Dietary Vitamin E Affects Lipid Oxidation and Total Volatiles of Irradiated Raw Turkey Meat

D.U. AHN, J.L. SELL, M. JEFFERY, C. JO, X. CHEN, C. WU, and J.I. LEE

ABSTRACT

Breast and leg meat patties, prepared from turkeys fed diets containing 25, 200, 400 or 600 IU of dl-α-tocopheryl acetate (TA) per kg diet, were irradiated at 0 or 2.5 kGy with vacuum or loose packaging. The effects of dietary TA on storage stability and production of volatiles in irradiated raw turkey meat were determined. Dietary TA at > 200 IU/kg decreased lipid oxidation and reduced total volatiles of raw turkey patties after 7-days of storage. However, the antioxidant effects of dietary TA were more notable when the patties were loosely packaged than when vacuum-packaged. Irradiation increased lipid oxidation of raw turkey meats only when loosely packaged but had limited effects on formation of total volatiles after storage at 4°C for 7 days or longer.

Key Words: vitamin E, lipid oxidation, volatiles, irradiation, turkey meat

INTRODUCTION

TREATMENTS SUCH AS IRRADIATION, carcass wash with organic acids, sanitizers, hot water, chlorine, phosphates, and ozone, have been tested to prevent, reduce or eliminate pathogenic bacteria on raw meat. Irradiation has been reported to guarantee safety by eliminating pathogenic bacteria in raw meat (Gants, 1996). It is permitted in poultry meat up to 3 kGy to control pathogenic microorganisms such as Salmonella, Escherichia coli, and Listeria. A major concern in irradiating meat, however, is its effect on meat quality, mainly related to the free radicals reaction and off-odor. Irradiation, at 1.5- to 10-kGy doses, has been reported to increase thiobarbituric acid values (TBARS) in turkey breast meat and fish muscles (Al-Kahtani et al., 1996; Hampson et al., 1996). Katusin-Razem et al. (1992) and Thayer et al. (1993) reported that irradiation-induced oxidative chemical changes were dose dependent and that the presence of oxygen had a notable effect on rate of oxidation.

Lynch et al. (1991) showed that irradiated turkey breast fillet produced unpleasant odor notes when stored in oxygen impermeable film and the odors were different from those from unirradiated samples. Heath et al. (1990) and Hashim et al. (1995) also reported that irradiating uncooked chicken meat produced a characteristic bloody and sweet aroma that remained after the meat was cooked. Others, however, indicated that irradiation had no detrimental effect on flavor of vacuum-packaged raw meat or cured meat and electron beam treatment had little effect on odor or flavor of reheated meat with sous-vide treatment (Shahidi et al., 1991; Shamsuzzaman et al., 1992). Little information is available on the nature and off-odor generation in irradiated meat, especially at low-dose irradiation (< 10 kGy).

The fundamental lipid oxidation mechanisms in irradiated meat are expected to be the same as those in unirradiated. The chemical conditions of irradiated meat, however, could be totally different from those of unirradiated. Irradiation would produce higher concentrations of hydroxyl radicals in meat because more than 75% of muscle cells are composed of water (Thakur and Singh, 1994). Lipid radicals would be formed via the free radical reactions, and lipid hydroperoxides would be formed when oxygen is available. We assume that both lipid oxidation and off-odor generation in irradiated meat are closely related to hydroxyl radicals, but the relationship between off-odor generation and lipid oxidation status in irradiated meat is not known. The oxidation of lipids in raw meat is closely related to the antioxidant potential of muscle tissues. Vitamin E is a major antioxidant in the cell membranes and protects the membrane fatty acids and cholesterol from peroxidative damages caused by reactive free radicals (Buckley et al., 1995; Liu et al., 1995). The free radicals generated by irradiation can destroy antioxidants in muscle, reduce storage stability and increase off-flavor production in meat (Thayer et al., 1993; Lakritz et al., 1995). Supplementation of diets with vitamin E has increased vitamin E concentration in muscle tissues, and its antioxidant effect in the raw meat during storage has been well documented (Ajuyah et al., 1993; Ahn et al., 1995; Winne and Dirinck, 1996; Morrissey et al., 1997). However, information on the antioxidant effect of dietary tocopherols on irradiated and further processed raw meat products is not well known.

The objectives of this research were to determine the effects of dietary vitamin E supplementation on (1) the storage stability of irradiated raw turkey meat as related to packaging and (2) off-flavor development in irradiated raw turkey meat as measured by TBARS and total volatiles during storage.

MATERIALS & METHODS

Dietary treatments and sample preparations

Male large white turkeys were fed diets containing 0, 25, 50, 75, or 100 IU of dl-α-tocopheryl acetate (TA) per kg from 1 to 105 days of age. At 105 days, two pens of turkeys previously fed those levels were randomly assigned to diets containing 200, 400, 600 IU of TA/kg diet. Then each of the 200, 400, and 600 IU TA diets was fed to 8 pens of poult, 8 poult per pen, from 105 to 122 days. Blood samples were collected (one bird/pen) 1 day before slaughter. Plasma was obtained from the blood samples and analyzed for vitamin E (α-tocopherol).

At the end of the trial, 2 birds per pen and the 8 turkeys on the 25 IU TA/kg diet (total 64 birds) were randomly selected and slaughtered following USDA guidelines (USDA, 1982). Carcasses were chilled in ice water for 3 hr and drained in a cold room. Breast and leg muscles were deboned from the carcasses 24 hr after slaughter. Skin and visible fat were removed. Breast and leg meats from two birds from the same pen were pooled (thus, 8 replicates), and ground twice through a 3-mm plate. Breast and thigh meat patties (~ 100g each) were prepared from each of the pooled ground breast and pooled leg meats representing each pen.

Twelve breast and 12 thigh patties from each pen were used. Half (6 patties) of the breast and thigh patties were vacuum-packaged in oxygen-impermeable plastic films, and the other half were placed on laminated foam trays and wrapped with oxygen permeable plastic film. The meats, packaged in oxygen permeable or impermeable bags, were irradiated with accelerated electrons by using a Linear Accelerator (Circe IIIR, Thomson CSF Linac, Saint-Aubin, France) to a dose of 0- to 2.5 kGy dose (127 kGy/min). The temperatures of the meat were kept at 2-4°C during irradiation, and after irradiation, they were stored up to 2 wk at 2-4°C. Degrees of lipid oxidation and α-tocopherol concentrations in the patties were measured after 0, 1, and 2 wk storage. Thiobarbituric acid reactive substances (TBARS) were measured to determine the degree and progress of lipid oxidation. A purge-and-trap unit was used to trap volatiles responsible for flavor changes in the meat patties. Plasma and tissue vitamin E levels were determined by HPLC (Shimadzu LC-10AS, Kyoto, Japan) as described elsewhere (Sato-Salanova and Sell, 1996).
Lipid oxidation

Lipid peroxidation was determined by the modified method of Buege and Aust (1978). A 5-g meat sample was placed in a 50-ml test tube and homogenized with 15 mL deionized distilled water (DDW) with a Brinkman Polytron (Type PT 10/35, Westbury, NY) for 15 s at speed 3. Standard kits (aldehyde- ketones, alcohols, hydrocarbons, and alkenes C6-C10) were purchased from Chromatography Research Supplies (Adison, IL), and 9 aldehydes, 11 alcohols, 8 ketones, and 16 hydrocarbons standards were used to identify peaks in meat volatiles. The area of each peak was integrated by ChemStation software (Hewlett Packard, Fullerton, CA), and the total peak area (pA*sec) was reported as an indicator of volatiles generated in the meat samples.

Table 2—Effect of dietary vitamin E, irradiation, and storage time (at 4°C) on TBARS of vacuum-packaged raw turkey breast meat pattiesa

<table>
<thead>
<tr>
<th>Dietary vitamin E (IU/kg)</th>
<th>Day 0</th>
<th>Day 7</th>
<th>Day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unirradiated</td>
<td>Irradiated</td>
<td>Unirradiated</td>
<td>Irradiated</td>
</tr>
<tr>
<td>Plasma</td>
<td>(mg MDA/kg meat)</td>
<td>Plasma</td>
<td>(mg MDA/kg meat)</td>
</tr>
<tr>
<td>25</td>
<td>0.22a</td>
<td>0.28b</td>
<td>0.30a</td>
</tr>
<tr>
<td>200</td>
<td>0.13by</td>
<td>0.20b</td>
<td>x</td>
</tr>
<tr>
<td>400</td>
<td>0.10by</td>
<td>0.21bx</td>
<td>0.09y</td>
</tr>
<tr>
<td>600</td>
<td>0.09y</td>
<td>0.19w</td>
<td>0.08yw</td>
</tr>
<tr>
<td>SEM</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

ab Different letters within a column are significantly different (P < 0.05).

RESULTS & DISCUSSION

Plasma and muscle vitamin E levels increased with each increment of dietary TA (Table 1), up to 3-fold when dietary TA increased from 25 IU to 200 IU/kg diet. However, the effects of additional dietary TA were not linear. Leg muscle had more than double the vitamin E of breast meat, but the vitamin E in leg muscle was more susceptible to irradiation than that in breast. Vitamin E in leg muscle was more susceptible to irradiation than that in breast. Vitamin E in leg muscle was more susceptible to irradiation than that in breast. Vitamin E in leg muscle was more susceptible to irradiation than that in breast. Vitamin E in leg muscle was more susceptible to irradiation than that in breast.

The TBARS values in vacuum-packaged breast and leg meat patties stored at 4°C for 14 days (Tables 2, 3) showed that irradiated and unirradiated breast meat patties prepared from the turkeys fed diets containing 200 to 600 IU TA/kg were lower than those fed the low-level TA diet (25 IU/kg). No differences were found among TBARS values for meats from turkeys fed 200, 400, or 600 IU TA/kg. Irradiated meat, except for the 25 IU TA diet, had greater TBARS values than did unirradiated meat in all three storage periods, but differences were small.

The TBARS values of irradiated and unirradiated breast meat patties remained unchanged during the first 7-days storage at 4°C in vacuum packaging. After 14-days storage at 4°C, however, the TBARS of raw meat patties were two times higher than those at 0 or 7 days (Table 2).
Table 5—Effect of dietary vitamin E, irradiation, and storage time (at 4°C) on TBARS of loosely packaged raw turkey leg patties

<table>
<thead>
<tr>
<th>Dietary vitamin E (IU/kg)</th>
<th>Day 0</th>
<th>Day 7</th>
<th>Day 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unirradiated</td>
<td>Irradiated</td>
<td>Unirradiated</td>
<td>Irradiated</td>
</tr>
<tr>
<td>25</td>
<td>0.52a</td>
<td>0.63a</td>
<td>4.39a</td>
</tr>
<tr>
<td>200</td>
<td>0.15by</td>
<td>0.24bx</td>
<td>0.73by</td>
</tr>
<tr>
<td>400</td>
<td>0.18b</td>
<td>0.22b</td>
<td>0.56by</td>
</tr>
<tr>
<td>600</td>
<td>0.13by</td>
<td>0.21bx</td>
<td>0.48by</td>
</tr>
<tr>
<td>SEM</td>
<td>0.03</td>
<td>0.04</td>
<td>0.18</td>
</tr>
</tbody>
</table>

a-d Different letters within a column are significantly different (P < 0.05).

Changes in TBARS values of vacuum packaged leg meat patties showed similar trends to those in breast meat (Table 3). Antioxidant effects of dietary vitamin E became significant after 14-days storage at 4°C. TBARS of vacuum-packaged turkey leg meat from the high-level TA diets (200 to 600 IU/kg) were half those of the 25 IU TA diet. Although large proportions of leg muscle vitamin E were destroyed by irradiation (Table 1), differences in TBARS between irradiated and unirradiated leg meat patties were slight (Table 3).

When patties were stored in oxygen permeable bags, however, oxidation rates (increasing TBARS), were much faster than when patties were stored in vacuum-packaging bags (Tables 4 and 5). Also, the antioxidant effect of dietary TA became more obvious for meat in oxygen-permeable bags than that in the vacuum-packaged bags. High-level dietary TA reduced peroxidation rate (P < 0.05) in loosely packed breast meat patties (Table 4), and high-level dietary TA (200 to 600 IU/kg) maintained TBARS of irradiated and unirradiated breast meat patties below 1.0 during 14-days storage. The critical TBARS value for oxidized flavor for sensitive consumers is around 1.0 (Gray et al., 1996), and the baseline TBARS of cooked meat is determined by the conditions of the raw meat patties. Also, irradi-
tion had a stronger effect on lipid oxidation of loosely packaged than vacuum packaged breast meat patties. Irradiated breast meat had higher TBARS than did unirradiated breast meat, and the effects were significant (P < 0.05) for loosely packaged patties stored 7 days or longer.

The development of lipid oxidation in loosely packaged leg meat was faster than that of the breast meat. In general, intact raw muscles are very resistant to lipid oxidation (Ahn et al., 1993, 1995). However, the ground raw turkey meat was quite unstable when oxygen was present, probably because oxygen was an initiator or required for breakdown of primary products of lipid oxidation. Iron contamination and disintegration of tissue structure the grinding may also have contributed to the high TBARS. Leg meat patties from turkeys fed 25 IU TA/kg produced very high TBARS after 7-days storage, but feeding high levels of dietary TA (200 to 600 IU/kg) maintained the TBARS of leg meat patties below 1.0 during 14-days storage in presence of oxygen. Irradiation increased the TBARS values of leg meat patties after 7-days storage, but high levels of dietary TA (200 to 600 IU/kg) greatly reduced the lipid oxidation in irradiated leg meat (Table 5). The prooxidant effect of irradiation became critical only when the meat was stored in oxygen presence > 7 days. However, 200 IU or more of dietary TA controlled lipid oxidation in irradiated and unirradiated raw meat patties during storage, even with oxygen-permeable packaging.

Winne and Dirinck (1996) reported that muscle α-tocopherol levels of chickens supplemented with 200 IU TA/kg diet were 6- to 7-fold higher than those fed the control diet (20 IU TA/kg diet). Vitamin E supplementation had a beneficial effect on the sensory and the oxidative stability of the meat. Wen et al. (1996) reported that dietary supplementation of 300 or 600 IU TA/kg diet reduced TBARS numbers in turkey burgers during refrigerated and frozen storage. The National Research Council (1994) recommendation for dietary vitamin E for growing turkeys is 12 IU/kg diet. However, research has indicated that at least a 200 IU TA/kg diet is required to ensure antioxidant effects in turkey meat products during storage for 2 wk at 4°C.

In the GC profile of volatiles from turkey meat (Fig. 1) all peak areas were added and reported as total volatiles. When stored in vacuum-packaging bags, the volatiles in irradiated and unirradiated breast meat patties from all dietary treatments remained unchanged for 7 days. After 14-days storage, however, the total volatiles of irradiated and unirradiated breast meat patties from turkeys fed 25 or 200 IU TA/kg increased, whereas those from turkeys fed 400 and 600 IU TA/kg remained unchanged (Fig. 2A, B). When packaged in oxygen permeable bags, the effect of dietary vitamin E on total volatiles of breast meat patties was less than in vacuum-packaged samples. Unirradiated turkey breast meat patties from turkeys fed 400 or more IU TA/kg and irradiated turkey breast meat patties from 600 IU TA/kg maintained relatively low volatiles levels for 7 days at 4°C. After 14-days storage, however, none of the dietary TA influenced the amount of total volatiles in turkey breast meat patties (Fig. 2C, D).

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**Fig. 3—**Effect of dietary vitamin E on production of total volatiles in irradiated and unirradiated turkey leg meat patties with different packaging and storage time (dietary TA/kg diet: □, 25 IU; ●, 200 IU; ◊, 400 IU; X, 600 IU). *abc* Different letters within a storage day are significantly different (P < 0.05).
Although tissue vitamin E contents in leg meat from turkeys fed each of the dietary TA treatments were two times higher than in breast meat (Table 1), the effects of dietary TA in controlling total volatiles of leg meat patties were less than that observed with breast meat patties (Fig. 3). Dietary TA up to the 400-IU/kg diet had no effect on total volatiles in vacuum-packaged leg meat patties (Fig. 3A). However, unirradiated, vacuum-packaged leg meat patties from turkeys fed 600 IU TA/kg maintained total volatiles at initial levels (0 day) for 7 days (Fig. 3B). Under oxygen-permeable packaging, the leg meat patties from turkeys fed 200 to 600 IU TA/kg of diet produced less total volatiles than those from turkeys fed 25 IU TA/kg of diet during the first 7-days storage. After 14-days storage, however, only the leg meat patties from turkeys fed > 400 IU TA/kg of diet produced less total volatiles than those from turkeys fed 25 IU TA/kg of diet (Fig. 3C, 3D). In irradiated, loosely packaged leg meat patties, 600 IU TA/kg was more effective than other TA treatments in maintaining lower total volatiles after 7-days storage (Fig. 3D). However, at this time the total volatiles of all the meats may have been beyond the critical range. Irradiated breast meat patties produced more total volatiles after 14 days in vacuum-packaging, and the rest of the meat patties after 7 days storage.

As has been described by other researchers (Lynch et al., 1991; Heath et al., 1990; Hashim et al., 1995), irradiated meat produced a characteristic odor. Hansen et al. (1987) reported that the levels of total volatiles in chicken skin increased with irradiation dose. The effect of irradiation on total volatiles in our study (2.5 kGy), however, was relatively slight and not consistent (Fig. 2, 3). Considering the low increase in total volatiles but high distinct off-odor observed when meat packages were open for sample preparation (data not shown), the critical levels for certain volatile compounds that produce off-odor in irradiated meat seem to be very low. Patterson and Stevenson (1995) reported that dimethyltrisulfide, cis-3- and trans-6-nonenal, oct-1-en-3-one, and bis(methylthio)methane were the most potent and objectionable compounds in irradiated raw chicken. Dietary vitamin E and ascorbate reduced the yields of irradiation volatiles from the chicken muscles. However, we could not identify those components in irradiated raw meat probably due to limitations of the detector (FID) sensitivity.

**CONCLUSION**

**DIETARY TA of > 200 IU/kg improved storage stability of irradiated and unirradiated turkey breast and leg meat patties. Production of total volatiles in turkey meat patties also was reduced by dietary TA but only at 400 or 600 IU/kg. Irradiation increased lipid oxidation of raw turkey meat under oxygen exposure but had limited effects on total volatiles after 7 days or longer storage at 4°C.**

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