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Effect of gamma irradiation and thermal pasteurisation on functional quality of liquid whole egg#

Linda S. Kumar [1*], V.N. Vasudevan[1*], T. Sathu[1], A. Irshad[1] and Deepa Jolly[2]

[1]Department of Livestock Products Technology, [2]Department of Veterinary Public Health, College of Veterinary and Animal Sciences, Mannuthy, Thrissur- 680 651, Kerala Veterinary and Animal Sciences University, Kerala, India

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Abstract

The present study aimed to assess the effect of gamma irradiation and thermal pasteurisation on the functional quality of liquid whole egg. Three separate liquid whole egg (LWE) homogenate samples were used in the study: Control untreated LWE (C), gamma irradiated at a previously validated pasteurisation dose of 3kGy, and thermally pasteurised at a core temperature of 60±1°C for 3.5 min (T). Samples were analysed for their functional properties on the day of pasteurisation. The foaming capacity and foaming stability were significantly ($p<0.05$) higher, whereas the viscosity was significantly ($p<0.05$) lower for G when compared to C and T. The emulsifying capacity of G was significantly ($p<0.05$) lower than C, whereas emulsifying stability of G did not differ significantly from C. According to the findings of this study, subjecting the LWE to gamma irradiation at 3kGy, showed no alterations in emulsifying capacity whereas foaming capacity and foaming stability was improved, when compared to the untreated control (C). The G showed lower viscosity and emulsifying stability.

Keywords: *Liquid whole egg, cold pasteurised, thermally pasteurised, functional properties*

Egg pasteurisation has become a significant concern addressed by food safety authorities, particularly due to recent media attention on illnesses linked to the consumption of products containing raw eggs. Pasteurisation of liquid eggs are commercially done by thermal methods, which requires careful monitoring of its temperature-time combination, besides resulting in loss of nutrients, textural changes and development of cooked flavour and increased chances of over cooking. Alternative methods of pasteurisation, such as cold pasteurisation using gamma irradiation, are known to ensure microbial safety in liquid whole egg. The functional characteristics of liquid whole eggs find application across diverse sectors, especially the food industry. Three-dimensional egg protein gels are stabilized by intermolecular linkages such as disulphide cross-links, hydrogen bonds, and hydrophobic interaction with heating for a desired texture in many food systems. Egg proteins are responsible for many functional properties such as foaming, whipping, and viscosity building (Hsieh and Resenstein, 1989). But irradiation generates free radicals capable of inducing substantial alterations in the quality and functional attributes of both eggs and egg-derived products (Branka *et al*., 1992). Raikos *et al*. (2007) mentioned that any alterations in gel formation and aggregation of proteins in eggs affect their rheological properties. Yasuda *et al.* (1986) mentioned these alterations as multistage complex processes dependent on protein concentration, ionic strength, pH as well as

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**Corresponding author: lindask189@gmail.com, Ph. 9656627411*

interactions with other surrounding components present in the environment. The goal of this study was to assess the effect of gamma irradiation and thermal pasteurisation on the functional properties of liquid whole egg.

Materials and methods

Table eggs, marketed by All India Coordinated Research Project (AICRP) on Poultry Breeding, Mannuthy, were procured for the experiments and utilised within 24 hours. Eggs were washed with 70 per cent ethanol and dried under laminar air flow (Patrignani *et al*., 2013). Eggs were aseptically broken and the contents were carefully homogenised in glass beakers for 60 sec using a hand-held blender (Butterfly Ivory plus, India) that had been previously washed and sterilised using 70 per cent ethanol (Seo *et al*., 2003). Liquid whole egg homogenate was prepared aseptically and about 100 mL each was transferred to 250 mL PET bottles and subjected to gamma irradiation and thermal pasteurisation. The LWE was irradiated at 3kGy in the Gamma Chamber GC5000 (BRIT-DAE, Mumbai) at the Department of Livestock Products Technology and Meat Technology Unit, College of Veterinary and Animal Sciences, Mannuthy, where the source of radiation was Cobalt 60 (60-Co). Gamma irradiated samples were labelled as G. The thermal pasteurisation of LWE homogenate was carried out as per the standards laid out by United States Department of Agriculture- Food Safety and Inspection Service (USDA-FSIS, 2000). This standard stipulates holding of LWE at a core temperature of at least 60°C for no less than 210 sec. Thermal pasteurisation was carried out using two precision water baths set at two different temperatures, i.e., riser water bath set at 79±1°C and holder water bath set at 64±1°C as per the modified method prescribed by Wong *et al*. (1996). Thermally pasteurised LWE samples were labelled as T and the remaining bottles served as the untreated control were as labelled C. The C, G and T samples were analysed for their functional properties on the day of pasteurisation.

Foaming capacity (FC), foaming stability (FS), emulsifying capacity (EC), emulsifying stability (ES) and viscosity are the predominant functional properties of egg. These were determined by the method used by Zhao *et al.* (2007). Viscosity was measured as per Kaya and Tekin (2001).

Foaming capacity

Hundred millilitres of 5 per cent LWE solution in deionised water was whipped at low speed in a 250 mL Warring Blender (Waring Commercial Inc., USA) for 5 min. Subsequently, the whipped LWE samples were carefully transferred immediately to a 250mL graduated measuring cylinder and the volume of the whipped foam was recorded after 30 sec. The forming capacity (FC) was calculated as follows (Zhao *et al*., 2021):

Forming capacity (per cent) = (V_L/V_0) x 100

Where: V_0 = Initial volume of homogenate (100mL) and V_L = Foam volume recorded 30 sec after whipping (mL).

Foaming stability

The whipped LWE homogenate was kept in the graduated measuring cylinder for 30 min and the forming stability (FS) was calculated as follows (Zhao *et al.,* 2021):

Forming stability (per cent) = (V_T/V_0) x 100

Where: V_0 = Initial volume of homogenate (100mL) and V_T = Foam volume recorded 30 min after whipping (mL).

Emulsifying capacity

To determine the emulsifying capacity (EC), 50 mL of 5 per cent LWE solution in deionised water was homogenised at 10,000 rpm for 30 sec using a Polytron homogeniser (Polytron PT 2500 E, Kinematica). Fifty milliliters of Soy Oil (Refined Soyabean oil, Fortune, India) were added, and homogenised for an additional min. The blended solution was then transferred to 15mL centrifuge tubes and centrifuged (Rotek Laboratory Instruments, India) at 1200×g for 5 min. This resulted in an upper emulsion layer and lower non-emulsified layer. The volume of the lower emulsion layer was recorded. EC was calculated as follows:

Emulsifying capacity (per cent) = (Volume of emulsified layer / Volume of whole layer in centrifuge tube) x 100

Table 1. Mean foaming capacity and stability of control (untreated), cold pasteurised and thermally pasteurised liquid whole egg samples

Samples	Foaming capacity (%)	Foaming stability (%)
C	105.75^{b} ± 3.03	87.83b ± 3.29
G	115.17^{a} ± 2.24	103.33a ± 4.88
T	81.50^{c} ± 2.14	73.33c ± 0.99
F -value (p- value)	48.135 ** (<0.001)	18.987 ** (<0.001)

**Significant at 0.01 level; Means with different lower-case alphabets as superscript differ significantly. The values are expressed as their Mean ± Standard error. C: Control; G: Cold pasteurised at 3kGy; T: Thermally pasteurised

Emulsifying stability

To determine emulsifying stability (ES), the centrifuge tubes containing the emulsion and non-emulsion layers (as described above) were subsequently heated in a water bath (Rotek Laboratory Instruments, India) at 80°C

for 30 min, then cooled to 20°C in on ice and centrifuged at 1200×g for 5 min. The ES was calculated as follows:

Emulsifying stability (per cent) = (Volume of emulsified layer remained after heating / Volume of emulsified layer before heating) x 100

Viscosity

The viscosity of LWE samples were measured at Verghese Kurien Institute of Dairy and Food Technology, Mannuthy using a Brookfield digital viscometer (Brookfield Engineering Labs. Inc., Middleboro, U.S.A.) equipped with a spindle no. 2. Measured volume (300mL) of the samples was taken in a 500mL beaker and the viscometer probe with spindle no. 2 was dipped in it for 10 sec, at 50 rpm. Three readings were taken for each sample. The dial reading obtained was corrected by the corresponding factor (16), supplied by the instrument manufacturer, to obtain the viscosity values in centipoise (cP). The value was then converted to pascal-sec (Pa s) by dividing by 1000 i.e., 1 cP is equal to 0.001 Pa s.

Samples: Eighteen samples (six replications per samples) for all three LWE samples (C, G and T) were evaluated for functional properties.

Statistical analysis

Data obtained for were statistically analyzed for one-way ANOVA using the Statistical Package for Social Sciences (SPSS) software 24.0 version (Snedecor and Cochran,1994).

Results and discussion

Foaming capacity

The mean foaming capacity of the C, G and T samples was significantly ($p < 0.05$) different for all the samples on the day of pasteurisation and were presented in Table 1. Gamma irradiated LWE had significantly higher foaming capacity than C and T samples. This was in accordance with the reports of Liu *et al*. (2009) who observed that irradiation at 1.5 and 2.0kGy resulted in a considerable increase in the foaming capacity and foaming stability of spray dried egg whites. This may be due to increased surface hydrophobicity by alterations in the protein's structure as explained Ma *et al.* (1990). Ma *et al.* (1990) showed that after shell eggs were exposed to up to 2.98kGy of gamma radiation, both foaming stability and foaming ability increased. This was explained by the partial denaturation of the protein present at the air-water interface, which produces an elastic layer that stabilizes the foam. Clark *et al*. (1992) and Liu *et al*. (2009) also reported improved functional properties in spray-dried egg whites irradiated at ≥2kGy, because irradiation caused changes in the secondary structure (from an α- helix to a random coil) and disulfide bond, thereby enhancing some functional properties.

The T samples got significantly lower values for foaming capacity which was in agreement with Radovčić *et al*. (2020) who attributed the lower foaming capacity to denaturation of conalbumin (heat sensitive egg white protein). Johnson and Zabik (1981) claimed that ovomucin, ovomucoid, conalbumin, and lysozyme by themselves had little to no ability to foam, but they did confirm that the interaction between globulins and lysozyme is crucial to the foaming process.

A foam is a type of colloidal dispersion that occurs when a liquid phase disperses a gaseous phase. A foam is produced when egg white is beaten because air bubbles are trapped in the liquid albumen. An egg white component called ovomucin creates an insoluble coating that stabilizes the froth (MacDonnell *et al.*, 1955). Because of its ability to foam, albumen may be used as a leavening agent, which gives some food items their characteristic lightness. Meringues are very aerated sugar-filled egg whites. Angel cakes are meringues with added flour that help with its structure. While both egg yolk and white are present in soufflés and frothy omelets, beaten white is primarily responsible for their lightness. Compared with egg white alone, foaming capacity of egg white dispersions with yolk and plasma had a significant reduction, which meant yolk and plasma might compete with egg white at the air–water interface (Serrano *et al.,* 1997).

Foaming stability

The mean foaming stability of the C, G and T samples was significantly ($p < 0.05$) different for all the samples on the day of pasteurisation and were presented in Table 1. G samples had significantly higher foaming stability which is in accordance with works of Liu *et al*. (2009) in which a considerable increase in the foaming stability was noted upon irradiation at 1.5 and 2kGy in shelled eggs. Ma *et al*. (1990) observed that the time for foam drainage, an index of foam stability, was increased by irradiation at higher dosages (2.37 and 2.98kGy) indicating an improvement in foam stability of shell eggs. Conversely, Min *et al*. (2012) noted that irradiation of egg white at 2.5kGy, did not change foam stability; however, at dose ≥ 5.0kGy, it decreased.

Kannan *et al*. (2013) noted that as the heating rate increased; the foam stability decreased and summed up that foam stability is quite sensitive to thermal treatment. Wang and Wang (2009) also noticed that egg white's foam stability decreased after pasteurisation at higher temperature (62°C or 64°C for 4 min). Griswold (1962) outlined the unfolding of protein molecules to produce polypeptide chains with long axes parallel to the surface as the process of foam generation. A portion of the albumen coagulates or loses its solubility due to this

change in molecular structure and gathers at the liquid-air interface. This adsorption film is crucial for maintaining the stability of foam. A liquid possessing strong elasticity or tensile strength is also necessary for the creation of stable foam. Low surface tension is frequently linked to foaming capability. Low surface tension is not as significant as high viscosity and low vapor pressure. There is minimal propensity for a viscous liquid to drain out of the air cells and little inclination for a low-vapor pressure liquid to evaporate (Baldwin, 1986).

Emulsifying capacity

The mean emulsifying capacity of the C, G and T samples was significantly ($p < 0.05$) different for on the day of pasteurisation (Table 2). The mean differed with the highest value recorded for control untreated samples. Ferrari *et al*. (2022) suggested that homogenisation of yolk releases more low-density lipoproteins (LDLs), enabling better binding between protein and oil droplets during emulsification.

Irradiated LWE samples had significantly lower emulsifying capacity than C. Egg yolks are effective emulsifiers. Therefore, whole eggs or egg yolks are utilised in the preparation of mayonnaise and salad dressings. The initial stage of emulsion formation is likely to be the reduction of interfacial tension, and the egg yolk's surface-active ingredients are crucial to the emulsification process (Baldwin,1986). Egg yolk contributes viscosity to emulsions, and viscous emulsions tend to be stable. The irradiated samples had significantly lower viscosity than the control, which might have contributed to the lowering of emulsifying properties of irradiated LWE samples.

Thermally pasteurised LWE samples had significantly lower emulsifying capacity than C. Ribeiro *et al*. (2023) observed significant reduction ($p < 0.05$) in the emulsifying activity index of thermally pasteurised (60°C, 3.5 min) LWE when compared to non-treated LWE. This differs from the findings of Le Denmat *et al*. (1999) who observed no significant effect of thermal pasteurisation below 69°C on emulsifying capacity liquid egg yolk. The observed decrease in the emulsifying capacity of T samples could be due to the denaturation and in solubilisation of proteins and lipoproteins including lipovitelline, livetine, ovotransferrin, and G2 globulin as observed by Herald and Smith (1989) in LWE samples subjected to thermal pasteurisation at 60°C for 3.5 min. Chapin (1951) identified the proteins and lipoproteins (the ether-insoluble portion) as the most important emulsifying substances in whole egg.

Emulsifying stability

The mean emulsifying stability values of the C, G and T samples on the day of pasteurisation were evaluated and presented in Table 2. The mean emulsifying stability (per cent) of the C and G did not differ significantly whereas that of T was significantly ($p<0.05$) lower than C and G. Ma *et al*. (1990) noted that upon irradiation at 2.37 and 2.98kGy the emulsification activity index (EAI) of freeze-dried egg white was also significantly ($p<0.05$) increased. Ribeiro *et al*. (2023) observed significant reduction ($p < 0.05$) in the emulsifying stability index of thermally pasteurised (60°C, 3.5 min) LWE when compared to non-treated LWE. This is contrary to the reports of Lechevalier *et al*. (2017) observed that whole egg pasteurisation at 60°C increases protein interfacial properties and generate more stable emulsions with lower droplet size.

Viscosity

The mean viscosity of the C, G and T samples was on the day of pasteurisation were evaluated and presented in Table 3. The mean viscosity (Pa s) of the G samples was significantly ($p<0.05$) lower on the day of preparation when compared to C and T. Li-Chan *et al*. (1995) reported that the viscosity of egg is largely determined by ovomucin, which imparts the gel like consistency of the albumen. Min *et al*. (2012) also reported that irradiation made liquid egg white more turbid but reduced its viscosity. Studies by Min *et al*. (2012), Al-Bachir and Zeino, (2006) and Kim *et al*. (2016) indicated that, in a dose-dependent way, gamma irradiation significantly reduced the egg white solution's viscosity values. Bacq and Alexander (1961) mentioned marked reductions of viscosity and changes of electrophoretic

Table 2. Mean emulsifying capacity of control (untreated), cold pasteurised and thermally pasteurised liquid whole egg samples

Samples	Emulsifying capacity (%)	Emulsifying stability (%)
C	$52.08^{a} \pm 0.53$	95.53a ± 0.28
G	$50.22^{b} \pm 0.22$	92.33a ± 1.63
T	$45.50^{c} \pm 0.90$	85.69b ± 1.82
F -value (p- value)	30.813 ** (<0.001)	12.494 * (0.001)

** Significant at 0.01 level. Means with different lower-case alphabets as superscript differ significantly. The values are expressed as their Mean ± Standard error. C: Control; G: Cold pasteurised at 3kGy; T: Thermally pasteurised

Table 3. Mean viscosity of control (untreated), cold pasteurised and thermally pasteurised liquid whole egg samples

Samples	Viscosity (Pa s)	F -value (p- value)
C	$0.047^{a} \pm 0.004$	10.898 * (0.001)
G	$0.020^{b} \pm 0.003$	
T	$0.044^{a} \pm 0.015$	

*Significant at 0.05 level. Means with different lower-case alphabets as superscript differ significantly. The values are expressed as their Mean ± Standard error. Control; G: Cold pasteurised at 3kGy; T: Thermally pasteurised

patterns would indicate molecular degradation. Radiation-induced main chain scissions and disruption of molecular structure have been reported.

There was no significant difference in the viscosity between C and T samples. Reinke and Baker (1966) have also reported absence of significant difference in viscosity between control and thermally pasteurised (64.4°C. for 2.5 min) liquid whole egg.

Conclusion

The present study, conducted at the Department of Livestock Products Technology, Meat Technology Unit, College of Veterinary and Animal Sciences, Mannuthy, aimed to shed light on the comparative effects of gamma irradiation at 3kGy and thermal pasteurisation on the functional properties of liquid whole egg. It is evident that both methods exhibit efficacy in reducing microbial load, ensuring safety, and extending shelf life. Overall, this study indicated that foaming properties of liquid whole egg improved with gamma irradiation of at 3kGy, whereas emulsifying capacity was lower than the control. The viscosity was significantly reduced upon irradiation at 3kGy, whereas thermally pasteurised liquid whole eggs samples had no difference in viscosity when compared with control. Thermally pasteurised samples had lower emulsifying properties as well as foaming properties. Hence, this work contributes valuable insights and offers guidance on the effect of two pasteurisation techniques on liquid whole egg.

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Conflict of interest

The authors do not have any competing interests among themselves or others related to this research work.

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