Food Sci. Biotechnol. Vol. 14, No. 5, pp. 676 ~ 680 (2005)

Food Science and Biotechnology

The Effect of Thawing Rate on the Physicochemical Properties of Frozen Ostrich Meat

Geun-Pyo Hong, Sung-Hee Park, Jee-Yeon Kim, Chi-Ho Lee, 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 investigated the effect of thawing rate on the physicochemical properties of frozen ostrich meat. Five different thawing rates (0.33, 0.54, 0.61, 0.68, and 0.78 cm/h) were delivered by controlling the air velocity as heat convection at 15°C. The pH value decreased with increasing thawing rate ($p<0.05$). In color measurement, L^*-values of all treatments were lower and b^*-values higher than those of control, but a^*-values were not significantly different among the treatments except at the thawing rate of 0.33 cm/h. Increasing thawing rate tended to improve the water holding capacity (WHC) of the samples. Thawing loss decreased with increasing thawing rate and significantly higher cooking loss was observed at the thawing rate of 0.33 cm/h. Thiobarbituric acid reactive substance (TBARS) levels of all treatments were significantly higher than that of control ($p<0.05$). Increasing thawing rate tended to decrease the total volatile basic nitrogen (TVBN) value. These results indicated that a rapid thawing process at 15°C improved the quality of frozen ostrich meat.

Keywords: thawing rate, physicochemical properties, frozen ostrich meat, air velocity

Introduction

Nowadays, ostrich meat has become an acceptable red meat and is readily found as either fresh meat or at restaurants in many countries. Initially, ostrich was assumed to be a healthy red meat containing low cholesterol (1, 2), although it is now accepted that ostrich has a cholesterol level similar to that of other lean meat types (3). A factor that does however make ostrich a healthy red meat is its low lipid content (1, 4). In addition, the ultimate pH values suggest that ostrich meat may be classified as an intermediate meat type between normal and extreme, dark, firm and dry (DFD) meat (5). The high ultimate pH of ostrich meat makes it an ideal red meat for processed products due to improved water binding property (6). However, an intermediate to high pH in meat results in a dark color which leads to the presumption of a limited shelf-life (5). In addition, the growth of microorganisms is favorable in high ultimate pH of meat. Consequently, research is being conducted into the optimum freezing and thawing process conditions in the ostrich meat industry.

Freezing has many advantages for the preservation of meat and facilitates its marketing, but there is some destruction of muscle fiber due to the formation of ice crystals. This may lead to problems such as drip loss during meat thawing and oxidation of muscle pigment, and reduction in gel-forming ability of myofibril proteins (7). Therefore, freezing of meat has been widely studied as a means to lower the amount of drip loss on thawing. The loss of fluid generally reduces the sensory properties, binding ability and weight of meat, all factors contributing to decreased value. The volume of drip produced on thawing has been extensively related to the rate of freezing, which in turn has been related to the size and location of ice crystals in frozen meat. While there is general agreement about the mechanism of freezing and the location of ice crystals in frozen meat, there are many conflicting reports in the literature about the effects of freezing and thawing on meat. In contrast to the extensive amount of literature about the effects of freezing rate on changes in physical, chemical and sensory meat properties, there are few reports about the effects of thawing rates on meat characteristics. Nevertheless, the results related to meat thawing are just as conflicting as those for freezing (8). Ambrosiadis *et al.* (9) and Deatherage and Hamm (10) have shown that a faster thawing rate resulted in a product with significantly less drip. In contrast, Gonzalez-Sanguinetti *et al.* (11) reported that drip volume increased for a thawing rate up to about 60 min to traverse the temperature range from -5°C to -1°C, while at a thawing rate greater than 60 min, drip volume was independent of the thawing rate. Nevertheless in the large amount of literature, there is a lack of agreement on the effects of thawing on the characteristics of frozen meat products. The aim of the present study, therefore, is to investigate the effect of various thawing rates on the physicochemical properties of rapidly frozen ostrich meat.

Materials and Methods

Materials and sample preparation Ostrich *M. femorotibialis medius* stored for 24 h at 4°C after slaughter was obtained from a local slaughterhouse. For each treatment, cylindrically formed samples (approximately 50 mm diameter × 100 mm length) were cut from the centre of the muscle with their axis parallel to fiber direction. Non-frozen samples were used as fresh controls. All samples had thermocouples inserted into their centre, along the longitudinal axis of the cylinder, and were placed at 5°C for pre-cooling process. Once the sample

*Corresponding author: Tel: 82-2-450-3680; Fax: 82-2-454-4146
E-mail: foodeng301@paran.com
Received August 22, 2005; accepted September 28, 2005

temperature in the center reached 5°C, the samples were rapidly frozen to a temperature of -20°C in their centre by cryogenic bath (-70°C) in order to minimize the quality loss during the freezing process. After freezing, the samples were stored in a deep freezer at -40°C for 4 weeks.

Thawing process All thawing treatments were conducted in a thawing chamber held at 15°C. Samples were thawed by natural air convection (air velocity of 0 m/s) or by forced air convection at air velocity of 0.3, 0.4, 0.87, 1.32, and 1.77 m/s. Thawing velocities were defined as the ratio of radius length to the thawing time to traverse the temperature range from -40°C to 0°C.

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 13,000 rpm for 1 min in an SMT process homogenizer (SMT Co. Ltd., Tokyo, Japan).

Color measurement Color measurements were taken with Color meter (JC801S, Color Techno System Co. Ltd., Tokyo, Japan) calibrated with a white standard plate (X = 97.83, Y = 81.58, Z = 91.51). CIELAB L^*, a^* and b^*-values were determined as indicators of lightness, redness and yellowness, respectively. Three measurements were taken from each surface of two strips.

Water holding capacity (WHC) The amount of expressed water in meat was determined by Grau and Hamm (12). A meat sample of approximately 300 mg was weighed onto Whatman No. 2 filter paper and pressed between two plastic sheets for 2 min. The areas of expressed water and sample were measured using a Planimeter (Koizumi, Type KP-21, Niigata, Japan). Water holding capacity (WHC) was determined as the percentage ratio between the two measurements.

Thawing loss Three plastic bags per treatment were used to determine the thawing loss of ostrich meat at each thawing process. Each sample was weighed before packaging and reweighed after thawing. Thawing loss was determined from the difference in weights between the two measurements expressed as a percentage of the initial weight.

Cooking loss and total loss Cooking loss was determined by assessing the value of exudation after thermal treatment. Three samples from each treatment were weighed before and after cooking at 75°C for 30 min, and expressed as a percentage of the initial weight. Total loss was determined as the sum of the thawing and cooking losses.

Lipid oxidation Lipid stability of ostrich meat was determined by measuring 2-thiobarbituric acid reactive substances (TBARS) using the extraction method described by Witte et al. (13). One gram of sample was mixed with 0.15 mL of butylated hydroxytoluene (BHT) and 9 mL of perchloric acid and was homogenized at 17,000 rpm for 2 min, after which 5 mL of distilled water was added and filtered using Whatman No 2 filter paper. One milliliter of filtrate was added to 1 mL of TBA, boiled at 100°C for 30 min, and cooled by ice water for 5 min. The readings were made on a UV/VIS spectrophotometer (OptizenIII, Mecasys, Seoul, Korea) at 531 nm. The conversion factor 6.2 was used for calculation of TBARS expressed as mg malonaldehyde per kg meat.

Total volatile basic nitrogen Total volatile basic nitrogen (TVBN) was determined by the Conway micro diffusion method (14). Ten grams of samples were homogenized at 17,000 rpm for 2 min with 30 mL distilled water. Homogenate was massed up to 100 mL and filtered using Whatman No 2 filter paper. One milliliter 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 milligrams of nitrogen per 100 g of meat.

Statistical analysis The data were analyzed by ANOVA using the SAS (15) 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 In natural convection treatment, the thawing time to traverse the temperature range from -40°C to 0°C was approximately 500 min, compared to 190 min at 1.77 m/s of forced air convection. The calculated thawing rates of all treatments were 0.30, 0.33, 0.54, 0.61, 0.68 and 0.78 cm/h at 0, 0.3, 0.4, 0.87, 1.32 and 1.77 m/s of air convection, respectively. As expected, the thawing rate was dependant on the air flowing velocity originated in the increased heat transfer coefficient and showed a linear relationship.

Changes in pH value of ostrich meat The changes in pH value of the ostrich meat are shown in Fig. 1. The pH value of control was 5.87, which generally agreed with the results of Sales and Mellett (5) of a range from 5.84 to 6.13 in six different muscles from ostrich carcasses at 24 h post-mortem. Otremba *et al.* (16) reported a pH of 6.4 and 6.2 in intact steaks and ground ostrich meat, respectively. The pH values of all treatments decreased significantly (p <0.05) with the increase of thawing rate and ranged from

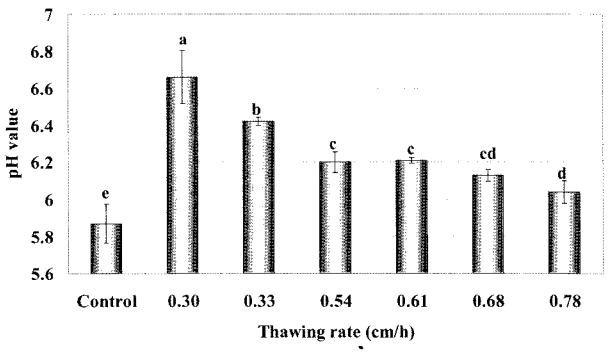

Fig. 1. Effects of thawing rate on the pH values of frozen ostrich meat. Means with different letters are significantly different (p<0.05). The vertical bars represent the standard deviation.

6.04 to 6.66, which was higher than the control. Similarly, Farouk and Swan (17) observed that frozen beef stored for 6 months had a higher pH value than fresh meat due to the release of free amino acids and dipeptides such as carnosine as a result of proteolysis. Braggins *et al.* (18) measured changes in free amino acids during chilled storage of sheep meat and concluded that the rise in pH value was probably due to an increase in basic free amino acids relative to acidic free amino acids. In the current study, the pH value of ostrich meat decreased with increasing thawing rate among the treatments. Changes in pH value could be explained by ice recrystallization during the thawing process causing changes in solutes concentration, thereby increasing the pH (19).

Changes in color of ostrich meat The changes in the color of ostrich meat are shown in Table 1. The mean L^*-value of unfrozen control was 40.75. All treatments had significantly lower ($p<0.05$) L^*-values than the control except the thawing rate of 0.61 cm/h. The tendency among the treatments, however, was not found in L^*-value. No differences ($p>0.05$) occurred in mean a^*-values between control and treatments with the exception of the thawing rate of 0.33 cm/h ($p<0.05$). All treatments showed significantly higher b^*-values ($p<0.05$) than that of the unfrozen control. Among the treatments, the highest b^*-value was obtained at natural air convection compared to forced air convection. In contrast with the current study, Sakata *et al.* (7) observed no discoloration by freezing in porcine *M. longissimus dorsi*. Boles and Swan (20) also observed that freezing had no effect on L^* and b^*-values of raw meat, but that thawed meat was slightly less red than fresh meat. However, a^* and b^*-values of the raw insides increased significantly if the meat was thawed in water compared to in air. Fabrouk *et al.* (19) suggested that the higher amounts of thaw drip in the slowly frozen samples, due to the reasons mentioned earlier, may have resulted in greater light reflection and lighter color in those samples compared to the quickly frozen samples. An increase in the lightness of thawed beef with storage time has been reported before (21, 22) and was attributed to the reflection of the thawed meat following the increased amount of free water in the meat resulting from muscle protein denaturation or increased lipid oxidation with time (23).

Changes in WHC of ostrich meat The changes in WHC of ostrich meat are shown in Fig. 2. The WHC of the control was 44.12% and no significant differences were found ($p>0.05$) between the control and treatments, with the exception of 38.08% at the thawing rate of 0.30 cm/h. However, increasing thawing rate tended to improve WHC of the samples which ranged from 38.08 to 45.10%. In general, WHC of frozen meat was related to the state of myofibrillar protein. Petrović *et al.* (24) found that slowly frozen beef *M. longissimus dorsi* had lower protein solubility than quickly frozen beef. Wagner and Añón (25) reported greater protein denaturation in slowly frozen myofibrillar proteins than in quickly frozen ones, and they attributed the difference to the partial unfolding of the protein molecules with exposure of hydrophobic groups. However, Fabrouk *et al.* (19) did not find any significant effect of freezing rate on the hydrophobicity of the extracted proteins in beef *M. semitendinosus*, which they attributed to the choice of muscle used, sample preparation and the functional attributes determined. However, Dawood (26) suggested a different standpoint that WHC of frozen meat was correlated with the fat content of meat due to the ratio of moisture to protein. They found lower WHC in camel ribeye than in others due to high fat content, which increased the ratio of moisture to protein. In the current study, no differences in WHC were found among the samples, which was probably due to the low fat content of ostrich meat, even if natural air convection caused some protein denaturation due to recrystallization compared to forced air convection.

Changes in thawing loss of ostrich meat Fig. 3 shows the changes in thawing loss of ostrich meat. The thawing loss of 4.28% at 0.30 cm/h decreased gradually with increasing thawing rate to 1.28% at the thawing rate of 0.78 cm/h. The same result was obtained by Ngapo *et al.* (27) who reported that drip loss of frozen meat increased significantly with increasing thawing time. In general, drip loss of thawed meat has been extensively related to the rate of freezing, which in turn has been related to the size and location of ice crystals in frozen meat (8). Hamm *et al.* (28) mentioned that drip loss at high freezing rate was decreased by increasing thawing rate, in contrast with that at low freezing rate, and emphasized the importance of

Table 1. Effects of thawing rate on the color of frozen ostrich meat

Thawing rate (cm/h)	Color values		
	L^*	a^*	b^*
Control	40.75±0.24^{a}	17.96±0.25^{ab}	2.18±0.18^{d}
0.30	39.31±0.24^{bc}	17.73±0.32^{ab}	4.00±0.32^{a}
0.33	37.33±0.35^{d}	16.93±0.53^{c}	3.06±0.38^{bc}
0.54	39.04±0.44^{c}	17.29±0.42^{bc}	2.89±0.15^{c}
0.61	40.21±1.26^{ab}	18.25±0.31^{a}	3.81±0.36^{ab}
0.68	38.43±1.21^{c}	18.35±1.26^{a}	2.85±0.80^{cd}
0.78	39.22±0.86^{bc}	17.62±0.50^{ab}	3.30±0.23^{b}

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

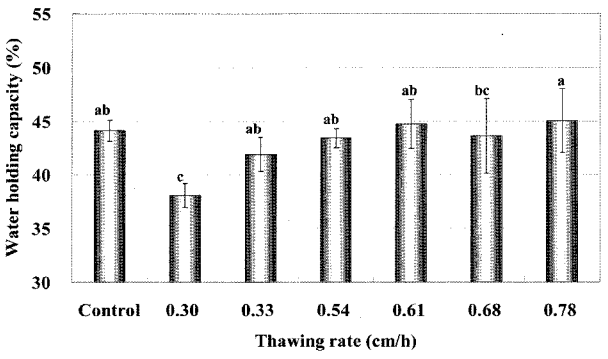

Fig. 2. Effects of thawing rate on WHC of frozen ostrich meat. Means with different letters are significantly different ($p<0.05$). The vertical bars represent the standard deviation.

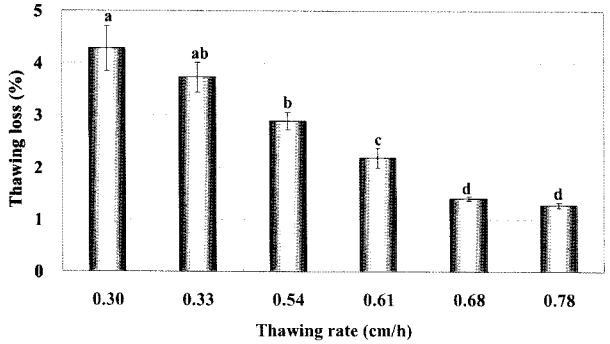

Fig. 3. Effects of thawing rate on the thawing loss of frozen ostrich meat. Means with different letters are significantly different ($p<0.05$). The vertical bars represent the standard deviation.

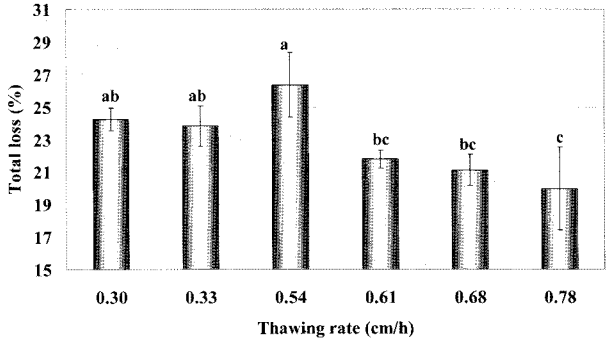

Fig. 5. Effects of thawing rate on the total loss of frozen ostrich meat. Means with different letters are significantly different ($p<0.05$). The vertical bars represent the standard deviation.

thawing rate as well as freezing rate. In the current study, thawing rate had significant effect ($P<0.05$) on thawing loss probably due to the recrystallization of ice during thawing which causes tissue destruction and protein denaturation.

Changes in cooking loss and total loss of ostrich meat The changes in cooking loss of ostrich meat are shown in Fig. 4. Cooking losses of the treatments showed no significant difference ($p>0.05$) with control, although significant increase ($p<0.05$) was observed at the thawing rate of 0.54 cm/h. Among the treatments, significantly higher total loss ($p<0.05$) was observed below 0.54 cm/h than above the thawing rate of 0.61 cm/h, indicating the guidance of the optimum thawing rate (Figure 5). On the contrary, Dawood (26) reported that the thawed meat appeared to lose less weight during cooking due to some loss of their original weight such as thawing loss. This phenomenon can be explained by the fact that their experiment was conducted at the traditional freezing process temperature of -20°C. In the present study, however, the decision to cool to 5°C before subsequently freezing to -20°C was based on suggestions by Reid (29) and Farouk *et al.* (19) that cooling a material very slowly to the point where crystal formation is initiated, followed by rapid freezing, can produce a frozen material with smaller ice crystals than if the material had been rapidly cooled throughout the whole process. In spite of the pre-cooling temperature of 5°C, therefore, subsequently rapid freezing processing is considered to give a stable yield during the thawing processing, resulting in an improved cooking yield above the thawing rate of 0.61 cm/h.

Changes in TBARS and TVBN values of ostrich meat TBARS values are often used as an indicator for the extent of lipid oxidation, with the results being shown in Table 2. The TBARS values of all treatments increased significantly ($p<0.05$) compared to that of control and ranged from 0.181 to 0.273 mg malonaldehyde/kg. Sakata *et al.* (7) reported that the TBARS value of frozen pork did not differ from that of unfrozen control, indicating that lipid oxidation did not occur during freezing. On the contrary, significant difference in TBARS value was found between control and treatments ($p<0.05$). Gray and Pearson (30) summarized the previous research and noted that rancid flavor was initially detected in meat products between TBARS values of 0.5 and 2.0 mg malonaldehyde/kg. Boles and Parrish (31) and Lin (32) reported that at TBARS values above 1.0 mg malonaldehyde/kg, a warm-over flavor could be detected in meat products. TVBN values of all treatments were increased significantly ($p<0.05$) compared to the control value of 5.46 mg/100g (Table 2). No significant difference among thawing treatments, however, was found ($p>0.05$), while increasing thawing rate tended to decrease the sample TVBN values from 13.45 to 12.89 mg/100 g. This phenomenon could be explained by the increasing heat transfer coefficient, which

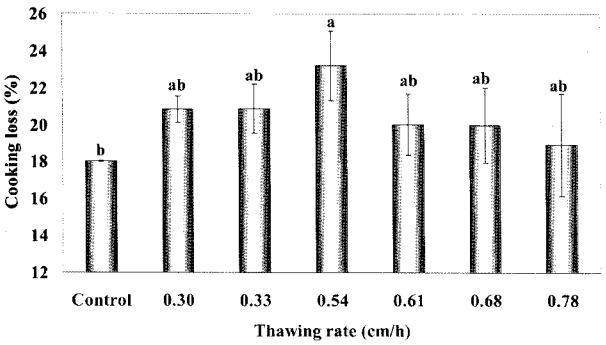

Fig. 4. Effects of thawing rate on the cooking loss of frozen ostrich meat. Means with different letters are significantly different ($p<0.05$). The vertical bars represent the standard deviation.

Table 2. Effects of thawing rate on TBARS and TVBN values of frozen ostrich meat

Thawing rate (cm/h)	TBARS (mg malonaldehyde/kg)	TVBN (mg/100 g of meat)
Control	0.115±0.005^{d}	5.46±1.92^{b}
0.30	0.194±0.002^{c}	13.45±0.00^{a}
0.33	0.273±0.005^{a}	13.17±1.16^{a}
0.54	0.236±0.004^{ab}	13.45±1.63^{a}
0.61	0.197±0.003^{bc}	12.89±0.00^{a}
0.68	0.233±0.008^{ab}	12.75±1.92^{a}
0.78	0.181±0.002^{c}	12.75±3.79^{a}

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

resulted from the increasing air convection velocity, producing no thermal deterioration among the treatments. In the current study, all samples recorded a TBARS value below 0.3 mg malonaldehyde/kg and a TVBN value below 20 mg/100 g, implicating the relative safety of the meats from any dangerous deterioration during frozen storage.

Acknowledgments

This study was financially supported by a grant of Digital Appliance Research Laboratory (LG Electronics Inc., Korea).

References

1. Paleari MA, Camisasca S, Beretta G, Renon P, Corsico P, Bertolo G, Crivelli G. Ostrich meat: Physico-chemical characteristics and comparison with turkey and bovine meat. Meat Sci. 48: 205-210 (1998)
2. Sales J. Fatty acid composition and cholesterol content of different ostrich muscles. Meat Sci. 49: 489-492 (1998)
3. Hoffman LC, Mellet FD. Quality characteristics of low-fat ostrich meat patties formulated with either pork lard or modified corn starch, soya isolate and water. Meat Sci. 65: 869-875 (2003)
4. Hoffman LC, Fisher PP. Comparison of meat quality characteristics between young and old ostriches. Meat Sci. 59: 335-337 (2001)
5. Sales J, Mellett FD. Post-mortem pH decline in different ostrich muscles. Meat Sci. 42: 235-238 (1996)
6. Fisher P, Hoffman LC, Mellett F. Processing and nutritional characteristics of value added ostrich products. Meat Sci. 55: 251-254 (2000)
7. Sakata R, Oshida T, Morita H, Nagata Y. Physico-chemical and processing quality of porcine M. longissimus dorsi frozen at different temperatures. Meat Sci. 39: 277-284 (1995)
8. Ngapo TM, Babare IH, Reynolds J, Mawson RF. Freezing rate and frozen storage effects on the ultrastructure of samples of pork. Meat Sci. 53: 159-168 (1999)
9. Ambrosiadis I, Theodorakakos N, Georgakis S, Lekas S. Influence of thawing methods on the quality of frozen meat and the drip loss. Fleischwirtschaft 74: 284-287 (1994)
10. Deatherage FE, Hamm R. Influence of freezing and thawing on hydration and charges of the muscle proteins. Food Res. 25: 623-629 (1960)
11. Gonzalez-Sanguinetti S, Añon MC, Calvelo A. Effect of thawing rate on exudates production of frozen beef. J. Food Sci. 50: 697-700 (1985)
12. Grau R, Hamm R. Eine einfache Methode zur Bestimmung der Wasserbindung im Muskel. Naturwissenschaften 40: 29-35 (1955)
13. Witte VC, Krause GF, Bailey ME. A new extraction for determining 2-thiobarbituric acid values of pork and beef during storage. J. Food Sci. 35: 582-584 (1970)
14. Conway EJ, Byrne A. An absorption apparatus for the micro-determination of certain volatile substances. Biochemistry 27: 419-429 (1933)
15. SAS Institute, Inc. SAS/STAT user's guide. Statistical Analysis Systems Institute, Cary, NC, USA (1996)
16. Otremba MM, Dikeman ME, Boyle EAE. Refrigerated shelf life of vacuum-packaged, previously frozen ostrich meat. Meat Sci. 52: 279-283 (1999)
17. Farouk MM, Swan JE. Effect of rigor temperature and frozen storage on functional properties of hot-boned manufacturing beef. Meat Sci. 49: 233-247 (1998)
18. Braggins TJ, Frost DA, Agnew MP, Podmore C. Changes in pH and free amino acids in sheepmeat during extended chilled storage. Proceedings of the 45th International Conference of Meat Science and Technology. Yokohama, Japan (1999)
19. Farouk MM, Wieliczko KJ, Merts I. Ultra-fast freezing and low storage temperatures are not necessary to maintain the functional properties of manufacturing beef. Meat Sci. 66: 171-179 (2003)
20. Boles JA, Swan JE. Meat and storage effects on processing characteristics of beef roasts. Meat Sci. 62: 121-127 (2002)
21. Farouk MM, Wieliczko KJ. Effect of diet and fat content on the functional properties of thawed beef. Meat Sci. 64: 451-458 (2003)
22. Sebranek JG, Sang PM, Topel DG, Rust RE. Effects of freezing methods and frozen storage on chemical characteristics of ground beef patties. J. Anim. Sci. 4: 1101-1108 (1979)
23. Akamittath JG, Brekke CJ, Schanus EG. Lipid oxidation and color stability in restructured meat systems during frozen storage. J. Food Sci. 55: 1513-1517 (1990)
24. Petrović L, Grujić R, Petrović M. Definition of the optimum freezing rate-2. Investigation of the physico-chemical properties of beef *M. longissimus dorsi* frozen at different freezing rates. Meat Sci. 33: 319-331 (1993)
25. Wagner JR, Añón MC. Effect of freezing rate on the denaturation of myofibrillar protein. J. Food Technol. 21: 9-18 (1985)
26. Dawood AA. Physical and sensory characteristics of Najdi-camel meat. Meat Sci. 39: 59-69 (1995)
27. Ngapo TM, Babare IH, Reynolds J, Mawson RF. Freezing and thawing rate effects on drip loss from samples of pork. Meat Sci. 53: 149-158 (1999)
28. Hamm R, Gottesmann P, Kijowski J. Einfrieren und Auftauen von Fleisch: Einfluesse auf Muskel gewebe und Tausaft bildung. Fleischwirtschaft 62: 6-11 (1982)
29. Reid DS. Factors which influence the freezing process on examination of new insights. Paper presented at the 20th International Congress of Refrigeration. IIR/IIF, Sydney (1999)
30. Gray JI, Pearson AM. Rancidity and warmed-over flavor. In: Prarson AM, Dutson TR, (eds). Advances in meat research. New York: Van Nostrand. pp. 221-261 (1987)
31. Boles JA, Parrish FCJr. Sensory and chemical characteristics of precooked microwave reheatable pork roasts. J. Food Sci. 55: 618-620 (1990)
32. Lin LC. Effect of different storage temperature on flavor and ATP-related compounds of pork chops. Asian-Austral. J. Anim. Sci. 6: 417-419 (1993)