Ohmic processing of liquid whole egg, white egg and yolk

Hosain Darvishi[1*], Mohammad Hadi Khoshtaghaza[2],
Mohammad Zarein[2], Mohsen Azadbakht[3]

(1. *Department of Engineering*, *Shahr-e Ray Branch*, *Islamic Azad University*, *Tehran*, *Iran*;
2. *Department of Farm Machinery Mechanical Engineering*, *Tarbiat Modares University*, *Tehran*, *Iran*;
3. *Department of Agricultural Machinery Mechanics*, *Agricultural Sciences & Natural Resources University of Gorgan*, *Gorgan*, *Iran*)

Abstract: The Ohmic heating rate of a food is highly influenced by its electrical conductivity. In this study, electrical conductivities, colour changes and system performance of liquid whole egg, white egg and yolk were determined on a laboratory scale static Ohmic heater by applying 30 V/cm voltage gradient. The samples were heated from room temperature through to pasteurization temperature (19 – 60℃). In all cases, the linear temperature dependent electrical conductivity relations were obtained. Conductivity measurements of liquid egg indicated that white egg is highly conductive compared to yolk and whole egg. The system performance coefficients for liquid egg samples were in the range of 0.814 to 0.857. Ohmic heating revealed better colour values from the values of heated samples for convectional heating.

Keywords: egg, Ohmic heating, electrical conductivity, colour

Citation: Hosain Darvishi, Mohammad Hadi Khoshtaghaza, Mohammad Zarein and Mohsen Azadbakht. 2012. Ohmic processing of liquid whole egg, white egg and yolk. Agric Eng Int: CIGR Journal, 14(4): 224−230.

1 Introduction

Egg is a rich and well-balanced source of essential nutrients for human diet composed by fatty acids, phosphorus, trace minerals, vitamins and proteins of high biological value (Table 1) (American Egg Board, 2012). It is one of the most consumed foods worldwide, being an important commodity in international trade (Coimbra et al., 2006; Telis-Romero et al., 2006).

Current regulations in the United States require that liquid whole egg is to be heated at 60℃ for a minimum of 3-5 min (Huang et al., 2006). Most researchers conclude that the functional performance of egg white is impaired when heated for several minutes above 57℃ (Ma et al., 1997; Huang et al., 2006). Thermal pasteurization of liquid egg is problematic because of its great instability to heat in the range of effective pasteurization (Geveke 2008, Icier and Bozkurt, 2009). Therefore, non-thermal processes to pasteurize liquid egg whites have been investigated.

Development of new technologies for thermal food treatment is still of great industrial and scientific interest. Ohmic heating is one of these new technologies. Ohmic heating is based on the passage of electrical current through a food product that serves as an electrical resistance. Heat is generated instantly inside the food and efficiency of Ohmic heating is dependent on products electrical conductivity (Icier, 2003; Shirsat et al., 2004).

The main advantages of Ohmic processing are the rapid and relatively uniform heating achieved, shorter operating time, high thermal efficiency, together with the lower capital cost compared to other electroheating methods such as microwave and radio frequency heating (Marra et al., 2009; Castro et al., 2004). Ohmic heating yields better product clear superior in quality than those processed by conventional heating (Allali et al., 2008; Icier and Bozkurt, 2009; Chen et al., 2010). Its advantages compared to conventional heating also

Received date: 2012-06-25 **Accepted date:** 2012-10-08
*** Corresponding author: Hosain Darvishi.** Tel: ++98 (21) 44194911-4; Fax: ++9(21) 44196524. Email: Hosaindarvishi@gmail.com.

include the more uniform and faster heating, higher yield and higher retention of nutritional value of food (Stancl and Zitny, 2010; Vikram et al., 2005; Nolsoe and Undeland, 2009; Marra et al., 2009; Castro et al., 2004). This is mainly due to its ability to heat materials rapidly and uniformly leading to a less aggressive thermal treatment.

Table 1 Composition of liquid whole egg, white egg and yolk

	Composition	Whole egg	White egg	Yolk
nutrients	Water /g (100 g)$^{-1}$	76.150	87.570	52.310
	Protein/g (100 g)$^{-1}$	12.560	10.900	15.680
	Fat/g (100 g)$^{-1}$	9.510	0.170	26.540
	Cholesterol/g (100 g)$^{-1}$	0.372	0	1.090
minerals	Calcium/mg (100 g)$^{-1}$	56	7	129
	Phosphorus/mg (100 g)$^{-1}$	198	15	390
	Potassium /mg (100 g)$^{-1}$	138	163	109
	Sodium/mg (100 g)$^{-1}$	142	166	48
vitamins	Vitamin E/mg (100 g)$^{-1}$	1.050	0	2.580
	Niacin/mg (100 g)$^{-1}$	0.075	0.105	0.024
	Vitamin A - IU	540	0	1442
	B6/mg (100 g)$^{-1}$	0.170	0.005	0.350
	B12/mcg (100 g)$^{-1}$	0.890	0.090	1.950
	Riboflavin/mg (100 g)$^{-1}$	0.457	0.439	0.528
Amino acids	Alanine/g (100 g)$^{-1}$	0.735	0.704	0.836
	Lysine/g (100 g)$^{-1}$	0.912	0.806	1.217
	Aspartic acid/g (100 g)$^{-1}$	1.329	1.220	1.550
	Leucine/g (100 g)$^{-1}$	1.086	1.016	1.399
	Serine/g (100 g)$^{-1}$	0.971	0.798	1.326
	Histidine/g (100 g)$^{-1}$	0.309	0.290	0.416

Icier and Bozkurt (2009) applied a medium voltage gradient of 25 V/cm to whole liquid egg. They found also a linear relationship between the electrical conductivity and temperature for the sample. Imai et al. (1998) discussed the effect temperature and frequency under a constant 10 V/cm on the electrical conductivity values of egg albumin solution. They reported that the heating rate of the solution was almost constant and increased slightly as the frequency increased.

Although several attempts have been made to characterize of liquid egg products, there is lack of information on behavior changes of liquid egg (whole egg, white and yolk) during Ohmic heating in open literature to the best of the authors' knowledge. Considering the lack of published information, the aim of this study was to give detailed electrical conductivity data for whole egg, white egg and yolk to be heated ohmically in the food industry. Effects of voltage gradient on colour changes, Ohmic heating system performance and Ohmic heating rates of liquid egg were studied. Then the results were compared with convectional heating of egg samples at temperature of 60℃.

2 Materials and methods

2.1 Materials

Fresh hen eggs (grade A, large size) used in this study were purchased from a local market in Tehran, Iran and stored at refrigeration conditions (4℃) prior to experiments. Shell eggs were washed with chlorinated water (200 mg/kg) to remove dirt from the shell, and then the water from the shell surface was drained. For each experiment, the eggs were broken and the contents (whites and yolks) of eggs were removed under aseptic conditions, and collected in a sterilized container and homogenized for 2 min by using a electric blender at minimum speed (Molinex, Type LM207041, French) (Icier and Bozkurt, 2009). Care was taken to prevent foaming during homogenization, and homogenized samples were stored under refrigeration conditions before measurements.

2.2 Experimental set-up

Ohmic heating experiments were conducted in laboratory scale Ohmic heating system consisting of a power supply, a variable transformer, power analyzer (Lutron DW-6090) and a microcomputer (Figure 1). The cell employed was constructed from PTFE (Teflon) cylinder with an inner diameter of 0.03 m, a length of 0.05 m and two removable stainless steel electrodes. Temperature at geometric center of the sample was continuously measured with a K-type, Teflon coated thermocouple to prevent interference from the electrical field. A digital balance (A&D GF 600, Japan) with accuracy of ±0.001 g was positioned on the down of the cell for mass sample determination. Temperature uniformity was checked during previous heating experiments by measuring temperatures at different locations in the test cell. If the temperature variation at different points inside the test cell was ±1.5℃ during heating, the Ohmic heating process was assumed as uniform. Therefore, only the temperature in the center of the test cell was measured.

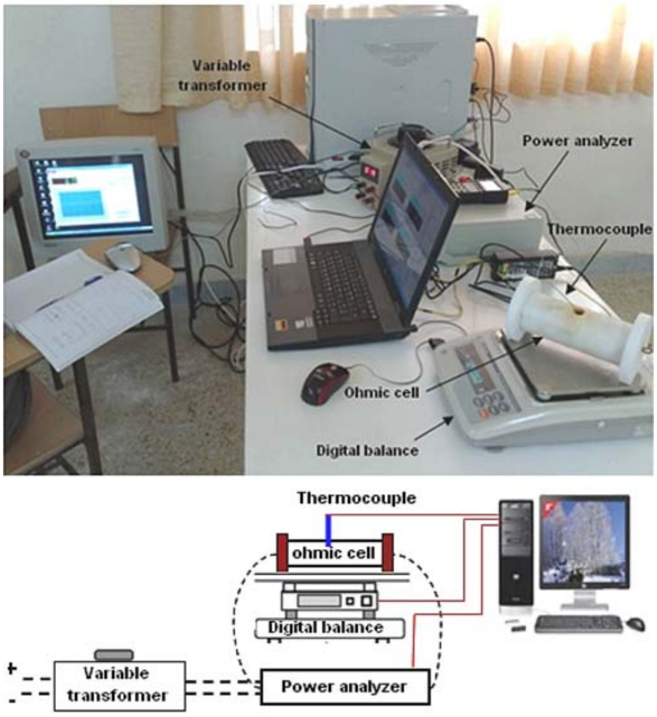

Figure 1 Schematic diagram of the experimental Ohmic heating system

2.3 Ohmic heating

The samples were placed in the test cell; the thermocouples were inserted and fitted into geometric center of the sample. The Ohmic samples were heated at 30 V/cm, 60 Hz. The voltage was chosen so that the heating rate of the Ohmic sample would be the same as that of conventional when heated to 60℃, with a processing time of 6.5 min. Other heating rates were not matched exactly because voltage would have to be changed, and we considered it more important to hold the voltage constant rather than the time/temperature history. Samples were heated to final temperature of 60℃. Temperature, current and voltage applied were monitored with and passed this information to the microcomputer at 1 s intervals.

2.4 Conventional heating

As a control treatment, egg samples were heated within an electrical oven which was set at 60℃. The K-type thermocouple was inserted in the centre of the sample and data were logged at 1 s time intervals during conventional heating. Three replicates were carried out in this study.

2.5 Electrical conductivity

Electrical conductivity (S m^{-1}) was determined from the resistance of the sample and the geometry of the cell using the following equation:

$$\sigma = \frac{IL}{AV} \quad (1)$$

where, L is the gap between two electrodes (m); A is the cross-section area of the sample in the heating cell (m^2); I is the current (A); and V is the voltage (V).

2.6 System performance

The energy given (E_g) to the system was calculated by using the current and voltage values recorded during the heating experiments:

$$E_g = \sum \Delta VIt \quad (2)$$

where, t is time (s) and E_g *is the* energy given (E_g) to the system (J).

The heat required to heat the sample to a prescribed temperature was calculated as:

$$E_t = mC_p(T_f - T_i) \quad (3)$$

where, E_t is the energy taken by sample (J); m is the mass of sample (kg); C_p is the specific heat (J (kg K)$^{-1}$); T_f is the final temperature of sample (℃); and T_i is the initial temperature of sample (℃) .

The energy given to the system will be equal to the energy required to heat the sample plus the energy loss (E_l). The detailed energy calculation method was given in Icier and Ilicali (2005a).

$$E_g = E_t + E_l \quad (4)$$

The Ohmic heating system performance coefficient (SPCs) was defined as:

$$\text{SPCs} = \frac{E_t}{E_g} \quad (5)$$

The energy loss term in Equation (4) represents the heat required to heat the test cell, the electrodes etc., and the heat loss to the surroundings by natural convection and the portion of the generated heat used for purposes other than heating the liquid, i.e. chemical reaction, phase change. The energy loss calculations for the experimental data were performed by using the method in Icier and Ilicali (2005b).

The physical properties used in the computations and the experimental parameters are given in Table 2. Properties of the samples were taken as constant for the given temperature range during Ohmic heating.

Table 2 Properties of egg composition used in the calculations

Property	White egg	Yolk	Whole egg
Density/kg m^{-3} *	1027±4	1134±5	1108±4
Specific heat/J (kg K)$^{-1}$ *	3571±38	2675±62	2854±57

Note: * Coimbra et al. (2006).

2.7 Colour

Colour measurements of the whole egg, white egg and yolk samples were carried out by using a HunterLab Colorflex (CFLX 45–2 Model Colorimeter, HunterLab, Reston, US). This instrument was calibrated with standard calibration plates provided by the manufacturer. The colour values were presented as L* (lightness/ darkness), a* (redness/greenness) and b* (yellowness/ blueness). The parameter L* values represent light-dark spectrum with a range from 0 (black) to 100 (white). Parameter a* values represent the green-red spectrum with a range from −60 (green) to +60 (red), and the parameter b* values represent the blue-yellow spectrum with a range from −60 (blue) to +60 (yellow). Measurements were performed in triplicate and average values are reported. In addition, hue angles (h*) were calculated by the following equations:

$$h^* = \arctan\left(\frac{b^*}{a^*}\right) \tag{6}$$

2.8 Statistical analysis

The electrical conductivity was determined with three replications for 30V/cm voltage. Experimental data were analyzed by using analysis of variance (One-way ANOVA) and the means were separated at the 5% probability level applying Duncan's multiple range tests in SPSS 17.0 software.

3 Results and discussion

3.1 Electrical conductivity

Electrical conductivity–temperature curves for white, yolk and liquid whole egg are shown in Figure 2. For all samples, electrical conductivity increased almost linearly with temperature, as is expected and consistent with literature data. The linear model (Equation (1)) by Icier and Ilicali (2005a,c) was used to fit the electrical conductivity data of egg samples.

$$\sigma = \sigma_0 + nT \tag{7}$$

where, T is the temperature of sample (℃).

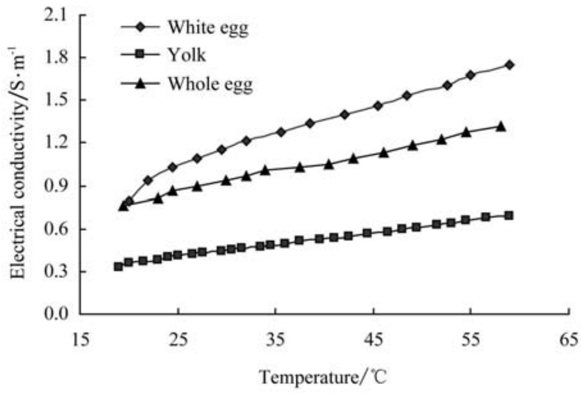

Figure 2 Electrical conductivity changes of the egg samples during Ohmic heating

Listed in Table 3, are the n, σ_0 and R^2 values. High coefficients of determination (R^2 > 0.98) indicate the suitability of the linear model for conductivity variation with temperature for all the samples tested. Increase in the electrical conductivity during heating of biological tissue occurs due to increase in the ionic mobility because of structural changes in the tissue like cell wall protopectin breakdown, expulsion of non conductive gas bubbles, softening, and lowering in aqueous phase viscosity. From Figure 2, it can be observed that the electrical conductivities of white, yolk and liquid whole egg were significantly different over the temperature range studied. The conductivity of whit egg was high compared to yolk and liquid whole egg. Higher electrical conductivity of white egg may be attributed to the high water and low fat content and hence higher ionic mobility in comparison to the low water and high fat content of yolk and liquid whole egg.

The increase in the heating time could have been explained by the effect of poor electrical conductivity of the fat itself decreasing effective electrical conductivity of the sample, and/or, fat regions creating barriers for the passage of electric current (Shirsat et al., 2004). Several researchers have concluded similarly that the electrical conductivity of fat substitutes were lower than meat, and would caused any decrease in effective electrical conductivity (Icier, 2003; Shirsat et al., 2004; De Halleux et al., 2005; Icier and Ilicali, 2005b; Bozkurt and Icier, 2010). Therefore, fat content to be an important factor affecting the electrical conductivity of egg.

Table 3 The constants and coefficients of electrical conductivity–temperature relationships of white, yolk and liquid whole egg heated ohmically at 30 V/cm

Material	n	σ_0	R^2
White egg	0.0221	0.4650	0.9813
Yolk	0.0086	0.1866	0.9978
Whole egg	0.0138	0.5136	0.9925

The values of electrical conductivity were comparable with the reported values of 0.375–0.825 S/m mentioned for whole egg at 20 V/cm and 10–60℃ (Icier and Bozkurt, 2009), 0.22 to 1.1 S/m for liquid egg products at 5 to 55℃ (Amiali et al. 2006), 0.4–1.0 S/m for lemon juice at 30–55 V/cm and 20–74℃ (Darvishi et al. 2011), 0.38–0.78 S/m for grape juice at 20–40 V/cm and 20–80℃ (Icier et al. 2008), 0.15–1.15 for orange juice at 20–60 V/cm and 30–60℃ (Icier and Ilicali 2005a), 0.51–0.91 S/m for peach puree and 0.61-1.2 S/m for apricot puree at 20–70 V/cm and 20–60℃ (Icier and Ilicali 2005c).

3.2 Ohmic heating rate

The ohmic heating rate of egg samples is shown in Figure 3. The egg composition (water and fat content) had significant effect on the heating time of egg samples during Ohmic treatment. The Ohmic heating rates were 3, 1.54 and 2.75℃/s for white, yolk and liquid whole egg at voltage gradient 30 V/cm, respectively. At higher water and low fat contens, the current passing through the sample was higher and this induced the heat generation faster. On the other hand, the solid contents of the white was lower than the other egg composition, the Ohmic heating rates of the white egg were obtained as higher than the yolk and whole egg. The drag for ionic movement increases when solids content increases and results in decrease of the heating rate.

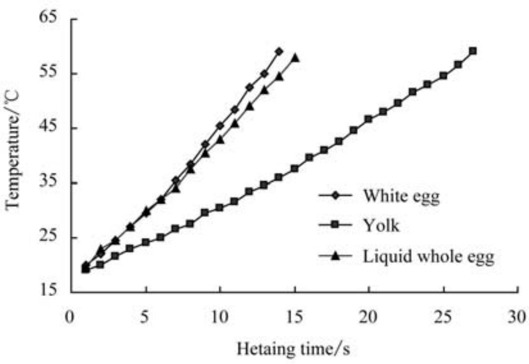

Figure 3 Heating rate curves of egg samples during Ohmic heating at 30 V/cm

3.3 System performance

The electrical energies given to the system and the heat taken by the egg samples were calculated by using the experimental data, and the system performance coefficients, SPCs calculated for each Ohmic heating experiment are also shown in Table 4. One way Anova and paired *t*-test results showed that no significant differences were obtained between the SPCs of the egg samples (P > 0.05). For the egg samples the SPCs varied from 0.814 to 0.857, which indicated that 14.3%–18.6% of the electrical energy given to the system was not used in heating up the test sample. Iicer and Iicali (2005b) reported that the SPCs values for the liquid samples were in the range of 0.47–0.92 during Ohmic heating. For white and whole egg, the conversion of electrical energy into heat was larger. Therefore, the system was performing better. The difference between the energies given and taken was called energy loss in this study. The energy loss to heat up the test cell was approximately 5%–8.6% of the energy given to the system. The heat transfer area was also small. Due to these reasons, the heat loss to the surroundings was small and could be neglected without any loss in accuracy. The energy losses mentioned above is only a small portion of the total energy losses. The energy losses can be mostly explained by the energies used for the purposes of physical, chemical and electrochemical changes during heating (Icier and Ilicali, 2005b; Assiry et al., 2003). It is rather difficult to comment on the exact nature of this loss. These reactions are not beneficial and further study must be conducted on the effects of them on food.

Table 4 The SPC values of the samples during ohmic heating

Material	E_g/kJ	E_t /kJ	SPCs	T_F	T_i
White egg	6.051±0.598	5.168±0.098	0.857±0.068	59±1	20±0.5
Yolk	4.467±0.467	3.945±0.130	0.814±0.027	59±2	19±1
Whole egg	5.082±0.731	4.116±0.154	0.855±0.033	58±2	19±1

3.4 Colour assessment

Table 5 shows the results of the colour measurements of fresh, Ohmic and convectional heated egg samples. Whiteness or brightness/darkness value, L*, of the conventional heated white egg was not significantly different from the values of white egg for Ohmic heating (P>0.5). On the other hand, the value for yellowness

(b^*) and greenness (a^*) of the Ohmic heated of egg samples differed significantly from the values conventional heating (P<0.05). h^* values of the Ohmic heated whole egg samples were not significantly different from the values of heated samples for convectional heating (P>0.05). In addition, a^* and b^* values of the convectional heating were largest from the values of heated egg samples for Ohmic heating. A larger value of hue angle indicates a more shift from red to yellow. A decrease in hue angels values of whole egg is an indication of more browning colour and shifting away from yellowness, while the values of hue angels of white egg increasing, shifting it towards yellow and red.

Table 5 Colour measurements of fresh, convectional and ohmic heated egg

Material	Fresh			
	a^*	b^*	L^*	h^*
Yolk	6.72±0.92	52.24±1.71	51.06±1.41	67.48±1.06
White egg	-0.67±0.08	2.84±0.83	20.57±1.12	-76.27±2.44
Whole egg	3.92±0.51	40.12±1.85	58.73±2.18	84.43±0.47
	Ohmic heating			
Yolk	16.68±1.17	40.21±0.72	70.86±0.93	67.12±1.04
White egg	- 0.80±0.04	11.36±1.34	80.16±1.59	-85.77±0.38
Whole egg	6.78±1.42	24.09±2.60	77.93±1.79	74.39±1.69
	Convectional heating			
Yolk	22.57±1.57	65.38±2.82	65.66±0.53	70.82±0.49
White egg	- 4.62±0.53	21.63±1.39	81.30±5.17	-77.86±1.98
Whole egg	10.31±0.74	35.04±1.96	69.57±6.62	73.59±0.93

4 Conclusions

The electrical conductivity of food systems is a key parameter for Ohmic heating process. The Ohmic heating behaviors of yolk, white and whole egg were investigated in a laboratory-scale Ohmic heating cell at a voltage gradient of 30 V/m with the temperature range 19–60℃. In all cases, conductivities increased linearly with temperature. Yolk and whole egg were less conductive than white egg samples. The Ohmic heating system performance coefficients were in the range of 0.814 to 0.857. Ohmic heating had high influence on the colour of egg samples as compared to convectional heating.

References

Allali, H., L. Marchal, and E. Vorobiev. 2008. Blanching of strawberries by ohmic heating: effects on the kinetics of mass transfer during osmotic dehydration. *Food and Bioprocess Technology*, 3(3): 406-414.

American Egg Board. 2012. Food Manufacturers, Egg Nutrition & Trends, Nutrient Composition. Available at: http://www.aeb.org/food-manufacturers/egg-nutrition-and-trends/nutrient-composition#2

Amiali, M., M. Ngadi, V.G.S. Raghavan, and D.H. Nguyen. 2006. Electrical conductivities of liquid egg product and fruit juices exposed to high pulsed electric fields. *International Journal of Food Properties*, 9(3): 533–540

Assiry, A., S.K. Sastry, and C. Samaranayake. 2003. Degradation kinetics of ascorbic acid during ohmic heating with stainless steel electrodes. *Journal of Applied Electrochemistry*, 33(2): 187–196.

Bozkurt, H. and F. Icier. 2010. Electrical conductivity changes of minced beef–fat blends during ohmic cooking. *Journal of Food Engineering*, 96(1): 86-92.

Castro, I., J. A. Teixeira, S. Salengke, S. K. Sastry, and A. A. Vicente. 2004. Ohmic heating of strawberry products: electrical conductivity measurements and ascorbic acid degradation kinetics. *Innovative Food Science and Emerging Technologies*, 5(1): 27–36.

Chen, C., K. Abdelrahim, and I. Beckerich. 2010. Sensitivity analysis of continuous ohmic heating process for multiphase foods. *Journal of Food Engineering*, 98: 257–265.

Coimbra, J.S.R., A.L. Gabas, L. A. Minim, E.E. Garcia Rojas, V.R.N. Telis, and J. Telis-Romero. 2006. Density, heat capacity and thermal conductivity of liquid egg products. *Journal of Food Engineering*, 74(2): 186–190.

Darvishi, H., A. Hosainpour, F. Nargesi, M.H. Khoshtaghza, and H. Torang. 2011. Ohmic processing: temperature dependent electrical conductivities of lemon juice. *Modern Applied Science*, 5(1): 210-216.

De Halleux, D., G. Piette, M.L. Buteau, and M. Dostie. 2005. Ohmic cooking of processed meats: Energy evaluation and food safety considerations. *Canadian Biosystems Engineering*, 47(3): 341–347.

Geveke, D. J. 2008. UV inactivation of E. coli in liquid egg white. *Food and Bioprocess Technology*, 1(2): 201–206.

Huang, E., G. S. Mittal, and M. W. Griffiths. 2006. Inactivation of salmonella enteritidis in liquid whole egg using combination treatments of pulsed electric field, high pressure and ultrasound. *Biosystems Engineering*, 94(3): 403–413.

Icier, F. and H. Bozkurt. 2009. Ohmic heating of liquid whole egg: rheological behavior and fluid dynamics. *Food Bioprocess Technology*, 4(7): 1253-1263

Icier, F. and C. Ilicali. 2005a. The Effects of concentration on electrical conductivity of orange juice concentrates during ohmic heating. *European Food Research and Technology,* 220(3-4): 406–414.

Icier, F. and C. Ilicali. 2005b. The Use of tylose as a food analog in ohmic heating studies. *Journal of Food Engineering*, 69(1): 67-77.

Icier, F. and C. Ilicali. 2005c. Temperature dependent electrical conductivities of fruit purees during ohmic heating. *Food Research International*, 38(10): 1135–1142.

Icier, F. 2003. The experimental investigation and mathematical modeling of ohmic heating of foods. PhD Thesis, Ege University Institute of Natural and Applied Sciences, Food Engineering Section, 245, electronic press in www.tez2.yok.gov.tr (No: 134687), in Turkish.

Icier, F., H. Yildiz, and T. Baysal. 2008. Polyphenoloxidase deactivation kinetics during ohmic heating of grape juice. *Journal of Food Engineering*, 85(3): 410–417.

Imai, T., K. Uemura, and A. Noguchi. 1998. Heating rate of egg albumin solution and its change during Ohmic heating. *Advances in experimental medicine and biology*, 434:101-108.

Ma, L., R J. Chang, and G. V. Barbosa-Canovas. 1997. Inactivation of E. coli in liquid whole eggs using pulsed electric fields technology. In *Proc. New Frontiers in Food Engineering, Fifth Conference of Food Engineering* (Barbosa- Canovas G V; Lombardo S; Narsimhan G; Okos M, eds), 216–221. American Institute of Chemical Engineers, New York, NY.

Marra, F., M. Zell, J.G. Lyng, D.J. Morgan, and D.A. Cronin. 2009. Analysis of heat transfer during ohmic processing of a solid food. *Journal of Food Engineering*, 91(1): 56–63.

Nolsoe, H. and I. Undeland. 2009. The acid and alkaline solubilisation process for the isolation of muscle proteins: state of the art. *Food and Bioprocess Technology*, 2(1): 1–27.

Shirsat, N., J. G. Lyng, N. P. Brunton, and B. Mchenna. 2004. Ohmic processing: Electrical conductivities of pork cuts. *Meat Science*, 67(3): 507–514.

Stancl, J. and R. Zitny. 2010. Milk fouling at direct ohmic heating. *Journal of Food Engineering*, 99(4): 437–444.

Telis-Romero, J., C.E.P. Thomaz, M. Bernardi, V.R.N. Telis, and A.L. Gabas. 2006. Rheological properties and fluid dynamics of egg yolk. *Journal of Food Engineering*, 74(2): 191–197.

Vikram, V. B., M. N. Ramesh, and S. G. Prapulla. 2005. Thermal degradation kinetics of nutrients in orange juice heated by electromagnetic and conventional methods. *Journal of Food Engineering*, 69(1): 31–40.