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Use of UV-C radiation as a non-thermal process for liquid egg products (LEP)

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Abstract

The efficacy of short wave ultraviolet light (UV-C) as a non-thermal process for liquid egg products (LEP) was investigated. Non-pathogenic *Escherichia coli* strain (ATCC 8739), which shows lower sensitivity to UV-C light than *E. coli* O157:H7 and *Salmonella typhimurium*, was chosen as a target microorganism. The inactivation of UV resistant strain of *E. coli* in LEP was examined by evaluating the effects of depth of liquid food medium (0.5, 0.3 and 0.153 cm), UV light intensity (1.314, 0.709 and 0.383 mW/cm^2) and exposure time (0, 5, 10, and 20 min) by using a collimated beam apparatus. The best reduction (>2-log) was achieved in liquid egg white (LEW) when the fluid depth and UV intensity were 0.153 cm and 1.314 mW/cm^2, respectively. Maximum inactivation was 0.675-log CFU/ml in liquid egg yolk (LEY) and 0.316-log CFU/ml in liquid whole egg (LWE) at the same conditions. The kinetics of UV inactivation of *E. coli* in LEP was nonlinear. Our results emphasize that UV-C radiation can be used as a pre-treatment process or combined with mild heat treatment to reduce the adverse effects of thermal pasteurization of LEP.

Keywords: Liquid egg products; Non-thermal process; Ultraviolet light; Inactivation; *E. coli*

1. Introduction

Egg products are classified as refrigerated liquid, frozen and dried products. Liquid egg products (LEP) are valuable due to their high protein content, low cost, and being used as ingredients in a prepared meal in order to provide texture, flavor, structure, moisture (Hamid-Samimi & Swartzel, 1985; Punidadas & McKellar, 1999).

Food-borne disease outbreaks involving *Escherichia coli O157:H7* and *Salmonella enteriditis* in liquid egg products are the major public health concern (Lee, Lee, Kim, & Park, 2001; Mañas, Pagán, Alvarez, & Usón, 2003). As a result, these products must be processed in sanitary facilities under continuous inspection and pasteurized before distributed for consumption. In the production of ready to use and shelf stable LEP; pasteurization is the fundamental process to eliminate pathogenic microorganisms from the product. The most common pasteurization method for LEP is the thermal treatment, having the principle of inactivation of microorganisms by application of heat for certain periods of time (Muriana, 1997). Minimum temperature and holding time requirements for the egg yolk is 60 °C and 6.2 min. For the egg white and whole egg, minimum temperature and holding time requirements are 55.6 °C and 6.2 min, 60 °C and 3.5 min, respectively (USDA-ARS, USA). Although thermal pasteurization still represents the most available and best understood technique, it may affect the coagulation, foaming and emulsifying properties and degrade the quality and functional properties (both technological and nutritive) of egg products (Góngora-Nieto, Pedrow, Swanson, & Barbosa-Cánovas, 2003; Hermawan, Evrendilek, Dantzer, Zhang, & Richter, 2004).

Alternative pasteurization methods including ultrasonic wave treatment, high electric field pulses, high hydrostatic

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pressure or ultrapasteurization combined with aseptic packaging have been explored to extend the shelf life and minimize disadvantages of thermal processing of LEPs (Ball, Hamid-Samimi, Foegeding, & Swartzel, 1987; Ma, Chang, Barbosa-Canovas, & Swanson, 1997; Ponce, Pla, & Sendra, 1999; Wrigley & Llorca, 1992). Most of these methods cause substantial changes in the structure of liquid egg products by causing coagulation and denaturation of proteins. In response to these limitations, UV-C radiation can be an alternative cost effective non-thermal process for LEP in order to achieve microbiologically safe and shelf stable products (Bintsis, Tzanetaki, & Robinson, 2000; Donahue, Canitez, & Bushway, 2004; Taghipour, 2004). In this process, microorganisms are eliminated by penetration of UV-C light to the outer membrane of the cell and damaging the DNA due to formation of thymine dimers, which prevent the microorganism from DNA transcription and replication, and eventually leading to cell death (Bank, Schmehl, & Dratch, 1990; Bintsis et al., 2000; Miller, Jeffrey, Mitchell, & Elasri, 1999).

UV-C light treatment has been used in the food industry for different purposes including air sanitation in the meat and vegetable processing, reduction of pathogen microorganisms in red meat, poultry and fish processing (Liltved & Landfald, 2000; Wong, Linton, & Gerrard, 1998). UV-C treatment of heat resistant yeasts, moulds, *Bacillus subtilis* and *Bacillus pumilus* spores are also common application in the orange juice processing (Tran & Farid, 2004). Additionally, UV-C radiation has been successfully applied for pasteurization of certain liquid foods such as milk and fruit juices (Koutchma, Keller, Chirtel, & Parisi, 2004; Matak et al., 2005).

There are much research cited in the literature about the efficacy of UV-C light for the reduction of different microorganisms by using either bench top collimated beam apparatus or continuous flow reactors (Lage, Teixeira, & Leitao, 2003; Sommer, Cabaj, Pribil, & Haider, 1998). Most of these works were conducted with drinking and wastewater samples and the microbial inactivation achieved in those studies with lower UV doses than those required for microorganisms suspended in liquid foods such as apple cider and milk. For example, Lage et al. (2003) treated *E. coli* suspension with UV exposure of 12 mJ/cm^2 UV dose and achieved 3-log reduction, whereas Sommer et al. (1998) inoculated water samples of 0.4 cm in depth with three different *E. coli* strains (ATCC 25922, ATCC 11229 and isolated from sewage) and applied 10–50 mJ/cm^2 UV dose to obtain maximum 6-log reduction. On the other hand, UV dosages applied by Wright, Sumner, Hackney, Pierson, and Zoecklein (2000) ranged from 9.4 to 61.5 mJ/cm^2 and the mean log reduction of *E. coli* O157:H7 strain for treated apple cider was found to be 3.81 log CFU/ml in flow through UV reactor. The milk samples treated with a UV dose of 15.8 ± 1.6 mJ/cm^2 in a continuous flow reactor in order to achieve 5-log reduction of *Listeria monocytogenes* (Matak et al., 2005).

The objective of this study was to investigate the efficiency of UV-C radiation as a non-thermal pasteurization process for liquid egg products (LEP) with UV resistant strain of *E. coli* (ATCC 8739) as the target microorganism. For this purpose, the effects of depth of liquid food medium, applied UV intensity (incident) and exposure time on the inactivation of *E. coli* (ATCC 8739) in three liquid egg products (LEP) namely liquid egg yolk (LEY), liquid egg white (LEW) and liquid whole egg (LWE) were evaluated.

2. Materials and methods

2.1. Measurement of absorbance and turbidity

Before each test, UV absorbance (A) was measured using a UV–VIS spectrophotometer (Cary 100 Bio, Varian Inc., CA, USA) set at a wavelength of 254 nm. The absorbance coefficient A_e (the fraction of UV intensity transmitted through 1 cm path length of the sample) was calculated. Additionally the turbidity of each sample was also determined by using a turbidimeter (2100AN, HACH Company, CO, USA).

2.2. Target microorganism and growth conditions

Different *E. coli* strains exhibit different UV sensitivity. UV sensitivity of *E. coli* O157:H7 compared to a non-pathogenic strain was determined to be more sensitive (Hijnen, Beerendork, & Medema, 2006). Usually, a non-pathogenic surrogate of *E. coli* O157:H7 strain that can be used safely in pilot plant studies is chosen as the target microorganism (Murakami, Jackson, Madsen, & Schickedanz, 2006).

Preliminary studies were conducted to select the target microorganism for UV-C inactivation in LEP. For this purpose, three different microorganisms including *E. coli* (ATCC 8739), *E. coli* O157:H7 (ATCC 700728) and *Salmonella typhimurium* (CCM 5445) were tested for the UV-C light sensitivity in only pasteurized LEW at the highest UV intensity (1.314 mW/cm^2) and the lowest depth (0.153 cm) for a time period of 5, 10 and 20 min. All the experiments were replicated twice. The survival data were evaluated in terms of Chick's law as log survival ratio (N/N_0) versus UV dose (Chick, 1908) which is explained in more detailed in Section 2.3. The plot of log survival ratio and UV Dose is a straight line with a slope of $-k$ known as inactivation rate constant. The inactivation rate constant (k) gives an idea about the sensitivity of the microorganism to UV-C light treatment, e.g. a UV-sensitive microorganism has a high k value and requires a low UV dose for inactivation. The inactivation rate constants (k, cm^2/mJ) of non-pathogenic *E. coli* (ATCC 8739), *E. coli* O157:H7 (ATCC 700728) and *S. typhimurium* (CCM 5445) were found to be 0.0204, 0.0317 and 0.0265 cm^2/mJ, respectively. The minimum dose to effectively eliminate all pathogens is the limiting factor for ideal UV-C radiation process. Therefore, non-pathogenic *E. coli* strain (ATCC 8739), which

shows lower sensitivity to UV-C light than *E. coli* O157:H7 and *S. typhimurium*, was chosen as a target microorganism for the routine evaluation of non-thermal UV-C radiation processing of LEP. Additionally, UV inactivation data from *E. coli* (ATCC 8739) will provide a conservative estimate of inactivation rate in LEP.

The non-pathogenic strain of *E. coli* (ATCC 8739) used in this study was kindly provided by Dr. Figen Korel (Izmir Institute of Technology, Department of Food Engineering, Izmir). During this study, it was maintained at −80 °C. A broth subculture was prepared by inoculating loop full from stock culture into a test tube containing nutrient broth (NB, Merck, Darmstadt, Germany) and strains were incubated 24 h at 37 °C. Incubation of 24 h allowed the respective bacteria to approach stationary phase of growth at a concentration of ca. 8 log unit CFU/ml.

The samples were placed in standard Petri-dishes and volume was adjusted to 0.153, 0.3 and 0.5 cm. Then, LEP samples were directly inoculated with the subculture to provide a final inoculum of 7–8 log units CFU/ml.

For enumeration, appropriate dilutions were made with 0.1% peptone water and surface plated in duplicate on Tryptic Soy Agar (TSA, Merck, Darmstadt, Germany). To determine the level of injured *E. coli* (ATCC 8739) cells, serial dilutions of the UV treated samples were spread on Violet Red Bile Agar (VRBA, Merck, Darmstadt, Germany) and Eosin Methylene Blue (EMB, Merck, Darmstadt, Germany) plates. All the plates were incubated at 37 °C for 24 h and counted. Incubation of 24 h allowed the respective bacteria to approach stationary phase of growth. All experiments were replicated twice.

2.3. UV irradiation equipment and inactivation treatments

UV irradiation of samples was conducted using a collimated beam apparatus as described by others (Bolton & Linden, 2003). The apparatus consisted of a low mercury UV lamp (UVP XX-15, UVP Inc., CA, USA) with peak radiation at 254 nm wavelength. The UV radiation was collimated with a flat black painted tube which was in the same size of a Petri dish. Samples were placed in 6 cm diameter Petri dishes directly below the collimated UV beam and stirred continuously during the irradiation with a vortex mixer (IKA, Yellowline TTS 2, IKA® Werke GmbH & Co. KG, Germany). The UV intensity at the surface of the sample (incident intensity (I_0) or irradiance at the surface) was measured using a radiometer with UVX-25 sensor (UVX, UVP Inc., CA, USA) calibrated by reference to a NIST (National Institute of Standards and Technology). The radiometer was placed at a similar distance from the UV lamp as the LEP samples. The UV lamp was switched on for about 30 min prior to UV treatment of LEPs samples in order to minimize fluctuations in intensity. Before each test, the collimated beam apparatus was cleaned and sanitized.

For the UV inactivation treatments, inoculated plates were subjected to different doses of UV-C radiation.The average UV intensity (average irradiance or fluence rate) in the stirred sample (I_{avg}) was calculated by an integration of Beer–Lambert law (Eq. (1)) over the sample depth (Morowitz, 1950):

$$I_{avg} = I_0(1 - e^{-A_e L})/A_e L \quad (1)$$

where I_0 is the incident intensity (mW/cm^2), A_e is the absorbance coefficient (cm^{-1}) at 254 nm wave length and L is the path length (cm). The UV dose was calculated with the Eq. (2):

$$\text{UV dose (mW s/cm}^2\text{)} = \text{irradiance } (I_{avg}) \times \text{exposure time} \quad (2)$$

Pasteurized products obtained from the egg product manufacturer (IPAY Izmir Pastörize San. And Tic. A.Ş., İzmir, Turkey) were selected for this study in order to make sure that samples did not contain significant levels of indigenous microflora. All products were belonging to the same batch of production. There was no settlement observed in LEP throughout the experiments. The products were stored in refrigerator prior to UV inactivation experiments. Total dry solid content (by weight percent) of each product determined in terms of AOAC 925.30 method (AOAC, 1990) and found to be $11.5 \pm 0.060\%$, $41 \pm 0.307\%$ and $23.5 \pm 0.079\%$ for LEW, LEY and LWE, respectively. The pH values of LEP measured by using pH meter (Metrohm, Switzerland) at room temperature were depicted as 6.72, 6.42 and 7.46 for LEW, LEY and LWE, respectively.

Inoculated LEW, LEY and LWE samples were exposed to UV-C radiation of known intensity levels (1.315, 0.709 and 0.383 mW/cm^2) for 5, 10 and 20 min and incubated at 37 °C for 24 h. All experiments were conducted within the UV Dose range of 0–100 mJ/cm^2 at 25 °C and replicated twice. The total elapsed time between inoculation and UV treatment was controlled in order not to allow extra microbial growth. Enumeration of *E. coli* (ATCC 8739) after each treatment was made as described in previous section.

The survival ratio of cells (S) after each treatment was calculated from the following equation:

$$S = \frac{N}{N_0} \quad (3)$$

where N is the microbial population after UV exposure (CFU/ml), N_0 is the initial inoculation level (CFU/ml). The inactivation of microorganism is generally reported interms of log reduction per unit UV Dose. The inactivation rate of microorganism can be described by a linear first order model (Chick, 1908):

$$\log\left(\frac{N}{N_0}\right) = y - k * d \quad (4)$$

where d is the UV Dose (in mJ/cm^2), k is described as the inactivation rate constant (in cm^2/mJ) and estimated from the slope of log (N/N_0) versus UV Dose curve, y is the intercept.

2.4. Statistical analysis

The effects of three factors, depth of liquid medium, UV intensity, and time, on the inactivation of UV resistant of *E. coli* (ATCC 8739) in LEP were investigated by using general full factorial design. Analysis of Variance (ANOVA, $p = 0.5$) was performed using the general linear model procedure of MINITAB 14 (Minitab Inc., State College, PA, USA) in order to determine the significance of each factor. Regression analysis was performed for the kinetics of UV inactivation data by using commercial spread sheet (Microsoft Excel, Redmond, WA, USA).

3. Results and discussion

Absorbance and turbidity of liquid egg product (LEP) samples at 254 nm wavelengths were summarized in Table 1. From these measurements, it is obvious that liquid whole egg and liquid egg yolk are more UV-opaque than liquid egg white.

The standard plate count for LEW samples was found to be 3–4 log units CFU/ml and *E. coli* was not detected in any of the tested LEP samples prior to inoculation. Additionally, the number of surviving microorganism on VRBA and EMB plates were not different than those enumerated on TSA plates indicating that *E. coli* (ATCC 8739) cells were mostly inactivated by UV-C radiation rather than just injured.

3.1. Inactivation of E. coli (ATCC 8739) in LEP samples

Influence of UV-C radiation on *E. coli* ATCC 8739 inactivation in LEP samples at different fluid medium depth and UV intensity (I_0) levels are depicted in Figs. 1–3. The inactivation curve was constructed by plotting the log reduction (log (N/N_0)) versus UV Dose (mJ/cm^2). The best reduction (2.2-log CFU/ml) was achieved in LEW samples subjected to the highest UV intensity (1.314 mW/cm^2), and the lowest medium depth (0.153 cm) after 20 min UV exposure (UV dose of 98 mJ/cm^2) (Fig. 1). Ngadi, Smith, and Cayouette (2003) applied 300 mJ/cm^2 (5 mW min/cm^2) UV dose at 0.315 mW/cm^2 incident UV intensity for 16 min in order to achieve 3.8-log (CFU/ml) reduction of *E. coli* O157:H7 (ATCC 35150) in LEW samples of 0.1 cm in depth. In their study, they calculated average UV intensity from Bouguer–Lambert law, which resulted

Table 1
Absorbance and turbidity of liquid egg products (LEP)

Product	Absorbance coefficient (cm^{-1})	Turbidity (NTU)
Liquid egg white (LEW)	104.65 ± 6.22	398 ± 8.86
Liquid whole egg (LWE)	807.5 ± 1.62	8369.83 ± 91.01
Liquid egg yolk (LEY)	630.75 ± 6.64	8114.25 ± 33.50

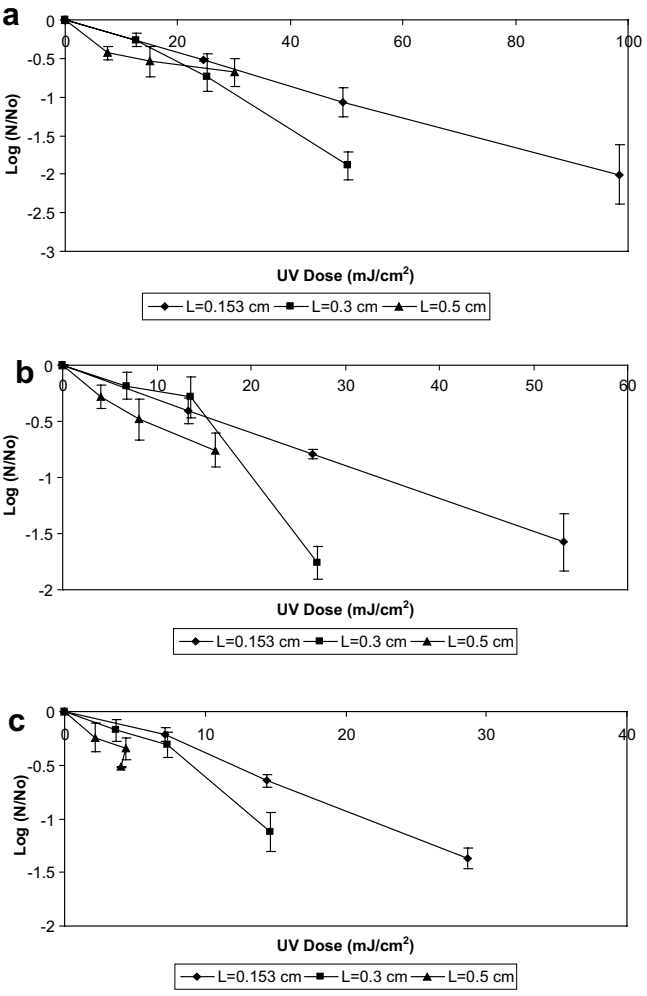

Fig. 1. Influence of UV-C radiation on *E. coli* ATCC 8739 inactivation in LEW at different fluid medium depth and UV intensity levels (I): (a) $I = 1.314$ mW/cm^2, (b) $I = 0.709$ mW/cm^2, (c) $I = 0.383$ mW/cm^2.

in higher UV dose values than Beer–Lambert law, used in this work. The variation in the log reduction values might be a result of differences in liquid depth, *E. coli* strains, background flora and absorbance of LEW samples used in these studies.

Ngadi et al. (2003) reported higher UV sensitivity of *E. coli* O157:H7 compared to non-pathogenic *E. coli* strain used in this study. Although, no *E. coli* cells were detected in LEW before treatment, initial population of aerobic mesophilic bacteria in LEW ranged from 10^3 to 10^4 CFU/ml. Ngadi et al. (2003) did not report any background flora in their work. Additionally, LEW samples used in our study had absorbance of 104.65 ± 6.22 (<0.01% UV transmittance) at 254 nm. Ngadi et al. (2003) measured UV transmittance of LEW as 0.02%. Decrease in UV transmittance reduces the absorbed UV dose by diminishing UV intensity and results in lower inactivation rate (Sommer, Haider, Cabaj, Pribil, & Lhotsky, 1997). As a result, it was expected to have higher UV dose (98 mJ/cm^2) and lower inactivation rate (2.2 log) for *E. coli* (ATCC 8739) in LEW than those reported by Ngadi et al. (2003).

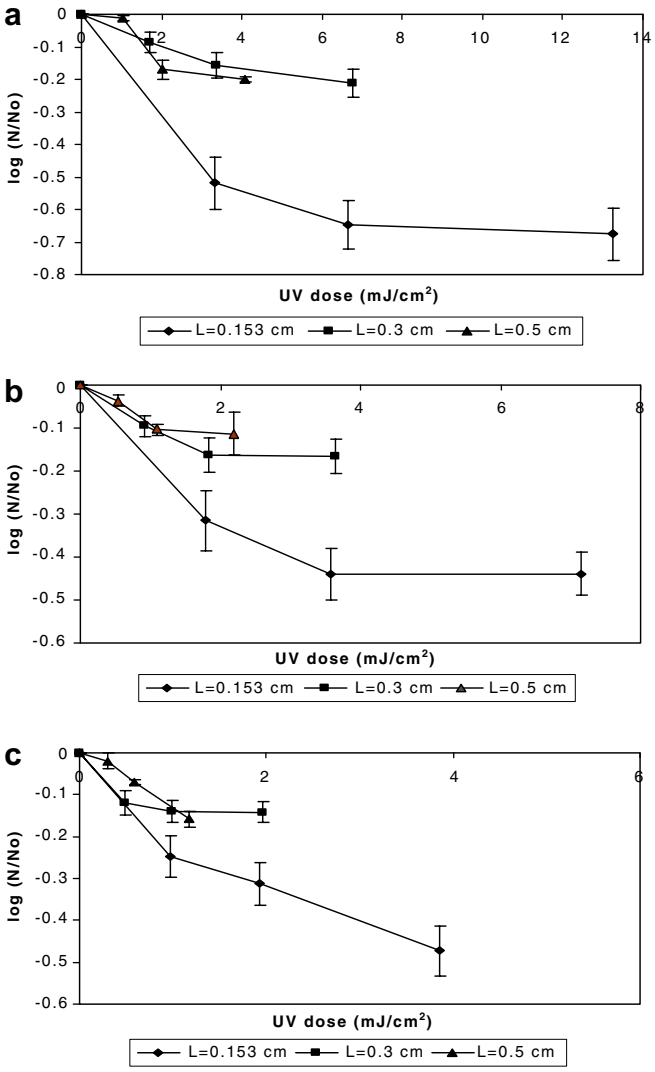

Fig. 2. Influence of UV-C radiation on *E. coli* ATCC 8739 inactivation in LEY at different fluid medium depth and UV intensity levels (I): (a) $I = 1.314$ mW/cm^2, (b) $I = 0.709$ mW/cm^2, (c) $I = 0.383$ mW/cm^2.

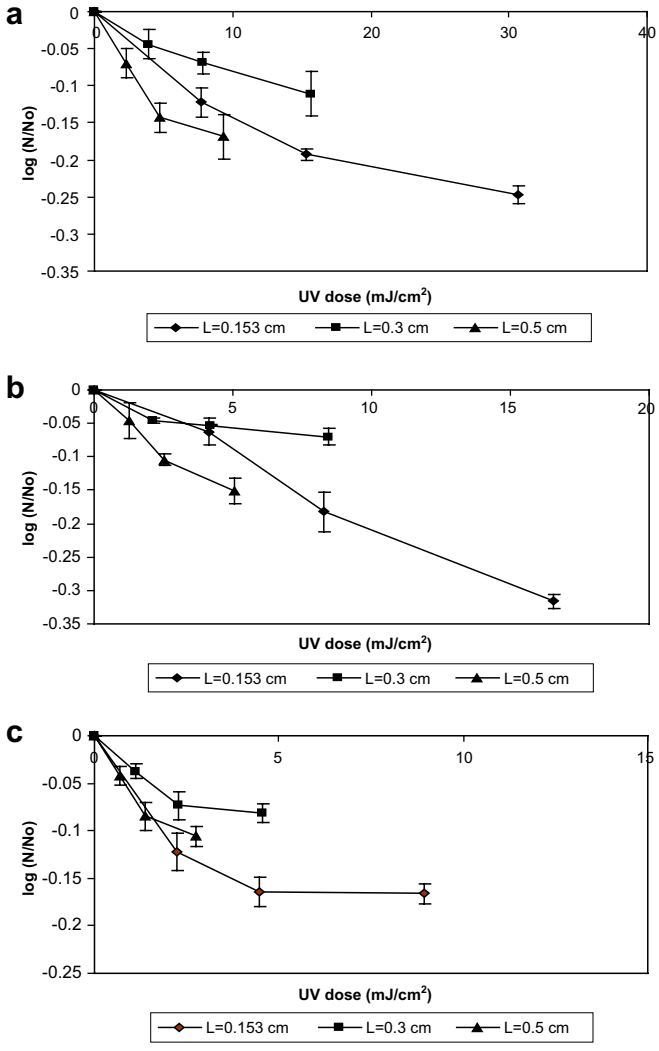

Fig. 3. Influence of UV-C radiation on *E. coli* ATCC 8739 inactivation in LWE at different fluid medium depth and UV intensity levels (I): (a) $I = 1.314$ mW/cm^2, (b) $I = 0.709$ mW/cm^2, (c) $I = 0.383$ mW/cm^2.

In LEY samples, maximum inactivation (0.675-log CFU/ml) was observed at the highest UV intensity (1.314 mW/cm^2) and the lowest medium depth (0.153 cm) after being exposed to treatment time of 20 min (UV dose of 13.25 mJ/cm^2) (Fig. 2). The amount of light that penetrates through a liquid decreases with increasing liquid medium absorbance (Murakami et al., 2006). Since absorbance of LEY was higher than LEW, the lower inactivation of *E. coli* was expected in these samples.On the other hand, LWE samples showed different inactivation response where the maximum reduction (0.316-log CFU/ml) was achieved at the medium UV intensity (0.709 mW/cm^2) and the lowest depth (0.153 cm) after 20 min treatment time (UV dose of 16.55 mJ/cm^2) (Fig. 3). This can be due to the fact that LWE samples have the highest absorbance and turbidity (suspended material) (Table 1). Suspended materials influence the inactivation of bacteria by protecting them during irradiation (Murakami et al., 2006; Quintero-Ramos, Churney, Hartman, Barnard, & Worobo, 2004). Therefore it was thought that the mixing was not homogeneous and microorganisms were shadowed by suspended material, which led to different inactivation pattern in LWE samples. This judgment was also supported by statistical analysis of full factorial design, which considers the factors (liquid depth, UV intensity and exposure time) and their interactions on the reduction of *E. coli* (ATCC 8739) in LEP. According to these results, it was determined that factors of liquid depth and exposure time were significant ($p < 0.001$) on the log reduction of LEW, LWE and LEY samples, whereas the effect of incident intensity was only significant on LEW and LEY samples. Similarly, the interactive effect of exposure time and incident intensity, exposure time and depth were found only significant ($p < 0.001$) on LEW, and LEW and LEY samples, respectively. To best of our knowledge there is no available literature on the inactivation of bacteria in LEY and LWE by UV-C; hence it is not possible to make comparison with any of

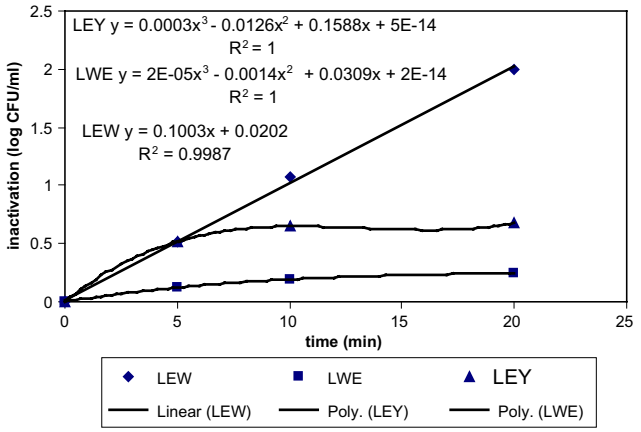

Fig. 4. Inactivation of *E. coli* ATCC 8739 as a function of treatment time.

the literature data. Overall, it can be concluded that increasing the liquid depth resulted in decrease of the inactivating effect of UV-C radiation on *E. coli* (ATCC 8739) in LEP ($p \ll 0.05$). The influence of exposure time on the inactivation of *E. coli* (ATCC 8739) was examined in Fig. 4. With exposure time between 0 and 20 min, killing rate of *E. coli* was linear in LEW samples. On the other hand, the log reduction of *E. coli* was parabolic in LEY and LWE samples suggesting that exposure time was also significant ($p \ll 0.05$) for UV-C radiation process.

Many researchers (Matak et al., 2005; Murakami et al., 2006; Ngadi et al., 2003; Quintero-Ramos et al., 2004; Wright et al., 2000; Yaun, Sumner, Eifert, & Marcy, 2003) found UV dose (time × UV incident intensity) as the major factor for inactivation of *E. coli*. Additionally, the relationship between time and UV incident intensity was reported to be important for the design of UV equipment (Murakami et al., 2006; Sommer et al., 1998). The evaluation of interaction data between time and incident intensity revealed the existence of time-incident intensity reciprocity for LEW whereas such a relationship was not observed in LWE and LEY samples. This means that the same level of microbial reduction can be achieved by applying higher incident intensity for a shorter period of time for the same UV dose level. Murakami et al. (2006) was also reported the same interdependence of time and incident intensity for UV inactivation of *E. coli* K12 in apple juice.

3.2. Inactivation kinetics

The kinetics of UV inactivation of *E. coli* (ATCC 8739) in LEP was studied. The kinetic parameters (k) calculated from Eq. (4) for the different fluid medium depths and UV intensities with regression coefficients are shown in Table 2. k values calculated in different depths at a fixed UV intensity show variations. UV light penetration was expected to decrease with increasing fluid depth. Even though UV intensity is kept at $I = 1.314\ \text{mW/cm}^2$, increasing the fluid depth did not show any decreasing trend in k values as expected. In some cases, regression coefficients were also found to be lower. This is attributed to have a nonlinear relationship between logarithm of the survival fractions and UV dose. The inactivation curves were in sigmoidal shape when the fluid depth was increased to 0.3 and 0.5 cm (Figs. 1–3). A sigmoidal curve has an initial lag in the slope called ‘‘shoulder ‘‘and tailing at the higher UV doses. While the fluid depth was 0.3 cm, shoulder curve was dominant for LEW and tailing curve was the main in LEY and LWE. When the fluid depth was 0.5 cm, tailing was more pronounced regardless of UV intensity. A sigmoidal shape is a common survival curve observed in the UV inactivation of microorganisms and explained with single-hit and multiple-hit phenomena (Fenner & Komvuschara, 2005). The cell injury starts in the initial lag (shoulder) phase of the survival curve. When the UV dose further increased, the inactivation increases and minimal additional UV dose becomes fatal (Matak et al., 2005). Tailing can result from suspended material in the medium showing high turbidity that protects bacteria during irradiation, aggregates of cells caused by inhomogeneous distribution of microorganisms in the liquid medium and in-homogeneity in radiation. Thus, Eq. (4) (Chick’s model of disinfection) can only be used to predict inactivation parameter k from the linear inactivation curve. In order to model the UV death kinetics

Table 2
Kinetic parameters for UV inactivation of *E. coli* (ATCC 8739) in liquid egg products (LEP)

Intensity (mW/cm^2)	Depth (cm)	LEW		LWE		LEY	
		k (cm^2/mJ)	R^2	k (cm^2/mJ)	R^2	k (cm^2/mJ)	R^2
1.314	0.153	0.0204	0.9987	0.0076	0.8791	0.0445	0.6421
	0.3	0.0386	0.9792	0.0068	0.9661	0.0305	0.9244
	0.5	0.0203	0.7986	0.0176	0.8650	0.0543	0.8222
0.709	0.153	0.0296	0.9999	0.0196	0.9866	0.0551	0.6581
	0.3	0.0657	0.8787	0.0074	0.7952	0.0427	0.7378
	0.5	0.0453	0.9681	0.0299	0.9569	0.0529	0.8252
0.383	0.153	0.0491	0.9907	0.0166	0.6530	0.1134	0.9031
	0.3	0.0776	0.9432	0.0174	0.8206	0.0613	0.5865
	0.5	0.0558	0.9298	0.0381	0.8938	0.1382	0.9836

more precisely, a nonlinear model needs to be developed to take into account variations in the UV intensity, suspended particles, contact time and microorganism sensitivity in liquid egg products.

4. Conclusions

UV-C inactivation data obtained by using UV resistant strain of *E. coli* (ATCC 8739) provides a conservative estimate of inactivation rate in liquid egg products. Maximum inactivation was 0.675-log CFU/ml in liquid egg yolk (LEY) and 0.316-log CFU/ml in liquid whole egg (LWE) indicating that UV-C light may not be the feasible inactivation process for LWE and LEY. On the other hand, a greater than 2 log reduction of *E. coli* (ATCC 8739) was achieved in LEW. Considering lower treatment cost of UV systems compared to thermal methods, it was suggested that UV-C light treatment can be used as a pretreatment process or alternative method when combined either with mild heat treatment or non-thermal technologies in order to reduce the initial microbial load and also adverse effects of thermal pasteurization of LEW. It may also be used in combination with other preventive methods such as good manufacturing practices and sanitizing treatments of egg shells, as part of an approved hazard analysis and critical control point plan. Further research needs to be done on the modeling of UV irradiation kinetics of *E. coli* (ATCC 8739) and the phenomenon of photo-regeneration in UV-C treated LEP. Future research should also assess the inactivation rate in LEP by using at least one surrogate of pathogenic bacteria.

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