Effect of Irradiating Shell Eggs on Quality Attributes and Functional Properties of Yolk and White

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Summary and Implications

The color of egg yolk was not influenced but the viscosity of egg white was dramatically lowered and became watery by irradiation. The foam capacity and foam stability of egg white were significantly decreased due to protein oxidation by irradiation. However, the texture characteristics of egg white were not changed by irradiation, indicating that irradiation may not alter the thermal characteristics of egg white proteins. Sulfur volatiles were generated by irradiation but disappeared during storage under aerobic conditions. Because egg white became watery, irradiation may not be advisable for table eggs, but may be useful for pasteurizing liquid egg white or liquid whole egg without significant deterioration of their quality and functionality. Especially, the dramatic decrease in the viscosity of egg white by irradiation will improve flow of liquid egg white or liquid whole egg, which could be highly useful for egg processing. Therefore, further studies on egg irradiation should be focused on liquid eggs rather than table egg.

Introduction

Salmonellosis in humans caused by *Salmonella enteritidis* (SE) has steadily increased throughout the past decades in the U.S. The rate of SE infections has increased from 2.38 per 100,000 populations in 1985 to 3.9 per 100,000 in 1995. Although the rate has declined to 1.98 per 100,000 in 1999, no further reduction in the rate of infection has been observed since 2001. During 1985 ~ 1999, a total of 841 cases of Salmonellosis outbreaks accounted for 29,763 illness and 79 deaths, and 80% of outbreaks with a confirmed food vehicle were associated with shell eggs and egg-containing products. Investigations of SE sporadic infections and outbreaks have indicated that undercooked and raw shell eggs are a major cause of SE infections in humans.

Eggs usually become infected in the upper oviduct of SE-infected laying hens. SE not only contaminates the surface of the egg shell but also exists in egg yolk and white. Therefore, a before pasteurization process that can eliminate SE in egg yolk and white is necessary. Irradiation is the only non-thermal method that can efficiently eliminate food borne pathogens such as *Salmonella*, *E. coli* and *Listeria* inside shell eggs. *Salmonella* and other pathogens in egg yolks can be controlled by an irradiation dose above 2 kGy and SE in shell eggs and liquid whole eggs could be effectively reduced (approximately 4 $\log_{10}$) by1.5 kGy of irradiation.

The Food and Drug Administration (FDA) approved irradiation of shell eggs with doses up to 3 kGy. Irradiation is known to produce free radicals that can cause significant changes in quality and functional properties of egg and egg products. Irradiation increased the oxidation of polyunsaturated fatty acids and cholesterol, changed color, and destroyed carotenoids in dehydrated egg products. Irradiation of shell eggs substantially deteriorated the internal and sensory quality of eggs, decreased the viscosity of egg white, and partially degraded egg proteins. However, 2.5 kGy-irradiation did not cause substantial changes in physical, chemical, and functional properties such as color, protein degradation, protein solubility, and emulsion capacity of frozen liquid egg yolk. An irradiation dose of 1.5 kGy did not affect color and thermal characteristics of shell eggs and liquid whole eggs. Some even suggested that important functional properties such as whipping, emulsion, and thermal gelation properties of shell eggs and egg products could be improved by low-dose irradiation (1 ~3 kGy). Irradiated liquid egg white showed higher foaming stability and more stable viscosity than thermally pasteurized one.

Irradiation is considered the most effective decontamination technique for shell eggs and egg products, but its effects on the physicochemical and functional properties of shell eggs and liquid egg yolk and white are still controversial. The objective of this study was to determine the effects of irradiation on the quality attributes of egg yolk and white in shell eggs.

Materials and Methods

Sample Preparation

Eggs were placed on pulp cartons and irradiated at 1 or 2 kGy using a linear accelerator (Circe IIIR) with 10 MeV of energy, and 61.3 kGy/min of average dose rate. Because of the height of eggs, all eggs were irradiated twice; after the first irradiation, eggs were turned upside down for the second irradiation. Alanine dosimeters were attached on the top and bottom of an egg per each cart and the absorbed doses were measured by 104 Electron Paramagnetic Resonance Instrument. The ranges of absorbed doses were 1.286 ~ 1.301 kGy for 1 kGy and 2.110 ~ 2.182 kGy for 2 kGy, respectively. Nonirradiated control samples were brought into the irradiation facility to expose to the same

environment as the irradiated ones. After irradiation, all eggs were broken, yolk and white separated, and then stored at 4°C until used.

Color Determination of Egg Yolk

Color of egg yolk was determined using both an objective and a subjective method. For the objective color measurement, separated egg yolk was placed into zipper bags (polyethylene, 4" x 6", 2 mil) and CIELAB color values were read on the surface of the zipper bags containing egg yolk using a LabScan colorimeter. An illuminant A was used as a light source to determine the CIELAB color values of lightness (L^*), redness (a^*), and yellowness (b^*). For the subjective method, the color of unbroken egg yolk was measured using a 10-point Improved Roche Color Fan (IRCF). The number of the closest matching color in the IRCF was used as the designated color score of the yolk.

pH and Viscosity of Egg White

The pH of separated egg white was determined using a pH meter (Model 420Aplus) after diluting the samples with 9-volumes of distilled water. Brook Field Viscometer (Model DV-II+) with No. 1 RV spindle rotating at 100 rpm was used to measure the viscosity of egg white, 400 ml of which was placed in a 600-ml beaker at room temperature.

Protein Oxidation in Egg White

The concentration of protein carbonyls in egg white was measured for the estimation of protein oxidation. One milliliter of egg white was diluted with 19 ml deionized distilled water (DDW) and then homogenized using a polytron (Type PT 10/35) for 5 s at high speed. One milliliter of diluted egg white was divided into two aliquots of 0.5 ml. Proteins in both aliquots were precipitated with 0.5 ml of 20% tricholoroacetic acid (TCA). Both aliquots were centrifuged at 3,000 × g for 10 min and then supernatants discarded. The pellet of one aliquot was treated with 1 ml of 2N HCl and the other with 1 ml of 0.2% 2,4-dinitrophenylhydrazine (DNPH) in 2N HCl (w/v). The samples were placed at room temperature for 1 h with regular stirring, precipitated with 1 ml of 20 % TCA, and then centrifuged at 3000 × g for 10 min. The pellets were collected and washed twice with ethanol/ethyl acetate (1:1), dissolved in 2 ml of 6 M guanidine-HCl in 20 mM sodium phosphate buffer (pH 6.5), and then centrifuged at 3,000 × g for 10 min to remove insoluble debris. The absorbance of supernatants from HCl-treated and DNPH-treated samples were taken to obtain protein carbonyl content using the molar extinction coefficient of 21,000 M^{-1} cm^{-1} for protein hydrazone. Protein concentration was determined at 280 nm with HCl-treated samples, using bovine serum albumin (BSA) in the 6M guanidine solution as a standard.

Foaming Properties of Egg White

Fifty-gram of egg white was weighed and mixed in a KitchenAid mixer at maximum speed for 3 min. To determine specific density, the foam formed was transferred into a weighing dish whose volume was previously measured and then weighed. Foam stability was determined by measuring drainage after 30 min holding the foam at room temperature. Drainage was collected in a 100-ml graduated volumetric cylinder and the volume was read.

Texture Profiling and Sensory Analysis of Hard-cooked Egg White

One hundred milliliter of egg white was poured into a 25-mm diameter cellulose casing to produce sausage-like cylindrical sticks. The products were heated in boiling water for 18 min and then cooled down to room temperature. After peeling the casing, the products were cut into 2.0 cm-long pieces and used for texture profile analysis (TPA). Texture was measured using a Texture Analyzer (Model TA-XT2*i*) with a 25-kg loading cell and a cylinder probe (TA-4, 38-mm diameter) attached to a converter (TA-71). The samples were compressed by two repeated cycles with 70% compression of the height at 1 mm/s of a crosshead speed. Three pieces from each stick were taken and measured, and then the data from these three pieces were averaged. Hardness, springiness, cohesiveness, chewiness, and gumminess obtained from the TPA curve were reported.

A 14-member trained sensory panel evaluated the texture characteristics of hard-cooked egg white. Training sessions were conducted to familiarize panelists with terms for texture characteristics. Hard-cooked egg white pieces with the same size and shape as described in TPA were served to each panelist in isolated booths. Samples were served to the panelists in random order after the sample was adjusted to room temperature. The panelists marked the intensity of each texture characteristic on a 15-cm unstructured line anchored from "very soft" to "very hard" for hardness, from "none" to "extremely cohesive" for cohesiveness, from "weak" to "extremely strong" for elasticity, and from "not acceptable" to "highly acceptable" for overall acceptance of texture. Volatiles from egg white were analyzed using a dynamic headspace GC/MS method.

Statistical Analysis

This study was conducted using a completely randomized design with 4 replications except for volatile analysis and the data were analyzed using a JMP software provided by SAS Institute Inc. Data were reported as means and standard error of the means (SEM). Tukey's method ($P \leq 0.05$) was used to compare the means of each treatment.

Results and Discussion

The yellowness (CIELAB b* value) was significantly decreased with the increase of irradiation dose, but

Improved Roche Color Fan (IRCF) values for egg yolks were not significantly changed by irradiation (Table 1). The changes in yellowness of egg yolks could be caused by the breakdown of carotenoids in egg yolks by irradiation. The b*-values between nonirradiated and irradiated egg yolk were significantly different but people could not recognize the differences. There might be certain threshold values for the organoleptic sensitivity of humans, which differs from that of instruments. Therefore, we suggest that irradiation dose up to 2 kGy does not cause significant color changes in egg yolks.

Irradiation did not change the pH of egg white (Table 2). The pH of egg white (pH = ~ 9) measured in this study was higher than that (pH = 7.6 ~ 8.5) of newly laid eggs. The pH of egg white during storage of shell eggs increases to a maximum value of pH ~ 9.7 because of the evacuation of CO_2 gas through pores in the shell. This indicated that irradiation did not affect the pore structure of the egg shell. Total carbonyl contents in egg white proteins increased with the increase of irradiation dose. Carbonyl contents can be considered as a marker for protein oxidation because amino acid residues. The free radicals produced by irradiation can cause protein oxidation, which can affect the structural and functional properties of proteins in egg white. Therefore, these changes in proteins may influence the physicochemical and functional properties of egg white.

The viscosity and foaming properties of liquid egg white from nonirradiated and irradiated shell eggs were shown in Table 3. The viscosity of egg white decreased dramatically by irradiation regardless of irradiation doses used. All egg white became watery even after irradiating shell eggs at 1.0 kGy, but the changes in the viscosity of egg white were independent to irradiation dose. Ovomucin plays an important role in the gel-like structure of egg white. It has been suggested that irradiation causes changes in carbohydrate and protein moieties involved in formation of ovomucin complex, resulting in a loss of gel-like structure. The dramatic decrease in the viscosity of egg white is an important physical change in egg by irradiation, which can be used in egg processing. Watery egg white will facilitate the separation of egg white and yolk and low viscosity can improve the flow of liquid egg white or liquid whole egg in the egg breaking plants.

Egg white is an excellent foaming agent. Both specific density and drainage of the foam formed from egg white significantly increased with the increase of irradiation dose (Table 3). The method for measuring specific density of foam is an indirect method for determining foam capacity. The foam stability was determined by measuring the volume of drain released from the foam in a given time. Thus, the data in Table 3 indicate that the foaming capability and foam stability of egg white decreased with the increase of irradiation dose. The formation of foam depends on the surface activity and film formation properties of protein components present in a food system. Therefore, the oxidative changes of proteins by irradiation, especially globulins, ovomucin, and lysozyme, would result in deterioration of foam properties in egg white. The formation of foam from egg white can be affected by various factors such as methods of beating, pretreatments, and addition of ingredients. Therefore, more studies are needed to determine the effect of irradiation on the functional properties of liquid egg white.

The texture profile analysis (TPA) showed that hardness, springiness (elasticity), cohesiveness, gumminess, and chewiness of irradiated cooked egg white were not different from that of nonirradiated (Table 4). Sensory analysis also could not detect any texture differences between irradiated and nonirradiated hard-cooked egg whites (Table 5). Therefore, we suggest that irradiation of shell eggs at < 2.0 kGy does not alter the thermal characteristics of egg white proteins.

Volatiles of egg white from nonirradiated and irradiated shell eggs were compared in Table 6. The amounts of several volatiles in nonirradiated egg white increased with the increase of irradiation dose, and several new volatiles were generated after irradiation. The amount of total volatiles generated from egg white irradiated at 2 kGy was significantly higher than that from nonirradiated and eggs irradiated at 1.0 kGy. Sulfur-containing compounds such as S-methyl thioacetate and dimethyl disulfide were newly generated by irradiation. Sulfur-containing compounds are highly irradiation-dependent and generated by the radiolysis of sulfur-containing amino acids. Many other volatiles can be formed from egg proteins and lipids by irradiation via the radiolytic degradation of amino acid side chain and the secondary reaction between products of the primary degradation. Sulfur compounds were responsible for irradiation off-odor in meat. However, the sulfur compounds produced by irradiation disappeared during storage under aerobic conditions because of their high volatility. Therefore, irradiation-dependent odor, which potentially exists in irradiated liquid egg white soon after irradiation, may be eliminated during processing under aerobic conditions.

Table 1. CIELAB color values and Improved Roche Color Fan values of egg yolk irradiated with different doses.[1]

	Nonirradiated	Irradiated		
Color values	Control	1 kGy	2 kGy	SEM
L*	54.89	55.57	56.95	0.82
a*	10.74[a]	10.04[ab]	9.81[b]	0.18
b*	75.00[a]	71.95[b]	71.83[b]	1.11
IRCF value[1]	8.83	8.33	7.88	0.44

[a-b]Means with different letters within the same row are significantly different ($P \leq 0.05$). n = 4.
[1]IRCF value = 10-point scale improved Roche Color Fan value
L*, a*, and b* = CIELAB lightness, redness; yellowness value, respectively.
SEM = Standard error of the means.

Table 2. pH and protein carbonyl content of liquid egg white irradiated with different doses.

	Nonirradiated	Irradiated		
Measurement	Control	1 kGy	2 kGy	SEM
pH	9.05	8.98	8.99	0.99
Protein oxidation[1]	4.40[b]	5.04[ab]	5.57[a]	0.19

[a-b]Means with different letters within the same row are significantly different ($P \leq 0.05$). n = 4.
[1]Unit of protein carbonyl content: nmol DNPH / mg protein
SEM = Standard error of the means.

Table 3. Viscosity and foaming properties of liquid egg white irradiated with different doses.

	Nonirradiated	Irradiated		
Measurement	Control	1 kGy	2 kGy	SEM
Viscosity (centipoise)	45.0[a]	25.4[b]	23.3[b]	0.63
Foam density (g/ml)	0.11[c]	0.14[b]	0.21[a]	0.01
Foam stability (ml)[1]	7.83[c]	11.70[b]	20.15[a]	0.87

[a-c]Means with different letters (a-d) within the same row are significantly different ($P \leq 0.05$).
n = 4.
[1]Foam stability: the volume of drainage
SEM = Standard error of the means.

Table 4. Texture profile analysis (TPA) of hard-cooked egg white made from liquid egg white irradiated with different doses.

Texture	Nonirradiated	Irradiated		
characteristics[*]	Control	1 kGy	2 kGy	SEM
Hardness	4.30	4.78	4.36	0.19
Springiness	0.88	0.88	0.86	0.01
Cohesiveness	0.23	0.25	0.18	0.02
Gumminess	1.05	1.26	0.84	0.12
Chewiness	0.92	1.10	0.73	0.10

n = 4. SEM = Standard error of the means.
[*]Unit: *hardness* (N, the peak force during the first compression cycle); *springiness* (the ratio of length between the first compression (L_1) and second compression (L_2): L_2/L_1); *cohesiveness* (the ratio of the area of work during the second (A_2) compression divided by the area of work during the first (A_1) compression: A_2/A_1); *chewiness* (hardness × cohesiveness × springiness).