New technologies to enhance quality and safety of table eggs: ultra-violet treatment and modified atmosphere packaging

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Abstract

In the present study the effect of ultra-violet (UV) treatment alone and in combination with 100% CO_2 modified atmosphere packaging (MAP) was evaluated both on the survival of naturally occurring bacteria, as well as on quality parameters of table eggs during 28 days of storage at 21°C. Table eggs were collected from the conveyor belt after the UV module, and placed on carton trays. A representative number of carton trays were packed in a high barrier multilayer pouch filled with 100% CO_2. All eggs were stored at 21°C and analysed at 0, 1, 7, 14, 21 and 28 days of storage. Eggs not treated with UV and not packed were also included. On the eggshells total colony count, total coliforms and faecal coliforms counts, as well as the detection of *Salmonella* spp. were investigated. Moreover, chemical-functional parameters such as weight loss, albumen pH and Haugh Unit (HU) were evaluated. The total colony count on UV treated table eggs was approximately 1 $\log_{10}$ CFU/g lower than untreated eggs (2.27 *vs* 3.29 $\log_{10}$ CFU/g). During storage, CO_2 packed eggs maintained the initial values of HU, whereas the albumen pH decreased up to 1.5-2 points in comparison to unpacked eggs. The UV treatment was effective in reducing the total colony count on the surface of table eggs. MAP showed a great potential in maintaining/enhance the technological properties of egg constituents (higher foam stability of the albumen for meringue preparation) without significantly impacting on the microbial load of table eggs.

Introduction

From a food safety perspective, table eggs represent a concern to public health. Egg and egg products are reported as the most frequently identified food vehicles of food-borne outbreaks (European Food Safety Authority, 2014). This food product category was related to the 22% of the 763 strong-evidence outbreaks reported in 2012 in Europe (European Food Safety Authority, 2014). Bacterial pathogens such as *Salmonella enterica* serovar Enteritidis as well as spoilage bacteria can contaminate the outer shell surface of the egg or the inner egg contents. Internal contamination might occur as a consequence of the penetration through the eggshell (Gantois *et al.*, 2010). In this regard, the disinfection of table egg surface is relevant in view of preventing both egg spoilage and egg-borne illnesses. For more than twenty years ultra-violet (UV) light, applied *in continuum* or pulsed, has been described as an effective surface decontamination technology of shell eggs (Turtoi and Borda, 2014; De Reu *et al.*, 2006; Keklik *et al.*, 2010; Wells *et al.*, 2010; Kuo *et al.*, 1997; Chavez *et al.*, 2002; Coufal *et al.*, 2003). The fate of bacteria on UV treated shell eggs along storage has not been described to our knowledge.

Regarding the quality of table eggs, during storage the egg constituents undergo a decrease of their functional quality (*i.e.* foam stability of the albumen) (Rocculi *et al.*, 2009, 2011). In this regard a food preservation technology might be envisaged.

Modified atmosphere packaging (MAP) is a widely used food preservation technique, which might contribute to the quality maintenance of the initial fresh food product. On fresh eggs, high CO_2 atmosphere packaging has a documented positive effect both on the quality maintenance of the product and on the technological properties of the egg constituents (Cotterill and Gardner, 1956; Moran, 1937; Rocculi *et al.*, 2009, 2011). In particular 100% CO_2 packed eggs showed a limitation of the Haugh Unit (HU) decrease and of the pH increase during storage (Rocculi *et al.,* 2009). These findings were linked to a statistically higher foam stability of the albumen (Rocculi *et al.,* 2011). From a microbiological point of view, the positive effect of MAP on the growth inhibition of spoilage bacteria has been widely documented for different food products (Genigeorgis, 1985; Hintlian and Hotchkiss, 1987; Wimpfheimer *et al.,* 1990; Faber, 1991; Rajkovic *et al.,* 2010). On table eggs, 100% CO_2 packaging showed to be more effective than 100% air in controlling spoilage bacteria during 30 days of storage at 4, 25 and 37°C (Pasquali *et al.,* 2012). The effect of 100% CO_2 in comparison to unpacked eggs along storage was not described to our knowledge.

In the present study the effect of UV treatment alone and in combination with 100% CO_2 MAP was evaluated both on the survival of naturally occurring bacteria as well as on quality parameters of the egg albumen during 28 days of storage at 21°C, and compared to untreated and unpacked table eggs.

Materials and Methods

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Table eggs were collected from a commercial packaging center selected for a high level of automation aimed to prevent possible cross-contaminations. All eggs originated from the same farm of laying hens reared in enriched cages.

For the UV treatment, a prototype UV-C disinfection system having a wavelength of 253.7 nm with an intensity of 10 mW cm^2 was used (UV-disinfection system; MOBA, Barneveld, the Netherlands). The UV-disinfection system was linked to a MOBA hygienic (double) roller infeed. The speed of the conveyor belt was of 0.171 m s^{-1}. As the UV-C disinfection system had a length of 119.2 cm, the exposure time for each egg was 7 s.

For MAP, eggs were placed on carton supports chosen in preliminary comparative experiments as the best supports in terms of humidity absorbance in an environment with Relative Humidity of 98%. Each support enclosing 6 or 12 eggs was packed in a high barrier multilayer pouch (Reber snc, Reggio Emilia, Italy) which was filled with gas using a quaternary mixer mod. KM100-4 (Witt-Gasetechnik, Witten, Germany) and a gas flushing welding machine mod. Multiple 315 (Orved srl, Venice, Italy).

For the evaluation of the efficacy of UV treatment alone on the reduction of the surface microbial load of table eggs, a total of 640 eggs were collected in 4 successive trials. For each trial, 16 samples were tested: eight replicate samples of eggs collected before the UV module (control samples) and eight replicate samples of eggs collected after the UV module. Each sample was a pool of eggshells of 10 eggs.

For the evaluation of the effect of UV treatment in combination to MAP on the reduction of the surface microbial load, 60 carton supports containing 12 eggs each were collected after the UV module. Of these, 30 supports were packed in 100% CO_2. All supports were stored at 21±2°C. At 1, 7, 14, 21 e 28 days of storage, 6 replicate samples of 100% CO_2 packed eggs were tested along with 6 replicate samples of unpacked eggs. Each sample was a pool of eggshells of 10 eggs belonging to the same carton support. For the evaluation of the combined effect of UV treatment and MAP on the quality maintenance of table egg constituents, one thousands of eggs were collected after the UV module, packed in 100% CO_2 and stored at 21±2°C. At 0, 3, 7, 11, 15, 21 e 28 days of storage, the weight loss, HU and pH of the albumen were evaluated on three eggs per pack. The pH of egg white was measured at 25°C using a pHmeter mod. Cyberscan 510 (Lennox, Dublin, Ireland), whereas the HU was determined at 25°C as previously described (Haugh, 1937). This index is yet extensively used to define interior egg quality, assaying the degree of egg freshness. Generally to a decrease of albumen quality corresponds a HU reduction.

For microbiological analyses conducted to evaluate the effect of UV treatment both alone and in combination with MAP, the pooled eggshell samples were submitted to total colony count, total and faecal coliform counts and detection of Salmonella following standard microbiological methods (ISO 4833:2003, ISO 6579:2004, ISO 4832:2006; ISO, 2003, 2004, 2006).

Results

As far as the effect of UV treatment alone on the survival of naturally occurring bacteria on the surface of table eggs is concerned, a significant reduction of the total colony count was registered comparing table eggs sampled before and after the UV treatment (from 3.29 to 2.25 $\log_{10}$ CFU/g) (Table 1). No effect of the UV treatment was registered on total and faecal coliforms, which showed loads close to the detection limit of one $\log_{10}$ CFU/g already before the UV treatment (Table 1). All samples were *Salmonella* spp. free.

Regarding the effect of UV treatment in combination with 100% CO_2 packaging on the survival of naturally occurring bacteria on the egg surface during storage at 21°C, no significant differences were registered for both total and faecal coliforms, whose loads were close to the detection limit from day 0 to day 1 and undetectable from day 7 to day 28 of storage at 21°C on both the surface of UV treated and 100% CO_2 packed eggs (UV+MAP eggs) and on UV treated and unpacked eggs (UV eggs). Due to this low load, no considerations on the effect of UV treatment and MAP on coliform bacteria might be envisaged.

A decrease of approximately 2 $\log_{10}$ CFU/g of the total colony count was registered over 28 days of storage on UV eggs, whereas an opposite trend, although not statistically significant, was registered on UV+MAP eggs (Figure 1). On the surface of not UV treated and not packed eggs (control) a substantial maintenance of the initial load of total bacteria was registered along the storage period suggesting the efficacy of UV treatment on the control of naturally occurring bacteria also during storage (Figure 1).

Regarding the effect of UV treatment in combination with 100% CO_2 packaging on the quality of egg constituents, the weight loss of unpacked eggs was registered around 7% whereas in packed eggs the weight loss was around 1.5% (Figure 2A). The reduced weight loss of 100% CO_2 packed eggs suggests the gas permeated inside the egg. This idea is confirmed by the pH values of the albumen. In particular already after 3 days of storage at 21°C the albumen pH of packed eggs decreased to 7.5 (Figure 2B). This value was maintained all over the remaining storage period. The reduced pH value was linked to the maintenance of the initial values of HU all over the storage period (Figure 2C).

Discussion

The load of naturally occurring bacteria was low both for total and faecal coliforms confirming previously reported studies (Hannah *et al*., 2011). The UV treatment alone was effective in reducing the load of total bacteria on the surface of table eggs of approx. one $\log_{10}$ CFU/g of eggshell. Similar reductions were registered by other authors testing a commercial UV treatment of 4.7 s (De Reu *et al.,* 2006). The

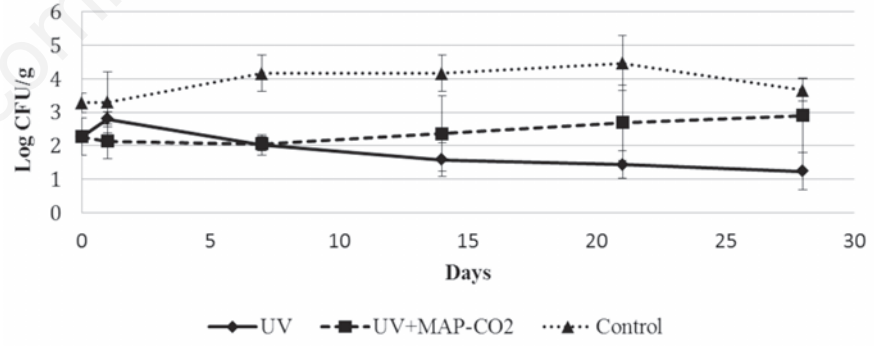

Figure 1. Total colony counts on the eggshells of eggs treated with ultra-violet and not packed (UV), eggs treated with ultra-violet and packed in 100% CO_2 (UV+MAP-CO_2), eggs not treated with ultra-violet and not packed (control) during storage at 21°C.

Table 1. Effect of ultra-violet treatment on total and faecal coliform counts, total colony counts and detection of *Salmonella* spp. on eggshells.

Egg collection	Total coliforms	Faecal coliforms	Total bacteria	*Salmonella* spp.
Before UV module	1.15±0.17*[a]	1.02±0.10[a]	3.29±0.06[b]	All negative
After UV module	1.01±0.09[a]	1.09±0.10[a]	2.25±0.14[a]	All negative

UV, ultra-violet. *Geometric mean ($\log_{10}$ CFU/g)±standard error calculated on 32 egg samples collected in N=4 trials. [ab]Values with different letters within a column differ significantly following the One-way ANOVA Post Hoc Fisher analysis (P<0.05).

effectiveness of the UV treatment was reinforced during storage. In particular, comparing the bacterial loads of UV treated not packed eggs (UV eggs) with UV not treated and not packed eggs (control), the log reduction of 1 log_{10} CFU/g registered immediately after the UV treatment increased to approx. 2 log_{10} CFU/g after 28 days of storage at 21°C (Figure 1). On the contrary 100% CO_2 packaging did not impact significantly on the load of total bacteria as well as total and faecal coliforms confirming previously reported results (Pasquali *et al.,* 2012)

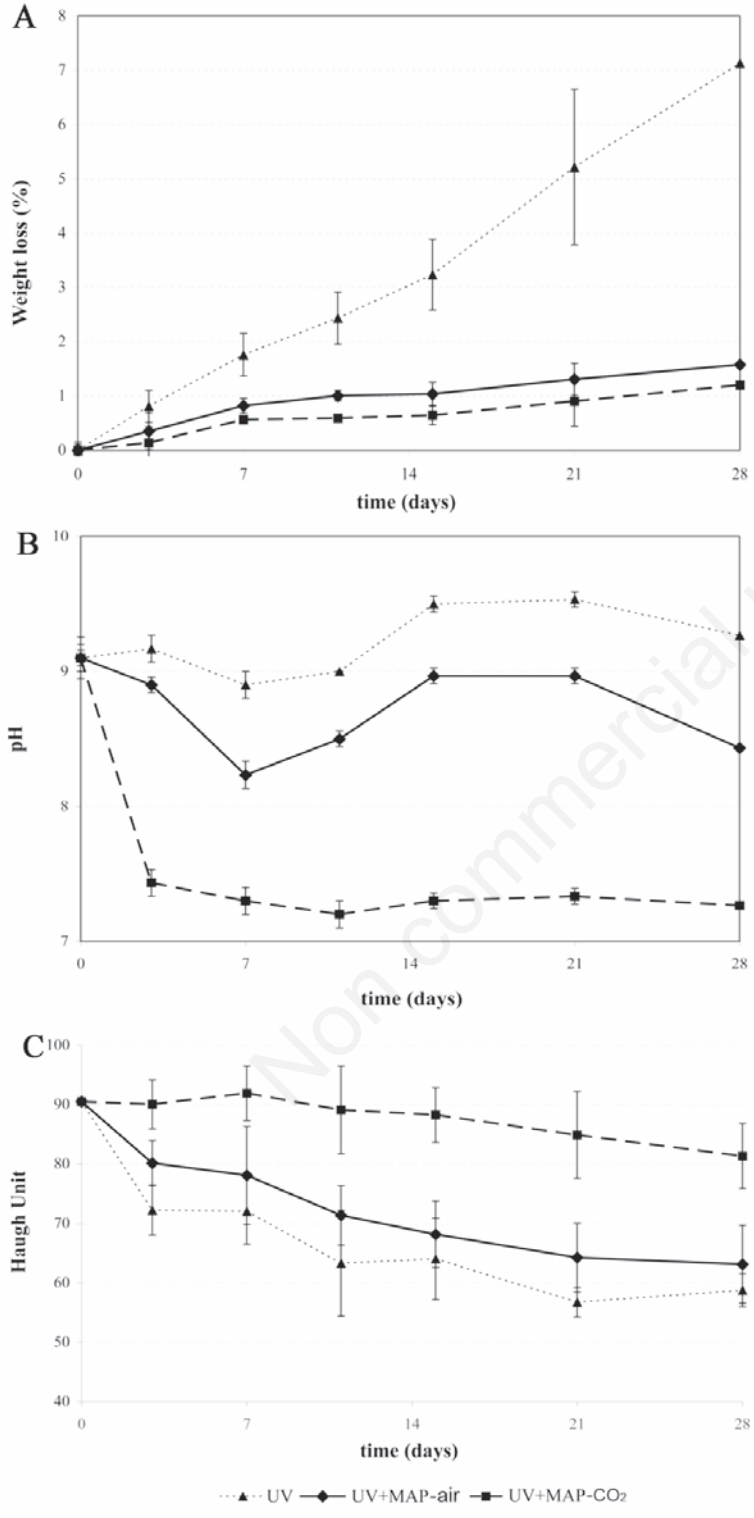

Figure 2. Effect of ultra-violet treatment in combination with modified atmosphere packaging on weight loss (g 100 g pi-1)(A), albumen pH (B), Haugh Unit (C) of table eggs during 28 days of storage at 21°C.

The weight loss of eggs during storage is mainly caused by evaporation of water and loss of CO_2 (Caner, 2005). A significant different weight loss was registered comparing 100% CO_2 packed eggs and unpacked eggs (1.5 *vs* 7%). The results on unpacked eggs confirm previous experiments showing a weight loss in a range of 6-10% (Caner, 2005; Rocculi *et al.*, 2009). In packed eggs the values reported in the present study are slightly higher than those previously reported [1.5% this study *vs* 0.5% Rocculi *et al.* (2009)]. Differences in weight loss between studies may be due to the storage conditions, temperature, egg size and shell porosity as well as, for packed eggs, inclusion of moisture adsorbent (Bhale *et al*., 2003; Caner, 2005; Rocculi *et al.*, 2009; Pasquali *et al.*, 2012).

In terms of pH (Figure 2B), the albumen of control samples showed an increasing trend from the beginning to the end of storage caused by CO_2 loss through the shell (Keener *et al.*, 2001; Li *et al.*, 1985). The albumen of samples packed in air evidenced quite constant values of pH during storage, while the use of 100% CO_2 was responsible of a fast and marked pH decrease (of about 1.5-2 points) as a consequence of CO_2 solubilisation in the albumen. Our results are in agreement with those obtained by Brooks and Pace (1938), who demonstrated that the pH of the white is bound to the partial pressure of CO_2 in the surrounding atmosphere and ranges roughly from 9.7 in air to 6.5 in 100% CO_2.

The average HU value of the fresh eggs used for our experiment (Figure 2C) was about 90, that corresponds to the one of a fresh, good quality egg (Caner, 2005). This value rapidly decreased for the control samples, in agreement with previous investigation about quality modification of fresh eggs during storage (Jones and Musgrove, 2005; Kahraman-Dogan *et al*., 1994). All packed samples better preserved eggs in terms of HU compared with unpacked ones.

Future studies will be conducted in order to evaluate the best indicator of the UV-C bactericidal efficacy. Since the bactericidal effect of UV-C is mainly due to DNA damage, the quantification of DNA strand breaks might be a useful indicator of UV-C treatment efficacy (Santos *et al*., 2013). Another subject for future studies regards the evaluation of the hygienic quality of inner content of the treated egg during storage. At present, the lactic acid content is used as chemical indicator of hygienic quality of raw material used in manufacture of egg products (European Commission, 2004). With regard to table eggs, lactic acid content might be a useful indicator of the presence and growth of spoilage bacteria as a consequence of the cross contamination due to the eggshell removal at consumer level.

Conclusions

The UV treatment was effective in controlling the total colony count on the surface of table eggs during 28 days of storage at 21°C. One hundred percent CO_2 packaging showed a great potential for quality maintenance of egg constituents. On the other hand 100% CO_2 packaging did not significantly impact on the microbial load of table eggs.

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