Effect of Irradiation on the Degradation of Nucleotides in Turkey Meat

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Summary and Implications

The degradation of nucleotides in cured ready-to-eat (RTE) as well as uncured raw and cooked turkey meat products by irradiation were determined to evaluate the potential impact of nucleotides on the taste changes in irradiated turkey meat. Four irradiation doses (0, 1.5, 3.0 and 4.5 kGy) were applied to cured RTE and uncured turkey meat products, and the amounts of nucleotides and their degradation products were measured. Results showed that irradiation had a significant impact to the amount of nucleotides (adenosine diphosphate, adenosine monophosphate and inosine monophosphate) and the breakdown of these nucleotides (inosine and hypoxanthine) in uncured turkey meat when irradiated at < 3.0 kGy. However, significant decreases in inosine and hypoxanthine were observed when the uncured turkey meat were irradiated at > 3.0 kGy might attribute to uric acid and other compounds formation. The increase in K-value (the percentage of inosine and hypoxanthine over the total content of adenosine triphosphate) at lower irradiation dose in uncured cooked than raw turkey meat indicated that cooked meat is more susceptible to oxidation. But little effect was found on the nucleotides and nucleotides degradation products in cured RTE turkey meat products because of the antioxidant effect of sodium nitrite.

Introduction

Irradiation is among the best methods to eliminate potential pathogens in meat products and prolong their shelf-life. However, irradiation produces aqueous electron (e_{aq}^-) and hydroxyl radical ($\cdot OH$) from water molecules in meat and can be involved in various reactions with amino acids, protein, lipids, vitamins, nucleotides and carbohydrates to form the off-odor volatiles and off-taste compounds in meat. The effect of irradiation on volatile production and taste changes in meat can vary depending upon fatty acid composition, protein content, amino acid composition, processing conditions used, and antioxidant content in meat. The phospholipid structure in muscle cell membranes are broken during cooking, and thus cooked meat are more sensitive to susceptible to oxidation-reduction environment changes than raw meat. Cured ready-to-eat meat products have stronger resistances to oxidative changes than uncured meat products because nitrite serves as a strong antioxidant in cured meat products. The degradation pathway of adenosine triphosphate (ATP) that generates intermediate compounds including adenosine diphosphate (ADP), adenosine monophosphate (AMP), inosine monophosphate (IMP), inosine (INO) and hypoxanthine (Hx) in muscle has been extensively documented. The role of IMP for the generation of meat odor and flavor has been demonstrated both in model system and sensory studies. The quality of fish can be maintained as long as IMP is not depleted. However, IMP can be degraded into inosine and hypoxanthine by enzymes. Once inosine and hypoxanthine are formed, they can produce bitter taste, and thus they are regarded as contributors to off-flavor.

The objectives of this study were to 1) determine the effect of irradiation on the degradation of nucleotides in turkey meat products, and 2) illustrate the nucleotides degradation pathway under different irradiation doses.

Materials and Methods

Raw turkey breast meat, sliced RTE turkey breast rolls, sliced RTE turkey ham, and RTE turkey sausages were purchased from a local grocery store. The turkey meat products were cut to 50 g pieces and individually packaged in vacuum bags. Cooked turkey breast meat was prepared by vacuum-packaging raw turkey breast meat in oxygen impermeable bags and heating in an 85 °C-water bath to an internal temperature of 75 °C. After draining meat juices from the bag, the cooked turkey breast meat were repackaged in vacuum bags. All meat samples were stored at 4 °C before irradiation. Standard AMP and IMP (1% w/v) were also prepared.

The packaged meat and solutions were irradiated at four target dose levels (0, 1.5, 3.0 and 4.5 kGy) using an electron beam accelerator with 10 MeV energy and 5.6 kW power level. Nucleotides and nucleotides degradation products were determined on the day of irradiation.

Nucleotides and nucleotides degradation products were measured using the HPLC method. K-value, I-value and H-value were calculated and were expressed as a percentage of the content of the last two final compounds of the ATP catabolic pathway (Inosine, Hypoxanthine) over the total content of ATP and its degradation products: ATP, ADP, AMP, IMP, Inosine and Hx. Data were analyzed by the GLM procedure of SAS for different treatments. The differences in the mean values were compared by Tukey's multiple comparison method.

Results and Discussion

Irradiation significantly impacted the nucleotides degradation of raw turkey meat: 27% decrease in ADP under irradiation doses from 0 to 1.5 kGy, 7% decrease in IMP from 1.5 to 3.0 kGy irradiation, and 1.4- / 1.1-fold increase of inosine and hypoxanthine from 0 to 3.0 kGy irradiation, respectively. As the irradiation dose increased further, the concentration of inosine and hypoxanthine decreased more ($P < 0.05$). The removal of a phosphate group from ADP by irradiation increased the amount of AMP, inosine and hypoxanthine in 1.5 kGy-irradiated cooked turkey meat. The degradation of ADP and AMP did not occur rapidly at irradiation dose between 1.5 and 4.5 kGy. However, a significant decrease in IMP (from 19.96 to 17.34 umol/g) was observed at irradiation dose between 3.0 and 4.5 kGy, and significant decreases in inosine and hypoxanthine were also observed at irradiation dose from 1.5 to 4.5 kGy ($P < 0.05$) (Fig. 1).

ADP and AMP remained at low concentrations (< 2.7 umol/g) in irradiated raw and cooked turkey meat samples, but cooked turkey meats had higher levels of ADP and AMP because of dehydration and condensation effects during cooking. Cooked meat is more susceptible to oxidation than raw meat because the integrity of muscle cell membranes are damaged during cooking. The changes of inosine and hypoxanthine under increasing irradiation doses showed a consistent pattern with this claim: the rapid increase of the two final nucleotides degradation products in cooked turkey meat was observed in 1.5 kGy, while similar increase was found at higher irradiation dose, 3.0 kGy, for raw turkey meat.

The decrease of inosine concentration after 3.0 kGy irradiation was expected to increase hypoxanthine, but no such observation was found here. Hypoxanthine can be degraded to xanthine by xanthine oxidase and further converted to uric acid. However, no xanthine was detected in this study. The possible explanation is that hypoxanthine was decomposed to uric acid or other components under high irradiation doses (> 3.0 kGy).

The K-value changes in turkey meat products under different irradiation doses were shown in Table 1. K-value is expressed as a percentage content of the last two final compounds of the ATP catabolic pathway (inosine and hypoxanthine) over the total content of ATP and its degradation products including ATP, ADP, AMP, IMP, inosine and Hx. Inosine and hypoxanthine are considered as the two final nucleotides degradation products and they can produce bitter taste and is regarded as contributors to off-flavor. Therefore, the K-value is used as an index of the freshness of seafood and a measurement how far ATP degradation could progress within the tissues. The initial K-values for the raw and cooked turkey meat were similar, but a sharp increase of K-value (22%) was observed in cooked turkey meat at 1.5 kGy irradiation, and a significant increase (14%) was noticed in raw turkey meat at 3.0 kGy, which further confirmed that cooked turkey meat is more susceptible to be oxidized.

The I- and H-value changes in raw and cooked turkey meat products under different irradiation doses were shown in Table 2. I-value and H-value are expressed as a percentage of the content of inosine and hypoxanthine over the total content of ATP and its degradation products, respectively. Table 2 indicated that increase of irradiation dose for raw turkey meat from 0 kGy to 1.5 kGy and 1.5 to 3.0 kGy increased the I-values by 30%, while only 7% increase in H-value was observed when the irradiation dose increased from 3.0 kGy to 4.5 kGy. For the cooked turkey meat, 28% increase of I-value was observed when irradiation dose increased from 0 to 3.0 kGy, while only half of such increase rate was found in H-value at the same irradiation dose. Those observations indicated that irradiation has a stronger impact to inosine than hypoxanthine.

Irradiation had little effect on the nucleotides degradation products in the cured turkey meat products ($P > 0.05$), even a significant difference was found in the concentration of inosine in turkey sausage under different irradiation doses (Table 3). No differences in the K-values of three cured meat products were detected (Table 1), indicating that the last two final compounds of the ATP catabolic pathway (inosine and hypoxanthine) were not affected by increasing irradiation doses. Sodium nitrite has a strong antioxidant effect on cured meat products.

Fig. 2 showed the mean concentraions (umol/mL) of nucleotides, nucleosides and bases in AMP model system. A 1.1-fold decrease in AMP from by 4.5 kGy irradiation, and 1.2 and 2.1-fold increase in the breakdown products of AMP, IMP and hypoxanthine, by irradiation at 3.0 and 4.5 kGy, respectively. A significant increase of inosine was observed between 0 and 3.0 kGy irradiation, but 2.3-fold decease of inosine was observed by 4.5 kGy irradiation. Fig. 3 showed the mean concentraions (umol/mL) of nucleotides, nucleosides and bases in IMP model system. A significant decrease of IMP was found after irradiation ($P < 0.05$), while IMP degradation products, inosine and hypoxanthine, were newly formed at 1.5 kGy. When higher irradiation doses were applied, inosine was further converted into hypoxanthine.

The proposed degradation pathway of necleotides by irradiation is as follow: Under irradiation conditions, ADP was degradated into AMP, which was confirmed in raw and cooked turkey meat. However, there are two possible pathways to form inosine from AMP: 1) IMP was formed through deamination from AMP first, then dephosphorylation took place to convert IMP into inosine; 2) The deamination and dephosphorylation occured simultaneously, in which inosine was produced directly from AMP without an intermediate, IMP. N-conaining gorup has relativly high hydrophilicity and low volatilites, and thus the deamination of nucleotides can progress rapidly with the aid of free radicals produced by irradiation in the aquous conditions. The AMP model system also showed an evidence that inosine can be produced directly from AMP without an intermediate, IMP. However, the resistance of purine derivatives to UV-irradiation depends on the character and position of the substituents in the heterocyclic ring. Adenine, adenosine and adenylic acids are highly resistant to UV-irradiation (> 230 nm). Once a carbonyl group is introduced into the purine ring, especially at C2 position, the sensitivity of the compound to UV-irradiation increases.

Conclusion

The nucleotides degradation by irradiation in turkey meat products indicated that the changes of nucleotide degradation products can contribute to the sensory attributes of irradiated meat. Irradiation has a significant effect ($P < 0.05$) on the degradation of nucleotides in uncured meat products, but had no impact in cured meat products ($P > 0.05$). Nitrite in cured meat products functioned as an antioxidant / radioprotector and minimized the effect of irradiation on nucleotides degradation in meat. K-value can be a good indicator of nucleotides resistance to irradiation in meat. The finding in the present study would provide some possible solutions (e.g., masking agents, antioxidants) to minimize the nucleotides degradation by irradiation that can reduce the possible negative effect of the irradiation on the sensory quality of meat products.

Table 1. Changes of K-values (%) in turkey meat products under different irradiation doses [1, 2]

	Uncured		Cured		
	Raw turkey meat	Cooked turkey meat	Turkey breast rolls	Turkey ham	Turkey sausages
0 kGy	49.87 [b]	42.06 [c]	34.39 [a]	54.54 [a]	30.66 [ab]
1.5 kGy	50.78 [b]	51.15 [a]	33.93 [a]	54.97 [a]	29.93 [ab]
3.0 kGy	58.08 [a]	49.99 [ab]	33.88 [a]	53.68 [a]	29.55 [b]
4.5 kGy	50.51 [b]	48.75 [b]	34.50 [a]	56.44 [a]	30.09 [a]

[1] Different letters (a, b, c) within a column of the same meat product differ significantly ($P < 0.05$).
[2] K-value (%) = [(Inosine + Hypoxanthine) / (ADP + AMP + IMP + Inosine + Hypoxanthine)] ×100

Table 2. Changes of I- and H-values (%) in raw and cooked turkey meat products under different irradiation doses [1]

	Raw turkey meat		**Cooked turkey meat**	
	I-value [2]	**H-value [3]**	**I-value**	**H-value**
0 kGy	23.54 [b]	26.33 [b]	20.93 [c]	21.13 [c]
1.5 kGy	24.13 [b]	26.64 [b]	26.82 [a]	24.33 [a]
3.0 kGy	31.33 [a]	26.75 [b]	27.18 [a]	22.81 [b]
4.5 kGy	21.97 [c]	28.54 [a]	23.38 [b]	25.37 [a]

[1] Different letters (a, b, c) within a column of the same meat product differ significantly ($P < 0.05$).
[2] I value (%) = [Inosine / (ADP + AMP + IMP + Inosine + Hypoxanthine)] ×100
[3] H value (%) = [Hypoxanthine / (ADP + AMP + IMP + Inosine + Hypoxanthine)] ×100

Table 3. Concentration of nucleotides and nucleotides degradation products (μmol/g) in turkey meat products under different irradiation doses

[1]Different letters (a, b) within a column of the same meat product differ significantly (*P* < 0.05).

	AMP	IMP	Inosine	Hypoxanthine
Turkey breast rolls				
0 kGy	0.49 ± 0.01	15.63 ± 0.01	ND	8.67 ± 0.29
1.5 kGy	0.55 ±0.01	16.52 ± 0.48	ND	8.98 ± 0.27
3.0 kGy	0.55 ± 0.02	16.60 ± 0.31	ND	9.00 ± 0.18
4.5 kGy	0.52 ± 0.06	15.87 ± 0.85	ND	8.85 ± 0.12
Turkey ham				
0 kGy	1.18 ± 0.06	14.83 ± 0.74	9.24 ± 0.39	9.98 ± 0.27
1.5 kGy	1.16 ± 0.08	14.41 ± 1.30	9.00 ± 0.27	9.99 ± 0.30
3.0 kGy	1.20 ± 0.07	15.44 ± 0.90	9.20 ± 0.50	10.08 ± 0.51
4.5 kGy	1.17 ± 0.04	13.95 ± 1.07	9.26 ± 0.43	10.33 ± 0.58
Turkey sausages				
0 kGy	0.57 ± 0.04	15.15 ± 0.46	3.85 ± 0.35 [a]	3.10 ± 0.11
1.5 kGy	0.50 ± 0.03	14.52 ± 0.33	3.41 ± 0.28 [ab]	3.01 ± 0.07
3.0 kGy	0.49 ± 0.01	14.69 ± 0.25	3.34 ± 0.10 [b]	3.03 ± 0.06
4.5 kGy	0.51 ± 0.04	14.62 ± 0.27	3.50 ± 0.34 [ab]	3.01 ±0.03

ND = not detected in all samples.

Fig. 1. The concentration of nucleotides and nucleotide degradation products in raw and cooked turkey meat with different irradiation doses (0 kGy, 1.5 kGy, 3.0 kGy, 4.5 kGy). Different letters (a, b, c) within a figure of the same meat product differ significantly (P < 0.05).

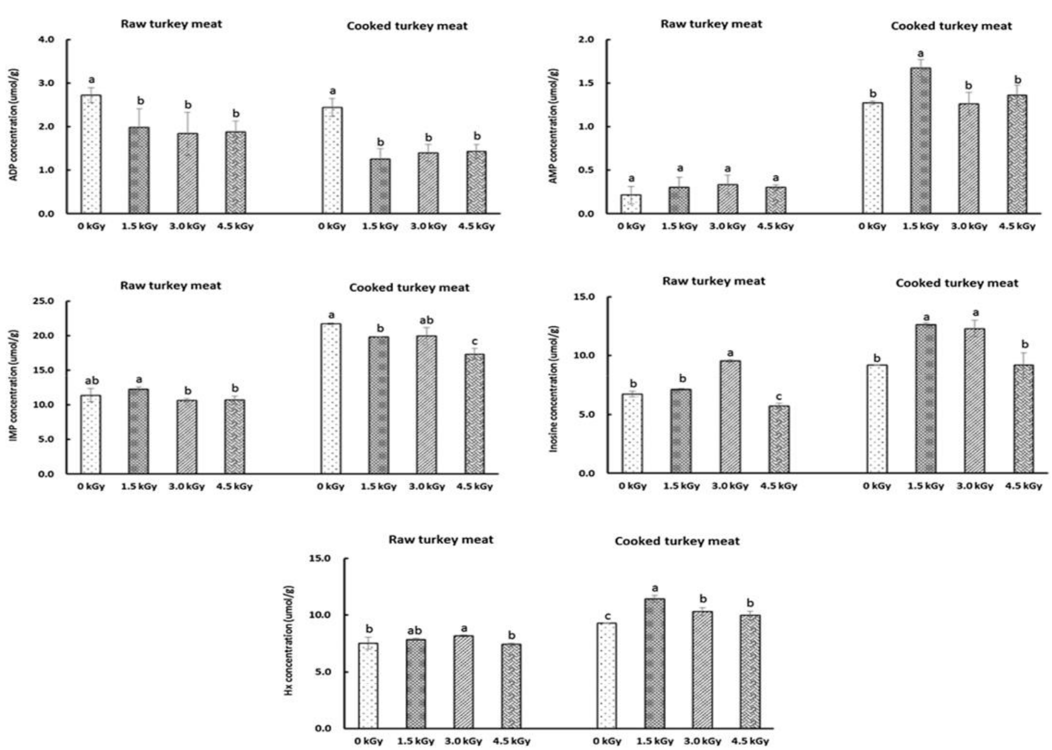

Fig. 2. The concentration of nucleotides and nucleotide degradation products in AMP solutions with different irradiation doses (0 kGy, 1.5 kGy, 3.0 kGy, 4.5 kGy) Different letters (a, b, c) of the same nucleotide or nucleotide degradation product differ significantly (P < 0.05).

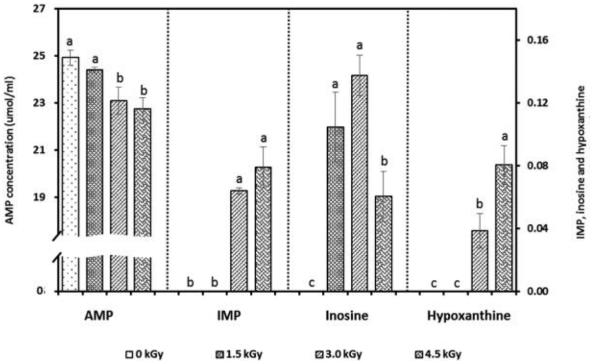

Fig. 3. The concentration of nucleotides and nucleotides degradation products in IMP solutions with different irradiation doses (0 kGy, 1.5 kGy, 3.0 kGy, 4.5 kGy) Different letters (a, b, c, d) of the same nucleotide or nucleotide degradation product differ significantly (P < 0.05).