EFFECTS OF DIETARY OXIDATION, PACKAGE AND IRRADIATION ON THE OXIDATIVE STABILITY IN BROILER CHICKEN PATTIES

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Abstract—This study was designed to evaluate the effects of dietary oxidation, package, and irradiation singly or in combination on the oxidative stability in thigh patties of broiler chicken. One hundred and twenty broiler chicks were fed a standard corn-soybean ration for 28 days. On day 29, chicks were assigned to 3 groups and raised for 2 weeks. The control group was fed with a diet containing fresh animal-vegetable fat blend with 25 IU vitamin E. The oxidized group was a diet containing the same animal-vegetable fat blend with thermal oxidation (PV=100). The antioxidants fortified group was fed with a diet containing fresh animal-vegetable fat blend with 500 IU vitamin E plus 200 ppm BHA. Meats were ground and patties were prepared and either oxygen-permeable packaged or vacuum-packaged. The samples were irridiated at the dose of 0 or 3 kGy. Lipid oxidation, protein oxidation, and color were measured at 24 h after irradiation. Oxidized diet significantly increased lipid ($p < 0.001$) and protein oxidation ($p < 0.001$), while antioxidants diet decreased lipid ($p < 0.001$) and protein oxidation ($p < 0.001$) of thigh meat patties. Samples treated with vacuum package had lower levels of lipid and protein oxidation than oxygen-permeable package ($p < 0.001$). Irradiation significantly increasd the degree of lipid and protein oxidation ($p < 0.001$). Significant interactions were found among diet, package and irradiation on TBARS ($p < 0.05$). A significant interaction on protein oxidation was only detected between package and irradiation ($p < 0.001$). These results indicated that oxidized diet had negative effects on chicken thigh meat evidenced by increased lipid and protein oxidation. Dietary antioxidants supplementation significantly decreased lipid and protein oxidation of chicken thigh patties. Therefore, combination of dietary antioxidants and vaccum package may help minimizing oxidative changes by irradiation.

***Index Terms*—Antioxidant, irradiation, protein and lipid oxidation**

I. INTRODUCTION

Oxidative deterioration including lipid and protein oxidation is a major problem for poultry industry. The adverse effects of oxidation are not only involved in the economic loss but also related to the quality decline, nutritional loss and health risks (Jensen, Enberg, Jakobsen, Skibsted & Bertelsen, 1997). Several intrinsic and extrinsic factors can affect oxidative stability of meat such as the content and composition of unsaturated fatty acid, the concentration and activity of antioxidant substances in meat muscle, and post-slaughter processing and treatments including storage temperature, restructuring, nonmeat ingredient, atmospherical packaging and irradiation (Decker, Faustman & Lopez-Bote, 2000). Use of dietary strategy to improve the oxidative stability of chicken meat is extensively studied. Dietary supplementation of vitamin E (α-tocopherol) is well accepted and is an effective method to minimize lipid oxidation and extend shelf-life of chicken meat during storage (Ann & Patrick, 1996).

In order to meet the high energy demand for fast growth rate, addition of oils or fats to broiler chicken diet is common. However, this could increase the dietary susceptibility to lipid oxidation, which may eventually influence the oxidation and storage stability of chicken meat (Galvin, Morrissey & Buckley, 1997). Oxygen is the most common and essential component for the progress of lipid oxidation. Restructuring, in particular, comminution increases lipid exposure to air. Many studies showed that vacuum package (Ahn, Ajuyah, Wolfe, & Sim, 1993) or oxygen-depleted modified atmosphere packaging decreased lipid oxidation during storage (Phillips, 1996).

With the approval of irradiation as a preservation tool to pasteurize poultry, the concern about negative quality changes (color, odor, lipid oxidation) accompanying with irradiation has been raised. Some technologies are used to minimize the negative effect of irradiation on poultry meat quality, which include adding antioxidant substances to poultry diet, modifying package method, and supplementing antioxidants to meat during processing (Ahn, Sell, Jo, Chen, Wu & Lee, 1998; Lee & Ahn, 2005).

Recent studies showed that lipid oxidation can produce reactive oxygen species which can modify many intracellular and membrane proteins in muscle. Formation of carbonyls is one of the most prominent changes in oxidized muscle proteins (Davies, 2005). Unfortunately, the information about how dietary treatments, package, and irradiation influence protein oxidation in meat is quite limited. In fact, protein (including myoglobin) in whole muscle are also susceptible to oxidation during storage because of depletion of endogenous antioxidant (Decker, Faustman & Lopez-Bote, 2000). The purpose of this study is to evaluate the effects of dietary addition of vitamin E or oxidized oil, irradiation and different packages on the oxidative stability of broiler chicken thigh patties.

II. MATERIALS AND METHODS

2.1 Animal and diet

One hundred and twenty 1-day-old commercial broiler chicks were fed with a standard broiler corn-soybean diet for 28 days. On the 29th day, 10 broilers were assigned into each of 12 floor pens. Four floor pens were randomly allotted to one of 3 experimental diets. All three diets were prepared using animal-vegetable fat blend (5%). Control diet was prepared with fresh animal-vegetable fat blend with 25 IU vitamin E, oxidized diet was prepared after oxidizing the same animal-vegetable fat by heating to PV value of 100, and antioxidants fortified diet was prepared with the fresh animal-vegetable fat supplemented with butylated hydroxyanisole (BHA 200 ppm) and vitamin E (500 IU). Each of the diet was fed to the broilers for 2 weeks with free access to water and diet.

2.2 Sample preparation

At the end of the feeding trial, eight birds per pen were randomly selected and slaughtered following USDA guidelines (USDA, 1982). Thigh muscles from each pen were chilled in ice water for 2 h, drained in a cold room, deboned from the carcasses at 24 h after slaughter. The thigh samples from each treatment were pooled, ground twice using a 3-mm plate. Thigh patties (approximately 100 g) were prepared from each pen of the pooled ground thigh meat as a replication. The patties from each treatment were packaged in oxygen-permeable bags (polyethylene, 4*6, 2 MIL, Associated Bag Company, Milwaukee, WI) and irradiated with accelerated electrons using a Linear Accelerator (Circe IIIR, Thomson CSF Linac, Saint-Aubin, France) to reach an average dose of 0 or 3.0 kGy. Irradiated samples were oxygen-permeable packaged or vacuum packaged storage in refrigerator for 1 day. Color, lipid oxidation and protein oxidation were determined.

2.3 Lipid oxidation

Lipid oxidation was determined by a TBARS method (Ahn, Sell, Jo, Chen, Wu & Lee, 1998). TBARS were expressed as mg of malondialdehyde (MDA) per kg of meat.

2.4 Protein oxidation

Protein carbonyl content was measured by derivatization with 2,4-dinitrophenylhydrazine (DNPH) as described by Lund, Hviid, Claudi-Magnussen and Skibsted (2008) with minor modification. The carbonyl content was calculated as nmol/mg protein using an absorption coefficient of 22,000 $M^{-1}cm^{-1}$ as described by Levine, Williams, Stadtman and Shacter (1994).

2.5 Color measurement

Color values were determined on the sample surface using a LabScan colorimeter (Hunter Associate Labs, Inc., Reston, VA) which had been calibrated against black and white reference tiles covered with the same packaging samples. The CIE L* (lightness), a* (redness) and b* (yellowness) values were obtained by an illuminant A (light source). Average two random readings from top and bottom locations on a sample surface for statistical analysis.

2.6 Statistical analysis

The experiment was a factorial design with three levels of diet, two levels of package and two levels of irradiation. Data were analyzed by the procedure of generalized linear model using SAS 9.1 software (SAS Institute, 1995). Mean values and standard error of the means (SEM) were reported.

III. RESULTS AND DISCUSSION

3.1 Lipid oxidation

The effects of diets, package and irradiation on TBARS value were presented in Table 1. Short-term (2 weeks) vitamin E supplementation resulted in decrease of lipid oxidation in thigh muscle ($p < 0.001$). These data agreed with the report of Zouari *et al*. (2010). Broilers fed with oxidized diet showed increased levels of TBARS in muscle. Similar result was documented by Galvin, Morrissey and Buckley (1997). Some studies shown that chicken muscle with vacuum packaging had lower lipid oxidation level during storage (Conchillo, Ansorena & Astiasarán, 2003). In this study, vacuum packaging decreased the level of TBARS compared to oxygen-permeable package ($p < 0.001$). The TBARS value was significantly increased by irradiation, which was consistent with previous report (Du, Ahn, Nam & Sell, 2000). These results suggested that oxidation level of diet, packaging method and irradiation strongly influence the oxidative stability of broiler chicken thigh meat. It was observed that diet×package ($p = 0.0002$), diet×irradiation ($p = 0.0157$), package×irradiation ($p = 0.0001$), and diet×package×irradiation ($p = 0.0007$) had significant interactions on TBARS.

3.2 Protein oxidation

Previous study indicated that vitamin E supplementation had a small effect on carbonyl content of turkey muscle (Batifoulier, Mercier, Gatellier & Renerre, 2002). In this study, it was found that the dietary addition of vitamin E and oxidized oil significantly decreased or increased carbonyl content of chicken thigh patties ($p < 0.001$). Vacuum-

packaged samples had lower levels of protein oxidation than oxygen-permeable samples ($p < 0.001$). Irradiation also significantly increased the protein oxidation ($p < 0.001$). Packaging×irradiation had a significant interactive effect on carbonyl content ($p < 0.001$) (Table 4).

3.3 Color

Many factors can contribute to meat color such as the concentration of heme pigments, in particular myoglobin, oxidation status and ligand formation of heme pigments, and the physical characteristic (pH, temperature, storage time, etc.) of meat (Qiao, Fletcher, Smith & Northcutt, 2001). Some authors shown that lipid oxidation could promote myoglobin oxidation (Faustman, Specht, Malkus & Kinsman, 1992). Consequently, the factors affecting lipid oxidation in meat can also influence meat color. Dietary antioxidants supplementation increased the lightless (L*) of chicken thigh meat patties comparing to control group (Table 5). This was consistent with the lower level of lipid oxidation in antioxidants-supplemented diet. Oxygen-permeable package increased color redness (a*) and decreased color yellowness (b*) in chicken thigh patties. Previous studies showed that irradiation increased the redness of turkey (Nam *et al*., 2003). The results of present study indicated that irradiation decreased color lightness (L*) and redness (a*), and packaging×irradiation shown interactive impact on color redness (a*) and yellowness (b*) ($p < 0.05$).

IV. CONCLUSION

Dietary treatment can directly influence lipid and protein oxidation during refrigerated storage in broiler chicken. Vacuum packaging minimized both lipid and protein oxidation. Irradiation not only shows negative impacts on lipid oxidation but also iecreases protein oxidation. Furthermore, dietary oxidation, package and irradiation have interactive effects on the oxidative status of chicken thigh patties. This suggestes that appropriate use of dietary supplementation of antioxidants in combination with packaging could be effective in minimizing the adverse oxidative effects resulting from irradiation.

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REFERENCES

Ahn, D. U., Ajuyah, A., Wolfe, F. H., & Sim, J. S. (1993). Oxygen availability affects in prooxidant catalyzed lipid oxidation of cooked turkey patties. *Journal of Food Science*, *58*, 278-282.

Ahn, D. U., Sell, J. L., Jo, C., Chen, X., Wu, C., & Lee, J. I. (1998). Effects of dietary vitamin E supplementation on lipid oxidation and volatiles content of irradiated, cooked turkey meat patties with different packaging. *Poultry Science*, *77*, 912-920.

Ann, D. W., & Patrick, D. (1996). Studies on Vitamin E and meat quality. 2. Effect of feeding high vitamin E levels on chicken meat quality. *The Journal of Agriculture and Food Chemistry*, *44*, 1691-1696.

Batifoulier, F., Mercier, Y., Gatellier, P., & Renerre, M. (2002). Influence of vitamin E on lipid and protein oxidation induced by H_2O_2-activated MetMb in microsomal membranes from turkey muscle. *Meat Science*, *61*, 389-395.

Conchillo, A., Ansorena, D., & Astiasarán, I. (2003). Combined effect of cooking (grilling and roasting) and chilling storage (with and without Air) on lipid and cholesterol oxidation in chicken breast. *Journal of Food Protection*, *66*, 840-846.

Davies, M. J. (2005). The oxidative environment and protein damage. *Biochimica et Biophysica Acta*, *1703*, 93-109.

Decker, Eric. A., Faustman, C., & Lopez-Bote, C. J. (2000). Antioxidants in Muscle Foods: Nutritional Strategies to Improve Quality. Protein oxidation and implication for muscle food quality. In: Chapter 4, Protein oxidation and implications for muscle food quality (Xiong, Y. L), John Wiley and Sons, New York, pp. 85-112.

Du, M., Ahn, D. U., Nam, K. C., & Sell, J. L. (2000). Influence of dietary conjugated linoleic acid on volatile profiles, color and lipid oxidation of irradiated raw chicken meat. *Meat Science*, *56*, 387-395.

Faustman, C., Specht, S. M., Malkus, L. A., & Kinsman, D. M. (1992). Pigment oxidation in ground veal: Influence of lipid oxidation, iron and zinc. *Meat Science*, *31*, 351-362.

Galvin, K., Morrissey, P. A., & Buckley, D. J. (1997). Influence of dietary vitamin E and oxidised sunflower oil on the storage stability of cooked chicken muscle. *British Poultry Science, 38*, 499-504.

Jensen, C., Enberg, R., Jakobsen, K., Skibsted, L. H., & Bertelsen, G. (1997). Influence of the oxidative quality of dietary oil on broiler meat storage stability. *Meat Science*, *47*, 211-222.

Lee, E. J. & Ahn, D. U. (2005). Quality characteristics of irradiated turkey breast rolls formulated with plum extract. *Meat Science*, *71*, 300-305.

Levine, R. L., Williams, J. A., Stadtman, E. R., & Shacter, E. (1994). Carbonyl assays for determination of oxidatively modified proteins. *Methods in Enzymology*, *233*, 346-357.

Lund, M. N., Hviid, M. S., Claudi-Magnussen, C., & Skibsted, L. H. (2008). Effects of dietary soybean oil on lipid and protein oxidation in pork patties during chill storage. *Meat Science*, *79*, 727-733.

Nam, K. C., Min, B. R., Yan, H. J., Lee, E. J. Mendonca, A., Wesley, I., & Ahn, D. U. (2003). Effect of dietary vitamin E and irradiation on lipid oxidation, color, and volatiles of fresh and previously frozen turkey breast patties. *Meat Science*, *65*, 513-521.

Phillips, C. A. (1996). Review: modified atmosphere packaging and its effects on the microbiological quality and safety of produce. *International Journal of Food Science*, *31*, 463-479.

Qiao, M., Fletcher, D. L., Smith, D. P., & Northcutt, J. K. (2001). The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. *Poultry Science*, *80*, 676-680.

Zouari, N., Elgharbi, F., Fakhfakh, N., Bacha, A. B., Gargouri, Y., & Miled, N. (2010). Effect of dietary vitamin E supplementation on lipid and colour stability of chicken thigh meat. *African Journal of Biotechnology*, *9*, 2276-2283.

Table 1: Effects of dietary treatments, package and irradiation on lipid oxidation of chicken thigh patties*

Treatment	TBARS (mg MDA/kg meat)			SEM	*P*
Diet	Control	Oxidized	Antioxidant		
	0.027[b]	0.040[a]	0.020[c]	0.0024	*P*<0.05
Package	O_2-permeable	Vacuum			
	0.036[a]	0.022[b]		0.0019	*P*<0.001
Irradiation	0 kGy	3 kGy			
	0.014[b]	0.045[a]		0.0019	*P*<0.001

*: On the same row, means with different letters differ significantly.

Table 2: Effects of dietary treatments, package and irradiation on protein oxidation of chicken thigh patties*

Treatment	Carbonyl (nmol/mg protein)			SEM	*P*
Diet	Control	Oxidized	Antioxidant		
	0.43[b]	0.51[a]	0.30[c]	0.011	*P*<0.001
Package	O_2-permeable	Vacuum			
	0.46[a]	0.37[b]		0.0086	*P*<0.001
Irradiation	0 kGy	3 kGy			
	0.31[b]	0.52[a]		0.0086	*P*<0.001

*: On the same row, means with different letters differ significantly.

Table 3: The interactive effects on lipid oxidation of chicken thigh patties among diet, package and irradiation

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Diet×Package	2	0.00198954	0.00099477	11.14	0.0002
Diet×Irradiation	2	0.00083413	0.00041706	4.67	0.0157
Package×Irradiation	1	0.00170408	0.00170408	19.09	0.0001
Diet×Package×Irradiation	2	0.00160304	0.00080152	8.98	0.0007

Table 4: The interactive effects on protein oxidation of chicken thigh patties among diet, package and irradiation

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Diet×Package	2	0.01000462	0.00500231	2.80	0.0742
Diet×Irradiation	2	0.00766804	0.00383402	2.14	0.1319
Pack×Irradiation	1	0.04284075	0.04284075	23.96	<.0001
Diet×Package×Irradiation	2	0.00211212	0.00105606	0.59	0.5592

Table 5: Effects of dietary treatments, package and irradiation on color of chicken thigh patties**

Treatment				SEM	*P*
Diet	Control	Oxidized	Antioxidant		
L*	53.08[c]	54.81[a]	54.31[ab]	0.42	*P*<0.001
a*	13.14	13.02	12.79	0.20	NS***
b*	16.29	16.48	16.56	0.19	NS
Package	O_2-permeable	Vacuum			
L*	54.52	56.61		0.34	NS
a*	14.01[a]	11.96[b]		0.17	*P*<0.001
b*	17.11[a]	15.77[b]		0.15	*P*<0.001
Irradiation	0 kGy	3 kGy			NS
L*	55.06[a]	53.07[b]		0.34	*P*<0.001
a*	13.39[a]	12.57[b]		0.19	*P*<0.05
b*	18.78[a]	14.11[b]		0.15	*P*<0.001

**: On the same row, means with different letters differ significantly.
***: No significant difference in the same row at the level of $P<0.05$.