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Effect of gamma radiation and cold storage on chemical and organoleptic properties and microbiological status of liquid egg white and yolk

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Abstract

This investigation aims to establish a feasible radiation dose for treating liquid egg white (LEW) and yolk (LEY) at room temperature to improve their microbial safety. Samples of LEW and LEY were subjected to gamma irradiation doses of 0,1,2,3 and 4 kGy at room temperature followed by storage at 4 ± 1 °C. Then the effects of irradiation and cold storage on proximate composition, pH, soluble protein and free sulfhydryl content (SH) were determined for LEW and LEY in addition to the contents of total carotenoids in LEY. Moreover, free fatty acids (FFA) and peroxide value (PV) were determined for lipids of LEY.The microbial safety of LEW and LEY was established during storage throughout the enumeration of the total plate count, enterobacteriaceae, *Staphylococcus aureus* as well as the detection of *Salmonella*. The effects of irradiation at 3 kGy dose, which was enough for improving the microbial safety of samples, on amino acid composition of LEW and LEY and fatty acid profiles of LEY lipids were studied. In addition, sensory evaluation was carried out for liquid and scrambled egg white and egg yolk samples. The results showed that gamma irradiation and refrigerated storage had no significant effects on proximate composition and pH of liquid egg samples, while significantly decreased the contents of total carotenoids in LEY samples. Furthermore, gamma irradiation had no significant effects on protein solubility and the contents of free SH in LEW, while induced significant slight decreases in protein solubility and the contents of free SH in LEY. Cold storage, however, showed no significant effects on protein solubility and free SH in all liquid egg samples. FFA contents and PV of LEY lipids significantly increased post irradiation treatments and during storage, but the observed values were relatively low and acceptable. In addition, gamma irradiation at 3 kGy dose had no significant effects neither on the amino acid composition of LEW and LEY nor on fatty acid profiles of LEY lipids. The sensory preference did not alter neither for the liquid egg samples nor for scrambled egg samples that prepared from irradiated liquid egg products. Finally, gamma irradiation at 3 kGy dose appeared to be the optimum for treating LEW and LEY at room temperature followed by cold storage at 4 ± 1 °C.

Keywords: Liquid egg white; Liquid egg yolk; Irradiation; Chemical changes; Safety; Sensory properties

1. Introduction

Microbial contamination of eggs is a well-established phenomenon and has important economic implications to the poultry industry (Bruce & Drysdal, 1994; Wong & Kitts, 2003). In recent year, *Salmonella* in eggs has been a major problem for public health agencies and the risk of illness is more when the egg is used as an ingredient in a food that is eaten by many people rather than when it is a single egg (Todd, 2001). The egg becomes contaminated either prior to oviposition, with the source of contamination originating in the egg-laying apparatus of the bird, or after oviposition by penetration of the shell (Bruce & Drysdal, 1994 and Serrano, Murano, Shenoy, & Olson, 1997), therefore, eating of

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raw or under cooked eggs has been cited as the primary cause of human Salmonellosis (Serrano et al., 1997 and USDA, 1998).

There has been an increasing proportion of eggs that broken out for processing as liquid egg products (Ahn, Kim, & Shu, 1997). Pasteurization is the only commercial process used presently to eliminate pathogens from liquid egg products; however, heat pasteurization can affect the quality of egg products (Serrano et al., 1997). Food irradiation provides significant advantages to food producers by destroying harmful pathogens and extending shelf life of foodstuffs (Durante, 2002 and Morehouse, 2002). The increasing number of foodborne bacteria and their worldwide outbreaks, particularly *Salmonella*, has increased interest in food irradiation as an effective technique for the elimination of these bacteria. As a cold processing, the process of irradiation can be more attractive for eliminating pathogens in heat-sensitive products like eggs (Radomyski, Murano, Olson, & Murano, 1994).

Irradiation of egg products has been used experimentally as an alternative to heat pasteurization and to eliminate *Salmonella* in frozen liquid egg products (Huang, Herald, & Mueller, 1997 and Wong, Herald, & Hachmister, 1996). However, there has been a gradual shift from frozen liquid egg products to egg products for immediate consumption because of lower cost energy and consumer demand for egg availability. The possibility of storing irradiated liquid egg products at refrigerated temperature would save energy and be cost effective, while refrigerated liquid egg products is easier to handle than frozen products, and therefore is more convenient (Wong et al., 1996). The objectives of this study were to improve the microbial safety of liquid egg white and yolk by gamma irradiation at room temperature and studying the changes in their chemical and organoleptic properties due to gamma irradiation at room temperature followed by cold storage at 4 ± 1 °C, and to determine the effects of irradiation (at dose appeared to be enough for improving the microbial safety of samples) on amino acid composition of egg white and yolk and fatty acid profiles of egg yolk lipids.

2. Materials and methods

2.1. Preparation of liquid egg white and yolk samples

One-day-old unfertile chicken white eggs were obtained and all damaged or cracked eggs were discarded. Eggs were washed by tape water, lift to dry, and manually broken. Then the eggs were separated into albumin (the egg white) and yolk with rejecting egg showed any defects such as blood spot. Egg white was mixed by passing through a Buchner funnel and filtered through eight layers of cheesecloth. The yolk was carefully cleaned of the adhering white and the liquid yolk was collected into a beaker by puncturing the vitelline membrane (Ma, Sahasrabudhe, Poste, Harwalkar, & Chambers, 1990). Each of the observed mixed common pool for egg white and egg yolk was portioned off into smaller portions (~100 ml) in polyethylene pouches, which were immediately sealed by heat and transported for irradiation treatment.

2.2. Irradiation of samples

Samples of liquid egg white and yolk were gamma irradiated at doses of 0, 1, 2, 3 and 4 kGy using an experimental Co-60 source (providing a dose rate of 5.7 kGy^{-1} h) at the National Center for Radiation Research and Technology, Nasr City, Cairo, Egypt. Irradiation was carried out at room temperature, while the dose rate was established using reference Physical National Laboratory (PNL), dichromate dosimeter, UK (ISO/ASTM, 2002).

2.3. Storage and sampling for analysis

Irradiated and non-irradiated liquid egg products under investigation were cold stored at 4 ± 1 °C for 14 days (regardless of the shelf life of samples) and subjected to the periodical analysis at 2 days intervals, except for amino acids and fatty acids as well as the sensory evaluation for scrambled egg samples which determined for samples on day zero only. After hydrolysis (for the determination of amino acids) and methylation (for fatty acids) the observed hydrolyzates and fatty acid methyl esters were stored at −18 °C till the end of storage. Then the required chromatographic analyses for amino acid composition and fatty acid profiles were carried out for control non-irradiated samples and those irradiated at 3 kGy dose (which appeared to be enough for improving the microbial safety of samples during their cold storage). All analyses were carried out using three replicate experimental runs per each treatment.

2.4. Proximate composition and chemical properties of egg white and yolk

The contents of moisture, total protein and ash were determined according to AOAC official methods (1995), while total lipids were extracted and determined as described by Egan, Kirk, and Sawyer (1981). Protein solubility was determined as described by Hamid-Samimi, Swartzel, and Ball (1984). Free sulfhydryl contents were determined by the method of Beveridge, Toma, and Nakai (1974). pH was assessed as described by Egan et al. (1981). The contents of total carotenoids in samples of liquid egg yolk were determined spectrophotometrically according to AOAC official methods (1995). Quantitative determination of amino acids

was carried out according to the method described by Kerese (1984) and using high performance amino acid analyzer for the separation of amino acids, while tryptophan was determined colorimetrically according to the method of Opienska-Blauth, Charinski, and Berlie (1963).

2.5. Analyses of liquid egg yolk lipids

Free fatty acids and peroxide value were determined according to AOCS official methods (1998). For the determination of fatty acid profiles, fatty acids of egg yolk lipids were converted to their methyl esters (Anon, 1966), and the analysis of fatty acid methyl esters was accomplished using a PYE Unicam gas chromatograph (Model 4550) equipped with flam ionization detector. The fractionation of fatty acid methyl esters was conducted using coiled glass column (1.6 mm × 4 mm) packed with cromosorb C and coated with 10% polyethylene glycol adipate. The oven temperature was 180 °C, while the temperatures of injector and detector were 250 and 300 °C, respectively. The hydrogen, nitrogen and air flow rates were 33, 30 and 300 ml^{-1} min, respectively. The peak areas and retention times were measured using Spectra Physics 4719 integrator.

2.6. Microbial safety

The microbial safety of irradiated and non-irradiated liquid egg white and yolk was assessed during storage of samples at 4 ± 1 °C throughout the enumeration of the total plate count, enterobacteriaceae, *S. aureus* as well as the detection of *Salmonella*. At time of withdrawal from refrigerated storage, the outer surface of pouches was sterilized using cotton witted by 70% ethanol. Then 10 ml aliquots of well mixed liquid egg product were removed aseptically from each of the analyzed pouches to prepare the initial 1/10 dilution which was used for the preparation of the other serial dilutions in 0.1% peptone water. The total plate count was enumerated by plating on plate count agar medium and incubation at 30 °C for 3 days (APHA, 1992). Enterobacteriaceae were counted on violet red bile glucose agar medium after incubation for 20–24 h at 37 °C according to Roberts, Hooper, and Greenwood (1995). *S. aureus* was counted using Baird-Parker RPF medium after incubation at 35 °C for 24–48 h (Oxoid, 1998), and confirmed by the coagulase test according to Collins, Lyne, and Grange (1989). The detection of *Salmonella* was carried out for liquid egg products using the most probable number technique. After enrichment at 37 °C for 24 h in buffer peptone at first then in selenite broth, the cultures were streaked on Brilliant green agar and incubated at 37 °C for 24 h, and then colonies were biochemically examined in triple sugar iron agar and lysine decarboxylate broth (ISO, 1978).

2.7. Sensory evaluation

Samples, of irradiated and non-irradiated liquid egg white and yolk, were subjected to sensory evaluation for their appearance and color as well as their odor post treatments and during cold storage. Moreover, sensory evaluation was carried out for the odor and taste of the scrambled egg white as well as egg yolk, that prepared from irradiated and non-irradiated liquid egg samples, on day zero only for safety precautions. In all panel tests, the panelists consisted of 10 non-expert members of Food Irradiation Laboratory using the following 9-point quality scores: 9 = excellent, 7 = good, 5 = fair, 3 = poor and 1 = extremely poor as described by Wierbicki (1981).

2.8. Statistical analysis

The results were statistically analyzed by randomized complete block design using a microcomputer programme for the design, management and analysis of agronomic research experiments (MSTAT-C), while the means were compared by Duncan's multiple range test (Nissen, 1993).

3. Results and discussion

3.1. Proximate chemical composition

The analysis for proximate composition of non-irradiated liquid egg white and yolk showed that their moisture contents were 877 and 478 g kg^{-1}, respectively, while their contents of protein, lipids and ash were 910.3, 24.6 and 65.1 and 339.1, 622.5 and 38.4 g kg^{-1} (referred to dry matter), respectively. The observed proximate composition was nearly similar to other reported amounts (Potter, 1986), however, it is well documented that there were many factors influencing the composition of hen's egg (Stadelman & Pratt, 1989). Irradiating liquid egg white and yolk at room temperature had no significant effects ($P > 0.05$) on the proximate chemical composition of these liquid egg products. Similar findings were observed for irradiated frozen liquid egg white and yolk (Ma, Harwalkar, Poste, & Sahasrabudhe, 1993). Moreover, cold storage at 4 ± 1 °C could not significantly ($P > 0.05$) affect the proximate composition of liquid egg samples (data not presented).

3.2. pH

Samples of non-irradiated liquid egg white and yolk had a pH value of 8.47 and 5.90, respectively. The pH values of liquid egg white and yolk were not significantly ($P > 0.05$) changed neither post irradiation treatments nor during the acceptable storage life at 4 ± 1 °C. The

observed results disagree with those reported by Huang et al. (1997) who found that the pH of irradiated frozen egg yolk samples was significantly higher than of non-irradiated samples during the first 15 days of frozen storage.

3.3. Soluble protein

The contents of soluble protein in cold stored (4 ± 1 °C) irradiated and non-irradiated liquid egg products are shown in Table 1. Neither irradiation nor cold storage could significantly ($P > 0.05$) affect the solubility of protein in samples of liquid egg white. Regarding liquid egg yolk samples, irradiation treatments caused small loss, but significant ($P < 0.05$), in their protein solubility, however, there was no significant ($P > 0.05$) differences in protein solubility between samples irradiated at doses of 3 and 4 kGy. The initial loss in protein solubility of liquid egg yolk may be attributed to radiation-induced changes that resulted in less soluble aggregates in egg yolk. On the other hand, protein solubility in irradiated and non-irradiated liquid egg yolk showed no significant ($P > 0.05$) changes during storage at 4 ± 1 °C as shown in Table 1. Thus, storing liquid egg products at refrigeration temperatures has no effects on their soluble protein if compared with frozen storage which significantly decreased the soluble protein content in egg yolk due to freezing-induced aggregation or gelation in other previous studies (Huang et al., 1997).

3.4. Free sulfhydryl

The free sulfhydryl (SH) contents of liquid egg white was not affected significantly ($P > 0.05$) by irradiation treatments, while gamma irradiation was found to cause a significant ($P < 0.001$) decrease in the free SH contents of liquid egg yolk (Table 2). The decrease in free SH contents may be attributed to alteration in SS/SH exchange reaction or SH oxidation in the egg yolk and these results agree with other previous findings (Ma et al., 1990). Refrigerated storage of irradiated and non-irradiated liquid egg products showed no significant ($P > 0.05$) effects on their free SH contents (Table 2).

3.5. Total carotenoids

Irradiation of liquid egg yolk samples significantly ($P < 0.01$) decreased their contents of total carotenoids and there was an inverse effect between the applied irradiation dose and the contents of carotenoids in the egg yolk (Table 3). Furthermore, the same table indicates that cold storage (4 ± 1 °C) induced another significant ($P < 0.05$) decrease in the total carotenoids for both irradiated and non-irradiated liquid egg yolk samples. Carotenoids had been reported to be sensitive to irradiation (WHO, 1994) and susceptible to oxidation (DeMan, 1985). The obtained results agree with the findings of Katusin-Razem et al. (1989) with irradiated dried egg products.

3.6. Free fatty acids and peroxide value of liquid egg yolk

Irradiation of liquid egg yolk samples caused a significant ($P < 0.01$) increase in the contents of free fatty acids (FFA) of their lipids indicating the liberation of some free fatty acids due to irradiation (Table 4). The differences in FFA contents between samples irradiated at doses of 1,2 and 3 kGy were insignificant, however, the differences between FFA contents for these samples and those irradiated at 4 kGy were significant ($P < 0.01$). During storage of liquid egg samples at 4 ± 1 °C, further significant ($P < 0.01$) increases in FFA contents were observed for lipids separated from both irradiated and non-irradiated samples which may indicate the lipolytic activity during storage.

On the other hand, irradiation treatments caused significant ($P < 0.001$) increase in the peroxide value in the fatty component of liquid egg yolk and the peroxide value increased with increasing the applied dose (Table 5). This may be attributed to radiation-induced degrada-

Table 1
Soluble protein in irradiated and non-irradiated liquid egg white and yolk during cold storage (4 ± 1 °C)

Storage (days)	Amount (g kg^{-1} dry matter)/irradiation dose (kGy)									
	Liquid egg white					Liquid egg yolk				
	0.0	1.0	2.0	3.0	4.0	0.0	1.0	2.0	3.0	4.0
0	844.0^{a}	839.7^{abc}	842.0^{ab}	841.0^{abc}	839.7^{abc}	106.0^{a}	104.0^{bc}	99.7^{efgh}	97.0^{ijkl}	96.0^{klmn}
2	840.7^{abc}	840.0^{abc}	840.0^{abc}	839.7^{abc}	841.0^{abc}	106.0^{a}	104.0^{bc}	99.0^{fghi}	96.0^{klmn}	95.0^{lmno}
4	839.0^{abc}	839.0^{abc}	837.7^{abc}	939.7^{abc}	833.7^{c}	105.0^{a}	102.0^{cd}	98.7^{ghij}	95.7^{klmn}	95.0^{lmno}
6	R	834.7^{bc}	842.0^{ab}	834.7^{bc}	838.7^{abc}	R	101.7^{cde}	97.7^{hijk}	95.0^{lmno}	95.0^{lmno}
8	–	839.0^{abc}	838.0^{abc}	839.0^{abc}	835.0^{bc}	–	102.0^{cd}	97.3^{ijkl}	94.7^{mnop}	94.3 ^{nop}
10	–	839.7^{abc}	840.0^{abc}	840.0^{abc}	838.0^{abc}	–	100.7^{defg}	96.7^{jklm}	96.0^{klmn}	94.0^{nop}
12	–	839.0^{abc}	841.0^{abc}	839.0^{abc}	839.0^{abc}	–	100.7^{defg}	96.0^{klmn}	93.0^{op}	93.0 ^{op}
14	–	834.7^{bc}	838.0^{abc}	840.0^{abc}	841.7^{abc}	–	101.0 ^{def}	95.0 ^{mno}	93.0^{op}	92.7 ^{p}

Means with the same letter for each of liquid egg fractions are not differ significantly ($P > 0.05$).
Means with different letter for each of liquid egg fractions are differ significantly ($P < 0.001$).
R, rejected due to spoilage organoleptically and their values were discarded after statistical analysis.

Table 2
Free sulfhydryl (SH) in irradiated and non-irradiated liquid egg white and yolk during cold storage (4 ± 1 °C)

Storage (days)	Free SH (g kg^{-1})/irradiation dose (kGy)									
	Liquid egg white					Liquid egg yolk				
	0.0	1.0	2.0	3.0	4.0	0.0	1.0	2.0	3.0	4.0
0	43.07^{ab}	43.13^{a}	42.97^{ab}	43.03^{ab}	42.93^{ab}	7.82^{a}	7.63^{c}	7.59^{c}	7.45^{d}	7.18^{f}
2	42.83^{b}	43.07^{ab}	43.17^{a}	43.10^{ab}	42.93^{ab}	7.78^{ab}	7.63^{c}	7.60^{c}	7.42^{de}	7.14^{fg}
4	43.03^{ab}	43.00^{ab}	43.13^{a}	43.07^{ab}	43.1^{ab}	7.73^{b}	7.61^{c}	7.59^{c}	7.41^{de}	7.11^{ghi}
6	R	43.03^{ab}	43.07^{ab}	43.07^{ab}	43.07^{ab}	R	7.60^{c}	7.58^{c}	7.39^{e}	7.11^{ghi}
8	–	43.07^{ab}	43.07^{ab}	42.9^{ab}	43.13^{a}	–	7.59^{c}	7.59^{c}	7.43^{de}	7.13^{fgh}
10	–	43.03^{ab}	42.97^{ab}	43.07^{ab}	42.90^{ab}	–	7.61^{c}	7.59^{c}	7.38^{e}	7.11^{ig}
12	–	43.03^{ab}	43.10^{ab}	43.07^{ab}	43.03^{ab}	–	7.59^{c}	7.59^{c}	7.40^{de}	7.07^{ig}
14	–	43.13^{a}	43.13^{a}	43.03^{ab}	43.03^{ab}	–	7.60^{c}	7.58^{c}	7.38^{e}	7.11^{hig}

Means with the same letter for each of liquid egg fractions are not differ significantly ($P > 0.05$).
Means with different letter for each of liquid egg fractions are differ significantly ($P < 0.001$).
R, rejected due to spoilage organoleptically and their values were discarded after statistical analysis.

Table 3
Total carotenoids in liquid egg yolk as influenced by gamma irradiation and cold storage (4 ± 1 °C)

Storage (days)	Amount (mg kg^{-1} dry matter)/irradiation dose (kGy)				
	0.0	1.0	2.0	3.0	4.0
0	6.222^{A}	5.558^{I}	5.032^{Q}	4.331^{Y}	3.121^{g}
2	6.217^{B}	5.539^{J}	5.002^{R}	4.288^{Z}	3.084^{h}
4	6.211^{C}	5.521^{K}	4.972^{S}	4.244^{a}	3.044^{i}
6	(R)	5.501^{L}	4.942^{T}	4.202^{b}	3.002^{j}
8	–	5.481^{M}	4.912^{U}	4.156^{c}	2.955^{k}
10	–	5.459^{N}	4.882^{V}	4.108^{d}	2.910^{l}
12	–	5.439^{O}	4.852^{W}	4.056^{e}	2.863^{m}
14	–	5.417^{P}	4.819^{X}	4.001^{f}	2.813^{n}

Means with different letter are differ significantly ($P < 0.05$).
(R), rejected due to spoilage organoleptically and their values were discarded after statistical analysis.

Table 4
Free fatty acids (FFA) of lipids separated from irradiated and non-irradiated liquid yolk during cold storage (4 ± 1 °C)

Storage (days)	FFA (g kg^{-1} lipid)/irradiation dose (kGy)				
	0.0	1.0	2.0	3.0	4.0
0	21.3^{x}	21.7^{w}	22.5^{vw}	23.0^{tuv}	23.5^{qrs}
2	23.1^{stu}	22.9^{uv}	23.2^{stu}	23.5^{rst}	24.0^{opq}
4	25.8^{kl}	23.8^{pqr}	24.0^{opq}	24.3^{op}	24.5^{no}
6	R	25.4^{mn}	25.5^{kl}	25.3^{lm}	25.0^{lm}
8	–	25.9^{k}	26.8^{ij}	26.5^{j}	25.9^{k}
10	–	27.1^{hi}	28.0^{fg}	27.2^{hi}	27.1^{hi}
12	–	28.7^{de}	29.1^{cd}	28.2^{f}	27.5^{gh}
14	–	31.5^{a}	29.7^{b}	29.4^{bc}	28.4^{ef}

Means with the same letter are not differ significantly ($P > 0.05$).
Means with different letter are differ significantly ($P < 0.001$).
R, rejected due to spoilage organoleptically and their values were discarded after statistical analysis.

tion of the carotenoids as there was a noticeable parallelism in peroxide formation and the observed degradation of carotenoids. Refrigerated storage of both irradiated and non-irradiated liquid egg yolk samples induced further significant ($P < 0.001$) increases in the peroxide value of their lipids, however, all values were relatively low and acceptable.

Table 5
Peroxide value (PV) of lipids separated from irradiated and non-irradiated liquid egg yolk during cold storage (4 ± 1 °C)

Storage (days)	PV (Meq kg^{-1} lipid)/irradiation dose (kGy)				
	0.0	1.0	2.0	3.0	4.0
0	0.34^{v}	0.54^{t}	0.78^{q}	0.85^{p}	1.03^{m}
2	0.42^{u}	0.60^{s}	0.80^{pq}	0.96^{no}	1.22^{l}
4	0.46^{u}	0.72^{r}	0.92^{o}	1.21^{l}	1.39^{j}
6	R	0.79^{q}	0.98^{n}	1.41^{j}	1.67^{gh}
8	–	0.96^{no}	1.20^{l}	1.50^{I}	1.72^{g}
10	–	1.06^{m}	1.30^{k}	1.78^{f}	2.02^{d}
12	–	1.18^{l}	1.40^{j}	1.92^{e}	2.46^{b}
14	–	1.21^{l}	1.60^{h}	2.11^{c}	2.95^{a}

Means with the same letter are not differ significantly ($P > 0.05$).
Means with different letter are differ significantly ($P < 0.001$).
R, rejected due to spoilage organoleptically and their values were discarded after statistical analysis.

3.7. Microbial safety

The results in Table 6 reveal a high microbial contamination in both non-irradiated liquid egg fractions, in addition to presence of *Salmonella* in samples, even up to 2 kGy radiation dose. This may indicate the contamination of the egg shells with high levels of *Salmonella* and other bacteria, while washing was insufficient for complete disinfection of the shell. These bacteria may be transmitted into the liquid egg products during breaking procedure and the separation of the egg fractions. Moreover, it is also possible that some eggs were naturally infected by *Salmonella* before the egg was laid. Both yolk and albumen have been identified as potential sites for internal *Salmonella* infection in eggs (Braun & Fehlhaber, 1995, and Gast & Beard, 1990). It has been found that the counts of total mesophilic aerobes and *Salmonella* spp. in freshly prepared unpasteurized liquid egg were 2.3×10^9 and 1.5×10^8 cfu g^{-1}, respectively, while *Salmonella* was isolated at levels exceeded 10^7 g^{-1} from the contents of clean intact egg (Kijowski, Lesnierowski, Zabielski, Fiszer, & Magnuski, 1994 and Salvat, Protais, Lahellec, & Colin, 1991).

Table 6
Microbiological properties of irradiated and non-irradiated liquid egg white and yolk during storage at 4 ± 1 °C

Storage (days)	Microbial determination/irradiation dose (kGy)									
	Liquid egg white					Liquid egg yolk				
	0.0	1.0	2.0	3.0	4.0	0.0	1.0	2.0	3.0	4.0
Total plate count (Log$_{10}$ cfu ml^{-1})										
0	7.50^{L}	6.86^{P}	5.61^{X}	4.04^{d}	2.99^{e}	6.81^{J}	5.99^{Q}	4.93^{X}	3.96^{d}	2.92^{e}
2	7.80^{J}	6.94^{O}	5.75^{W}	4.14^{ed}	3.00^{e}	6.90^{H}	6.00^{P}	4.99^{W}	4.00^{d}	2.96^{e}
4	7.93^{H}	7.14^{N}	5.83^{V}	4.27^{bc}	3.04^{e}	7.00^{G}	6.25^{N}	5.20^{V}	4.14^{cd}	3.00^{e}
6	8.44^{E}	7.49^{M}	5.93^{U}	4.41^{ab}	3.07^{e}	7.56^{E}	6.47^{M}	5.50^{U}	4.27^{bc}	3.07^{e}
8	8.69^{D}	7.68^{K}	5.99^{T}	4.46^{a}	3.11^{e}	7.71^{D}	6.60^{L}	5.73^{T}	4.34^{b}	3.11^{e}
10	8.88^{C}	7.89^{I}	6.20^{S}	4.57^{Z}	3.14^{e}	7.90^{C}	6.70^{K}	5.89^{S}	4.46^{a}	3.14^{e}
12	8.98^{B}	7.98^{G}	6.54^{R}	4.69^{Y}	3.17^{e}	8.00^{B}	6.85^{I}	5.95^{R}	4.54^{Z}	3.20^{e}
14	9.23^{A}	8.25^{F}	6.79^{Q}	4.75^{Y}	3.23^{e}	8.32^{A}	7.04^{F}	6.07^{O}	4.66^{Y}	3.23^{e}
Enterobacteriaceae (Log$_{10}$ cfu ml^{-1})										
0	4.86^{I}	4.04^{P}	2.90^{R}	(N.D)	(N.D)	4.81^{I}	3.99^{N}	2.81^{O}	(N.D)	(N.D)
2	4.94^{G}	4.14^{O}	2.93^{R}	(N.D)	(N.D)	4.89^{G}	4.00^{N}	2.83^{O}	(N.D)	(N.D)
4	5.00^{F}	4.25^{N}	2.95^{R}	(N.D)	(N.D)	4.92^{F}	4.14^{M}	2.87^{O}	(N.D)	(N.D)
6	5.25^{E}	4.30^{M}	2.98^{QR}	(N.D)	(N.D)	5.11^{E}	4.25^{L}	2.92^{O}	(N.D)	(N.D)
8	5.50^{D}	4.38^{L}	3.04^{QR}	(N.D)	(N.D)	5.44^{D}	4.30^{L}	2.97^{O}	(N.D)	(N.D)
10	5.67^{C}	4.50^{K}	3.07^{QR}	(N.D)	(N.D)	5.60^{C}	4.44^{K}	3.07^{O}	(N.D)	(N.D)
12	5.90^{B}	4.77^{J}	3.14^{QR}	(N.D)	(N.D)	5.81^{B}	4.66^{J}	3.07^{O}	(N.D)	(N.D)
14	6.20^{A}	4.92^{H}	3.20^{Q}	(N.D)	(N.D)	5.97^{A}	4.86^{H}	3.14^{O}	(N.D)	(N.D)
Staphylococcus aureus (Log$_{10}$ cfu ml^{-1})										
0	3.04^{H}	2.77^{O}	(N.D)	(N.D)	(N.D)	3.25^{I}	2.88^{N}	1.96^{T}	(N.D)	(N.D)
2	3.11^{G}	2.80^{O}	(N.D)	(N.D)	(N.D)	3.27^{H}	2.89^{N}	2.04ST	(N.D)	(N.D)
4	3.30^{F}	2.85^{N}	(N.D)	(N.D)	(N.D)	3.38^{F}	2.92^{M}	2.11ST	(N.D)	(N.D)
6	3.50^{E}	2.90^{M}	(N.D)	(N.D)	(N.D)	3.55^{E}	2.96^{L}	2.23^{RS}	(N.D)	(N.D)
8	3.61^{D}	2.95^{L}	(N.D)	(N.D)	(N.D)	3.69^{D}	3.04^{K}	2.30^{QR}	(N.D)	(N.D)
10	3.76^{C}	2.99^{K}	(N.D)	(N.D)	(N.D)	3.82^{C}	3.11^{J}	2.39^{R}	(N.D)	(N.D)
12	3.85^{B}	3.07^{J}	(N.D)	(N.D)	(N.D)	3.90^{B}	3.14^{I}	2.49^{P}	(N.D)	(N.D)
14	3.93^{A}	3.15^{I}	(N.D)	(N.D)	(N.D)	4.04^{A}	2.23^{G}	2.69^{O}	(N.D)	(N.D)
Presence of Salmonella										
0	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
2	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
4	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
6	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
8	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
10	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
12	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve
14	+ve	+ve	+ve	−ve	−ve	+ve	+ve	+ve	−ve	−ve

Means with different letter are differ significantly ($P < 0.05$). cfu, colony forming unit.
(N.D), not detected (below the detection level).
+ve, positive. −ve, negative.

From the results summarized in the same table, the dose of 3 kGy appeared to be an optimum irradiation dose for improving the microbial safety of liquid egg white and yolk. This dose was effective in the destruction of *Salmonella*, *S. aureus* and enterobacteriaceae, which were not detected in samples received this dose during their storage at 4 ± 1 °C, in addition to the observed significant ($P < 0.05$) reduction in the total plate count (Table 6). According to the published microbiological criteria for liquid egg products, the maximum acceptable levels for the total plate count and enterobacteriaceae were reported to be 1×10^5 and 1×10^2 cfu ml^{-1}, respectively, in addition to the absence of *S. aureus* and *Salmonella* in the liquid egg products (Great Britain, 1993). Therefore, samples irradiated at 3 kGy dose were chosen to determine the effects of irradiation on amino acid composition for liquid egg white and yolk as well as fatty acid profiles for liquid egg yolk lipids.

3.8. Amino acid composition

As shown in Table 7, 18 amino acids could be identified for non-irradiated liquid egg white and liquid egg yolk. Gamma irradiation at 3 kGy dose caused no significant changes in the levels of amino acids neither for liquid egg white nor liquid egg yolk. These results

agree with the findings of Ma et al. (1993) for irradiated frozen egg.

3.9. Fatty acid profiles

The results in Table 8 show that, lipids of non-irradiated liquid egg yolk contained 35% saturated fatty acids and palmitic acid was the predominant saturated fatty acid reaching 25% of the total fatty acids followed by stearic acid (9.1%). Meanwhile, the total unsaturated fatty acids amounted to 64.7% of the total fatty acids and oleic acid was the predominant unsaturated fatty acid (40.7%) followed by linoleic (16.8%), palmitoleic (3.7%), arachidonic (1.8%) and linolenic (1%). Similar trends were also reported for egg yolk fatty acids (Cotterill & Glauert, 1979 and Sasser, 1993). Irradiation of liquid egg yolk samples at 3 kGy showed no significant ($P > 0.05$) effects on the fatty acid profiles of their lipids except one of the unknown compounds which significantly ($P < 0.01$) decreased (Table 8).

3.10. Sensory evaluation

As shown in Table 9, irradiation treatments had no significant ($P > 0.05$) effects on the acceptability of appearance and color for liquid egg white and yolk as recorded by the panelists. Although significant decrease in the total carotenoids were observed as a function of dose and a slight loss in the visual yellowness was noticed upon irradiation with the highest dose, the visual yellow color of the egg yolk was still highly acceptable by the panelists. Similar results were observed by Serrano et al. (1997). Cold storage of irradiated and non-irradiated liquid egg white showed no significant ($P > 0.05$) effects on the appearance and color of samples. Moreover, non-irradiated samples of liquid egg yolk showed no significant ($P > 0.05$) changes in their appearance and color till 6 days of cold storage, then storage of samples significantly ($P < 0.05$) affected their visual color, but they still scored as acceptable samples. However, all irradiated liquid egg yolk samples showed no significant ($P > 0.05$) changes in the acceptability of their appearance and color till the end of their refrigerated storage (Table 9).

With regards to the odor of liquid egg samples, Table 10 shows that gamma irradiation did not significantly ($P > 0.05$) affect the odor of liquid egg white. Also irradiation of liquid egg yolk samples at doses up to 3 kGy showed no significant ($P > 0.05$) effects on their odor, while irradiation at 4 kGy significantly ($P < 0.05$) affected the scores of odor acceptability for liquid egg yolk, but samples were still highly acceptable (Table 10). Furthermore, non-irradiated samples of liquid egg white as well as liquid egg yolk showed no significant ($P > 0.05$) changes in their odor acceptability for 4 days, then storage significantly ($P < 0.05$) affected their acceptability and scored as unacceptable due to the detection of the putrid off-odor on day 6 of storage. Cold storage, however, showed no significant ($P > 0.05$) effects on the odor acceptability of all irradiated samples neither for liquid egg white nor liquid egg yolk.

Table 7
Total amino acids in liquid egg white and yolk as affected by gamma irradiation at 3 kGy dose

Amino acids	Amount (g kg^{-1} protein)/dose (kGy)			
	Liquid egg white		Liquid egg yolk	
	0.0	3.0	0.0	3.0
Asp	89.6^a	89.2^a	73.5^a	73.2^a
Thr	43.6^a	43.5^a	45.1^a	44.9^a
Ser	74.0^a	73.7^a	79.6^a	79.3^a
Glu	104.1^a	103.6^a	85.1^a	84.7^a
Pro	35.8^a	35.8^a	36.1^a	36.0^a
Gly	53.8^a	53.6^a	42.2^a	41.9^a
Ala	76.2^a	75.8^a	60.2^a	59.9^a
Cys	23.7^a	24.0^a	15.6^a	15.5^a
Val	62.5^a	62.2^a	53.4^a	53.1^a
Met	29.8^a	30.1^a	18.1^a	18.3^a
Ile	43.1^a	43.3^a	43.4^a	43.7^a
Leu	74.6^a	74.2^a	70.1^a	69.7^a
Tyr	26.3^a	26.4^a	28.4^a	28.4^a
Phe	43.4^a	43.5^a	31.4^a	31.5^a
Lys	23.7^a	53.4^a	55.4^a	55.1^a
His	17.6^a	17.9^a	19.7^a	19.9^a
Arg	37.1^a	37.1^a	41.7^a	41.4^a
Try	12.2^a	12.2^a	11.1^a	11.0^a

Means with the same letter (a) within a row for each amino acid are not differ significantly ($P > 0.05$) for each of liquid egg fractions.

Table 8
Fatty acid profiles of liquid egg yolk lipids as affected by gamma irradiation at dose of 3 kGy

Fatty acids	Percentage of total fatty acids/dose (kGy)	
	0.0	3.0
6:0	0.100^a	0.101^a
8:0	0.020^a	0.019^a
Unknown(1)	0.050^a	0.049^a
12:0	0.030^a	0.030^a
14:0	0.482^a	0.484^a
14:1	0.678^a	0.680^a
16:0	25.093^a	25.131^a
16:1	3.676^a	3.672^a
18:0	9.194^a	9.203^a
18:1	40.777^a	40.759^a
Unknown(2)	0.079^a	0.078^a
18:2	16.814^a	16.796^a
18:3	0.998^a	0.998^a
Unknown(3)	0.071^a	0.068^b
20:0	0.160^a	0.162^a
20:4	1.778^a	1.770^a
Total saturated	35.079^a	35.130^a
Total monounsaturated	45.131^a	45.111^a
Total polyunsaturated	19.590^a	19.564^a
Total unsaturated	64.721^a	64.675^a

Means with the same letter within a row for each fatty acid are not differ significantly ($P > 0.05$).

Table 9
Sensory evaluation for appearance and color of irradiated and non-irradiated liquid egg white and yolk during storage at 4 ± 1 °C

Storage (days)	Mean of scores/irradiation dose (kGy)									
	Liquid egg white					Liquid egg yolk				
	0.0	1.0	2.0	3.0	4.0	0.0	1.0	2.0	3.0	4.0
0	8.0^{A}	7.9^{A}	7.9^{A}	7.8^{A}	7.7^{A}	8.4^{A}	8.3^{AB}	8.3^{AB}	8.1^{AB}	7.7^{AB}
2	7.9^{A}	7.8^{A}	8.0^{A}	7.7^{A}	7.7^{A}	8.1^{AB}	8.1^{AB}	8.2^{AB}	8.3^{AB}	7.5^{AB}
4	7.9^{A}	8.0^{A}	7.2^{A}	7.9^{A}	7.6^{A}	8.2^{AB}	8.2^{AB}	7.9^{AB}	8.0^{AB}	7.6^{AB}
6	7.6^{A}	7.7^{A}	7.6^{A}	7.6^{A}	7.8^{A}	7.9^{AB}	7.9^{AB}	8.1^{AB}	7.9^{AB}	7.6^{AB}
8	7.3^{A}	7.6^{A}	7.7^{A}	7.6^{A}	7.5^{A}	6.1^{C}	8.0^{AB}	8.0^{AB}	8.1^{AB}	7.4^{AB}
10	7.4^{A}	7.5^{A}	7.5^{A}	7.6^{A}	7.4^{A}	5.4^{C}	8.1^{AB}	7.7^{AB}	7.8^{AB}	7.5^{AB}
12	7.2^{A}	7.4^{A}	7.6^{A}	7.5^{A}	7.6^{A}	5.0^{D}	7.8^{AB}	7.9^{AB}	8.0^{AB}	7.3^{AB}
14	7.0^{A}	7.2^{A}	7.5^{A}	7.3^{A}	7.7^{A}	5.0^{D}	7.7^{AB}	7.6^{AB}	7.7^{AB}	7.3^{AB}

Means with the same letter for each of liquid egg fractions are not differ significantly ($P > 0.05$).
Means with different letter for each of liquid egg fractions are differ significantly ($P < 0.01$).

Table 10
Sensory evaluation for the odor of irradiated and non-irradiated liquid egg white and yolk during storage at 4 ± 1 °C

Storage (days)	Mean of scores/irradiation dose (kGy)									
	Liquid egg white					Liquid egg yolk				
	0.0	1.0	2.0	3.0	4.0	0.0	1.0	2.0	3.0	4.0
0	8.0^{A}	7.8^{A}	7.9^{A}	8.0^{A}	7.7^{A}	8.2^{A}	8.0^{A}	8.1^{A}	7.8^{AB}	6.5^{CDE}
2	7.9^{A}	7.7^{A}	7.8^{A}	7.6^{A}	7.6^{A}	7.9^{A}	7.9^{A}	7.7^{ABC}	7.7^{ABC}	6.6^{BCDE}
4	7.6^{A}	7.9^{A}	7.9^{A}	7.7^{A}	7.7^{A}	7.6^{ABC}	7.8^{AB}	7.7^{ABC}	7.8^{AB}	6.6^{BCDE}
6	3.3^{C}	7.9^{A}	7.7^{A}	7.6^{A}	7.5^{A}	3.1^{F}	7.8^{AB}	7.8^{AB}	7.7^{ABC}	6.5^{CDE}
8	2.5^{C}	7.6^{A}	7.7^{A}	7.3^{A}	7.6^{A}	2.0^{G}	7.5^{ABC}	7.6^{ABC}	7.6^{ABC}	6.2^{E}
10	1.1^{D}	7.7^{A}	7.8^{A}	7.5^{A}	7.4^{A}	1.5^{G}	7.6^{ABC}	7.6^{ABC}	7.5^{ABC}	6.3^{DE}
12	1.1^{D}	7.5^{A}	7.6^{A}	7.4^{A}	7.6^{A}	1.2^{G}	7.4^{ABCD}	7.7^{ABC}	7.6^{ABC}	6.1^{E}
14	1.1^{D}	6.6^{AB}	7.6^{A}	7.6^{A}	7.5^{A}	1.1^{G}	6.5^{CDE}	7.5^{ABC}	7.5^{ABC}	6.0^{E}

Means with the same letter for each of liquid egg fractions are not differ significantly ($P > 0.05$).
Means with different letter for each of liquid egg fractions are differ significantly ($P < 0.01$).

Table 11
Sensory evaluation of scrambled egg white and egg yolk as prepared from irradiated liquid egg samples (on day zero of storage)

Properties	Mean of scores/irradiation dose (kGy)									
	Scrambled egg white					Scrambled egg yolk				
	0.0	1.0	2.0	3.0	4.0	0.0	1.0	2.0	3.0	4.0
Odor	7.9^{A}	7.8^{A}	7.7^{A}	7.7^{A}	7.3^{A}	8.1^{A}	8.0^{AB}	7.9^{AB}	7.2^{B}	6.2^{C}
Taste	7.8^{A}	7.8^{A}	7.6^{A}	7.5^{A}	7.0^{A}	8.2^{A}	7.9^{A}	7.8^{A}	7.4^{A}	6.0^{B}

Means with the same letter within a row for property of each of egg fractions are not differ significantly ($P > 0.05$).
Means with different letter within a row for property of each of egg fractions are differ significantly ($P < 0.01$).

On the other hand, samples of scrambled egg white, that prepared from irradiated and non-irradiated liquid egg white, showed no significant ($P > 0.05$) differences neither for their odor nor their taste (Table 11). The same results were observed for samples of scrambled egg yolk except for those prepared from liquid egg yolk samples that irradiated at 4 kGy which significantly ($P < 0.05$) differed for their odor as well as taste. However, they were highly acceptable such as the other scrambled egg yolk samples as recorded by the panelists. Therefore, the results of sensory evaluation generally indicate that subjecting liquid egg products to gamma irradiation doses of 1–4 kGy at room temperature induced no changes that can adversely affect their sensory preference.

4. Conclusion

It could be concluded that 3 kGy dose of gamma irradiation can be used as an optimum dose for treating liquid egg white and yolk at room temperature followed by refrigerated storage (4 ± 1 °C) to improve their microbial safety without adverse chemical changes that may affect their sensory or functional properties.

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