Effects of Irradiation on Meat Color

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Abstract Irradiation is the best method to control pathogens in meat, but causes quality changes such as color, odor, and flavor in raw and cooked meat. Color is an important quality parameter that influences consumer acceptance of meat. Although the mechanism of color changes in irradiated meats would be the same or at least similar to those of nonirradiated meat, the expression of color varies depending upon irradiation dose, animal species, muscle type, and packaging type. Usually light meat produces pink color while dark meat become brown or gray after irradiation. The compounds responsible for the pinkness in light meat were CO-heme pigments and changes in redox potential by irradiation facilitated the formation of CO-heme pigment complexes. The production of carbon monoxide and changes of oxidation-reduction potential (ORP) in red meats by irradiation were similar to those of light meat, but color changes are different from those of light meat due to high pigment content in red meat. Preventing or minimizing pink color development in irradiated poultry after cooking is especially important because consumer acceptance of irradiated meat depends on cooked meat color. A few strategies to minimize color changes in irradiated meat are discussed in the review.

Keywords: irradiation, meat color, heme pigments, mechanisms of color change, prevention of color change

Introduction

Low-dose (<10 kGy) irradiation is permitted for use in poultry and red meats to control pathogenic bacteria in the U.S., and very low dose (<1.0 kGy) irradiation has also been permitted in pork to kill trichina, in flour and spices to control insects, and in fruits and vegetables to control germination. Irradiation is the best-known method to control potential pathogens in raw meat, and to extend shelf life of meat products by reducing spoilage microorganisms (1, 2). However, irradiation has not been used extensively in meat because of quality concern and consumer prejudice against irradiation. Irradiation is known to generate hydroxyl radicals and produces an objectionable odors and flavors that significantly impact upon consumer acceptance. Furthermore, previous studies showed that irradiation accelerated lipid oxidation especially when meats were packaged aerobically, and produced objectionable odors and colors in meat (3-6). The mechanisms of lipid oxidation and off-odor production in irradiated meats were well established by a number of studies related to irradiation chemistry and meat biochemistry. The color changes in meat by irradiation, however, started to receive attentions from meat industry recently.

Color is a prime sensory parameter that determines consumer acceptance of a meat. Consumers want to have the color of their meat within a normal range (7, 8), and discolored meats are considered as inferior in quality or contaminated. The estimated loss of value in beef due to discoloration at the retail market in the U.S. is over 700 million dollars per year (9). Irradiation induces color changes but the degree of the changes can be different depending on various factors such as irradiation dose, animal species, muscle type, and packaging type (10-13). However, there are only limited amounts of work done in the color changes of red meat by irradiation. Therefore, the discussion of this review will mainly be on the color changes in irradiated light meats.

Factors affecting color changes in meat

Heme pigments The color of meat depends upon the chemical status of heme pigments, muscle structure, and environmental conditions, but the most crucial attributes are the concentration and chemical status of heme pigments. Among heme pigments (myoglobin, hemoglobin, and cytochrome c), myoglobin is the main heme pigment in well-bled muscle tissues and it constitutes about 70 to 95% of the total pigments in meat (14-16). The pigments consist of two components: one is heme ring and the other is globin protein. The amino acid residues of globin are oriented so that their hydrophobic portion points inward. The only polar amino acids inside myoglobin are two histidines, which have a critical function at the heme-binding sites (17). The oxidation status of iron in heme ring is very important because the ability of heme iron to coordinate with a sixth ligand is determined by the chemical states of heme iron (16). When heme iron is in oxidized form (ferric state), only water or nitric oxide (NO) molecule can bind with heme pigments. When
heme iron is in reduced form (ferrous state), however, O₂, CO, S or NO can be the sixth ligand of heme pigments (16). Table 1 shows various conditions of heme iron and sixth ligands that determine the color properties of myoglobin.

The concentration of heme pigments is as critical as the chemical state of pigments for meat color (18). Heme pigment concentration varies with animal age, species, and muscle type. Myoglobin concentration increases with the age of animal. The content of myoglobin in beef cuts ranges from 4 to 10 mg/g and pork cuts from 1 to 3 mg/g on wet tissue basis (19). The leg and thigh muscles of poultry have 5 to 10 times more heme pigments than their breast muscles (20). The myoglobin content in poultry red muscles is 1.0 to 2.5 mg/g wet tissue whereas the content in white muscles is 0.5 mg/g wet tissue or less (21, 22).

**Myoglobin forms in nonirradiated meat** Bright red color is generally considered as a desirable fresh meat color except for poultry breast muscles. Purplish white is normal color for poultry breast meat due to very low heme pigment concentration. Although three common forms of myoglobin exist in different proportions, fresh meat color is imparted by mainly bright red oxymyoglobin and purple deoxymyoglobin (23). Oxymyoglobin has a reduced heme iron combined with oxygen as the sixth ligand and this molecule imparts bright red color, desirable for fresh meat. The bright red color of fresh meat depends on the depth of oxymyoglobin, which is determined by oxygen partial pressure, oxygen diffusion rate, and oxygen consumption rate at meat surface (24). Under normal conditions, enzymes use up all oxygen available and generate reducing conditions inside meat block. Thus, the pigments in the middle of meat block are usually in the reduced form and weakly bind with water molecule or are stabilized by distal histidine of globin (25). The color of such pigment is purple and is called deoxymyoglobin or reduced myoglobin.

Discoloration in fresh meat is mainly caused by oxidation of myoglobin to metmyoglobin resulting in an unattractive brown color. If oxygen partial pressure is low in meat, heme iron of myoglobin becomes oxidized into a brown color. The increase of metmyoglobin in fresh meat is not desirable because most consumers consider the meat as an old or low quality. Differences between species and muscles in their ability to form metmyoglobin vary depending upon the concentration of mitochondria, activity of mitochondrial enzymes, and content of accessory factors (26). Partial or complete loss of tertiary structure of globin results in an increased rate of oxidation of oxymyoglobin (27). The brown discoloration of fresh meat is predominantly found in spoiled meat. Even in fresh meat, however, discoloration can occur. Light illumination results in relatively high autoxidation of purified myoglobin (7). Autoxidation is more rapid with deoxymyoglobin because oxymyoglobin is more stable due to hydrogen bonding between the bound oxygen and the distal histidine (24, 26). The brown oxidized color can be turned into bright red color under air (blooming or oxygenation) if the meat has strong enough reducing power or purple red under absolute vacuum conditions.

**Off-color in nonirradiated poultry meat** A pink color in uncurdled poultry breast meat is a major concern because consumer suspects such meat as an undercooked or contaminated with chemicals. The generation of pink defect has been attributed to undenatured myoglobin, contamination with nitrite or nitrate (28), severe stress at preslaughter stages (29), or absorption of combustion gases such as nitric oxide or carbon monoxide (28). Cooked meat color must be grayish brown, which is hemichrome or denatured metmyoglobin. Insufficient heat processing promotes the pink color associated with undenatured meat pigments. In some cases, however, pink color can be found even in fully cooked meat (30). Oxidation-reduction potential measurements of cooked turkey rolls showed that hemochrome formation was promoted by reducing conditions (31). Cytochrome c has been suggested as a contributing factor to pink color development in cooked turkey breast meat. Girard et al. (32) stated that cytochrome c was responsible for the pink color in both turkey breasts and pork loins. The half-denaturation temperatures of hemoglobin, myoglobin, and cytochrome c were 62, 78.5 and 105°C, respectively (33).

Poultry breast meat was more susceptible to pinking than highly pigmented beef in the presence of sodium nitrate (34). Although usual concentration of nitrate and nitrite in turkey breast meat was not high enough to cause a pink color defect, the possibility of pinking may be high by nitrate or nitrite under certain combined conditions such as high nitrate levels in feed or water supplies, a high

<table>
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<th>Heme protein</th>
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<td>Globin</td>
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<td>H₂O</td>
<td>Brown</td>
<td>Metmyoglobin</td>
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<td>Bright red</td>
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<td>Purple</td>
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<td>Denatured globin</td>
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<td>Denatured globin</td>
<td>Ferrous</td>
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<td>Denatured CO-hemichrome</td>
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microbial load, and long storage conditions (35). Ahn and Maurer (35) also reported that as little as 1 ppm nitrite caused a pink color in oven-roasted turkey breast. The heme complex forming ligands such as pyridine and its derivatives were suggested as possible nitrite substitutes to fix meat color. During cooking in a gas oven, as little as 0.4 ppm of nitrogen dioxide gas caused pinking of turkey roll, but the solubility of nitrogen monoxide gas at meat surfaces was much lower than that of nitrogen dioxide (36). Ahn and Maurer (37) reported that binding of denatured ferrocyanochrome c with several ligands could form the pink color of turkey breast. The pinking in poultry was inhibited by the addition of some ingredients such as nonfat dry milk or citric acid (38). Phosphates increased the heat stability of myoglobin due to increased pH and decreased heat stability of cytochrome c (39). Salt was also reported to decrease the heat stability of myoglobin but increased the stability of cytochrome c (39).

Effect of pH on meat color The ultimate pH of muscle has a strong relationship with the color of meat (40). A low ultimate pH enhances unfolding of globin moiety, and heat and low pH combination enhances autoxidation of myoglobin and is responsible for color fading observed in pale-soft-exudative (PSE) pork. The paleness of PSE meat is caused by high proportion of extracellular free water, which increases the intensity of reflection. The color intensity of PSE meat is greatly reduced and L-value (lightness) increased (16, 41).

The color of meat with high ultimate pH is usually darker than normal meat. In dark-cutting beef (dark-firm-dry, DFD), the high pH accelerates respiratory activity of the tissue and formation of purple deoxymyoglobin (27). Dark-cutting beef had lower oxidation-reduction potential than controls (42), but it can be autoxidized more rapidly than normal meat. The high pH of meat also can influence the meat color after cooking. Schmidt and Trout (43) reported that persistent pinking in ground beef, pork, and turkey was caused by high pH, which inhibited the formation of a normal brown cooked color, especially in beef. Ground beef patties with higher pH had redder appearance than normal meat when cooked because lower amount of myoglobin was denatured at higher pH (43, 44).

Color changes in irradiated meat

Irradiated meat color Irradiation is an emerging technology to control pathogenic microorganisms in raw meat, but can influence color of meat significantly. When water was mixed with metmyoglobin and gamma-irradiated, the color of the solution became red (45). Gamma-irradiation converted the brown metmyoglobin to a red pigment, which is similar but not identical to oxymyoglobin (10). The color changes in irradiated meat vary depending on various factors such as irradiation dose, animal species, muscle type, and packaging conditions (10-13, 46). Paul et al. (47) showed that freshly ground mutton irradiated at 2.5 K Gy had better color than nonirradiated samples. Millar et al. (46) found that irradiated chicken breasts had a definite color change from usual brown or purple to a more vivid pink or red as a result of 5.0 kGy ionizing irradiation in oxygen-permeable film. Irradiation of pork Biceps femoris, Semitendinosus, and Semimembranosus muscles in vacuum packaging increased the redness of those muscles (48). Irradiation increased the redness of pork Longissimus dorsi muscle, but decreased that of Psoas major and femoris muscles in vacuum packaging (49). Jo et al. (50) found a significant increase in redness of cooked pork sausages after irradiation. Irradiation made the color of pork loin and poultry breast meat redder or pinker, but turned the color of beef loin into greenish brown (51).

Irradiation increased redness regardless of pork-quality type, and the increases were proportional to irradiation dose (52, 53). Irradiation and subsequent storage of pork improved the red color even in PSE pork, indicating that irradiation can be used to increase the acceptability of low-quality pork (53).

Packaging environment is an important factor that influences the color of irradiated meat during storage. Irradiated pork loin muscle showed increased redness, and the red color was stable during refrigerated storage even under aerobic conditions (51). The red color formed in pork steaks by irradiation, however, was more intense and stable under anaerobic than aerobic conditions (12). Irradiation increased the a-value of both aerobically and vacuum-packaged turkey breast, but vacuum-packaged meat was redder than aerobically packaged meat and was stable during storage (54, 55). Nanke et al. (13) reported that irradiated raw pork and turkey became redder in anaerobic conditions, and their reflectance spectra showed that irradiation induced the formation of an oxymyoglobin-like pigment in pork. During the frozen storage, irradiation increased pink color in both aerobically and vacuum-packaged turkey breast, and the pink color was stable (56).

Sensory evaluations of irradiated raw turkey breast meat indicated that sensory panelists preferred the red color of irradiated meats to nonirradiated ones (57, 58). If the red color of irradiated meats persists in meat after cooking, however, the meat is not acceptable. Tappel (59) noted that when precooked meat was irradiated, the normal gray-brown hematin pigments were converted to red pigments. The brown color of cooked meat is partially converted to red by ionizing radiation. The increased red color in cooked meat is considered as a defect, but little information on the consumer response to the color of irradiated meat is available.

Ligand-forming compounds in irradiated meat

Many ligands can bind to the iron atom in heme-ring of myoglobin and increase color intensity of meat (60). Binding of ligand to heme pigment is decided by the oxidation status of heme iron, and the ligands formed with ferrous heme iron produce stronger red color intensity than those with ferric heme iron. Thus, any conditions that change the status of heme-iron and that produce ligand compounds in meat can influence color of meat. Myoglobin exhibits marked difference in reactivity toward diatomic ligands such as oxygen, nitric oxide and carbon monoxide, and
the affinity of CO to ferrous myoglobin was 100 times greater than that of metmyoglobin (61). Natural heme pigments can make ligands with small gaseous compounds such as O₂, CO and NO, but heat-denatured myoglobin (e.g., one in cooked meats) can form ligands with larger molecules such as proteins, nicotinamide, nicotinic acid and pyridine and produce pink color under reducing conditions (31, 62-66). Furthermore, higher cooking endpoint temperatures, slower chilling rates, and increased storage time promoted the pink defect formed by nicotinamide-denatured globin hemochromes (63). Ahn and Maurer (37) reported that the binding of denatured ferrocytochrome c with several ligands could form the pink color of turkey breast.

Irradiation also produces ligand-forming compounds that can act as a sixth ligand of myoglobin. Giddings and Markakis (67) reported that hydrogen peroxide and other radiolytic products of water were responsible for the production of ferrylmyoglobin, which was produced from irradiated metmyoglobin. Thiol is particularly susceptible to attack by free radicals and hydrogen sulfide was produced when cysteine was irradiated (68). Swallow (69) noted that when sulfhydryl group and peptide bonds were attacked by hydrated electrons, gas compounds such as hydrogen sulfide and ammonia were produced. At medium-dose level of irradiation, the three-dimensional structure of proteins can be denatured, and irradiation can break the hydrogen bonds and other linkages of protein at high dose level resulting in denaturation. Brown and Akyounoglu (70) proposed that gamma irradiation split small peptides from globin protein and induced deamination from myoglobin molecule. Green pigment was formed during gamma-irradiation of meat because of hydrosulfide produced from glutathione or thiol-containing compounds (71). Satterlee et al. (10) suggested that the red pigment after irradiation could be formed by the loss of amide nitrogen from heme protein and the addition of the compound to heme iron. Cornforth et al. (72) suggested that irradiation might produce nitric oxide or other precursors to the cured meat pigment, nitrosyl hemochrome, particularly if nitrite or nitrate ions are present. Thomas (73) noted that nitric oxide radical could be generated from nitrogen-containing amino acids side chain (e.g., arginine, glutamine) by an oxidative stress such as irradiation. Furuta et al. (74) reported that considerable amounts of carbon monoxide were produced by radiolysis of organic components in irradiated frozen meat and poultry. Carbon monoxide can be produced from various types of organic compounds such as alcohols, aldehydes, ketones, carboxylic acids, amides, and esters as a radiolytic product (68). The production of CO in meat was proportional to irradiation dose in turkey breast meat (54, 55). Radiolytic carbon dioxide can be produced from carboxylic fatty acids and esters, and hydrogen, carbon monoxide and methane are largely formed from acetone at extremely high electron dose rates (75). Low concentration (0.4%) of carbon monoxide in modified atmosphere packaging resulted in higher a* values in beef and pork (76).

Oxidation-reduction potential in irradiated meat. The redox potential of meat is related to NADH as coenzyme, which facilitates the conversion of ferrymyoglobin to its ferrous form (77). Once meat is oxidized by longer storage, however, it is difficult to revert meat to reducing conditions. Once the reducing equivalence in the meat is exhausted, complete metmyoglobin formation occurs (78). Because the color intensity of ferrous heme pigment is stronger than that of the ferric state, oxidation-reduction potential of meat is very important for color changes.

The redox properties of irradiated meats were shifted towards more reducing conditions (79). Shahidi et al. (11) proposed that irradiation might increase the reducing potential of sodium ascorbate, and freshly irradiated pork patties had higher Hunter a*-values than nonirradiated patties in vacuum packaging. Irradiation decreased the oxidation-reduction potential, which provided more reduced environments to the heme pigments in turkey breast (54, 55). Ionizing radiation has a sufficient energy to activate orbital electrons from atoms when it passes through meat. This incidence can cause secondary electrons to be ejected and generate charged radicals, and various radiolytic radicals could be produced from water. Hydrogen electrons (aqueous e⁻), a radiolytic radical, can act as a powerful reducing agent and react with ferricytochrome to produce ferrocytochrome (69). Irradiated meats need reducing conditions to maintain heme iron in ferrous state. Giddings and Markakis (67) proposed that oxymyoglobin-like pigment was formed by the reduction of heme iron by a radiolytic water product, hydrated electron, and the oxygenation from either residual oxygen or generated oxygen during irradiation.

Heme pigments in irradiated meat. Hydrogen peroxide and other radiolytic products of water were reported to be responsible for the production of ferrylmyoglobin from irradiated metmyoglobin (67). Tappel (80) found a bright red color after gamma irradiating fresh meat in an inert atmosphere, and postulated that this bright red pigment was oxymyoglobin formed by the reaction between metmyoglobin and hydroxyl radicals. Nanne et al. (13, 48) also speculated that the red color produced in irradiated raw pork and turkey as an oxymyoglobin-like pigment. The red pigment, however, cannot be an oxymyoglobin because the red color formed by irradiation has been produced mainly in anoxic conditions. Satterlee et al. (10) reported that the presence of air inhibited the formation of red color in irradiated bovine metmyoglobin solutions. Millar et al. (46) postulated that the red/pink color in irradiated meat was due to a ferrous myoglobin derivative such as carboxy-myoglobin or nitric oxide-myoglobin other than oxymyoglobin. For red pigments to be expressed in irradiated meat, reduced conditions are needed to maintain heme-iron in ferrous state. The production of carbon monoxide in meat was proportional to irradiation dose and irradiation provided more reduced environments to the heme pigments in turkey breast (54, 55). Nam and Ahn (54, 55) suggested that increased a*-values (redness) in irradiated turkey breast were caused by the decreased redox potential and heme
pigment-CO ligand formation.

The spectra of myoglobin derivatives vary considerably depending on the states of heme-iron and the molecule bound to the sixth ligand of heme iron. Satterlee et al. (10) reported that the red pigment formed by gamma irradiation of bovine metmyoglobin had absorption maxima at 580, 540, and 412 nm. They also noted that this compound was similar to oxymyoglobin in its absorption maxima at 580 and 540 nm, but not identical to oxymyoglobin, which has an absorption maximum at 420 nm. Nam and Ahn (54) found that the absorption spectra of meat drip from irradiated turkey breast were similar absorption maxima to that of CO-myoglobin (absorption maxima at 541 and 577 nm) and concluded that CO-myoglobin was the major heme pigment responsible for the red or pink color in irradiated turkey breast. The reflectance of meat and the absorption spectra of myoglobin solution supported the conclusion that the CO-myoglobin was the pigment in irradiated precooked turkey breast (55). Only one type of pigment, however, cannot explain all irradiated meat colors. Much more specific identification will be needed under various specific conditions such as meat species, muscle type, pH and packaging environments.

Prevention of off-color

Non-meat additives Several chelators have been tested in an attempt to reduce the pink defects in poultry meat. Schwarz et al. (81) reported that pink color in cooked uncurd ground turkey was successfully inhibited by the addition of 3% nonfat dry milk in the presence of pink generating ingredients (150 ppm nitrite and 1% nicotinamide). Of the 14 ingredients evaluated, trans 1,2-diaminocyclohexane-N,N, N,N-tetraacetic acid monohydrate (CDTA), diethylenetriamine pentacetic acid (DTPA), ethylenedinitrilo-tetraacetic acid disodium salt (EDTA), and nonfat dry milk were the most effective in reducing the pink defect in samples produced with added nicotinamide or nitrate. These chelators have the potential to bind heme iron, particularly upon unfolding or denaturation of the globin during heat processing. Dairy proteins including nonfat dry milk, sodium caseinate, whey protein concentrates, and milk protein concentrates were evaluated for their ability to reduce pink color in ground turkey samples and all of the dairy proteins reduced a*-values in nicotinamide treated samples (82, 83). These authors found that whey protein concentrates at 1.5% level was effective in reducing a*-value regardless of ligand treatment, whereas sodium caseinate was not.

Acid is commonly used as a preservative in meat further processing (84). Incorporation of 0.3% citric acid to ground turkey reduced the pinkness of nicotinamide (1%)-treated and sodium nitrite (10 ppm)-treated cooked samples by 63% and 43% compared with the control, respectively (85). Polyphosphates like sodium tripolyphosphate are excellent metal chelators and inhibitors against lipid oxidation. However, when added to raw meat, they are ineffective due to rapid hydrolysis to monophosphate by endogenous phosphatase enzymes (86). Food-grade oxidants were compared for prevention of undesirable raw appearance of cooked dark-cutting beef patties (44). Lactic acid showed acceptable cooked appearance and increased myoglobin denaturation during cooking, but produced a tangy off-flavor. Calcium peroxide increased myoglobin denaturation by 69%, but caused excessive oxidation. Addition of acid to meat lowers the pH and also increases the lightness of meat. The addition of citric or ascorbic acid did not affect the a*-values of irradiated meat but increased the L-values, resulting in lighter overall color impression to meat (87).

Antioxidants added to nonirradiated fresh and further processed meat prevented oxidative rancidity, retarded development of off-flavors, and improved color stability (88, 89). Antioxidants may be effective in controlling and reducing the discoloration of irradiated meat because they either produce reducing conditions or scavenge free radicals. Vitamin E functions as a lipid-soluble antioxidant and is capable of quenching free radicals in meat during storage (90). Some phenolic compounds are believed to interrupt autoxidation of lipids either by donating hydrogen atom or quenching free radicals. Therefore, addition of phenolic antioxidants may be effective in reducing the oxidative reactions in irradiated meat by scavenging free radicals produced by irradiation (91).

Packaging conditions Packaging with high oxygen partial pressure can extend the shelf life of fresh meat color (92). At high oxygen tension, oxymyoglobin can persist for several days before discoloration occurs. Vacuum-packaged meats have mainly purple deoxymyoglobin if the partial oxygen pressure reaches zero (93). Attempts are made to utilize anoxic atmospheres in master packs for shipment to retail and subsequent display the meat cuts in traditional oxygen-permeable packaging to improve blooming. Failure to remove oxygen (to less than 1%) completely, however, can result in oxidizing conditions associated with low partial oxygen pressure. The use of modified atmosphere packaging can discolored fresh meat because the inner gases such as carbon dioxide or nitrogen lowers the pH or oxygen partial pressure and results in brown color (8). Low pH also facilitates oxidation of myoglobin to metmyoglobin. Therefore, the discoloration concepts can be utilized to prevent the chances of ligand formation and to decrease pink color intensity previously described in pink color defects. The impacts of irradiation on meat color are related to oxygen availability and the amount of free radicals formed at the time of irradiation. Nanke et al. (13) reported that irradiated meat in aerobic packaging discolor more rapidly than nonirradiated samples during display. In general, vacuum packaging or controlled atmosphere packaging is satisfactory measure in preventing color and rancidity problems in nonirradiated raw meat during storage. In irradiated meat, vacuum packaging was better than aerobic packaging in preventing lipid oxidation and oxidation-dependent volatile production, but increased pink color intensity during frozen storage (56, 94). Aerobic packaging was more desirable for the irradiated meat color than vacuum packaging if lipid oxidation can be controlled (4,
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6, 95). Exposing meat samples to aerobic conditions for a certain period of time was helpful in reducing irradiation off-color because of competition between atmospheric oxygen and carbon monoxide produced by irradiation (87, 95). Exposing irradiated meats to aerobic conditions increased oxidation-reduction potential and increased the competition of CO with O₂, which decreased the chances for CO-Mb ligand formation, and thus, pink color intensity (95). Vacuum packaging is an excellent strategy to inhibit lipid oxidation in meat during storage because oxygen is essential for the progress of lipid oxidation (5). An appropriate combination of aerobic and anaerobic packaging conditions (e.g., double packaging) was effective in minimizing both off-odor volatiles and lipid oxidation in irradiated raw turkey breast during the storage, and it also was effective in reducing the generation of pink color in irradiated meat compared to vacuum packaging alone (95, 96). The term “double packaging” is to describe a packaging method in which meat pieces are individually packaged in oxygen permeable bags at first and then a few of them are vacuum packaged in a larger vacuum bag. After certain period of storage time, the outer vacuum bag is removed and stored until the last day of storage. The use of double packaging alone, however, was not enough to reduce red or pink color of irradiated turkey meat to the level of nonirradiated meat (87, 95). Currently, FDA/USDA regulations allow no additives added in meat before irradiation, and the double-packaging concept is an attempt to minimize odor and color problems in irradiated raw meat without adding any additives. However, when a new petition, which will allow the use of irradiation in meat with additives, is approved, this double packaging concept can be used in combination with other additives such as antioxidants, acids, or gas absorbers in both raw and ready-to-eat cooked meat products (96). Gallate plus α-tocopherol or sesamol plus α-tocopherol along with double packaging was very effective in reducing red color of irradiated meat during storage and after cooking (96). Therefore, the combinational use of antioxidant and double packaging can be a useful strategy to control the color of irradiated raw and cooked meat (95, 96).

References


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