Korean J. Food Sci. An.
Vol. 33, No. 6, pp. 723~729(2013)
DOI http://dx.do.org/10.5851/kosfa.2013.33.6.723

ARTICLE

Effects of Various Thawing Methods on the Quality Characteristics of Frozen Beef

Young Boong Kim*, Ji Yun Jeong, Su Kyung Ku, Eun Mi Kim, Kee Jae Park, and Aera Jang[1]
Division of Convergence Technology, Processing Technology Research Group, Korea Food Research Institute, Sungnam 463-746, Korea
[1]Department of Animal Products and Food Science, Kangwon National University, Chuncheon 200-701, Korea

Abstract

In this study, the quality characteristics due to the influence of various thawing methods on electro-magnetic and air blast frozen beef were examined. The loin and round of second grade Hanwoo were sliced into 5-7 cm thickness and packed with aerobic packaging. The packaged beef samples, which were frozen by air blast freezing at -45°C and electro-magnetic freezing at -55°C, were thawed by 4 thawing methods with refrigeration (4±1°C), room temperature (RT, 25°C), cold water (15°C), and microwave (2450 MHz). These samples were thawed to the point, which were core temperature reached 0°C. Analyses were carried out to determine drip and cooking loss, water holding capacity (WHC), moisture contents and sensory evaluation. Frozen beef thawed by microwave indicated a lower drip loss (0.66-2.01%) than the other thawing methods (0.80-2.50%). Cooking loss after electro-magnetic freezing indicated 52.0% by microwave thawing for round compared with 41.8% by refrigeration, 50.1% by RT, and 50.8% by cold water. WHC thawing by microwave with electro-magnetic freezing didn't showed any difference depending on the thawing methods, while moisture contents was higher thawing by microwave with electro-magnetic freezing than refrigeration (71.9%), RT (75.0%), and cold water (74.9%) for round. The texture of sensory evaluation for round thawed by microwave result was the highest than refrigeration (4.7 point), RT (6.4 point) and cold water (6.6 point), while sensory evaluation was no significant difference. Therefore, it was shown that microwave thawing is an appropriate way to reduce the deterioration of meat quality due to freezing.

Key words: frozen meat, thawing method, beef, moisture contents, water holding capacity

Introduction

The application of freezing for the preservation of foods has been practiced for several years in order to maintain quality during storage, distribution and marketing (Hanenian and Mittal, 2004; Li and Sun, 2002). Most frozen foods are able to maintain the freshness by inhibiting the growth and proliferation of microorganisms other than psychotropic microbes (Tomaniak *et al.*, 1998). Frozen meats are used after thawing. The most common methods to thaw frozen food include RT thawing, cold water thawing, steam thawing and contact thawing. These thawing methods are time consuming and require external heating, after which change in the quality of the meat occur (Kang *et al.,* 2007). Changes which take place during the thawing processes of frozen meat include the growth of microorganisms, weight loss due to drip loss, and color change (Berry, 1994; Kondratowicz *et al.,* 2008), effect of WHC (Miller *et al.,* 1980; Sebranek, 1979; Zhuang, 2012), increase of rancidity (Lannari and Zaritzky, 1991; Sebranek *et al.,* 1978), denaturation of protein (Wagner and Anon, 1985; Wagner and Anon, 1986) and softening of tissues, which results in a changes which are quite apparent to the consumer (Fennema, 1973; Jason, 1974; Kim *et al*., 1990).

Recently, various thawing methods have been actively researched using high-pressure thawing, microwave thawing, ohmic thawing and acoustic thawing in order to minimize amount of drip occurring at thawing time and deterioration of quality (Dong *et al.,* 2011; Hong *et al.,* 2007; Kim *et al.,* 2006; Lee and Park, 1999; Li and Sun, 2002). However, these thawing methods require special equipments or devices, the cost of which limits their availability (Li and sun, 2002). In addition, many researches have attempted to identify how freezing and thawing conditions affect meat (Mortensen, 2006; Muela, 2010; Vieira, 2009; Xia, 2009). Jung (1999) reported that rapid thawing for frozen meat results in a greater breakage of myofibril and that this has an influence upon the quality

*Corresponding author: Young Boong Kim, Division of Convergence Technology, Korea Food Research Institute, Sungnam 463-746, Korea. Tel: 82-31-780-9012, Fax: 82-31-780-9076, E-mail: kybaaa@kfri.re.kr

of meat after thawing (Yu *et al.*, 2010). Park *et al.* (2012) reported that refrigeration thawing is the most suitable for frozen pork, while Song and Lee (2002) reported that repeating chilling and thawing negatively affects the quality of meat. Szmańko *et al.* (1995) reported that the storage period of meat frozen under -10°C did not affect the WHC. Electro-magnetic freezing has recently been used to minimize quality change during freezing. Electro-magnetic freezing is maintain super-cooling of ice crystal vibrating water molecule of freezing materials with energy in magnetic field and freeze both the inside and outside of material at the same time. Dropping the temperature below a certain level to prevents the destruction of cellular tissues, which prevents water molecules from moving (Iwasaka *et al.*, 2011).

In this study, the effects of various thawing methods of frozen beef are characterized for electro-magnetic and air blast frozen loin and round.

Materials and Methods

Samples

Samples of this study are beef (Hanwoo) sampled one day after slaughter. The beef was used grade 2 and loin and round were sampled. The samples were cut to 5-7 cm and were packed with aerobic packaging (23×32 cm, PE) by the 500 g.

Thawing and freezing

For thawing beef, thawing by refrigeration at 4±1°C (MicomCA-A11AC, LG, Korea), thawing by RT, and thawing by cold water were carried out at 25°C and 15°C, respectively, and thawing by microwave was carried out using a microwave (RE-551B, 2450 MHz, 700 W, Samsung Co., Korea) until the temperature of the meat reached 0°C. Samples were evaluated until their core temperature reached at 0ºC and repeated 20 time for each sample as a preparatory experiment about overheating of surface. Thawing time using refrigeration, RT, cold water and microwave was 164.9 h, 5.0 h, 1.5 h and 0.4 h, respectively. Samples were frozen using the electro-magnetic freezing and air blast freezing method. Electro-magnetic freezing (AVI Co., Japan) samples were frozen at -55°C using refrigeration of Dine jeju Co., while air blast frozen samples were frozen at -45°C using a refrigeration of Meat bank Co. Data logger (176T4, Testo, Germany) was used to measure temperature, while a thermocouple (NiCr-Ni thermocouple, SEF GmbH, Germany) was used for sensing.

Analysis items and methods

Thawing time was used in sampling as a result of preparatory experiment and temperature of sample for analysis was measured after thawing. After thawing of frozen beef, physicochemical and sensory evaluation was carried out in order to compare the quality of each result and repeated three times for each sample. Sensory evaluation was carried out after heating the thawed samples and the results were applied to statistical analysis.

Drip loss

Drip loss (%) is measured for frozen beef until the temperature in center of meat reaches at 0°C.

Drip loss (%) = {(weight before thaw − weight after thaw) / weight before thaw} × 100

Cooking loss

According to specific methods of thawing, the sample weight is measured before/after cooking of the sample by heating at 75°C in a water bath, and is taken out when the temperature in center of the test material reaches at 65°C, and then cooled, after which cooking loss is calculated by following formula.

Cooking loss (%) = {weight before cook − weight after cook) / weight before cook} × 100

Water holding capacity (WHC)

WHC of meat depending on each thawing method, using the modified Kristensen and Purslow (2001) method, is calculated by heating 5 g of minced meat at 70°C in a water bath for 30 min and then cooling it, and then centrifuging at 1,000 rpm for 10 min and measuring total moisture, after which is calculated by the following formula.

WHC (%) = (total water content − separated water content) × 0. 951* / total water contents × 100

*0.951: pure water amount for meat moisture which is separated under 70°C

Moisture contents

Moisture content is analyzed at 105°C by an ambient drying method according to AOAC (1990).

Sensory evaluation

A sensory evaluation of samples was carried out based on appearance, flavor, texture, taste and overall acceptability with a scale of 9 points, and by 15 inspectors who are chosen among personnel with more than 1 year of experience in meat-related and sensory testing. Its score is indicated by 1 point (very poor) to 9 point (very good). For this sensory test, the samples are cut to 1 cm of thickness and heated using an electrical grill (HD-4417, Phillips, Netherland) until the core temperature of meat reaches 75°C, after which was provided to the inspectors for sensory evaluation on a white dish.

Statistical analysis

The results from this test were applied to analysis of variance using SAS program (2002) and its significance was verified at the level of 5% using Duncan's multiple range test.

Results and Discussion

Drip loss

The change of drip loss of beef after thawing according to different thawing methods is shown in Figs. 1 and 2. Drip loss after electro-magnetic freezing (Fig. 1) showed significant differences depending on thawing methods ($p<0.05$). Drip loss from loin and round with microwave thawing indicated the lowest rate with 0.66% and 1.25% respectively. This showed that there was 17.5-25.0% and 10.1-23.3% of drip loss effect for loin and round compared with thawing by refrigeration, RT and cold water. In terms of each part of meat, thawing by refrigeration (1.57%), RT (1.63%), cold water (1.39%) and microwave (1.25%) in round showed higher drip loss than thawing by refrigeration (0.80%), RT (0.88%), cold water (0.81%) and microwave (0.66%) in loin ($p<0.05$). This is similar to the result of Lee and Park (1999), indicating that thawing by microwave is faster than thawing by common methods, and that the amount of drip loss is reduced compared with thawing at temperature higher than 4°C.

Drip loss by thawing after air blast freezing (Fig. 2) showed a similar pattern to variations depending on thawing methods after electro-magnetic freezing ($p<0.05$). In general, drip loss by any thawing method after air blast freezing was higher than thawing after electro-magnetic freezing. Drip loss rate by microwave thawing indicated 20.0-50.0% in loin and 7.0-20.0% in round compared with reduction by refrigeration, RT and cold water. Drip loss from round depending on each thawing method indicated for refrigeration (2.15%), RT (2.50%), cold water (2.31%) and microwave (2.01%), which is higher compared with those in loin with thawing by refrigeration

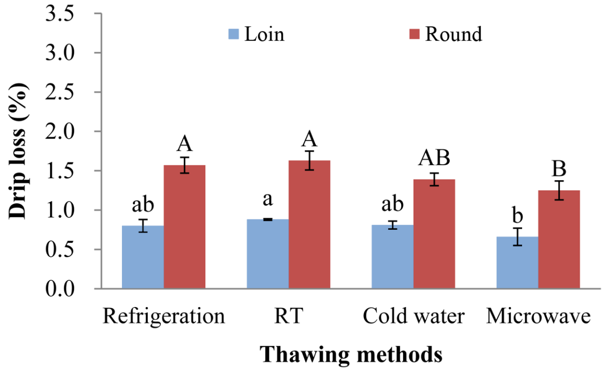

Fig. 1. Drip loss of beef in electro-magneticfreezing[1)] by thawing methods. $^{a\text{-}b}$Means in loin with different superscripts are significantly different ($p<0.05$). $^{A\text{-}B}$Means in round with different superscripts are significantly different ($p<0.05$). Refrigeration, 4±1°C; RT (Room temperature), 25°C; Cold water, 15°C tap water; Microwave, Thawing method using microwave oven. [1)] Electro-magnetic freezing: -55°C

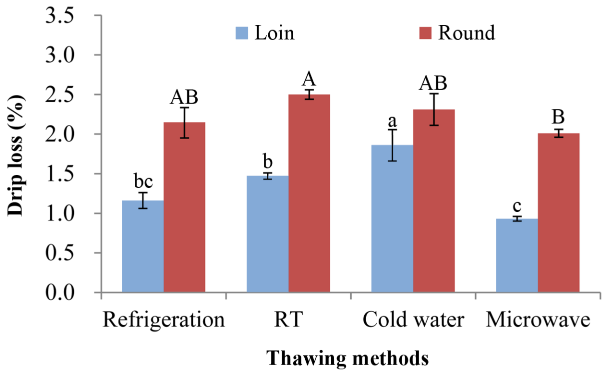

Fig. 2. Drip loss of beef in air blast freezing[2)] by thawing methods. $^{a\text{-}c}$Means in loin with different superscripts are significantly different ($p<0.05$). $^{A\text{-}B}$Means in round with different superscripts are significantly different ($p<0.05$). Refrigeration, 4±1°C; RT (Room temperature), 25°C; Cold water, 15°C tap water; Microwave, Thawing method using microwave oven. [2)]Air blast freezing: -45°C

(1.16%), RT (1.47%), cold water (1.86%) and microwave (0.93%) ($p<0.05$). High drip loss means water soluble losses from muscle fiber indicating a loss of nutrition. Therefore, if meats from the results of this study are used microwave thawing, drip loss from thawing would be reduced, which is believed to contribute to the maintenance of quality.

Cooking loss, WHC and moisture contents

Cooking loss, WHC and moisture contents for beef which is thawed by each thawing method after electro-magnetic freezing is shown in Table 1. Cooking loss was 43.7% after thawing by refrigeration in loin and 52.0%

after thawing by microwave for round, which were higher than those of other thawing methods ($p<0.05$). Although cooking loss didn't shown a tendency for each part of beef, low cooking loss from thawing by RT for loin and thawing by refrigeration for round was due to it exhibiting greater drip loss than the other thawing methods. Although WHC for each part of beef had no difference, it showed 62.2% for thawing by microwave is higher than that of refrigeration thawing (60.7%) in loin. Thawing by microwave (63.3%) in round showed higher WHC than thawing by RT (61.8%) and refrigeration (61.9%). Moisture contents of loin and round are thawed by microwave 66.6% and 75.4% respectively. Table 2 showed results of cooking loss and WHC for thawed beef depending on the thawing methods after frozen by air blast freezing. Cooking loss was 32.9-35.6% for loin depending on the thawing methods and 41.0-49.1% in round. Although cooking loss for loin had no difference, cold water thawing in loin the lowest value (32.9%). WHC thawing by microwave in loin (60.6%) was higher than refrigeration thawing (57.9%), while that in round (61.5%) indicated higher than RT thawing (59.9%) and refrigeration thawing (57.7%) ($p<0.05$). Moisture contents from loin and round with microwave thawing indicated the highest rate at 66.4% and 74.7% respectively ($p<0.05$). Cooking loss thawed by microwave for round of frozen beef was lower than other thawing methods by contrast with drip loss. WHC and moisture contents of samples after thawing were higher regardless of the cut of meat. Yu *et al*. (2010) reported that with the higher thawing rate, the myofibril is disrupted, and that drip and cooking loss by thawing affect the quality of beef. It has also been reported that the reduction of drip loss when meat processing by thawing frozen meat makes it possible to enhance the overall quality of the sausage nutritional aspect (Tsukamasa *et al.,* 1992).

Sensory evaluation

Sensory evaluation was carried out for thawed beef depending on thawing method (refrigeration, RT, cold water and microwave) after both electro-magnetic freezing and air blast freezing. The sensory evaluation of samples was carried out for appearance, flavor, texture, taste and overall acceptability with a scale of 9 points. Samples

Table 1. Cooking loss, water holding capacity, and moisture contents of beef in electro-magnetic freezing[1)] by thawing methods

(Unit: %)

	Refrigeration[2)]		RT[3)]		Cold water[4)]		Microwave[5)]	
	Loin	Round	Loin	Round	Loin	Round	Loin	Round
Cooking loss	43.7±1.1^{a}	41.8±2.4^{B}	34.7±0.4^{c}	50.1±0.7^{A}	35.7±0.6^{bc}	50.8±0.5^{A}	37.0±0.4^{b}	52.0±0.7^{A}
WHC[6)]	60.7±0.9	61.9±1.9	61.6±0.9	61.8±0.4	61.8±0.3	62.0±0.2	62.2±0.5	63.3±0.4
Moisture contents	67.1±0.5^{a}	71.9±2.3^{B}	64.2±0.4^{b}	75.0±0.2^{AB}	64.3±0.3^{b}	74.9±0.1^{AB}	66.6±0.5^{a}	75.4±0.2^{A}

$^{a\text{-}c}$Means in loin with different superscripts are significantly different ($p<0.05$).
$^{A\text{-}B}$Means in round with different superscripts are significantly different ($p<0.05$).
1) Electro-magnetic freezing: -55°C,
2) Refrigeration: 4±1°C,
3) RT (Room temperature): 25°C,
4) Cold water: 15°C tap water,
5) Microwave: Thawing method using microwave oven,
6) WHC: Water holding capacity.

Table 2. Cooking loss, water holding capacity, and moisture contents of beef in air blast freezing[1)] by thawing methods (Unit: %)

	Refrigeration[2)]		RT[3)]		Cold water[4)]		Microwave[5)]	
	Loin	Round	Loin	Round	Loin	Round	Loin	Round
Cooking loss	35.2±1.2	41.0±1.2^{C}	33.7±0.1	48.3±2.0^{AB}	32.9±0.2	45.5±0.8^{B}	35.6±1.6	49.1±0.1^{A}
WHC[6)]	57.9±1.0^{b}	57.7±0.8^{C}	59.8±0.2^{a}	59.9±0.1^{B}	58.1±0.2^{b}	59.8±0.3^{B}	60.6±0.0^{a}	61.5±0.5^{A}
Moisture contents	64.2±0.3^{b}	70.7±0.1^{C}	63.6±0.3^{b}	73.8±0.4^{B}	63.7±0.3^{b}	74.1±0.2^{AB}	66.4±0.4^{a}	74.7±0.2^{A}

$^{a\text{-}b}$Means in loin with different superscripts are significantly different ($p<0.05$).
$^{A\text{-}C}$Means in round with different superscripts are significantly different ($p<0.05$).
1) Air blast freezing : -45°C,
2) Refrigeration : 4±1°C,
3) RT (Room temperature) : 25°C,
4) Cold water : 15°C tap water,
5) Microwave : Thawing method using microwave oven,
6) WHC : Water holding capacity.

were cut to 1 cm thickness and were heated using an electrical grill (HD-4417, Phillips, Netherland) until the core temperature of meat reached 75°C, and provided to the inspectors for sensory testing on a white dish. The result is shown in Table 3. Texture from sensory evaluation for loin depending on each thawing method after frozen by electro-magnetic freezing indicated 8.0 point for thawing by microwave, 8.0 point for cold water and 7.9 point for RT and 5.7 point thawing by refrigeration. Round showed higher value (7.9 point) in texture for microwave than thawing by cold water (6.6 point), RT (6.4 point) and refrigeration (4.7 point). In addition, overall acceptability showed difference for each thawing method and it showed the highest value for thawing by microwave and the lowest value for thawing by refrigeration. Sensory evaluation for loin and round didn't show significant differences.

Results of sensory evaluation against beef frozen by air blast freezing are showed for each thawing method in Table 4. The texture of loin indicated 6.7 point for RT and 7.3 point for refrigeration thawing, while that of round showed 6.0 point for refrigeration thawing and 7.3 point for microwave thawing. In addition, its overall acceptability at loin showed 6.3 point for RT thawing and 7.3 point for refrigeration thawing. Although sensory evaluation no significantly different depending on freezing and thawing methods, evaluation was the highest when applied to microwave thawing. Lee *et al*. (2007) reported that there is a difference in texture and juiciness when frozen beef is thawed at varying temperature, and similarly, results from this study showed differences for each thawing method.

Conclusion

Freezing has been applied to food to retain quality and freshness, and to inhibit microbial growth. This research was carried out on quality characteristics of frozen beef by thawing methods (refrigeration, RT, cold water and microwave). This study showed that meat thawed by microwave indicated low drip loss by thawing, high cooking loss and high WHC with higher moisture contents than other thawing methods regardless of the cut of beef which was thawed by each thawing method (refrigeration, RT, cold water and microwave). Sensory evaluation was better for beef thawed by microwave, regardless

Table 3. Sensory evaluation of beef in electro-magnetic freezing[1)] by thawing methods (unit: point)

	Refrigeration[2)]		RT[3)]		Cold water[4)]		Microwave[5)]	
	Loin	Round	Loin	Round	Loin	Round	Loin	Round
Appearance	6.6±1.3	6.1±1.5	8.0±0.0	7.6±1.1	7.6±0.5	7.9±0.3	7.6±0.7	7.6±0.5
Flavor	7.4±0.7	5.9±1.4	7.2±0.7	6.9±1.2	8.0±0.7	7.6±0.7	7.8±0.7	7.4±0.7
Texture	5.7±2.1	4.7±2.0	7.9±0.6	6.4±1.5	8.0±0.5	6.6±1.1	8.0±0.5	7.9±0.8
Taste	6.3±2.0	5.2±1.9	7.4±0.7	7.0±1.0	7.9±0.6	7.6±0.9	7.6±0.5	7.9±1.2
Overall quality	6.3±1.8	4.8±1.9	7.4±0.7	6.9±0.9	7.9±0.6	7.6±0.9	8.0±0.5	7.9±1.2

[NS]Not significant.
1) Electro-magnetic freezing: -55°C,
2) Refrigeration: 4±1°C,
3) RT (Room temperature): 25°C,
4) Cold water: 15°C tap water,
5) Microwave: Thawing method using microwave oven.

Table 4. Sensory evaluation of beef in air blast freezing[1)] by thawing methods (unit: point)

	Refrigeration[2)]		RT[3)]		Cold water[4)]		Microwave[5)]	
	Loin	Round	Loin	Round	Loin	Round	Loin	Round
Appearance	7.5±0.5	7.0±0.9	7.0±0.7	7.6±0.5	7.1±0.6	7.3±0.9	6.7±0.7	7.6±0.5
Flavor	7.6±0.5	7.4±0.9	7.0±1.0	7.6±0.5	7.3±1.0	8.0±0.0	7.6±0.7	7.7±0.5
Texture	7.3±0.9	6.0±0.7	6.7±0.9	7.0±1.0	7.1±0.9	7.0±0.5	7.1±1.1	7.3±1.0
Taste	7.1±0.4	6.1±0.9	6.0±0.7	7.1±0.8	6.1±0.6	7.6±0.5	6.9±0.9	7.6±0.5
Overall quality	7.3±0.5	5.8±0.7	6.3±0.9	7.1±0.8	6.6±0.7	7.6±0.5	7.0±0.7	7.6±0.7

[NS]Not significant.
1) Air blast freezing : -45°C,
2) Refrigeration : 4±1°C,
3) RT (Room temperature) : 25°C,
4) Cold water : 15°C tap water,
5) Microwave : Thawing method using microwave oven.

of the cut. Therefore, it was shown that microwave thawing is an appropriate way to reduce the deterioration of quality by freezing.

References

1. AOAC. (1990) Official methods of analysis. 15th ed, Association of Official Analytical Chemistry, Arlington, USA, p. 931.
2. Berry, B. W. (1994) Fat level, high temperature cooking and degree of doneness affect sensory, chemical and physical properties of beef patties. *J. Food Sci.* **59**, 10-14.
3. Dong, Q., Li, Y., Liang, N., and Mao, Q. (2011) Selection and optimization of thawing treatment for the frozen pork. *ShengwuJiagongGuocheng.* **9**, 66-70.
4. Fennema, O. R. (1973) Nature of freezing process. In: Low temperature preservation of foods and living matter. Fennema, O. R., Powrie, W. D., and Marth, E. H. (eds) Marcel Dekker Inc., NY, pp. 151-222.
5. Hamm, R. (1972) Das Wasserbindungsvermögen des Muskeleiweßes in Theorie und Praxis. Nahrung. **16**, 689-690.
6. Hanenian, R. and Mittal, G. S. (2004) Effect of freezing and thawing on meat quality. *J. Food Agri. Environ.* **2**, 74-80.
7. Iwasaka, M., Onishi, M., Kurita, S., and Owada, N. (2011) Effects of pulsed magnetic fields on the light scattering property of the freezing process of aqueous solutions. *J. Appl. Phys.* **109**, 07E320-07E320-3.
8. Jason, A. C. (1974) Rapid thawing of foodstuff. *IFST-Proceeding*.**7**, 146-157.
9. Jung, I. C. (1999) Effect of freezing temperature on the quality of beef loin aged after thawing. *J. Kor. Soc. Food Sci. Nutr.* **28**, 871-875.
10. Kim, J. Y., Hong, G.P., Park, S. H., Lee, S., and Min, S. G. (2006) Effects of ohmic thawing on the physicochemical properties of frozen pork. *Food Sci. Biotechnol.* **15**, 374-379.
11. Kim, Y. H., Yang, S. Y., and Lee, M. H. (1990) Quality changes of thawed porcine meat on the thawing methods. *Korean J. Food Sci. Technol*. **22**, 123-128.
12. Kondratowicz, J., Chwastowska, S. I., and Burczyk, E. (2008) Technological properties of pork thawed in the atmospheric air or in the microwave oven as determined during a sixmonth deep-freeze storage. *Anim. Sci. Pap. Rep.* **26**, 175-181.
13. Kristensen L. and Purslow, P. P. (2001). The effect of ageing on the water-holding capacity of pork: Role of cytoskeletal proteins. *Meat Sci.* **58**, 17-23.
14. Lannari, M. C. and Zaritzky, N. E. (1991) Effect of packaging and frozen storage temperature on beef pigments. *Int'l. J. Food Sci. Technol*. **26**, 629.
15. Lee, E. S., Jeong, J. Y., Yu, L. H., Choi, J. H., Han, D. J., Choi, Y. S., and Kim, C. J. (2007) Effects of thawing temperature on the physicochemical and sensory properties of frozen pre-rigor beef muscle. *Food Sci. Biotechnol.* **16**, 626-631.
16. Lee, J. K. and Park, J. Y. (1999) Rapid thawing of frozen pork by 915 MHz microwave. *Korean J. Food Sci. Technol.* **31**, 54-61.
17. Li, B. and Sun, D. W. (2002) Novel methods for rapid freezing and thawing of foods - A review. *J. Food Eng*. **54**, 175-182.
18. Miller, A. J., Ackerman, S. A., and Palumbo, S. A. (1980) Effects of frozen storage on functionality of meat for processing. *J. Food Sci.* **45**, 1466-1471.
19. Mortensen, M., Andersen, H. J., Engelsen, S. B., and Bertram, H.C. (2006) Effect of freezing temperature, thawing and cooking rate on water distribution in two pork qualities. *Meat Sci*. **73**, 34-42.
20. Muela, E., Sanudo, C., Campo, M. M., Medel, I., and Beltran, J.A. (2010) Effect of freezing method and frozen storage duration on instrumental quality of lamb throughout display. *Meat Sci*. **84**, 662-669.
21. Park, M. H., Kwon, J. E., Kim S. R., Won, J.H., Ji, J. Y., Hwang, I. K., and Lim, M. R. (2012) Physicochemical and microbiological properties of pork by various thawing methods. *J. East Asian Soc. Dietary Life*. **22**, 298-304.
22. SAS. (2002) SAS/STAT Software for PC. Release 9.0, SAS Institute Inc., Cary, NC, USA.
23. Sebranek, J. G., Sang, P. N., Rust, R. E., Topel, D. G., and Kraft, A. A. (1978) Influence of liquid nitrogen, liquid carbon dioxide and mechanical freezing on sensory properties of ground beef patties. *J. Food Sci.* **43**, 842-844.
24. Sebranek, J.G. Sang, P. N., Topel, D. G., and Rust, R. E. (1979) Characteristics of ground beef patties effects of freezing methods and frozen storage on chemical. *J. Anim. Sci.* **48**, 1101-1108.
25. Song, M. S. and Lee, S. J. (2002) Effect of freezing/thawing cycles on physical properties of beef. *Food Eng. Progress.* **6**, 101-108.
26. Szmańko, T., Honikel, K. O., and Hofmann, K. (1995) Changes in histological structure and physiochemical properties of raw, cured, smoked pork loins resulting from freezing near cryoscopic temperature. *Nahrung.* **39**, 432-451.
27. Tomaniak, A., Tyszkiewicz, I., and Komosa, J. (1998) Cryoprotectants for frozen red meats. *Meat Sci*. **50**, 365-37.
28. Tsukamasa, Y., Fukumoto, K., Ichinomiya, M., Sugiyama, M., Minegishi, Y., Akahane, Y., and Yasumoto, K. (1992) Characterization and utilization of a drip exuding from frozen-thawed pork. *J. Jap. Soc. Food Sci. Technol*. **39**, 862-869.
29. Vieira, C., Diaz, M. T., Martinez, B., and Garcia-Cachan, M. D. (2009) Effect of frozen storage conditions (temperature and length of storage) on microbiological and sensory quality of rustic crossbred beef at different states of ageing. *Meat Sci*. **83**, 398-404.
30. Wagner, J. R. and Anon, M. C. (1985) Effect of freezing rate on the denaturation of myofibrillar proteins. *J. Food Technol*. **20**, 735.
31. Wagner, J. R. and Anon, M. C. (1986) Effect of frozen storage on protein denaturation in bovine muscle. . Influence on solubility, viscosity and electrophoretic behabiour of myofibrillarproteins. *J. Food Technol*. **21**, 547.
32. Xia, X., Kong, Q., and Liu, J. (2009) Physicochemical change and protein oxidation on porcine longissimusdorsi as influenced by different freeze-thaw cycles. *Meat Sci*. **83**,

239-245.
33. Yu, X. L., Li, X. B., Zhao, L., Xu, X. L., Ma, H. J., Zhou, G. H., and Boles, J. A. (2010) Effects of different freezing rates and thawing rates on the manufacturing properties and structure of pork. *J. Muscle Food* **21**, 177-196.
34. Zhuang, H. and Savage, E. M. (2012) Postmortem aging and freezing and thawing storage enhance ability of early deboned chicken pectoralis major muscle to hold added salt water. *Poultry Sci*. **91**, 1203-1209.

(Received 2013.6.28/Revised 2013.11.8/Accepted 2013.11.11)