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Effects of Ohmic Thawing on the Physicochemical Properties of Frozen Pork

Jee-Yeon Kim, Geun-Pyo Hong, Sung-Hee Park, Sung Lee[1], and Sang-Gi Min*

Department of Food Science and Biotechnology of Animal Resources, Konkuk University, Seoul 143-701, Korea
[1]Department of Foods and Biotechnology, Hanseo University, Seosan, Chungnam 356-706, Korea

Abstract This study was carried out to investigate the physicochemical properties of frozen pork muscle which has been thawed using the ohmic thawing process, and to establish the optimal ohmic power intensity. The samples were frozen at -40 °C and thawed at 0, 10, 20, 30, and 40 V by ohmic thawing. Increasing ohmic power intensity correlated with increased thawing rates. The relationship between ohmic power intensity and thawing rate can be represented as a polynomial function. The pH value decreased with increasing ohmic power intensity (p<0.05). With regard to color measurement, the L^*, a, and b values of thawing at all ohmic power intensities were not significantly different. The water holding capacity showed a peak value of 41.62% with an ohmic thawing intensity of 30 V. Cooking losses were lowest at the lowest ohmic thawing intensity of 10 V. Thiobarbituric acid reactive substance (TBARS) levels with all thawing processes were slightly higher than that of the control (p<0.05). Increasing ohmic power intensity did not tend to change the total volatile basic nitrogen (TVBN) value.

Keywords: ohmic power intensity, thawing rate, physicochemical properties, pork muscle

Introduction

Freezing is a convenient method of food preservation. The quality of frozen food is related mainly to the processes of freezing and thawing. Thawing generally occurs more slowly than freezing, because the thermal conductivity of food is greater in the frozen state than in the non-frozen state (1). Therefore, minimizing thawing times can reduce microbial growth, chemical deterioration, and excessive water loss caused by dripping or dehydration (2). A range of thawing systems has been developed for food, based on various thawing media and heat generation techniques including the use of air, liquids, steam, microwaves, and ohmic heating. The use of air, liquids, and steam carries heat to the surface of the frozen foodstuff by convection, and heat is then transferred by conduction from the surface of the frozen foodstuff to its center. Accordingly, there have been new methods developed to accomplish rapid thawing of food at low temperature such as high pressure thawing, microwave thawing, far-infrared heating, acoustic thawing, and ohmic thawing. Today, among these advanced thawing methods, ohmic thawing is considered to be an especially promising one with regard to improving frozen food quality.

Due to the limited application of heat transfer to frozen food, Jamieson and Williamson (3) postulated ohmic, microwave, and radio frequency thawing to be the most promising technologies for electro-heating on an industrial scale. A major problem with the microwave thawing of meat, the most popular method, is run-away heating (localized over-heating), where part of the product is heated while other parts are still frozen. Ohmic thawing technology is postulated to improve thawing time, high energy conversion efficiency, volumetric heating, etc. (4, 5). When electric current passes through food, its resistance converts electrical energy to heat and is called ohmic heating or electro-heating (6). Ohmic heating is thought to allow the continuous sterilization of liquid-particle mixtures. It can also result in better flavor retention and particulate integrity compared to conventional processes (7).

Using the ohmic thawing method, frozen food can be thawed rapidly in a temperature range -3 to 3°C, in particular. Yun *et al.* (8) examined ohmic thawing of frozen chunks of meat in combination with conventional water immersion thawing at 60-210 V (AC) and frequencies of 60 Hz-60 kHz. This approach was found to require a lower voltage for thawing with lower drip loss and higher water holding capacity. At present, ohmic processing is often used in meat processing, especially with regard to heating. In contrast to the extensive amount of literature about the effects of the rate of freezing on changes in physical, chemical, and sensory properties of meat, there are few reports about the effects of ohmic thawing on meat characteristics and, in particular, the ultrastructure of thawed meat (9). Therefore, knowledge of the ohmic thawing process of frozen meat as a whole is essential for designing a successful thawing process. From previous studies it is clear that the innovative ohmic thawing process can decrease thawing time, thus increasing the rate of thawing and improving meat quality (10). This study was conducted to investigate the effects of ohmic power intensity and increased thawing rates on the quality characteristics of frozen pork.

Materials and Methods

Materials and sample preparation All samples in this study were obtained from pork (*porcine M. longisimus dorsi*) that had been stored for 24 hr at 4°C after slaughter. Pork was purchased from a local market and ground (ϕ 5

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*Corresponding author: Tel: 82-2-450-3680; Fax: 82-2-454-4146
E-mail: foodeng301@paran.com

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mm) after trimming visible fat.

The Ohmic thawing process Approximately 450 g of the ground pork meat was put in a rectangular sample holder consisting of an acrylic box (120×56×60 mm), two copper electrodes and three thermocouples (type K). In order to minimize thermal influence from the surroundings during the thawing process, the rectangle sample holder was kept in a refrigerator set at 5°C (Fig. 1). An ACP power supply (AC Power Korea Co., Ltd., Gyeonggi-Do, Korea) was used as an alternating current source of 60 Hz (sine wave) to provide different voltages (0, 10, 20, 30, and 40 V). During operation constant electric power was applied and monitored (TES 2730 Multimeter, Shanghai, China). The distance between the copper electrodes connected to the power supply was 60 mm. Time and temperature were recorded (MV 100 Mobile Corder; Yokogawa, Tokyo, Japan) during the freezing and thawing process. To monitor the temperature profile of the frozen pork, three thermocouples were established at regular intervals. The first thermocouple (P1) was fitted at the geometric center of the rectangular sample holder. The second thermocouple (P3) was placed close to the electrode and the third one (P2) was placed midway between P1 and P3.

Sample preparations Pork samples were frozen in a deep freezer (Nihon Freezer, Tokyo, Japan) at -40°C. When the core temperature of pork samples reached - 20 °C, the frozen meat was thawed to a temperature of 5°C by ohmic thawing as described above. In this study, the thawing rate was defined as the ratio of radius length to the thawing time required for the temperature to increase from -20 to 5°C. Each experiment was done in triplicate.

Determination of pH pH measurements were carried out with a pH meter (Model 440; Corning, Schiphol-Rijk, the Netherlands) on 5 g of sample mixed with 20 mL of water and homogenized at 4220×g for 1 min in an SMT process homogenizer (SMT Co., Ltd., Tokyo, Japan).

Color measurement Color measurements were performed using a color meter (JC801S; Color Techno System Co., Ltd., Tokyo, Japan) calibrated with a white standard plate (X=97.83, Y=81.58, Z=01.51). L*, a, and b values were determined as indicators of lightness, redness, and yellowness, respectively. Three measurements were taken from each surface of two slices. One reading was taken for each sample.

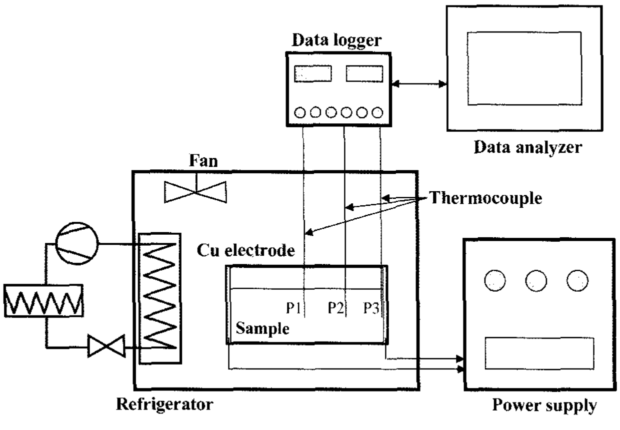

Fig. 1. Schematic diagram of ohmic thawing unit.

Water holding capacity (WHC) The amount of water in the pork samples was determined in triplicate using the method of Grau and Hamm (11). Approximately 300 mg of pork sample was placed onto a piece of Whatman No. 1 filter paper and pressed between two plastic sheets for 3 min with a weight. The areas of compressed water and sample were measured using image analysis program (Image Tool 3.0, Uthscsa, TX, USA).

Cooking loss Cooking loss was determined by weighing the meat before and after cooking. The bagged samples were immersed in a 75°C water bath for 30 min as described by Kim and Lee (12). After cooling to room temperature, the polyethylene bags were opened, and the free juice was drained.

Thiobarbituric acid reactive substance (TBARS) One g of sample was mixed with 0.15 mL of butylated hydroxytoluene (BHT) and 9 mL of perchloric acid followed by homogenization at 7200×g for 2 min, after which 5 mL of distilled water was added and the mixture was filtered using Whatman No. 2 filter paper. One mL of filtrate was added to 1 mL of TBA, boiled for 30 min, and cooled in ice water for 5 min. Readings were taken with a UV/VIS spectrophotometer (OptizenIII; Mecasys, Seoul, Korea) at 531 nm. A conversion factor of 6.2 was used for the calculation of TBARS which was expressed as mg malonaldehyde per kg meat.

Total volatile basic nitrogen (TVBN) TVBN was determined by the Conway micro diffusion method (13). Ten g of each sample was homogenized at 7200×g for 2 min with 30 mL distilled water. The homogenate was brought up to 100 mL with distilled water and filtered using Whatman No. 2 filter paper. One mL of filtrate was added to 1 mL of K_2CO_3, incubated at 37°C for 120 min, and titrated with 0.02 N of hydrochloric acid. Results are expressed in mg of nitrogen per 100 g of meat.

Statistical analysis The data were analyzed by ANOVA using the SAS (14) statistical program and differences among the means were compared using Duncan's multiple range test. The entire experiment was replicated twice, and all determinations were done in triplicate.

Results and Discussion

Thawing rate of pork meat due to ohmic power intensity The thermal change of frozen pork during ohmic thawing with five different power levels is presented in Fig. 2. It was observed that the thawing process between -20 and -5°C was not affected by level of ohmic power intensity. The ohmic power intensity in the temperature range of -5 to 0°C, generally described as the maximum ice crystal forming zone, showed a faster thawing time than the control. The fastest thawing time

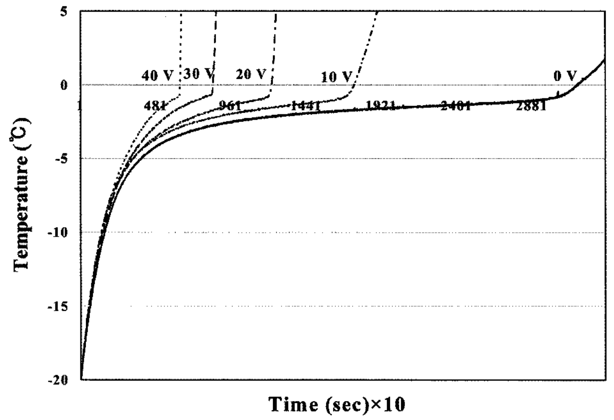

Fig. 2. Thawing curves (P1) of frozen pork muscle due to different ohmic power intensities.

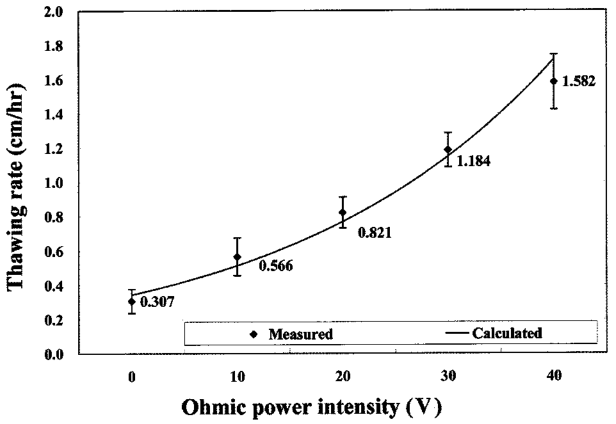

Fig. 4. The measured and calculated thawing rates of frozen pork muscle at different ohmic power intensities.

was 106 min at 40 V of ohmic power intensity. In contrast, the slowest thawing time was 557 min at 0 V.

Generally, a temperature gradient due to electric current from the surface of the meat sample into the core was not observed. The results in Fig. 3 show uniform thawing in the frozen pork block at 40 V. Similar results were seen with all ohmic power treatments except for 0 V. As the phase change from ice to water, the temperature rose suddenly to 5°C.

Ohmic processing generally leads to heat generation due to the current, thus heat distribution throughout the product is far more rapid and even (15). Therefore, it is advantage that the ohmic thawing procedure is able to achieve a uniformity of sample temperature.

The calculated thawing rates of all treatments were 0.307, 0.566, 0.821, 1.184, and 1.582 cm/hr at 0, 10, 20, 30, and 40 V of ohmic power intensity, respectively. These results show that the thawing rate at 40 V (1.582 cm/hr) is about 5 times faster than the thawing rate at 0 V (0.307 cm/hr). The thawing rate can be expressed as an exponential function of the data in Fig. 4. As shown in Eq. 1 below, the thawing rate was dependant on the ohmic power intensity and the relationship between thawing rate and ohmic power intensity can be represented as a polynomial function:

$$Y=0.3135+0.0206 \cdot X+0.00027 \cdot X^2 \quad (R^2=0.9968) \qquad \text{Eq.1.}$$

where, Y : Thawing rate (cm/hr), X : Power (V).

During the ohmic thawing process, over heating or edge heating could not be observed. Bing and Da-Wen (16) demonstrated that quick thawing at low temperature to avoid a significant rise in temperature and excessive dehydration of food is desirable to assure food quality. Thawing in a refrigerator can be undesirably slow, but it restricts bacterial surface growth due to the low temperature (17). Thus ohmic thawing combined with refrigeration might be preferable.

Changes in pH value Changes in the pH value of pork in relation to the ohmic power intensity are shown in Fig. 5. The pH value of the control was 5.77, which generally agreed with the results of Ryu and Kim (18) which ranged from 5.57 at 45 min post-mortem to 6.01 at 24 hr post-mortem in the *longissimus dorsi* muscle from pig carcasses. In the current study, the thawed pork meat had the lowest pH value of 5.63 at 40 V and the highest pH value of 5.70 at 10 V. Although the pH value during the

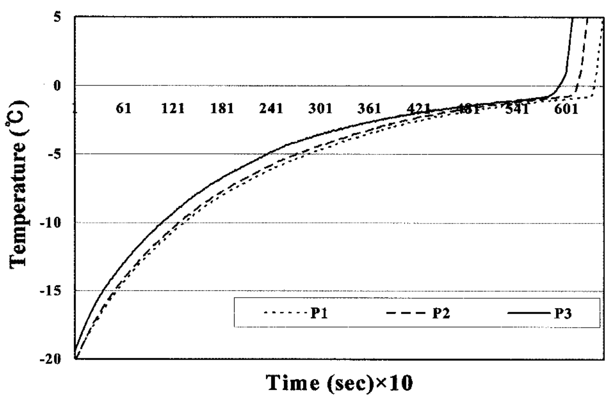

Fig. 3. Thawing curves (P1, P2, and P3) of frozen pork muscle at an ohmic power intensity of 40 V.

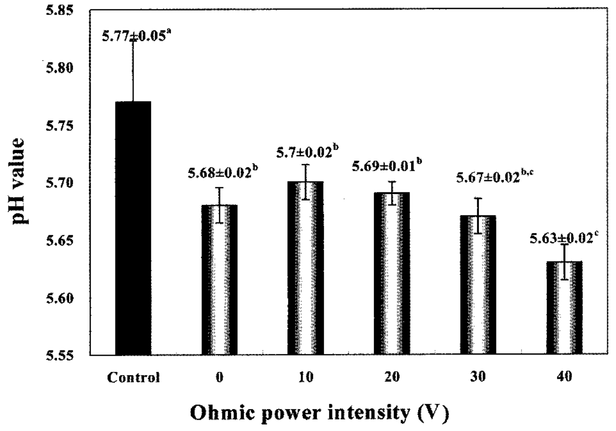

Fig. 5. Changes in pH values of thawed frozen pork muscle depending on the ohmic power intensity. Means with different letters are significantly different ($p<0.05$).

ohmic thawing process showed a gradual decrease with increasing ohmic power intensity from 10 to 40 V, the pH value was not significantly different (p>0.05) with variable ohmic power intensity except at 40 V. The impact of pH decline has been observed with both ohmic thawed and non-ohmic thawed muscles. However, due to the rapid pH decline at 40 V with an increased thawing rate, ohmic power intensity could allow rapid rates of pH decline and might change the meat structure. This result agrees with reports that the application of electrical stimulation causes accelerated pH decline (19). Furthermore, Melissa *et al.* (20) observed that protein denaturation is strongly influenced by the rate of pH and temperature decline with rapid rates of pH decline post slaughter due to electrical stimulation. They have also shown that early post-mortem electrical stimulation of carcasses reduces the possibility of cold and thaw shortening. Different pH decline rates are seen when different currents, voltages, and times of application are used (21).

Changes of color value One of the more important aspects of meat appearance is color, which the consumer uses as an indicator of quality and freshness (22, 23). The results from the color test are summarized in Table 1. The L* values of thawed pork samples ranged from 54.61-56.10. Ohmic thawing at 40 V resulted in the lowest average L* value (55.35), however the differences between the control and treated samples were small. The a and b values were not significantly influenced (p>0.05) by the ohmic thawing process. The three color values (L*, a, and b value) were virtually the same for the control and the ohmic thawed samples. It is worth noting that undesirable consequences associated with microwave thawing that can cause changes in the color of thawed pork meat, such as overheating or edge heating, were not observed. Therefore, ohmic thawing with a high thawing rate appears to be sufficient for rapid thawing without discoloration.

Changes in water holding capacity (WHC) Changes in the WHC of pork due to ohmic thawing are shown in Fig. 6. As shown, the application of ohmic thawing to frozen pork muscle resulted in a decreased WHC relative to the control. The influence of various ohmic power intensities on WHC was greatest at 30 V with a 1.184 cm/hr thawing rate, but there was no significant difference (p> 0.05) between non-ohmic and ohmic thawing treatments. In this view, increasing the ohmic power intensity tended to improve the WHC of the samples, which ranged from 35.01 to 41.62%, due to the higher thawing rate. The WHC of the meat might also influence the juiciness regardless of the pH (24). Margit *et al.* (25) observed that the pork with a lower WHC and the group with the lower pH were correlated with a higher cooking loss. The WHC of thawed meat is generally related to the state of myofibrillar protein. Petroviæ *et al.* (26) found that slowly frozen beef *M. longissimus dorsi* had lower protein solubility than quickly frozen beef. Also, when frozen muscles were thawed, moisture tended to be lost as thaw drip (27). In this study, the application of ohmic thawing to frozen meat generally decreased the water holding capacity in comparison with a control, regardless of the ohmic power intensity.

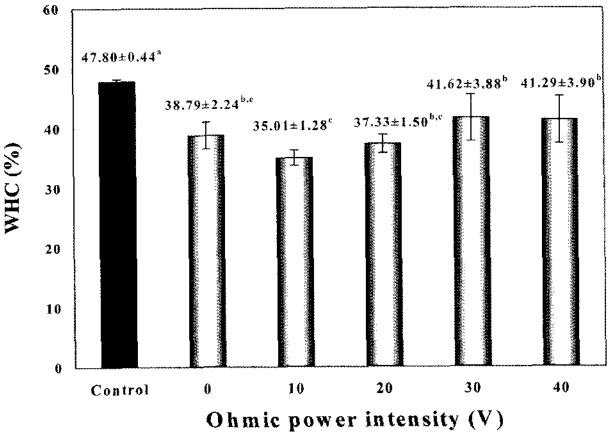

Fig. 6. Changes in water holding capacity of thawed pork muscle in relation to the ohmic power intensity. Means with different letters are significantly different (p<0.05).

Table 1. Effects of ohmic power intensity on the color of thawed pork meat

Ohmic power intensity (V)	Color values		
	L*	a	b
Control	54.61±0.21^{b}	14.44±0.25^{ab}	5.40±0.14^{b}
0	56.07±0.37^{a}	14.66±0.79^{ab}	6.84±0.45^{a}
10	55.73±0.39^{ab}	15.61±0.72^{a}	6.91±0.40^{a}
20	55.75±0.86^{ab}	14.69±0.31^{ab}	5.92±0.05^{b}
30	56.10±0.91^{a}	14.64±0.94^{ab}	6.87±0.12^{a}
40	55.35±0.27^{ab}	13.72±0.36^{b}	5.65±0.30^{b}

$^{a-b}$Means within the same column with different superscript letters are significantly different (p<0.05). Mean±standard deviation of triplicate determinations.

Changes in cooking loss In this study, cooking loss from the pork meat did not take into account any thawing loss because the pork meat was cooked immediately after ohmic thawing. Figure 7 show that cooking loss slightly increased with higher ohmic power intensity. The control had a lower cooking loss of 18.65% compared with the ohmic thawed muscle. A higher cooking loss of 23.45% was seen with an ohmic power intensity of 40 V and a 1.582 cm/hr thawing rate. Among the various treatments, significantly lower cooking loss (p<0.05) was observed below 10 V than for ohmic power intensities above 20 V. This was probably due to the electrical stimulation which would have a negligible impact on the WHC of the meat during ohmic thawing. However, cooking losses were not significantly different (p>0.05) with ohmic thawing above 20 V. Sheard *et al.* (28) worked with pork enhanced with water and polyphosphates and showed an average of cooking loss of 35% when the cooking endpoint was 72.5°C, and 42% when cooked to 80°C. Thus the higher losses occurred when the samples were cooked to a higher endpoint temperature (28). Contrary to this result, the current study showed a very low cooking loss of less than 23.34% with a cooking endpoint of 75°C. On the other

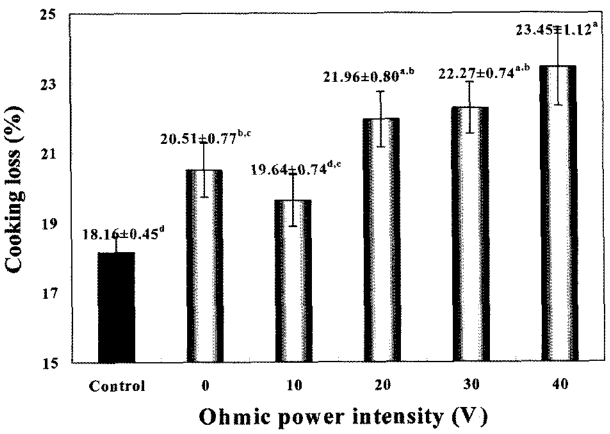

Fig. 7. Changes in cooking loss of thawed pork muscle in relation to the ohmic power intensity. Means with different letters are significantly different ($p<0.05$).

hand, Davide and Marina (29) reported that cooking loss correlated significantly with the cooking time, rather than the cooking temperature.

Changes in TBARS and TVBN values Lipid oxidation is considered one of the main causes for functional, sensory, and nutritional quality deterioration in meat and meat products (30). TBARS values are often used as an indicator for the extent of lipid oxidation (31). One of oxidative parameters is the TBARS value which is indicated in Table 2. Muscle thawed by the ohmic thawing process tended to show higher TBARS values than observed for that of the control ($p<0.05$). In general, lipids play an important role in food product quality from a nutritional point of view. Some studies have revealed that electrical heating such as microwave heating strongly affects lipid oxidation and fatty acid isomer formation (32, 33). From this point of view, ohmic heating as an electroheating method could lead to undesirable changes in lipids. However, little work has been done to study the effect of ohmic thawing on lipid oxidation in meat. In this study, the TBARS value of all thawed muscle increased with faster thawing rates due to increasing ohmic power intensity. TBARS values varied only slightly between 10 and 40 V, indicating that lipid oxidation was not due to increased thawing rates. This result might suggest that ohmic power intensity influences the formation of peroxide which can lead to lipid oxidation. Although the TBARS values of ohmic thawed muscle showed an increase, for all pork meat samples the malonaldehyde (MDA) content was well below the threshold value for rancidity for 1-2 mg/kg of meat (34). Also, Ohmic thawed pork tends to show higher TVBN values than observed in that of the control ($p<0.05$). An ohmic power intensity of 20 V with a thawing rate of 0.821 cm/hr showed both the highest TBARS value and the lowest TVBN value in the ohmic thawing process. However, the TVBN-value did not vary significantly ($p>0.05$) due to ohmic power intensity.

Table 2. TBARS and TVBN-values of thawed pork in relation to ohmic power intensity

Ohmic power intensity (V)	TBARS-value (mg/kg)	TVBN-value (mg%)
Control	0.12 ± 0.30^{d}	9.52 ± 0.45^{d}
0	0.16 ± 0.61^{c}	12.33 ± 0.45^{a}
10	0.19 ± 0.01^{a}	$10.79\pm0.53^{b,c}$
20	0.21 ± 0.00^{a}	$10.37\pm1.07^{c,d}$
30	0.19 ± 0.06^{b}	12.05 ± 1.02^{a}
40	0.20 ± 0.04^{b}	11.63 ± 0.53^{a}

$^{a\text{-}d}$Means within the same column with different superscript letters are significantly different ($p<0.05$). Mean±standard deviation of triplicate determinations.

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