature of the patties ranged from –13 to –7°C. After the completion of both irradiation treatments, the boxes of patties were transported on Dry Ice back to Duncan, SC and held at –40°C for 1 to 4 d before they were shipped on Dry Ice overnight to the U.S. Meat Animal Research Center (**MARC**). Boxes of patties were stored at –28°C for 27 to 29 d (trained panel) or 62 to 104 d (consumer panel) after irradiation before evaluation. Each box contained a temperature data logger (model RD-Temp-XT, Omega Engineering, Stamford, CT) to record product temperature from the time of original boxing until arrival at MARC. All patties remained frozen throughout all phases of the experiment.

Table 1. Dosimetry to estimate minimum and maximum absorbed irradiation dose within a box

		Minimum		Maximum	
Dose, kGy	n	Mean	SD	Mean	SD
3.0	6	3.2	.08	3.9	.10
4.5	6	4.4	.41	5.5	.53

Before conducting the experiment, three replications of dosimetry mapping were conducted on boxes of patties after they were warmed to room temperature (the dosimeters cannot operate at < –1°C). The dosimetry mapping was conducted with 16 dosimeters on the exterior of the box and 20 dosimeters inside the box. This mapping process was used to establish the relationship between a reference location on the exterior of the box and the patty locations with the highest and lowest absorbed doses. Regression equations were used to estimate the minimum and maximum absorbed dose within a box from the absorbed dose of the reference location on the exterior of the box for all experimental samples (Table 1). The dosimetry system used radiochromic film (Far West Technology, Goleta, CA). The films are calibrated annually at a NIST traceable laboratory.

Cooking

Frozen patties were cooked from the frozen state with a belt grill conveyor cooking system (model TBG-60 MagiGrill, MagiKitch'n, Quakertown, PA). Belt grill settings (top heat = 204°C, bottom heat = 204°C, preheat = 204°C, height [gap between the platens] = 10.9 mm, cook time = 2.53 min) were designed to achieve a final internal temperature of 80°C. After the patties exited the belt grill, a 20-gauge needle thermocouple was inserted into the geometric center of the patty and post-cooking temperature rise was monitored with a hand-held thermometer (Cole-Parmer, Vernon Hills, IL). The maximum temperature, which occurred about 30 s after the patty exited the grill, was recorded as the final internal cooked temperature. The mean cooked temperature was 83.4°C with a SD of 2.9.

Trained Sensory Evaluation

A seven-member trained descriptive attribute panel was screened, selected, and trained according to AMSA (1995) to evaluate ground beef aroma intensity, off-aroma, and off-flavor on 4-point scales (4 = intense, none, and none; 1 = none, intense, and intense, respectively) and ground beef flavor intensity, tenderness, and juiciness on 8-point scales (8 = extremely intense, tender, or juicy; 1 = extremely bland, tough, or dry). "Off-aroma" and "off-flavor" were defined as atypical ground beef aromas or flavors. One box of each treatment was evaluated each week for six consecutive weeks. On each of 3 d/wk, one stack of patties was sampled per treatment. Because of the absorbed dose differences, patties 2, 5, and 9 within each stack were sampled and evaluated separately each day. Cooked patties were cut into 16 triangular wedges. Each panelist evaluated two warm wedges from each patty for all traits and averaged the two scores. A nonexperimental, warm-up sample was used to initiate each session.

Consumer Evaluation

A total of 64 male and 46 female consumer panelists volunteered to participate in response to a memorandum sent to all employees of MARC, the Great Plains Veterinary Education Center, and the University of Nebraska South Central Research Center, all located at the MARC headquarters. Panelists were not compensated. Panelists were informed that the study would include samples that had been irradiated. Patties used for consumer evaluation came from all six irradiation batches. In two sessions per day, 3 d/wk for 2 wk, consumers evaluated one sample per irradiation dose (each wedge-shaped sample was one-fourth of a hamburger) with condiments of their choice (salt, pepper, white bread buns, cheese, pickle, tomato, onion, lettuce, mustard, ketchup, and mayonnaise were available). Consumers prepared the three one-fourth size, wedge-shaped buns with condiments of their choice then entered the MARC sensory testing booths. They were provided the samples (one-fourth of a patty) one at a time (identified by random, three-digit codes), added them to their buns, and evaluated each one for taste on a 10-point scale (10 and 9 = excellent, 8 and 7 = great, 6 and 5 = fair, 4 and 3 = poor, 2 and 1 = terrible). Consumers were asked to rinse their palates with tap water between samples. Patties were cooked as described for trained panel evaluation.

Proximate Composition

Three locations of two patties each were selected from the fourth stack of 10 patties (location 1 = patties 1 and 2; location 2 = patties 5 and 6; location 3 = patties 9 and 10) from each box for proximate analysis. The two-patty samples from each location were split into two replicates (one-half of each patty per replicate) and wrapped in cheesecloth (grade 50: 28 × 24 threads per 6.45 cm^2). Moisture content was determined by oven drying at 100°C for 24 h, and total lipids were determined on dried samples after diethyl ether Soxhlet extraction (AOAC, 1984).

Statistical Analyses

Trained sensory panel data were analyzed with mixed model analysis of variance with PROC MIXED of SAS (1997) for a split, split-plot design (Steel and Torrie, 1980). Random effects were replication (week of patty production) and replication × treatment dose. Irradiation dose (0, 3.0, or 4.5 kGy) was the whole-plot treatment. The first split-plot treatment was stack of patties within the box (one, two, or three), and the second split-plot treatment was patty within a stack (two, five, or nine). The effect of treatment dose was tested with replication × treatment dose as the error term. The effect of stack was tested with replication × treatment dose × stack as the error term. The effect of patty was tested with the overall error term.

Consumer data were normalized within gender class to remove panelist differences in response to the rating scale (Tull and Hawkins, 1984). The data then were analyzed by analysis of variance with the GLM procedure of SAS (1997) for a completely randomized design with the main effects of treatment dose (0, 3.0, or 4.5 kGy), gender (men or women), and their interaction.

Proximate composition data were analyzed with mixed model analysis of variance with PROC MIXED of SAS (1997) for a split-plot design. Random effects were replication and replication × treatment dose. Irradiation dose (0, 3.0, or 4.5 kGy) was the whole-plot treatment. The split-plot treatment was patty location within the stack (patties one/two, five/six, or nine/ten). The effect of treatment dose was tested with replication × treatment dose as the error term. The effect of patty location was tested with the overall error term.

Mean separation for significant ($P < .05$) treatment effects was accomplished by the PDIFF option (a pair-wise *t*-test) of the least squares procedures (SAS, 1997). There were no significant interactions ($P > .05$).

Table 2. Effect of irradiation treatment, stack within box, and patty location within stack on sensory traits[a] of frozen ground beef patties

	Treatment (T), kGy			Stack (S)			Patty (P)				P > F						
Sensory trait	0	3.0	4.5	1	2	3	2	5	9	SEM	T	S	P	T × S	T × P	S × P	T × S × P
Aroma intensity[b]	3.1[g]	2.6[h]	2.5[h]	2.7	2.8	2.7	2.7	2.8	2.7	.05	.01	.27	.35	.95	.60	.28	.06
Off-aroma[c]	3.3[g]	2.6[h]	2.6[h]	2.8	2.8	2.8	2.9	2.8	2.8	.05	.001	.94	.85	.95	.19	.64	.30
Flavor intensity[d]	4.9[g]	4.2[h]	4.3[h]	4.4	4.6	4.4	4.4	4.5	4.4	.08	.006	.62	.54	.93	.08	.55	.73
Off-flavor[c]	3.0[g]	2.5[h]	2.6[h]	2.6	2.7	2.7	2.6	2.7	2.7	.05	.001	.38	.81	.90	.08	.86	.70
Tenderness[e]	6.3	6.6	6.7	6.5	6.6	6.7	6.6	6.6	6.5	.05	.06	.30	.86	.43	.82	.80	.12
Juiciness[f]	5.7	5.9	5.8	5.8	5.8	5.8	5.9	5.8	5.7	.06	.48	.99	.32	.09	.18	.55	.18

[a]Trained descriptive attribute panel.
[b]Ground beef aroma intensity: 1 = none, 4 = intense.
[c]1 = intense, 4 = none.
[d]Ground beef flavor intensity: 1 = bland, 4 = slightly bland, 8 = extremely intense.
[e]1 = extremely tough, 6 = moderately tender, 8 = extremely tender.
[f]1 = extremely dry, 5 = slightly juicy, 8 = extremely juicy.
[g,h]Means in a row within treatment lacking a common superscript differ ($P < .05$).

Results

Trained Sensory Panel

Control patties had more intense ($P < .05$) ground beef aroma, less ($P < .05$) off-aroma, more intense ($P < .05$) ground beef flavor, and tended ($P = .06$) to be less tender than irradiated patties (Table 2). There were no differences ($P > .05$) in any sensory trait between frozen ground beef patties treated with 3.0 or 4.5 kGy of gamma irradiation. There were no differences ($P > .05$) among treatments for juiciness. There was no effect ($P > .05$) on sensory traits of stack within a box or of patty within a stack.

Consumer Evaluation

Hamburgers made with patties treated with 4.5 kGy of irradiation were rated lower ($P < .05$) in taste than control hamburgers or those made with patties treated at 3.0 kGy (Table 3). Gender of panelist did not affect ($P > .05$) ratings for taste. A greater ($P < .05$) proportion of consumers rated hamburgers made with 4.5 kGy patties 3 units lower in taste than control patty hamburgers than they did hamburgers made with 3.0 kGy patties (Table 4). Furthermore, a greater ($P < .05$) proportion of women rated hamburgers made with patties treated with 3.0 or 4.5 kGy of irradiation at least 3 units (on a 10-point scale) lower in taste than control patty hamburgers. Treatment dose and gender did not affect ($P > .05$) the proportion of consumers that rated hamburgers made with irradiated patties more desirable in taste than hamburgers made with control patties. The frequency of use by consumers of each condiment made available was as follows: bun (98.8%), salt (48%), pepper (35%), ketchup (65%), mustard (42%), mayonnaise (21%), cheese (70%), pickles (46%), tomato (50%), lettuce (45%), or onion (30%).

Proximate Composition

There were no effects ($P > .05$) of irradiation dose or patty location on percentages of fat or moisture of patties (Table 5). Replications (week of patty production) differed ($P < .05$) in percentage fat (16.5^c, 19.7^a, 18.7^{ab}, 19.5^a, 19.5^a, and $17.8\%^b$; means with different superscripts differed). However, these differences did not interact with treatment effects on sensory traits.

Discussion

Radiolytic products can cause oxidation of myoglobin and fat, leading to discoloration and rancidity or off-odors and off-flavors (Murano, 1995). The development of off-odors and off-flavors in irradiated meat can be

Table 3. Effect of ground beef patty irradiation treatment and gender on consumer ratings of hamburgers for taste[a]

Main effect	n	Taste[b]
Treatment, kGy		
0	110	6.5[c]
3.0	110	6.6[c]
4.5	110	6.1[d]
P > F		.01
Gender		
Men	64	6.3
Women	46	6.5
P > F		.99
Pooled SEM		.10
Interaction		
Men		
0	64	6.3
3.0	64	6.6
4.5	64	6.3
Women		
0	46	6.6
3.0	46	6.6
4.5	46	6.0
P > F		.13
Pooled SEM		.15

[a]Consumers evaluated one-fourth of a hamburger for each treatment with condiments of their choice.
[b]10/9 = excellent, 8/7 = great, 6/5 = fair, 4/3 = poor, 2/1 = terrible.
[c,d]Means in a column within main effect lacking a common superscript differ ($P < .05$).

Table 4. Proportion of consumers rating[a] hamburgers made with irradiated patties three units higher or lower than those made with control patties

	Rated three units lower than control[b]		Rated three units higher than control[c]	
Treatment, kGy	Men, %	Women, %	Men, %	Women, %
3.0	4.7	8.7	10.9	8.7
4.5	7.8	26.1	4.7	13.0
SEM	3.80	4.49	3.60	4.25

[a]10/9 = excellent, 8/7 = great, 6/5 = fair, 4/3 = poor, 2/1 = terrible.
[b]Treatment $P = .01$, gender $P = .01$, interaction $P = .09$.
[c]Treatment $P = .81$, gender $P = .44$, interaction $P = .14$.

affected by a number of factors, including radiation dose, dose rate, temperature and within-package environment during irradiation, postirradiation storage time, temperature and packaging, and the condition of the meat before irradiation (Thayer, 1990; Olson, 1998). In order to minimize the development of objectionable off-odors and -flavors, it has been recommended to irradiate meat in the frozen state with reduced oxygen or oxygen-free atmosphere at the minimum required dose to meet safety goals (Olson, 1998).

A number of studies of the effect of irradiation on meat quality have been conducted on various meat products, including whole and minced chicken and chicken pieces, pork loins and chops, beef steaks and ground turkey, pork, and beef. Results from most of these studies indicate that at low levels (≤ 1 kGy) no problems with odor or taste occurred. However, as dose increased to 2 kGy or higher, the frequency of off-odors and off-flavors increased (Thayer, 1993).

In the limited number of studies specifically designed to test the effect of irradiation on sensory quality of ground beef, the results are mixed. Weese et al. (1997) studied ground beef patties irradiated at 0, 1, 3, 5, and 7 kGy then stored at −18°C for 6 wk. Trained sensory panel evaluation was conducted weekly over the 6 wk. No significant differences were detected between irradiated and nonirradiated patties until after 5 wk of frozen storage, and then only at the 7 kGy dose. After 6 wk of storage, patties irradiated at 7 kGy had a strong aftertaste that controls did not have. Luchsinger et al. (1997) studied frozen ground beef patties irradiated at 0, 2, or 3.5 kGy then stored at −19°C for 1 d. Patties were formulated at either 10 or 22% fat with either aerobic or vacuum packaging. No effect of irradiation was detected on odor or various flavor notes by a trained flavor profile panel, perhaps because storage was limited to 1 d. Lefebvre et al. (1994) studied ground beef irradiated at 0, 1, 2.5, and 5 kGy and stored 16 d at 4°C. A 10-member "nonexpert" panel detected an objectionable odor in the raw, irradiated product (all doses), although this effect was less detectable after cooking and occurred only for 2.5 and 5 kGy doses. The cooked flavor of samples irradiated at 2.5 and 5 kGy was disliked compared to control samples. They recommended a dosage of 1 kGy to avoid consumer acceptance problems. Fu et al. (1995) studied ground beef irradiated at 0, .6, and 1.5 kGy then stored for 7 d at 7°C. No effect on odor of raw product immediately after irradiation was detected by an untrained sensory panel. Murano et al. (1997) studied ground beef, pork, and turkey patties irradiated at 0, 2, and 5 kGy then stored at −25°C for 3 d with a trained sensory panel. In triangle tests, irradiated ground turkey could not be distinguished from the control whether stored in air or under vacuum. Irradiated ground pork and beef could be distinguished from the control if stored in air but not if stored under vacuum. No flavor differences were detected between control and irradiated ground beef samples. Montgomery et al. (1997) reported that ground beef patties irradiated at 2.1 kGy had greater off-odors and off-flavors than control patties when evaluated 4 d after irradiation (0°C storage) with a trained sensory panel. They also reported that there was no difference between high- and low-oxygen-permeability vacuum bags. Emmerson et al. (1998) reported that irradiated ground beef had higher thiobarbituric acid values than controls and, thus, greater oxidation. However, they concluded that antioxidants (rosemary, vitamin E, and erythorbate) reduced the effect of irradiation on thiobarbituric acid values and may retard irradiation-induced oxidation. In a review, Olson (1998) stated that most irradiation-induced off-odors seem to be reduced or eliminated upon cooking and, thus, may not be a problem. However, our data contradict that assertion.

Effects of irradiation on odor and flavor have been studied with sensory panels of varying degrees of training; however, few consumer studies have been conducted. Luchsinger et al. (1996) reported that the only difference detected by a trained panel among flavor notes between control and irradiated (2.5 to 3.85 kGy) frozen pork chops was higher metallic notes in irradi-

Table 5. Effect of irradiation treatment and patty location within stack on proximate composition of frozen ground beef patties

	Treatment (T), kGy			Patty (P)[a]				P > F		
Trait	0	3.0	4.5	1/2	5/6	9/10	SEM	T	P	T × P
Fat, %	18.7	18.8	18.3	18.5	18.7	18.7	.29	.51	.94	.83
Moisture, %	60.8	60.6	61.2	60.8	60.9	60.9	.15	.44	.79	.37

[a]1/2, 5/6, 9/10 = patties 1 and 2, 5 and 6, 9 and 10, respectively, from stack four within a box.

ated chops compared to control chops. Furthermore, these authors reported that a 108-member consumer panel found no differences between control pork chops and those irradiated frozen at 2.5 kGy for overall acceptance, meatiness, freshness, juiciness, or tenderness. Our data indicate that, despite changes in aroma and flavor due to irradiation at 3.0 or 4.5 kGy large enough to be detected by a trained descriptive attribute panel, consumers rated all hamburgers at some level of "fair" in taste. Individual sensitivities to various taste and smell stimuli are quite variable, and women are generally more sensitive than men (Amerine et al., 1965). Thus, as expected, consumer ratings were quite variable. A majority were able to detect slight or no differences in taste of hamburgers made with patties from different irradiation doses, and a small proportion of consumers rated hamburgers made with irradiated patties better or worse than those made with control patties.

Implications

Hamburgers made from ground beef patties irradiated under the conditions of this experiment would likely encounter little, if any, consumer acceptance problems at the 3.0 kGy dose and only slightly greater problems at the 4.5 kGy dose.

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