Irradiation in Contrast to Thermal Processing of Pepperoni for Control of Pathogens: Effects on Quality Indicators

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ABSTRACT: Differences in product quality resulting from use of irradiation or thermal processing for control of pathogens in pepperoni were investigated. Treatments consisted of irradiation doses of 1.25 kGy or 3.0 kGy, a heat treatment, and a control without heat or irradiation. Results showed that irradiating meat prior to production of dry, fermented sausage such as pepperoni, can yield products with quality indicators closely resembling those of traditional dry sausage, while still providing the required 5-log reduction of *E. coli* O157:H7.

Key words: irradiation, thermal processing, dry sausage, color, texture

Introduction

WHEN THE USDA ESTABLISHED THE REQUIREMENT OF A 5-log reduction in *Escherichia coli* O157:H7 for dry sausage (Reed 1995), the traditional means of producing dry sausage such as pepperoni, along with the traditional characteristics of these products, were significantly changed. Traditional production techniques relied on a low pH and low water activity achieved by fermentation and drying to control spoilage and pathogenic microorganisms. However, this traditional process only served to provide a 2-log reduction in *E. coli* O157:H7 (Faith and others 1997; Riordan and others 1998), requiring the addition of a thermal processing step to ensure product safety. This additional thermal processing step may alter the traditional texture of dry sausage, along with other quality aspects of the product such as color.

Various studies have shown that heat processing at temperatures sufficient for microbial control in meat leads to increased shear and compression values due to the denaturation of proteins (Ledward and Lawrie 1975; Fernandez-Martin and others 1997). Although textural changes have been observed for meat irradiated at high doses, lower doses such as those that would be used within the meat industry cause minimal differences in texture (Kirn and others 1956; Luchsinger and others 1996; Abu-Tarboush and others 1997). A hypothesis for the current study was that the texture of pepperoni manufactured with irradiated raw materials will resemble that of traditional pepperoni produced before governmental regulations requiring a 5-log reduction in *E. coli* O157:H7. The implementation of such an irradiation process will eliminate the need for thermal processing, currently used to accomplish USDA mandates.

A large amount of pepperoni is used as a pizza topping, which requires increased attention to processing parameters that yield high-quality pepperoni slices for pizza manufacturing. One concern for pepperoni used for pizza toppings is its potential for "cupping" (a condition when slices, after heating on a pizza, curl into a bowl shape, holding pools of liquid fat, resulting in an undesirable appearance). A second hypothesis for this study was that irradiation will aid in the prevention of cupping. It is believed that cupping is more likely when pepperoni is heat-treated, which causes a greater degree of denatured/dehydrated proteins on the surface of the sausage. During subsequent heating of slices, the center will rehydrate and expand faster than that of the outer surface, causing cupping.

A third hypothesis for the study was that irradiation will permit faster fermentation. Previous work conducted by Dickson and Maxcy (1985) showed that when meat was irradiated prior to the addition of starter culture, the rate of pH decline was greater than those treatments not irradiated. Irradiation of meat prior to the addition of the starter culture may serve to eliminate competitive bacteria, thus allowing the starter culture to reach its growth potential more rapidly. This would potentially save processors time and money by decreasing the total fermentation time.

Preblending meat with salt and nitrite prior to formulation is a practice utilized for some sausage products to increase color development and microbial control. Fu and others (1995) reported a greater effect of irradiation on total plate counts and pathogens when used with salt and nitrite than when used without salt and nitrite. Consequently, preblending prior to irradiation might be a feasible treatment combination for sausage ingredients.

One concern for irradiation treatments of meat products is the production of free radicals and potential for oxidative reactions resulting in off-odors and off-flavors (Murano 1995). Irradiation has been reported to result in increased thiobarbituric acid (TBA) values and carbonyl content in ground meat (Kanatt and others 1998; Jo and Ahn 2000). It is obvious that while irradiation and heating both serve as excellent microbial barriers, the resultant products may vary significantly between processes. The following research was based on the hypotheses that irradiation of pork trimmings prior to the production of pepperoni will result in a more desirable texture, less cupping and a faster rate of pH decline than if the product is heat-treated for control of pathogens. Many of these quality aspects are significant concerns for the production of many other dry and semi-dry meat products in addition to pepperoni. Thus, the objective of this study was to determine if dry sausage, in this case pepperoni, could be produced with minimal quality change while still meeting the USDA requirement for a 5-log reduction in *E. coli* O157:H7.

Materials and Methods

Pepperoni production and irradiation procedures

Eight treatments of pepperoni were each evaluated five times, resulting in a total of 40 observations. Three separate batches were manufactured; the first production batch consisted of eight treatments, whereas the second and third batches were each divided into two 8-treatment blocks with treatments randomly placed on the smokehouse truck to minimize variations in the thermal processing unit. The experiment used a 2 × 4 factorial treatment design, with the treatments as follows: 1.25-kGy irradiation dose; 3.0-kGy irradiation dose; nonirradiated with a heat treatment; control-nonirradiated without a heat treatment; preblend with 1.25-kGy irradiation dose; preblend with 3.0-kGy irradiation dose; preblend (nonirradiated) with a heat treatment; preblend (nonirradiated) without a heat treatment.

Fresh 80% lean pork picnic trim was purchased from local suppliers. The meat was ground through a 1.27-cm plate (Biro model 7552; The Biro Mfg Co., Marblehead, Ohio, U.S.A.), after which the meat was divided into two lots for preblended and non-preblended treatments. The batches to be preblended were then mixed (Leland model L-100 DA; Leland Detroit Mfg Co., Detroit, Mich., U.S.A.) with all the salt (2.1%) and one-half the cure for approximately 5 min, after which all batches were stored in a 4 °C cooler. Batches (both preblended and not preblended) requiring irradiation were then boxed in fiberboard boxes with liners appropriate for irradiation processing and received a double-sided irradiation treatment of 1.25 or 3.0 kGy using the linear accelerator facility (Linear Accelerator-circle III R; Saint-Aubin, France) at Iowa State University. Actual measured minimum doses were 1.24, 1.26 and 1.30 kGy in the three replications. Maximum estimated doses were 1.45, 1.76 and 1.88 kGy, respectively. The higher dose treatments were measured at a minimum 2.85, 2.98 and 3.17 kGy in the three replications with estimated maximum doses of 3.31, 4.17 and 4.44 kGy, respectively. Irradiation was conducted at room temperature and required 8 to 10 min per treatment. Product temperature did not increase by more than 1 °C during the irradiation treatment. Doses were determined in accordance with the USDA-FSIS, which reported that the D-value for *Escherichia coli* O157:H7 was 0.25 kGy for refrigerated product (Federal Register, 1999). This requires a minimum dose of 1.25 kGy to provide a 5-log reduction in *E. coli* O157:H7, as mandated by the USDA (Reed, 1995). The doses were measured by placing alanine pellet dosimeters (Bruker Instruments, Inc., Billerica, Mass., U.S.A.) on the top and bottom of boxes for each treatment (ASTM 1996). The dosimeters were read by electroparamagnetic resonance (EMS 104; Bruker Analytiscne Messtechnik, Karlsruhe, Germany). All of the treatments were then held in a 4 °C cooler overnight, after which the 8.6-kg batches were mixed with spices, salt, dextrose, and 78 or 156 parts per million (ppm) sodium nitrite in a grinder-mixer (Hollymatic model 175; Hollymatic Corp., Park Forest, Ill. U.S.A.). It is important to note that half of the cure for the preblend treatments was added initially, with the remaining half being added with the spices at the final mixing. Paprika oleoresin flavoring (Pepperoni Oleoresin Flavor; Chr. Hansen Inc., Milwaukee, Wis., U.S.A.) was added which contained antioxidants BHA (1.12%), BHT (1.12%), and citric acid (1.12%). The starter culture (LL2; Diversitech Inc., Gainesville, Fl., U.S.A.) was added last in accordance with manufacturers directions (2.95 g with 41 g water). The batches were then ground through a 0.318-cm plate and vacuum-stuffed (Risco model RS 4003-165, Stoughton, Mass., U.S.A.) into 1S × 30 fibrous cellulose casings. Samples were taken during stuffing for measurement of initial pH and proximate analysis. Initial weight of stuffed products was measured after stuffing.

Pepperoni was placed in a computer-controlled one-truck smokehouse (Alkar, Lodi, Wis., U.S.A.), which was programmed for fermentation at 27 °C dry bulb, 26 °C wet bulb, (96% RH) until the required pH was reached. The fermentation was considered complete when the pH of the pepperoni declined below 5.0 as periodically measured by a hand-held pH-Star probe (pH-Star S; SFK Technology Inc., Cedar Rapids, Ia., U.S.A.). The pepperoni treatments were removed, and fermentation time recorded, as they reached the target pH. Sticks were weighed, and samples were taken for moisture:protein content and texture analysis. The sticks were then transferred to a computer-controlled one-truck environmental chamber (Alkar, Lodi, Wis., U.S.A.) operating at 10 °C and 75% RH until the M:P ratio reached 1.6:1. Periodic samples were taken during drying for moisture:protein ratios and texture analysis (Instron Series 4500; Instron Corp. Canton, Mass., U.S.A.).

Pepperoni sticks to be subjected to a heat treatment were placed in a computer-controlled one-truck smokehouse (Alkar, Lodi, Wis.) after drying, to be heated (70 °C, 85% RH) to an internal temperature of 60 °C. It should be noted that irradiation treatments in this study did not involve the finished processed products but rather the raw meat materials which were subsequently used to manufacture the pepperoni.

Proximate analysis/yield measurements

Proximate analysis consisted of moisture (oven drying), fat (ether extraction), and protein (combustion method) and was performed according to AOAC (1993) procedures. Samples were measured for proximate composition throughout the drying treatment to confirm moisture:protein ratios. All measurements were performed in duplicate.

Yields were recorded by labeling sticks of pepperoni for each treatment and taking an initial weight immediately after stuffing. Weights were then taken periodically throughout drying and at the completion of drying and/or heat treatment.

Texture/color analysis

Texture measurements were recorded using both compression of sticks and puncture of slices periodically during drying and at the completion of drying for each treatment. The stick compression consisted of three repeated measurements taken with an Instron Universal Testing Machine (Instron Series 4500; Instron Corp., Canton, Mass., U.S.A.). The measurement was done by compressing a stick of pepperoni by 30% of the diameter of the sausage with a 3.5-cm dia compression anvil (Model 2830-011) attachment. The 30% compression was chosen from preliminary work on commercial pepperoni which suggested that 30% was effective for detecting product differences. The Instron was equipped with a 1-KN load cell with conditions for a one-cycle compression at 200 mm per min crosshead speed and by using a preload of 0.5 kg. The hardness of pepperoni slices was measured by the force needed to puncture a 0.2-cm slice with a 1.27-cm dia probe on the Instron equipped with a 1-KN load cell. Conditions used for a one-cycle break of the slices were 400 mm per min crosshead speed and a preload of 0.05 kg. Five measurements per treatment were taken for slice hardness.

Color measurements of 0.2-cm slices were conducted by using a HunterLab LabScan Spectro Colorimeter (Hunter Associates Lab, Inc., Reston, Virg., U.S.A.) with an illuminant A and 10° observer light source (representing an incandescent lamp) and a 2.54-cm port insert. Color was first measured when the product processing was completed (drying or heating) and again after 4 wks of storage at 4 °C.

Lipid oxidation analysis

Samples were measured for oxidative rancidity by using the modified 2-thiobarbituric acid (TBA) procedure of Tarladgis and others (1960). The initial TBA measurements were done for all treatments immediately following irradiation of appropriate batches. Measurements were also conducted after the completion of drying and/or heating, and every 3 wk thereafter during 5-mo of storage at 4 °C. Additional samples of each treatment were also stored at room temperature and in direct sunlight to be evaluated at the end of the 5 mo period.

Cupping measurements

Because cupping of pepperoni slices results from a rigid outer edge on slices for which the center of the slice expands during heating, cupping of the pepperoni slices was measured for each treatment after cooking, using 0.2-cm slices. Slices were arranged on frozen double-cheese pizzas (Jacks® Great Combinations® 12" Double Cheese pizza; Jacks Frozen Pizza, Inc., Dist. Little Chute, Wis., U.S.A.) to evaluate cupping after cooking. The pizza was divided into eight equal portions, with two pepperoni slices per treatment on each pie-shaped portion of pizza, one pepperoni slice near the crust and the other near the center. The pizzas, with added pepperoni slices, were cooked according to the manufacturer's recommendations (preheat oven to 425 °F, cook 10-12 min or until the cheese is golden brown) in a conventional oven (GE model CN60; General Electric, Chicago Heights, Ill., U.S.A.) with a total cooking time of 11 minutes. Objective measurements for cupping were taken by removing the slices from the cooked pizzas, removing excess cheese, placing the slices upside down on a countertop, and measuring the height from the countertop to the apex of the slice.

Table 1—Percentage moisture, protein, fat and yield for finished pepperoni from experimental treatments

Treatment	Final moisture	Final protein	Final fat	Yield
1.25 kGy[a]	40.5	29.3	26.2	61.4
3.0 kGy[b]	39.9	27.6	26.8	61.9
With heat	40.1	27.6	27.0	60.8
Without heat	40.9	27.0	26.1	61.8
SEM	0.40	0.90	0.56	0.57

[a]Irradiated at 1.25 kGy
[b]Irradiated at 3.0 kGy

Table 2—The effect of irradiation dose, heat treatment and preblending on pH values during fermentation

Treatment	0 h	8 h	20½ h	29 h	30 h	30½ h	31½ h
1.25 kGy[a]	6.06	6.00[c]	5.52[c]	5.09[c]	5.02[c]	4.99[c]	4.98[c]
3.0 kGy[b]	6.01	5.98[c]	5.57[d]	5.11[c]	5.08[d]	5.06[d]	5.01[c]
With heat	6.10	5.99[c]	5.48[c]	5.02[d]	4.98[c]	4.97[c]	4.97[c]
Without heat	6.11	5.99[c]	5.44[c]	5.00[d]	4.96[c]	4.96[c]	4.92[c]
Preblend	6.07	6.00[c]	5.51[c]	5.05[d]	4.99[c]	5.01[c]	4.99[c]
Non-preblend	6.06	5.97[c]	5.49[c]	5.06[d]	5.02[c]	5.01[c]	4.98[c]

[a] Irradiated at 1.25 kGy.
[b] Irradiated at 3.0 kGy.
[c,d] Means within a column with different letters are significantly different at $P < 0.05$.

Sensory analysis

Sensory analysis was conducted by using a panel consisting of 9-12 experienced members, all being students, staff, or faculty in the Meat Science program at Iowa State University. All panelists were volunteers and were informed of the experimental protocols according to Iowa State University requirements for utilization of human subjects. Training of the panelists consisted of preliminary evaluation of pepperoni slices from each treatment combined with discussion of the properties to be measured and the scales to be used. Each panelist was then given slices in random order to evaluate texture, flavor, and color. Color evaluations were conducted separately from that of texture and flavor, which were evaluated with red lighting to prevent any color differences influencing panelists. Line scales were used for three textural attributes (initial chewiness, chewiness, and hardness) with values reported on a graduated scale of 0 to 150. The scales ranged from none to intense; flavor attributes included pepperoni flavor and off-flavor ranging from none to intense; and color evaluation ranged from light to dark. All sensory evaluations were conducted within two weeks of completion of processing and were repeated three times. Treatments that were not irradiated or cooked to eliminate risk of pathogens were not included in the sensory evaluations.

Statistical analysis

Statistical analysis was performed using the general linear model (GLM) procedure PROC GLM (SAS Institute, Inc., 1990). The pH data were analyzed by plotting the values measured during fermentation and using the linear portion of the graph to best represent the rate of pH decline to a final pH below 5.0. Statistical analyses of all other measurements were done with a 2 × 4 factorial design with fixed effects of preblend and thermal processes.

Results and Discussion

Proximate analysis and yield measurements

There were no differences ($P < 0.05$) between the irradiated and heated samples for final moisture, protein, or fat content in the finished product (Table 1). Preblending also had no effect on moisture in the final measurements. The protein contents were different ($P < 0.05$) for the initial product samples taken during stuffing (data not shown); however, this difference was not evident for the final protein measurement, with no difference observed for the finished product between treatments. Preblending had no effect on protein content for either the initial or final measurements. It is important to note that the moisture, protein, and fat contents were not significantly different in the finished product, from which all of the objective and subjective measurements are taken. Consequently, observed differences in product properties were not due to differences in composition. Further, no differences ($P < 0.05$) were observed between preblended and non-preblended or between irradiated and heated treatments for final yields (Table 1).

pH measurements during fermentation

The rate of pH decline in pepperoni during fermentation was measured to compare rate of pH change. The data in Table 2 show the pH decline for treatments over 31 1/2 h of fermentation. Preblending had no effect ($P < 0.05$) on rate of pH decline, while the highest irradiation dose of 3.0 kGy extended ($P < 0.05$) the time to reach the final pH of < 5.0 as compared with the remaining treatments. This contradicts the initial hypothesis that irradiation will eliminate competitive bacteria allowing the starter culture to rapidly multiply, forming lactic acid and lowering the pH. However, because very high quality (fresh) raw materials were used for this study, it is likely that the number of competitive bacteria was relatively low in all treatments. If such was the case, irradiation to reduce competitive bacteria would not result in much change compared to that in raw materials with high initial microbial numbers.

Texture measurements

Texture of pepperoni sticks was measured immediately after stuffing, periodically (days 1, 4, 6, 10, 12, 13, and 16) during drying, and for finished products using an Instron compression test. A hardness value was achieved by measuring the force needed to compress the stick 30% of its diameter, and calculating the average of three measurements per treatment. Results showed that preblending did not affect either stick or slice hardness (data not shown). This is similar to the report from Hand and others (1987), who found that preblending had no effect on the textural properties of frankfurters. An increase ($P < 0.05$) in hardness was observed for heated pepperoni relative to irradiated treatments and to controls without heat (Table 3). Results ob-

Table 3—The effect of irradiation dose and heat treatment on stick compression (30%) and slice puncture hardness of pepperoni

Treatment[c]	Stick hardness (Kg)	Slice hardness (Kg)
1.25 kGy[a]	17.0[c]	0.99 [c]
3.0 kGy[b]	16.7[c]	0.91 [c]
With heat	40.5[d]	1.29 [d]
Without heat	16.0 [c]	0.92 [c]
SEM	0.98	0.07

[a] Irradiated at 1.25 kGy
[b] Irradiated at 3.0 kGy.
[c,d] Means within a column with different letters are significantly different at P< 0.05.

Table 4—The effects of irradiation dose and heat treatment on lightness (L*), redness (a*), and yellowness (b*) color values for pepperoni slices

Treatment	Initial L*	Final L*	Initial a*	Final a*	Initial b*	Final b*
1.25 kGy[a]	44.5 [c]	45.5 [c]	30.9	33.03 [c]	30.8	31.6 [c]
3.0 kGy[b]	44.8 [c]	45.1 [c]	29.9	33.00 [c]	30.8	32.6 [c]
With heat	49.1 [d]	49.5 [d]	30.9	31.63 [d]	30.0	29.6 [d]
Without heat	46.6 [e]	46.0 [c]	30.7	33.93 [e]	29.5	32.4 [c]
SEM	0.56	0.54	0.37	0.25	0.71	0.57

[a] Irradiated at 1.25 kGy.
[b] Irradiated at 3.0 kGy
[c,d,e] Means within a column with different letters are significantly different at P< 0.05.

served for the hardness of pepperoni slices, as measured by the force required to puncture slices on the Instron, were also similar to stick compression values. The lower hardness values observed for irradiated samples as compared with heated samples support the initial hypothesis for this study. Ledward and Lawrie (1975) discussed the dependence of texture on heating temperature. They reported that a temperature of 50 °C caused an approximate fourfold increase in meat toughening due to coagulation of the actomyosin complex, while subsequent heating to a temperature of 65 °C continued to increase toughness due to collagen shrinkage. Bailey and Rhodes (1964) researched the effects of irradiation doses of 2 and 4 Mrad (corresponding with 20- and 40-kGy doses) on the texture of beef and pork. Taste panelists had reported a softening of meat after an irradiation treatment, although meat considered initially tender was not over-tenderized by irradiation. Although Bailey and Rhodes (1964) found that high doses increased softening, there was no detectable softening in pepperoni due to irradiation in the current study. The results reveal that the texture of irradiated pepperoni (1.25 kGy and 3.0 kGy) was not as hard as that of heated pepperoni, with no difference ($P < 0.05$) between irradiation treatments. The irradiated product in this study was similar to pepperoni dried without heat, which is considered to be a traditional pepperoni process. Thus, irradiation allows production of pepperoni similar to that produced prior to the regulation requiring a 5-log reduction in *E. coli* O157:H7, which led to the implementation of the heating treatment. Figure 1 shows the change in texture of pepperoni sticks throughout the drying process. Drying was complete after 16 days with no differences in hardness. The heating treatment was then applied for the appropriate treatment group; the hardness was measured after chilling and recorded as 18 d samples.

Color measurements

The color of pepperoni slices was measured initially after drying and subsequent heat processing for the final product, with a second color measurement performed 4 wk after the first color measurement. The Hunter Lab objectively measured the color giving L* (0-100, with 100 being perfect white), a* (positive numbers increasing with intensity of redness,), and b* (positive numbers increasing with intensity of yellowness) values. Preblending (data not shown) had no significant effect on color characteristics of pepperoni slices. This conflicts with results of Hand and others (1987), who reported that preblended franks had significantly lower L* values (representing a darker colored product) compared with non-preblended franks. The addition of paprika in pepperoni production is likely to mask small color differences. Heat treatments yielded the lightest pepperoni slices ($P < 0.05$) compared with the other treatments used in this study (control without heat and 1.25-kGy and 3.0-kGy irradiation treatments) (Table 4). The unheated control treatment, while darker than heat-treated pepperoni, was significantly lighter than either irradiated treatment for the initial lightness measurement. Thus, both irradiated treatments produced the darkest-colored pepperoni slices observed during the first color measurements (immediately after drying). The final lightness measurement (4 wk later) also revealed a lighter coloration ($P < 0.05$) for pepperoni slices from heated treatments relative to irradiated samples or controls without heat. The redness values (a*) of pepperoni slices were not different initially, but at 4 wk, the treatment with heat was less red ($P < 0.05$) relative to that of either irradiated treatments or the unheated control (Table 4). The unheated control, however, was redder than the other treatments. These results indicate that the heating process decreased the redness of the pepperoni. The degree of yellowness (b*) was not different initially; however, the final color measurement showed that heated pepperoni was less yellow ($P < 0.05$) than the other treatments (Table 4). These color results show that by using irradiation rather than heating to provide a reduction in pathogens, lightness, redness, and yellowness color attributes will also be modified with a darker, redder color resulting.

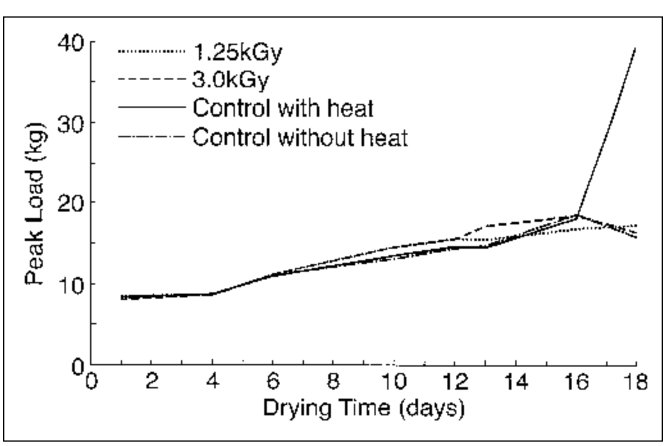

Figure 1—Hardness of pepperoni sticks from control, irradiated, or heated treatments during and after drying

Sensory analysis

The sensory panel evaluated pepperoni slices for initial chewiness, chewiness, sustained hardness, pepperoni flavor, off-flavor, and color by using a line scale in graduations of 0 to 150. The treatment which served as a control, without heat or irradiation, was not included in the sensory analyses because of the possible presence of pathogens. Slices from the unheated control were evaluated by the panel for visual color attributes, however. The treatment with heat had a higher ($P < 0.05$) initial chewiness score, higher sustained chewiness score, and higher hardness score than irradiated treatments (Table 5). These results are similar to the objective measurement of hardness by stick compression and slice puncture as previously described. The hardness values for the irradiated samples in the sensory panel revealed a large difference (56 to 59 as compared with

Table 5—The effects of irradiation dose and heat treatment on pepperoni texture determined by sensory panel evaluation

Treatment	Initial chewiness	Sustained chewiness	Hardness
1.25 kGy[a]	69.6 [c]	69.6 [c]	59 [c]
3.0 kGy[b]	70.2 [c]	68.8 [c]	56 [c]
With heat	93.3 [d]	99.8 [d]	100 [d]
Without heat	N/A[e]	N/A	N/A
SEM	2.25	2.10	3.14

[a]Irradiated at 1.25 kGy
[b]Irradiated at 3.0 kGy
[c,d]Means within a column with different letters are significantly different at P< 0.05
[e]not available

Table 6—The effect of irradiation dose and heat treatment on sensory panel flavor and color of pepperoni

Treatment	Flavor Intensity	Off-Flavor	Color
1.25 kGy[a]	79.7	35.3	97.5 [c]
3.0 kGy[b]	82.7	34.3	97.0 [c]
With heat	85.1	33.6	61.3 [d]
Without heat	N/A[c]	N/A	87.9 [c]
SEM	2.33	2.86	2.91

[a]Irradiated at 1.25 kGy
[b]Irradiated at 3.0 kGy
[c,d]Means within a column with different letters are significantly different at P< 0.05
[e]not available.

Table 7—The effect of irradiation dose and heat treatment on thiobarbituric acid (TBA) numbers (mg malonaldehyde/kg sample) for pepperoni

Treatment	Final TBA number of refrigerated products	TBA number of products stored at room temperature
1.25 kGy[a]	0.350[c]	0.187[c,d]
3.0 kGy[b]	0.446[d]	0.221[d]
With heat	0.157[e]	0.163[c,d]
Without heat	0.164[e]	0.141[c]
SEM	0.023	0.024

[a]Irradiated at 1.25 kGy
[b]Irradiated at 3.0 kGy
[c,d,e] Means within a column with different letters are significantly different at P< 0.05.

100), much like the large difference observed with the Instron machine (16 to 17 as compared with 40). Although the control without heat was not evaluated by the taste panelists, differences between irradiated and unheated treatments were minimal, based on the objective texture measurements with the Instron. There was no difference ($P < 0.05$) for pepperoni flavor or off-flavor between the treatments (Table 6). The color attributes of the pepperoni slices, measured on a line scale from light (0) to dark (150), showed a lighter color ($P < 0.05$) resulting from the heat treatment relative to that of irradiated or unheated treatments (Table 6). This was similar to the measurements from the Hunter Lab for objective L* values. This also showed that the panelists perceived that irradiation treatments more closely resembled the color of unheated controls. Preblending had no significant effect on any sensory measurements (data not shown).

Lipid oxidation measurements

TBA measurements on pepperoni sticks, vacuum packaged and stored at refrigerated temperatures, were taken initially after production and at 3-wk intervals thereafter until the end of the 5-mo storage period. The TBA measurements at the end of the 5-mo period consisted of samples from vacuum-packaged pepperoni stored at refrigerated temperatures in addition to samples that were subjected to direct sunlight at room temperature (representing abused pepperoni). For the refrigerated samples, the 3.0-kGy treatment resulted in higher TBA values ($P < 0.05$) than the other treatments (Table 7). The 1.25-kGy treated samples had lower TBA values than the 3.0-kGy treatments, but were higher than treatments with or without heat, which did not differ (Table 7). Interestingly, it was noted that the TBA values of irradiated samples tended to decrease slightly over time, while the heated and control treatments changed very little. This decline in TBA values over time may imply that TBA measurement for irradiated samples is not an accurate indication of lipid oxidation, perhaps due to other compounds formed during the irradiation process that result in an increase in TBA-positive absorbance. The samples stored at room temperature showed similar differences between treatments, with the 3.0-kGy dose treatments exhibiting higher TBA values ($P < 0.05$) than treatments without heat, which had the lowest TBA values. These data support conclusions by Reineccius (1979) in that further processing steps (irradiation and heating) increase cell disruption, leading to increased lipid deterioration observed by increased TBA values. However, all TBA values for the pepperoni in this study were low, indicating limited oxidation. Even samples stored at room temperature showed relatively little change, probably due to superior vacuum packaging.

Cupping evaluation

The slices placed on pizzas and cooked for cupping measurements showed few differences. The degree of cupping was not severe for any treatment, with no significant difference in cupping between cooking, irradiation levels, or preblending (data not shown). This contradicts research by Newkirk and others (1995), who reported that pepperoni cooked to an endpoint internal temperature of 60 °C resulted in slices with higher cupping scores than unheated controls. In that study, slices were arranged on a frozen pizza and cooked in a conveyer-fed impingement oven for 3.5 minutes at 260 °C. The differing results by Newkirk and others (1995) relative to the current research may be due to the different cooking procedures.

Conclusions

Irradiation of meat raw materials prior to the production of dry, fermented sausage, such as pepperoni will provide the required 5-log reduction of *E. coli* O157:H7 and result in products with quality characteristics closely resembling those of traditional dry sausage. A heat treatment performed with proper time/temperature relationships is known to be very effective for destruction of pathogens, but the quality characteristics of pepperoni observed in this study show that texture and color are significantly altered. Implementing irradiation for raw meat materials as a microbial control measure rather than heating the dried product will permit production of pepperoni with characteristics which more closely resemble traditional pepperoni products.

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