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EFFECT OF GAMMA IRRADIATION ON THE ATTRIBUTES OF TURKEY, DUCK, GOOSE AND CHICKEN EGG WHITES AND YOLKS

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Abstract

Irradiation can control pathogens in eggs without heat, thereby preserving eggs for long periods. The aim of this study was to determine the effects of gamma radiation on the chemical composition and protein quality of the whites and yolks of duck, goose, turkey, and chicken eggs. Ten eggs from each species were placed in pulp cartons and irradiated with an absorbed dose of 4 kGy. After irradiation, the eggs were broken, and yolks and whites were separated, dried and milled into fine particles. Protein efficiency ratio (PER), essential amino acid index (EAAI), biological value (BV), nutritional index (NI), essential amino acid score (EAAS), and other parameters of protein quality were insignificant differences between control and radiation eggs. In general, our results show that gamma radiation does not exert significant effects on the chemical composition and protein quality of the whites and yolks of eggs. Gamma radiation at 4 kGy can be used to preserving eggs for long periods.

Keywords: Egg quality; food chemistry; Egg conservation; Egg Radiation.

Introduction

Egg proteins are of high biological value in comparison to other dietary proteins, and possess desirable functional and nutritional properties. As such, they are widely used in food products. For example, whole egg protein is superior to both milk and meat proteins (Ruxton *et al.*, 2010; Mench *et al.*, 2011), both of which are generally considered to be good sources of protein. Whole egg protein is of such high quality that it is commonly used as a standard for measuring the nutritional quality of other food proteins. Several studies on the nutritional value of egg proteins have been reported (Sakanak *et al.*, 2000). Moreover, eggs also contain other biologically functional substances such as immune proteins, enzymes, and a number of defense factors that are known to protect against bacterial and viral infection (Nowaczewski *et al.*, 2013; Yang *et al.,* 2018 and Tolik *et al.*, 2014).

Patrick *et al.* (2004) reported that cases of salmonellosis were associated with shell eggs and egg-containing products. Gast and Beard (1990) reported that *Salmonella enteritidis* not only contaminates the surface of eggshells but is also found in the interior, in egg whites and yolks. *Salmonella* and other pathogens found in egg yolks have been shown to be controlled by the nonthermally by irradiation at a dose greater than 2 kGy (Narvaize *et al.*, 1992) and at a dose of 1.5 kGy (Serrano *et al.*, 1997). However, doses of irradiation of up to 4 kGy have been approved by the USDA Food Safety and Inspection Service (2000). However, free radicals produced by irradiation can cause changes in the quality and functional properties of eggs and egg products, such as increases in the oxidation of polyunsaturated fatty acid cholesterol, changes in yolk color, and the breakdown carotenoids in dehydrated egg products (Du and Ahn, 2000). The irradiation of shell eggs has also been shown to decrease the viscosity of egg whites and partially degrade egg proteins (Ma *et al.*, 1990). Thus, irradiation may not be advisable for table eggs, but may be useful for pasteurizing liquid egg whites or liquid whole eggs without significant deterioration of their quality and functionality. In particular, the dramatic decrease in the viscosity of egg whites by irradiation improves the flow of liquid egg whites or liquid whole eggs, which could be highly useful for egg processing (Min *et al.*, 2005).

Although chicken eggs are the most widely consumed as a relatively cheap animal protein, eggs from other birds are also used for daily consumption. For example, duck eggs are gaining popularity in Southeast Asian countries (Adeyeye, 2013), while goose and turkey are a valuable source of eggs and meat and are considered to be niche products (Poławskaa *et al.*, 2015). Contaminated eggs that have not undergone heat treatment or other decontamination processes may pose a potential risk to public health. Egg quality is of great economic importance in terms of economic costs and human health; Fathi *et al.*, 2007; Radwan *et al.*, 2010, 2015 and Radwan 2015 studied egg quality properties. Irradiation is considered the most effective decontamination technique for shell eggs. The objective of this study was to determine the effects of irradiation on the quality attributes of the white and yolk of turkey, duck, goose and chicken eggs.

Materials and Methods

Sample preparation and irradiation

One-day-old unfertilized turkey, duck, goose, and chicken eggs were obtained from commercial egg production farms at Giza governorate. The eggs were processed (washed, graded, and packaged) online on the same day and stored at 4°C until irradiation (February 15, 2018). Ten eggs from each species were placed in pulp cartons and irradiated at 4 kGy using the Russian Cobalt Irradiator model ISS LE DOVATED at room temperature. All eggs were irradiated twice; after the first irradiation, the eggs were turned upside down for the second irradiation (Min *et al.*, 2005).

Nonirradiated (control) samples were brought into the irradiation facility for exposure to the same environment as irradiated eggs. After irradiation, all eggs were broken, and the yolks and whites were separated, dried, milled into fine particles, and stored at 4°C for chemical analyses.

Proximate composition and chemical properties of egg whites and yolks

Proximate analysis

The moisture, lipid, ash, and total protein contents of the egg samples were determined according to the official methods of the AOAC (2012a).

Fatty acid analysis

Saturated and unsaturated fatty acids were determined from the oils using the methyl esters boron trifluoride method (AOAC, 2000).

Amino Acid Analysis

The determination of amino acids was performed according to AOAC methods (2012 b).

Estimation of the nutritional quality of egg whites and yolks

The nutritional quality of egg white and yolk samples was determined from amino acid profiles. The essential amino acid index (EAAI) was calculated using the method as cited by Ijarotim and Keshinro (2011) according to the following equation: EAAI

$$= \sqrt[8]{\frac{[Lys \times Thero \times Val \times Meth \times Isoleu \times leu \times Phynylal \times Histi]a}{[Lys \times Thero \times Val \times Meth \times Isoleu \times leu \times Phynylal \times Histi]b}}$$

where each amino acid XXX, *a* represents the test sample and *b* represents the egg protein standard (%).

The nutritional index of egg white and yolk samples was calculated using the formula below: Nutritional index

$$[\%] = \frac{\text{EAAI} \times \%\,\text{protein}}{100}$$

The BV was calculated according to Oser (1959) using the following equation: BV = 1.09 × EAAI – 11.7

The PER was estimated according to the regression equations developed by Alsmeyer *et al.* (1974) as follows:

PER = -0.468 + 0.454 (LEU) – 0.105 (TYR).

The amino acid score (%) was calculated using the following formula: Amino acid score %

$$= \frac{\text{Essential amino acids in egg samples (g/100 g cp)}}{\text{egg stander for essential amino acids}} \times 100$$

Calculation of other protein quality parameters

In addition, we determined the ratio of the total essential amino acid content (TEAA content) to TAA, and the percentage of cysteine in TSAA (Cys/TSAA). Total aromatic amino acids (TArAA), total neutral amino acids (TNAA), total acidic amino acids (TAAA) and total basic amino acids (TBAA) were estimated from the amino acid profiles.

Statistical analyses

Data were subjected to a one-way analysis of variance with irradiation effect using the general linear models procedure in the SAS User's Guide (2005) as follows:

$$Y_{ijk} = \mu + R_i + e_{ij}$$

where μ= overall mean, Ri = irradiation effect and eij = experimental error.

Results and Discussion

Proximate composition

The proximate compositions of irradiated (4 kGy) turkey, goose, duck, and chicken eggs in comparison to those of the nonirradiated controls are presented in Table 1. Our results show that, the chemical compositions of Fayoumi chicken irradiated and nonirradiated egg yolks exhibited the lowest protein and ash contents, but the highest lipid contents. Additionally, we found that the chemical composition of goose egg yolk is very similar to that of Fayoumi chicken egg yolk. Moreover, the ash and protein contents were slightly higher in irradiated egg yolks than in control egg yolks (nonirradiated) in all four species. On the other hand, the lipid, ash, and protein contents of irradiated egg yolks were slightly lower than those of nonirradiated egg yolks for all species examined. In contrast, moisture content was higher in the irradiated egg yolks than in the nonirradiated egg yolks of all four species. Finally, turkey eggs exhibited the highest protein contents in both egg whites and yolks, followed by the Fayoumi chicken, with decreases in protein content when irradiated. Sun *et al.* (2019) recorded that goose egg had the highest moisture and lowest crude protein compared chicken, duck, goose, turkey, quail, and pigeon eggs.

Table 1 : Proximate composition (%) of the irradiated (4 kGy) and nonirradiated (control) egg whites and yolks of the white turkey, Pekin duck, white goose, and Fayoumi chicken (referred to dry matter).

Proximate (g%) analysis	**White turkey**		**Pekin duck**		**White goose**		**Fayoumi chicken**	
	Control	**Irradiated**	**Con.**	**Irrad.**	**Con.**	**Irrad.**	**Con.**	**Irrad.**
	Egg White							
Ash	4.93±0.02	5.07±0.09	6.10±0.11	6.07±0.08	5.39±0.07	5.26±0.12	5.88±0.10	5.84±0.14
Probability		NS		NS		NS		NS
Protein	81.56±0.87	83.0±0.94	78.52±0.94	78.79±0.72	79.85±0.59	79.86±0.61	79.61±0.93	79.49±0.81
Probability		NS		NS		NS		NS
Lipid	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Probability	Egg Yolk							
Ash	4.01±0.06	4.10±0.08	4.01±0.12	4.06±0.10	3.50±0.07	3.63±0.10	3.30±0.06	3.38±0.07
Probability		NS		NS		NS		NS
Protein	34.29±0.79	34.47±0.23	34.45±0.42	34.74±0.61	33.51±0.58	34.10±0.33	33.55±0.37	33.87±0.31
Probability		NS		NS		NS		NS
Lipid	57.69±0.82	57.38±0.91	57.42±0.47	56.85±0.61	58.26±0.63	58.08±0.79	59.12±0.77	58.67±0.48
Probability		NS		NS		NS		NS

Means within the same row followed by different superscripted letters are significantly different. P ≤ 0.05. NS = not significant; Irrad. = Irradiated, Con.= Control.

Fatty acid Composition

The fatty acid profiles of the irradiated and nonirradiated yolks of turkey, goose, duck, and chicken eggs are presented in Table 2. Our results show that the irradiated eggs of all species exhibited slightly lower contents of total unsaturated fatty acids than the controls. The percent composition of stearic acid increased in irradiated egg yolks. Lastly, myristic and arachidonic acids both decreased in irradiated eggs in comparison to the nonirradiated controls in the yolks of all four poultry species (Table 2). Moreover, oleic acid a monounsaturated fatty acid is present in insignificant high concentrations in all egg yolks tested, and was lower in irradiated egg yolks than in the nonirradiated eggs of all four species. Palmitoleic acid was lower in irradiated egg yolks than in nonirradiated yolks, but this difference was not significant. These results were consistent with Al-Bachir and Zeinou (2006). In summary, it can be established that irradiation resulted in a considerable insignificant increase in the amount of saturated fatty acids, with the exception of myristic acids.

Table 2 : Fatty acid profiles of irradiated (4 kGy) and nonirradiated (control) egg yolks of the white turkey, Pekin duck, white goose, and Fayoumi chicken (mg/100 mg d.w.).

Fatty acids	White turkey		Pekin duck		White goose		Fayoumi chicken	
	Control	**Irrad.**	**Con.**	**Irrad.**	**Con.**	**Irrad.**	**Con.**	**Irrad.**
Myristic acid C14:0	0.60±0.04[a]	0.55±0.03[b]	0.60±0.07[a]	0.55±0.05[b]	0.50±0.04[a]	0.45±0.11[b]	0.40±0.02[a]	0.35±0.06[b]
Probability		0.05		0.05		0.05		0.05
Palmitic acid C16:0	27.90±0.12	29.30±0.21	30.00±0.29	33.00±0.26	34.00±0.31	35.45±0.40	32.20±0.51	34.70±0.20
Probability		NS		NS		NS		NS
Palmitoleic acid C16:1	1.60±0.08	1.50±0.05	2.00±0.04	1.90±0.10	1.70±0.06	1.60±0.02	1.50±0.07	1.35±0.11
Probability		NS		NS		NS		NS
Stearic acid C18:0	1.35±0.06[b]	2.20±0.07[a]	1.85±0.05	2.20±0.12	1.40±0.08	1.80±0.04	2.30±0.10	2.60±0.13
Probability		NS		NS		NS		NS
Oleic acid C18:1	49.50±0.89	49.20±0.88	49.45±0.59	47.30±0.41	49.40±0.71	48.70±0.65	49.25±0.91	48.40±0.63
Probability		NS		NS		NS		NS
Linoleic acid C18:2	14.25±0.31	12.90±0.17	10.00±0.11	9.60±0.08	8.20±0.15	7.60±0.20	10.50±0.12	9.30±0.11
Probability		NS		NS		NS		NS
Linolenic acid C18:3	0.40±0.05[a]	0.35±0.03[b]	0.60±0.008[a]	0.45±0.01[b]	0.50±0.007[a]	0.40±0.05[b]	0.35±0.10[a]	0.30±0.03[b]
Probability		0.05		0.001		0.001		0.05
Arachidonic acid C20:0	4.40±0.21	4.00±0.19	5.50±0.34	5.00±0.29	4.30±0.27	4.00±0.31	3.50±0.42	3.00±0.19
Probability		NS		NS		NS		NS
T. Fatty acid	100±0.03	100±0.04	100±0.06	100±0.01	100±0.08	100±0.09	100±0.02	100±0.07
Probability		NS		NS		NS		NS
T. Saturated	34.25±0.86	36.05±0. 96	37.95±0.65	40.75±0.45	40.20±0.86	41.70±0.43	38.90±0.65	40.68±0.28
Probability		NS		NS		NS		NS
T. Unsaturated	65.75±0.51	63.95±0.64	62.05±0.43	59.25±0.38	59.80±0.43	58.30±0.39	61.60±0.28	59.35±0.21
Probability		NS		NS		NS		NS

Means within the same row followed by different superscripted letters are significantly different. $P \leq 0.05$. NS = not significant; Irrad. = Irradiated, Con.= Control.

Amino Acid Profile and Quality

The amino acid profiles of the irradiated and nonirradiated turkey, duck, goose, and chicken eggs analyzed in the present study are shown in Tables 3 and 4. We found that the most concentrated amino acid in nonirradiated egg whites was glutamic acid (GLU), with a trend of duck < chicken < turkey < goose. The next most abundant acidic amino acid in egg whites was aspartic acid (ASP). Irradiation resulted in an increase in ASP in both Fayoumi chickens and ducks, and also increased GLU in goose and turkey eggs (Table 3).

Our observations of ASP/GLU show that the levels of ASP appeared to affect GLU and vice versa. This trend was evident in goose and turkey egg whites and the higher levels of Asp that were associated with lower levels of Glu in the irradiated egg whites of Fayoumi chickens and ducks. The lowest Asp/Glu was recorded in goose eggs, while the highest Asp/Glu was recorded in Fayoumi chicken eggs (Table 3).

Glutamic acid was also the most concentrated amino acid in egg yolks with a decreasing trend of Fayoumi chicken > goose > chicken > turkey (Table 4). The next most abundant amino acid in egg yolks of the four species was arginine (ARG). In contrast, Adeyeye (2013) observed the opposite trend for GLU and ASP. However, in the present study, irradiation resulted in a decrease in GLU and ASP in all egg yolks except for ASP in the Fayoumi chicken.

In the irradiated egg samples, the highest concentration of GLU was observed in goose egg whites and yolks, while the second highest concentration of GLU was observed in Fayoumi chicken egg whites and yolks (Tables 3 and 4). The highest concentration of ASP in egg whites was observed in irradiated chicken eggs, while the highest was in ducks. In egg yolks, the highest concentration of ASP was observed in turkey eggs, followed by goose eggs. While ASP can be synthesized in the body, eggs are an exceptional animal-based source of ASP. Good vegetable-based sources of ASP include sprouting seeds and legumes (Abdallah and Abo El-Naga 2013 and Ibrahim 2017). Therefore, irradiated eggs can be used with seed sprouts for the production of biscuits and cakes that are rich in nutrition and dietarily safe.

Table 3 : Amino acid profile of the irradiated (4 kGy) and nonirradiated (control) egg whites of the white turkey, Pekin duck, white goose, and Fayoumi chicken (g/100 g).

Amino acids	White turkey		Pekin duck		White goose		Fayoumi chicken	
	Control	Irradiated	Con.	Irrad.	Con.	Irrad.	Con.	Irrad.
Essential AA								
Isoleucine (ILE)	4.43±0.31	4.57±0.18	4.50±0.32	4.60±0.27	4.69±0.37	4.93±0.22	4.70±0.40	4.76±0.19
Probability		NS		NS		NS		NS
Valine (VAL)	4.57±0.09	4.39±0.11	4.60±0. 21	4.68±0.16	4.41±0.11	4.72±0.33	4.75±0.41	4.67±0.36
Probability		NS		NS		NS		NS
Lysine (LYS)	4.84±0.17	5.16±0.21	4.84±0.29	5.00±0.15	6.88±0.31	5.32±0.49	4.91±0.16	4.93±0.19
Probability		NS		NS		NS		NS
Leucine (LEU)	6.40±0.13	6.76±0.21	6.80±0.10	6.86±0.15	6.32±0.09	6.81±0.12	6.86±0.20	5.10±0.25
Probability		NS		NS		NS		0.03
Phenylalanine (PHE)	5.76±0.11	6.17±0.12	6.03±0.09	6.03±0.10	5.90±0.21	6.30±0.18	4.31±0.26	6.22±0.21
Probability		NS		NS		NS		NS
Threonine (THR)	4.50±0.31	4.45±0.26	4.57±0.14	4.43±0.17	4.45±0.34	5.10±0.16	4.68±0.42	4.54±0.38
Probability		NS		NS		NS		NS
Methionine (Meth)	3.74±0.08	3.63±0.05	2.99±0.11	3.60±0.07	3.77±0.12	3.47±0.19	3.86±0.04	3.40±0.09
Probability		NS		NS		NS		NS
Histidine (HIS)	2.70±0.12	2.92±0.10	2.89±0.09	2.79±0.06	2.89±0.17	3.18±0.19	3.12±0.20	3.33±0.16
Probability		NS		NS		NS		NS
Total	36.94±0.43	38.05±0.51	37.22±0.31	37.99±0.63	39.31±0.26	39.83±0.36	39.19±0.81	36.95±0.73
Probability		NS		NS		NS		NS
Nonessential AA								
Alanine (ALA)	5.66±0.32	4.93±0.42	6.05±0.73	6.23±0.35	5.98±0.49	6.32±0.25	6.29±0.19	6.24±0.22
Probability		NS		NS		NS		NS
Aspartic acid (ASP)	7.46±0.31	8.10±0.24	8.12±0.35	8.69±0.62	7.50±0.18	8.02±0.26	8.27±0.48	9.01±0.65
Probability		NS		NS		NS		NS
Serine (SER)	4.84±0.52	5.25±0.71	5.42±0.21	5.49±0.16	5.29±0.98	5.29±0.43	5.23±0.15	5.45±0.23
Probability		NS		NS		NS		NS
Glutamic acid (GLU)	11.06±0.12	11.92±0.10	11.52±0.09	11.50±0.13	11.25±0.21	12.15±0.17	11.85±0.13	11.76±0.21
Probability		NS		NS		NS		NS
Proline (PRO)	2.90±0.14	3.31±0.10	3.24±0.23	3.26±0.18	3.25±0.20	3.24±0.11	3.56±0.10	3.33±0.22
Probability		NS		NS		NS		NS
Glycine (GLY)	3.58±0.23	3.54±0.26	3.51±0.16	3.54±0.10	3.47±0.17	4.03±0.21	3.80±0.12	3.62±0.18
Probability		NS		NS		NS		NS
Cysteine (CYS)	3.50±0.32	2.38±0.21	0.86±0.46	1.10±0.55	1.36±0.64	2.00±0.21	1.53±0.32	1.07±0.29
Probability		NS		NS		NS		NS
Tyrosine (TYR)	4.74±0.43	5.03±0.28	5.04±0.51	4.80±0.46	4.97±0.23	5.10±0.29	5.49±0.62	5.35±0.71
Probability		NS		NS		NS		NS
Arginine (ARG)	6.46±0.22	6.58±0.31	6.88±0.46	6.75±0.32	4.72±0.49	4.16±0.26	3.86±0.17	3.74±0.43
Probability		NS		NS		NS		NS
Total	50.20±0.88	51.04±0.91	50.64±0.55	51.36±0.76	47.79±0.68	50.31±0.84	49.88±0.46	49.57±0.44
Probability		NS		NS		NS		NS
Total AA	87.14±0.51	89.09±0.46	87.86±0.76	89.35±0.88	87.10±0.81	90.14±0.59	89.07±0.54	86.52±0.61
Probability		NS		NS		NS		NS

Means within the same row followed by different superscripted letters are significantly different. $P \leq 0.05$. NS = not significant; Irrad. = Irradiated, Con.= Control.

Table 4 : Amino acid profiles of the irradiated (4 kGy) and nonirradiated (control) egg yolks of the white turkey, Pekin duck, white goose, and Fayoumi chicken (g/100 g).

Amino acids	White turkey		Pekin duck		White goose		Fayoumi chicken	
	Control	Irradiated	Con.	Irrad.	Con.	Irrad.	Con.	Irrad.
Essential AA								
Isoleucine (ILE)	4.54±0.18	4.49±0.21	4.62±0.17	4.22±0.11	4.55±0.31	4.20±0.23	4.60±0.19	4.18±0.32
Probability		NS		NS		NS		NS
Valine (VAL)	4.26±0.31	4.22±0.38	4.49±0.29	4.26±0.33	4.61±0.21	4.20±0.29	4.50±0.41	4.11±0.37
Probability		NS		NS		NS		NS
Lysine (LYS)	5.23±0.33	4.78±0.40	5.41±0.52	5.10±0.39	5.36±0.35	4.80±0.36	5.08±0.19	4.95±0.41
Probability		NS		NS		NS		NS
Leucine (LEU)	6.44±0.39	5.91±0.42	6.86±0.55	6.35±0.61	6.97±0.76	6.44±0.23	6.71±0.29	6.35±0.18
Probability		NS		NS		NS		NS
Phenylalanine (PHE)	4.97±0.13	4.50±0.33	5.11±0.18[a]	3.95±0.19[b]	5.33±0.23	5.00±0.29	5.69±0.31[a]	4.60±0.27[b]
Probability		NS		0.03		NS		0.05
Threonine (THR)	4.91±0.12	4.24±0.18	4.68±0.10	4.24±0.15	4.63±0.20	4.39±0.13	4.65±0.15	4.21±0.21
Probability		NS		NS		NS		NS

Methionine (Meth)	2.14±0.09	1.84±0.11	2.54±0.13	2.56±0.16	2.23±0.08	1.83±0.04	2.61±0.15	2.17±0.12
Probability		NS		NS		NS		NS
Histidine (HIS)	4.43±0.26[a]	3.04±0.31[b]	3.76±0.24	3.49±0.17	3.51±0.33	3.31±0.21	3.82±0.22	3.06±0.16
Probability		0.05		NS		NS		NS
Total	35.92±0.31	33.02±0.23	37.47±0.47	34.17±0.27	37.19±0.27	34.17±0.26	37.66±0.13	33.63±0.25
Probability		NS		NS		NS		NS
Nonessential AA								
Alanine (ALA)	5.02±0.41	4.90±0.19	5.28±0.26	5.51±0.22	5.76±0.23	5.16±0.19	5.76±0.22	5.25±0.25
Probability		NS		NS		NS		NS
Aspartic acid (ASP)	7.88±0.22	6.77±0.41	6.80±0.32	6.51±0.28	6.90±0.21	6.67±0.51	5.32±0.34	6.45±0.46
Probability		NS		NS		NS		NS
Serine (SER)	5.05±0.41	4.78±0.46	5.98±0.66	5.44±0.29	5.95±0.18	5.34±0.10	5.66±0.31	5.47±0.37
Probability		NS		NS		NS		NS
Glutamic acid (GLU)	10.59±0.13	9.43±0.31	10.83±0.15	9.54±0.13	10.94±0.10	10.77±0.21	10.96±0.24	10.06±0.51
Probability		NS		NS		NS		NS
Proline (PRO)	2.98±0.16	3.04±0.11	2.97±0.24	3.22±0.22	3.10±0.14	2.95±0.19	3.65±0.10	3.57±0.15
Probability		NS		NS		NS		NS
Glycine (GLY)	3.46±0.17	3.53±0.09	3.10±0.11	3.02±0.17	3.13±0.19	2.63±0.23	3.36±0.14	3.29±0.17
Probability		NS		NS		NS		NS
Cysteine (CYS)	2.97±0.12	2.19±0.10	.081±0.05	0.84±0.02	0.73±0.03[b]	1.15±0.08[a]	0.88±0.04[a]	0.70±0.07[b]
Probability		NS		NS		0.04		0.01
Tyrosine (TYR)	5.55±0.23	5.32±0.31	5.30±0.25	5.15±0.29	5.19±0.24	4.79±0.29	5.62±0.19	4.90±0.22
Probability		NS		NS		NS		NS
Arginine (ARG)	8.03±0.14	7.72±0.22	7.74±0.16	7. 32±0.19	7.58±0.21	7.26±0.24	7.82±0.32	7.43±0.27
Probability		NS		NS		NS		NS
Total	51.58±0.92	47.68±0.83	48.82±0.75	46.55±0.77	49.28±0.57	46.72±0.48	49.03±0.39	47.12±0.65
Probability		NS		NS		NS		NS
Total AA	87.45±0.97	80.70±0.76	86.28±0.67	80.72±0.54	86.47±0.45	80.89±0.36	86.69±0.43	86.75±0.49
Probability		NS		NS		NS		NS

Means within the same row followed by different superscripted letters are significantly different. $P \leq 0.05$. NS = not significant; Irrad. = Irradiated, Con.= Control.

The TEAA contents in the egg whites of control eggs were with a decreasing trend of goose > chicken > duck > turkey, while those of egg yolks were with a decreasing trend of chicken > duck > goose > turkey. Irradiation resulted in a decrease in the TEAA content of both egg whites and yolks of all four species (Table 5).

The results of the nutritional quality assessments of egg whites and yolks in irradiated and control eggs are presented in Table (5). The total EAAs (with HIS and ARG) as a percentage of TAAs was lower in irradiated egg whites and yolks in all species except in the turkey, in which the percentage in of EAAs in egg whites increased to 53.37% and to 54.22% in egg yolks. The TEAA content without HIS and ARG as a percentage of TAAs decreased in the irradiated egg yolks of all species and in goose and chicken egg whites, but increased in turkey and duck egg whites in comparison to control eggs (Table 5). The opposite results were obtained for the percentage of total NEAAs as a percentage of TAAs, which increased in the irradiated egg yolks of all species and in goose and chicken egg whites, but decreased in turkey and duck egg whites in comparison to control eggs. The percentage of TEAAs with respect to TAAs in egg whites was approximately 42.36% to 45.13%, while that of egg yolks was approximately 40.92% to 43.44%. The total sulfur amino acid (TSAA) content was lower in the irradiated eggs of turkeys and chickens for both egg whites and yolks, but increased in irradiated duck and goose eggs in comparison to control eggs. Total BAAs (ARG + LYS) and ArAAs (Phe + TYR) were lower in both the whites and yolks of irradiated eggs, with the exception of ArAAs in turkey and goose egg whites (Table 5).

The total AAAs (ASP + GLU) increased in the whites of irradiated eggs from all four species and in the yolks of chicken eggs only. The percentage of CYS with respect to TSAAs was the highest in control and irradiated turkey eggs. However, more precipitous increases in these percentages were observed after the irradiation of goose egg whites (approx. 38% increase) and yolks (approx. 56.5% increase) in comparison to the whites and yolks of control eggs. Interestingly, most animal proteins are low in CYS (e.g., the CYS/TSAA percentage ranges from 27.3% to 32.8% in female freshwater crab (Adeyeye 2008b); 23.8% to 30.1% in fishes (Adeyeye 2008a); and 26.0% to 26.5% in turkey hen meat (Adeyeye and Ayejuyo, 2007). Our results for duck egg whites and yolks and for Fayoumi chicken egg whites and yolks were consistent with the findings of those previous studies. In contrast, the proteins of turkey egg yolks contain substantially more CYS than Meth according to the present study. Thus, in diets consisting of animal protein or in mixed diets containing animal protein, CYS is unlikely to compose as much as 50% of the TSAAs (FAO/WHO, 1991). As vegetable proteins contain substantially more CYS than Meth (Adeyeye 2004), turkey eggs can also be considered a good source of CYS, similar to vegetables. Although CYS is known to exert positive effects on mineral absorption, particularly zinc (Mendoza 2002), CYS is not an essential amino acid. However, as CYS can be synthesized from methionine, a dietary source of CYS would thus "spare" methionine.

The highest values for PER were recorded in the irradiated and nonirradiated egg whites of Pekin ducks, followed by chicken egg whites. However, the PER of the egg yolks of all species decreased with irradiation treatment (Table 5).

Essential AA index (EAAI) values increased as a result of irradiation in the egg whites of all four bird species, but decreased in the egg yolks of all species (Table 5). The NI and BV followed trends similar to those of the EAAI, except that they decreased as a result of irradiation in chicken egg whites (Table 5). Generally, a protein is said to be of good nutritional quality when its BV is high (70–100%) and when the EAAI is greater than 90% (Oser, 1959).

BV is a very important nutritional parameter because it is directly related to metabolism and describes the degree to which the pattern of the absorbed amino acids matches that of the metabolic demand. Thus, BV can never exceed a value of 1 (or 100%, if expressed as a percentage). As, the BV of egg whites in the present study was greater than 80% and the BV of egg yolks was greater than 70%, we consider eggs to be a good source of nitrogen, with the exception of irradiated turkey and chicken egg yolks, which had BVs below 70%. These results are similar to those of Renner (1983) for whole chicken egg protein.

We found that egg whites exhibited the lowest NI)Table 5). The control and irradiated egg whites from all four bird species displayed NI values below 12% in duck and turkey. In contrast, the highest NI was obtained in egg yolks. However, while irradiation did not affect duck, goose, and chicken eggs, irradiation decreased the NI of turkey egg whites and yolks.

Table 5 : Nutritional quality of irradiated (4 kGy) and nonirradiated (control) egg whites and yolks of white turkey, Pekin duck, white goose and Fayoumi chicken.

Amino acids	White turkey		Pekin duck		White goose		Fayoumi chicken	
	Control	Irradiated	Con.	Irrad.	Con.	Irrad.	Con.	Irrad.
	Egg White							
TEAA + HIS +ARG /TAA(%)	52.90±0.32	53.37±0.24	53.48±0.18	53.20±0.12	53.87±0.21	52.33±0.26	51.84±0.41	50.88±0.25
Probability		NS		NS		NS		NS
TEAA / TAA(%)	42.39±0.23	42.71±0.27	42.36±0.19	42.52±0.11	45.13±0.31	44.19±0.28	44.0±0.21	42.71±0.31
Probability		NS		NS		NS		NS
TNEAA/ TAA(%)	57.61±0.21	57.29±0.28	57.64±0.23	57.48±0.19	54.87±0.34	55.81±0.44	56.0±0.49	57.29±0.51
Probability		NS		NS		NS		NS
TSAA (Meth + CYS)	7.24±0.41	6.01±0.76	3.85±0.34	4.70±0.44	5.13±0.39	5.47±0.27	5.39±0.20	4.47±0.31
Probability		NS		NS		NS		NS
Ar AA (PHE +TYR)	10.50±0.23	11.20±0.12	11.07±0.19	10.83±0.17	10.87±0.10	11.40±0.21	11.80±0.14	11.57±0.19
Probability		NS		NS		NS		NS
TEAA / TNE AA(%)	73.59±0.87	74.55±0.26	73.50±0.55	73.97±0.39	82.26±0.98	79.17±0.51	78.57±0.23	74.54±0.18
Probability		NS		NS		NS		NS
CYS / TSAA(%)	48.34±0.32[a]	39.60±0.24[b]	22.34±0.26	23.40±0.43	26.51±0.12[a]	36.56±0.35[b]	28.39±0.19	23.94±0.61
Probability		0.01		NS		0.01		NS
TAAA (ASP + GLU)	18.52±0.31	20.02±0.28	19.64±0.65	20.19±0.43	18.75±0.23	20.17±0.20	20.12±0.19	20.77±0.11
Probability		NS		NS		NS		NS
TBAA (ARG + LYS)	11.30±0.11	11.74±0.18	11.72±0.21	11.75±0.14	11.60±0.17	9.48±0.32	8.77±0.19	8.67±0.23
Probability		NS		NS		NS		NS
LEU/ ILE	1.44±0.19	1.48±0.31	1.51±0.17	1.49±0.19	1.35±0.15	1.38±0.16	1.46±0.13	1.07±0.10
Probability		NS		NS		NS		NS
PER	1.94±0.13	2.07±0.19	2.09±0.10	2.14±0.18	1.88±0.12	2.09±0.21	2.09±0.20	2.09±0.19
Probability		NS		NS		NS		NS
EAAI%	87.40±0.43	89.79±0.49	87.27±0.21	89.48±0.23	92.45±0.54	94.20±0.52	92.90±0.27	88.33±0.89
Probability		NS		NS		NS		NS
BV%	83.57±0.15	86.17±0.31	83.42±0.23	85.83±0.29	89.07±0.54	90.98±0.76	89.56±0.21[a]	84.58±0.37[b]
Probability		NS		NS		NS		0.04
Nutritional index(%)	71.28±0.43	74.53±0.39	68.52±0.51	70.50±0.32	73.82±0.26	75.23±0.64	73.96±0.37	70.21±0.32
Probability		NS		NS		NS		NS
	Egg Yolk							
TEAA + HIS +ARG /TAA%	54.18±0.11	54.25±0.18	56.76±0.54	55.72±0.21	55.83±0.26	55.31±0.76	56.87±0.54	54.64±0.88
Probability		NS		NS		NS		NS
TEAA / TAA(%)	41.07±0.12	40.92±0.20	43.43±0.23	42.33±0.32	43.01±0.76	42.24±0.87	43.44±0.91	41.65±0.32
Probability		NS		NS		NS		NS
TNEAA/ TAA(%)	58.93±0.43	59.08±0.65	56.57±0.23	57.67±0.45	56.99±0.76	57.76±0.93	56.56±0.12	58.35±0.53
Probability		NS		NS		NS		NS
TSAA (Meth + CYS)	5.11±0.14	4.03±0.53	3.35±0.23	3.40±0.51	2.96±0.18	2.98±0.27	3.49±0.31	2.87±0.28
Probability		0.03		NS		NS		NS
Ar AA (PHE +TYR)	10.52±0.43	9.82±0.19	10.41±0.22	9.10±0.23	10.52±0.43	9.79±0.43	11.31±0.75[a]	9.50±0.87[b]
Probability		NS		NS		NS		0.03
TEAA / TNE AA(%)	69.71±0.87	69.25±0.98	76.77±0.43	73.40±0.65	75.47±0.48	73.14±0.59	76.81±0.75	71.37±0.69
Probability		NS		NS		NS		NS
CYS / TSAA(%)	58.12±0.17[a]	54.34±0.21[b]	24.18±0.23	24.71±0.19	24.66±0.19[b]	38.59±0.21[a]	25.21±0.26	24.39±0.29
Probability		NS		NS		0.01		NS
TAAA (ASP + GLU)	18.47±0.21	16.20±0.18	17.63±0.43	16.05±0.54	17.84±0.66	17.44±0.26	16.28±0.13	16.51±0.22
Probability		NS		NS		NS		NS
TBAA (ARG + LYS)	13.26±0.17	12.50±0.19	13.15±0.21	12.42±0.20	12.94±0.25	12.06±0.17	12.90±0.19	12.38±0.23
Probability		NS		NS		NS		NS

LEU/ ILE	1.42±0.21	1.32±0.17	1.48±0.11	1.50±0.15	1.53±0.17	1.53±0.16	1.46±0.13	1.52±0.11
Probability		NS		NS		NS		NS
PER	1.87±0.09	1.66±0.11	2.09±0.10	1.87±0.12	2.15±0.15	1.95±0.16	1.99±0.19	1.90±0.11
Probability		NS		NS		NS		NS
EAAI(%)	79.94±0.63^{a}	73.11±0.41^{b}	84.14±0.29^{a}	77.07±0.32^{b}	82.58±0.44^{a}	75.32±0.27^{b}	84.74±0.19^{a}	74.91±0.25^{b}
Probability		0.01		0.01		0.02		0.01
BV(%)	75.43±0.43^{a}	67.99±0.63^{b}	80.01±0.41^{a}	72.31±0.29^{b}	78.31±0.35^{a}	70.40±0.61^{b}	80.67±0.33^{a}	69.95±0.28^{b}
Probability		0.01		0.01		0.02		0.01
Nutritional index(%) (NI)	24.41±0.22	25.20±0.24	28.99±0.19	26.77±0.11	27.67±0.27	25.68±0.31	28.43±0.15	25.37±0.18
Probability		NS		NS		NS		NS

Means within the same row followed by different superscripted letters are significantly different. P ≤ 0.05. NS = not significant; Irrad. = Irradiated, Con.= Control.

The most abundant essential amino acids in nonirradiated egg whites were lysine and leucine. Irradiation resulted in an increase in leucine in turkey, duck and goose egg whites and decreased leucine in chicken egg whites. The EAAs with the highest concentrations were leucine in irradiated duck, goose and turkey eggs and phenylalanine in irradiated goose eggs, although these differences were not significant. Furthermore, leucine was also the most concentrated EAA in egg yolks in both control and irradiated eggs, with a decreasing trend of goose > duck (> chicken > turkey. In contrast, the least abundant EAAs in control and irradiated eggs were histidine in egg whites and methionine in egg yolks. A decrease in methionine was observed following irradiation in the egg yolks of all species except duck, while histidine decreased only in duck egg whites and increased in other samples (Table 6). The essential amino acid scores (EAAS) of the samples with respect to the amino acid profile of a standard hen's egg show that histidine had the highest scores, followed by phenylalanine (> 1.0), in both the egg whites and yolks of all turkey, duck, goose, and chicken samples (Table 6). Furthermore, the scores for histidine were greater than 1.0 in irradiated chicken egg whites. On the other hand, the lowest EAAS was that of valine in irradiated egg whites; while methionine had the lowest EAAS in irradiated egg yolks. In contrast, the values obtained for methionine in irradiated egg whites were high. We also noted that the LEU/ILEU ratio was low in the present study. This ratio is much lower than that of the values for turkey hen meat reported by Adeyeye and Ayejuyo (2007).

Table 6 : Essential amino acid scores of irradiated (4 kGy) and nonirradiated (control) egg whites and yolks with respect to a standard hen's egg (amino acid values are expressed as g/100 g).

Essential AA	White turkey		Pekin duck		White goose		Fayoumi chicken	
	Con.	**Irradiated**	**Con.**	**Irrad.**	**Con.**	**Irrad.**	**Con.**	**Irrad.**
	Egg White							
Isoleucine (ILE)	0.47±0.06	0.46±0.03	0.47±0.09	0.46±0.03	0.52±0.08	0.52±0.05	0.52±0.04	0.50±0.06
Probability		NS		NS		NS		NS
Valine (VAL)	0.34±0.08	0.32±0.04	0.35±0.01	0.33±0.04	0.35±0.07	0.36±0.05	0.38±0.04^{a}	0.35±0.04^{b}
Probability		NS		NS		NS		0.05
Lysine (LYS)	0.49±0.04	0.50±0.07	0.50±0.09	0.48±0.07	0.75±0.04^{a}	0.54±0.02^{b}	0.53±0.06	0.50±0.03
Probability		NS		NS		0.01		NS
Leucine (LEU)	0.46±0.03	0.47±0.02	0.49±0.07	0.47±0.05	0.48±0.04	0.49±0.07	0.52±0.04^{a}	0.37±0.02^{b}
Probability		NS		NS		NS		0.001
Phenylalanine (PHE)	0.59±0.06	0.60±0.08	0.62±0.04	0.58±0.02	0.64±0.06	0.66±0.05	0.68±0.03^{a}	0.64±0.02^{b}
Probability		NS		NS		NS		0.04
Threonine (THR)	0.55±0.03	0.57±0.11	0.56±0.10^{a}	0.51±0.09^{b}	0.58±0.06^{a}	0.63±0.01^{b}	0.61±0.04^{a}	0.56±0.03^{b}
Probability		NS		0.02		0.02		0.02
Methionine (Meth)	0.63±0.12^{a}	0.58±0.16^{b}	0.50±0.09^{b}	0.57±0.10^{a}	0.67±0.14^{a}	0.58±0.06^{b}	0.68±0.08^{a}	0.57±0.11^{b}
Probability		0.02		0.01		0.01		0.001
Histidine (HIS)	0.66±0.10	0.68±0.12	0.71±0.08^{a}	0.64±0.05^{b}	0.75±0.010^{b}	0.78±0.09^{a}	0.81±0.05^{b}	1.23±0.11^{a}
Probability		NS		0.01		0.05		0.001
	Egg Yolk							
Isoleucine (ILE)	0.49±0.01^{a}	0.45±0.03^{b}	0.43±0.01	0.41±0.02	0.42±0.09	0.41±0.05	0.47±0.03^{a}	0.41±0.04^{b}
Probability		0.04		NS		NS		0.02
Valine (VAL)	0.38±0.08^{a}	0.35±0.02^{b}	0.35±0.01	0.35±0.04	0.35±0.03	0.34±0.07	0.38±0.01^{a}	0.34±0.03^{b}
Probability		0.05		NS		NS		0.04
Lysine (LYS)	0.45±0.08^{a}	0.38±0.06^{b}	0.40±0.04	0.40±0.07	0.39±0.03	0.37±0.01	0.41±0.03	0.39±0.02
Probability		0.01		NS		NS		NS
Leucine (LEU)	0.47±0.06^{a}	0.40±0.05^{b}	0.43±0.01	0.42±0.03	0.43±0.06	0.43±0.02	0.46±0.08^{a}	0.43±0.09^{b}
Probability		0.01		NS		NS		0.05
Phenylalanine (PHE)	0.77±0.05^{a}	0.65±0.07^{b}	0.68±0.05^{a}	0.55±0.03^{b}	0.70±0.02	0.70±0.09	0.84±0.06^{a}	0.66±0.08^{b}
Probability		0.001		0.001		NS		0.01
Threonine (THR)	0.54±0.02^{a}	0.43±0.05^{b}	0.44±0.01	0.42±0.03	0.44±0.01	0.44±0.07	0.49±0.08^{a}	0.43±0.03^{b}
Probability		0.01		NS		NS		0.01
Methionine (Meth)	0.26±0.10^{a}	0.21±0.09^{b}	0.27±0.04	0.28±0.11	0.23±0.06	0.20±0.04	0.30±0.07^{a}	0.24±0.03^{b}
Probability		0.01		NS		NS		0.01
Histidine (HIS)	0.85±0.08^{a}	0.70±0.04^{b}	0.80±0.10	0.78±0.08	0.74±0.03	0.74±0.07	0.90±0.05^{a}	0.70±0.09^{b}
Probability		0.01		NS		NS		0.001

Means within the same row followed by different superscripted letters are significantly different. P ≤ 0.05. NS = not significant; Irrad. = Irradiated, Con.= Control.

Conclusions

The PER, BV, and EAAI values of egg whites for both nonirradiated and irradiated eggs were generally high (> 90%), and thus eggs white are therefore considered a good source of protein. In general, our results show that gamma radiation does not exert significant effects on the chemical composition and protein quality of the whites and yolks of eggs. We recommendation used Gamma radiation at 4 kGy preserving eggs for long periods.

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