



Food and Applied Bioscience Journal



ISSN : 2286-8615
VOLUME 11 ISSUE 2
(MAY - AUGUST 2023)

Food and Applied Bioscience Journal

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ISSN : 2286-8615
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Effect of freezing under high voltage electrostatic fields on physical characteristics of chicken breast

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Submit: 2 February 2023, Received: 17 February 2023, Revised: 14 July 2023, Accepted: 26 July 2023,
Publish online: 25 August 2023

Abstract

Freezing is one of the most common methods for preserving food as it is an effective way to extend shelf life and preserve flavor and color. Currently, the high voltage electrostatic field (HVEF) has been studied to assist freezing meats such as lamb and pork. The results showed that the drip loss decreased, and textures were closed to unfrozen meat. However, many works had studied the effect of HVEF assisted freezing on texture of thawed small meat samples (around 1 – 15 g), and there was little information on texture of cooked products. The objective of this research is to study the physical characteristics of cooked chicken breast, with higher weight (38 ± 2 g.), frozen under different HVEF intensities. The chicken breasts were cut into 2 cm thickness and sealed in plastic bag (LDPE). The HVEF intensities (0, 1.25, 1.875, 2.5 and 3.125 kV/cm) were applied with freezing temperature at -20°C for 5 h. Frozen samples were kept at -40°C until they were analyzed. Then the samples were thawed at ambient temperature and cooked at $95-100^{\circ}\text{C}$. The drip loss and cooking loss of HVEF treatment decreased when they were compared to conventional freezing. The moisture content of cooked products was higher than those of products without HVEF. For texture, the hardness and chewiness of cooked products were decreased statistically significant difference from non-HVEF treatment, but the springiness and cohesiveness were not significantly different.

Keywords: Chicken breast, freezing, high voltage electrostatic field, texture

1. Introduction

Freezing is one of the ancient and most preferred process, used for preservation in meat products. In the frozen states, enzyme activity and microbial growth are inhibited (Hu *et al.*, 2022). Compared to the other processes, it has lower effect on deterioration of food properties such as color, flavor, nutrition (Delgado and Sun, 2001; Reid, 1993). However, during freezing process, ice crystal formations damage meat cells leading to drip loss, cooking loss and texture change. Therefore, many researchers have studied new emerging technologies to assist freezing process for instance ultrasound (Cheng *et al.*, 2015; Kiani *et al.*, 2011), high pressure (Chevalier *et al.*, 2000; Su *et al.*, 2014), magnetic electric field (Abedini *et al.*, 2011; Mohanty, 2001), radio frequency (Anese *et al.*, 2012) and high voltage electrostatic field (HVEF). The most promising technology to apply frozen food industry is HVEF because of its cost effectiveness and easy to integrate with commercial machines (Dalvi-Isfahan *et al.*, 2016; Le-Bail *et al.*, 2011; Wang *et al.*, 2019; Xanthakis *et al.*, 2013). High voltage electrostatic field can be produced by applying high voltage electricity to parallel electrodes. The lines of electrostatic flux are in between oppositely charged electrodes. By increasing the electrostatic fields, nucleation temperatures are shifted to higher values (Jia *et al.*, 2017; Orłowska *et al.*, 2009) leading to reduce freezing times, increase freezing rates, and create abundant small ice crystals (Wang *et al.*, 2019).

For recent years, HVEF has been studied to improve the qualities of frozen meats such as pork (Xanthakis *et al.*, 2013), lamb (Dalvi-Isfahan *et al.*, 2016; Dalvi-Isfahan *et al.*, 2018), shrimp (Liu *et al.*, 2022) on drip loss, color, texture of thawed samples etc. However, these works have been done with a small piece of meat samples (1.06 ± 0.04 g. for pork, 2.3 ± 0.2 g for lamb, 14.7 ± 1.9 g for shrimp). Moreover, there are still limited results on cooking loss and texture of cooked samples. Therefore, the aim of this study was to investigate drip loss, cooking loss and texture of cooked chicken breasts, in which the chicken breasts (around 38 g.) are frozen under HVEF.

2. Materials and Methods

2.1 Materials

Chicken breasts were bought from Ya-Mo market (Nakornratchasima, Thailand) on the slaughtered day and packed in the ice boxes in the morning. The breasts were cut into 2 cm thickness, weighed for 38 ± 2 g. per piece and sealed in low density polyethylene (LDPE) vacuum bag. The length and width of samples depended on the shape of breasts which were not fixed. All samples were cut and frozen under each condition on the same day. The moisture content of samples was measured by using moisture analyzer (Model 350-8860/K HA 300, Precisa Instruments AG, Dietikon, Switzerland).

2.2 Freezing under high voltage electrostatic fields

2.2.1 Freezing time

The freezing time was investigated by using thermocouples (Benetech, Model GM1312, Shenzhen, China). The thermocouples inserted to the center of chicken breasts and temperatures were observed (without HVEF). The temperature of samples reduced from 8.7 and 10°C to lower than -10°C for 4.2 h. Therefore, in this experiment, the samples were frozen under different HVEF intensities in the freezer for 5 h.

2.2.2 High voltage electric field apparatus

Fig 1. showed the diagram of experimental set up. High voltage electrostatic field, HVEF, was generated from a direct power supply (CYXJ300AN, China). Electrodes were made from 304 stainless plates with dimensions of 20 × 25 cm placed in parallel. The distance between electrodes was 8 cm. The samples, contained in LDPE vacuum bags, were placed between electrodes and applied voltages at 10, 15, 20 and 25 kV (electrostatic field intensities of 1.25, 1.875, 2.5 and 3.125 kV/cm) inside the freezer (Sanyo, SF-C992 NG, Thailand) at -20°C for 5 h. The freezer dimensions were 105 × 65 × 87 cm. The control samples (0 kV/cm) were simultaneously frozen with all experimental treatments. Then the frozen samples were stored in freezer at -40°C until they were analyzed. Electrostatic field intensities (I_{HVEF}) were calculated by applied voltages (V) dividing with the distance between electrodes (D) following Equation (1).

$$I_{HVEF} \text{ (kV/cm)} = (V \text{ [kV]}) / (D \text{ [cm.]}) \quad (1)$$

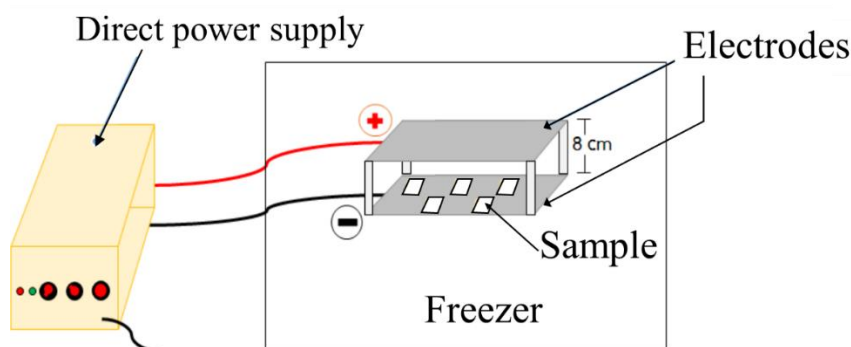


Fig 1 Diagram of the experimental set up

The samples of cut chicken breasts, 7 pieces, were arranged on the electrode as shown in fig 2.



Fig 2 Arrangement of chicken breasts, with 2 cm. thickness and weighted for 38 ± 2 g in LDPE vacuum bag, on electrode.

2.2.3 High voltage measurement

High voltages, generated from a direct power supply (TZZT, Model CYXJ300AN, Shenzhen, China), were measured by using voltage divider method. Using ohm's law, the resistors were connected in series circuit as shown in Fig 3. The voltage was divided by 10 resistors, in which $R_1 - R_9$ had resistance of 56 M Ω and R_{10} had resistance of 10 k Ω . The voltage drop across the tenth resistor (V_{measured}) was measured by using digital multimeter. Voltage of power supply (V_{in}) was calculated from Equation (2) (Irwin and Nelms, 2020).

$$V_{\text{in}} = V_{\text{measured}} \times \frac{(R_1 + R_2 + \dots + R_{10})}{R_{10}} \quad (2)$$

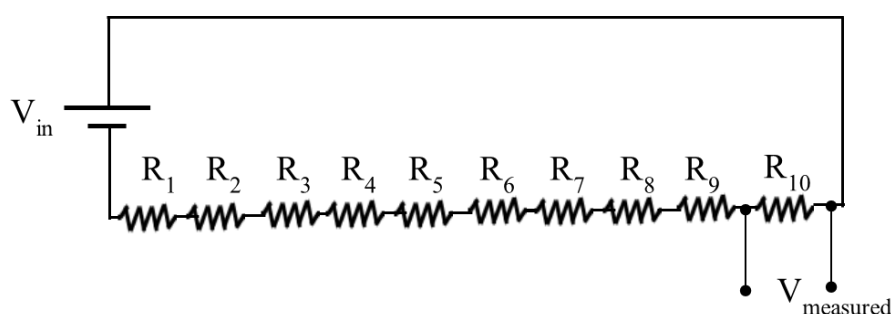


Fig 3 Schematic diagram of Voltage divider method.

2.3 Physical characteristics

2.3.1 Drip loss and cooking loss

Frozen samples were weighed (W_1) and then thawed at ambient temperature (24-26°C) before they were weighed (W_2). As thawing time at ambient temperature was reduced around 70% compared to thawing time at refrigerator temperature (Xu *et al.*, 2021). Furthermore, there were no significant differences in firmness (Xu *et al.*, 2021) and tenderness (Gomes *et al.*, 2021) of thawed frozen at ambient and refrigerator temperature. Drip loss percentage was calculated and expressed using Equation (3).

$$\% \text{ Drip loss} = \frac{W_1 - W_2}{W_1} \times 100 \quad (3)$$

The thawed samples were sealed in polyethylene bags and cooked in hot water at 95-100°C with water bath (Julabo, SW22, Thailand) until the temperature of center reached 75°C. Then the cooked samples were cooled in water at 25°C and then weighed cooked sample (W_3). Cooking loss percentage was determined and shown using Equation (4).

$$\% \text{ Cooking loss} = \frac{W_2 - W_3}{W_2} \times 100 \quad (4)$$

2.3.2 Texture measurement

After cooking, the samples were cut into cubic pieces ($1.5 \times 1.5 \times 1.5$ cm.) for texture analysis using texture profile analysis (TA-XT plus Texture Analyzer, UK) with probe P/36R. The parameters were set with the pretest speed of 2 mm/s, the test speed of 1 mm/s and the post-test speed of 5 mm/s and compressed samples to 0.6 cm. (Zhang *et al.*, 2020). The cutting samples of all treatments were measured in longitudinal and transverse fiber muscle directions. Hardness, springiness, cohesiveness, and chewiness were calculated.

2.4 Statistical analysis

A completely randomized design (CRD) was used to study the electrostatic field intensity factors of 0, 1.25, 1.875, 2.5 and 3.125 kV/cm. Three replications were performed for all treatments. SPSS software version 16 (SPSS Inc., IL, USA) was used for statistical analysis. Duncan's multiple range test was applied to compare the difference of means between each treatment at 95 %confidence interval.

3. Results and Discussion

3.1 Effect of HVEF assisted freezing on drip loss, cooking loss and moisture content of cooked chicken meats

In this study, all chicken breast samples had initial moisture contents around 70% wet basis with no statistically significant difference as shown in Table 1. The results in Table 1 also showed the effect of freezing chicken breasts under different high voltage electrostatic field (HVEF) intensities on drip loss, cooking loss percentages and moisture content of cooked chicken breasts.

By using HVEF intensities from 1.25 to 3.125 kV/cm assisted freezing chicken breasts, the drip loss was lower than that of freezing with non-HVEF conditions. But the drip loss had no significant difference with the different HVEF intensities. These results were similar to the works of Dalvi-Isfahan *et al.*, 2016; Dalvi-Isfahan *et al.*, 2018; Jia *et al.*, 2017. The cooking loss of the samples first decreased at lower HVEF intensities (1.25 and 1.875 kV/cm.) and then increased at higher HVEF intensities (2.5 and 3.25 kV/cm.). As the drip loss and cooking loss of HVEF treatments were lower than those of the control (0 kV/cm.), therefore the moistures of cooked meats treated with HVEF were higher than those of conventional freezing.

Table 1 % Initial moisture content, %drip loss, %cooking loss and %moisture content of cooked products of frozen chicken breasts under different high voltage electrostatic field intensities (I_{HVEF}).

I_{HVEF} (kV/cm)	% MC _{wb} of initial meats	% Drip loss	% Cooking loss	% MC _{wb} of cooked meats
0	70.62 ± 0.74 ^a	2.07 ± 0.62 ^b	21.15 ± 3.77 ^{bc}	65.67 ± 0.91 ^a
1.25	70.63 ± 0.08 ^a	1.40 ± 0.48 ^a	19.51 ± 3.37 ^{ab}	67.23 ± 0.57 ^b
1.875	69.98 ± 0.08 ^a	1.59 ± 0.66 ^a	17.87 ± 4.49 ^a	67.36 ± 0.17 ^b
2.5	70.09 ± 0.67 ^a	1.41 ± 0.62 ^a	22.78 ± 3.05 ^c	67.01 ± 0.39 ^b
3.125	70.75 ± 0.22 ^a	1.50 ± 0.68 ^a	23.35 ± 2.38 ^c	66.95 ± 0.16 ^b

Note: ^{a, b, c} Means ± Standard deviation of 3 pieces × 3 replicates ($n = 9$) were presented with different superscripts are significantly different ($P < 0.05$) in the same column.

Generally, big ice crystals are formed during conventional freezing process, which caused cell tissue damage leading to drip loss during thawing (Orlowska *et al.*, 2009). Then the cell loses muscle fluid and texture changes (Morrison, 1993). On the other hand, the freeze-thaw process induces protein denaturation and aggregation with ice crystallization on solute concentrations, cold denaturation, and protein oxidation leading to loss of qualities (Amiri *et al.*, 2019; Lee *et al.*, 2022; Xia *et al.*, 2009). The freezing under HVEF process produces smaller and more uniform ice crystals than conventional process (Dalvi-Isfahan *et al.*, 2016, Jia *et al.*, 2017, Xanthakis *et al.*, 2013). Wei *et al.*, 2008 explained that water molecules tended to align along the direction of the electrostatic field and nucleation in water supercooled can be induced to raise the temperature of supercooling. Dalvi-Isfahan *et al.*, (2018) presented micrographs of frozen lamb meats with different HVEF intensities and non-HVEF, in which the ice crystal diameters of HVEF treatments are smaller. However, there are no significant differences among of the HVEF treatments. Dalvi-Isfahan *et al.*, (2017) have described the mechanism of ice crystal size reduction that HVEF reduces the entropy due to destruction of some hydrogen bonds and arranges water molecule in the direction of electric field, enhancing ice nucleation process. Then the hydrogen bonds are stronger, and the water structural clusters are changed. These might also be results of lower drip loss, cooking loss and higher moisture content due to the different size of ice crystals produced from HVEF and non-HVEF assistance.

3.2 Effect of HVEF assisted freezing on texture of cooked chicken meats in direction of longitudinal and transverse fiber muscles

Textural properties (hardness, springiness, cohesiveness, and chewiness) of the cooked samples, obtained from 4 pieces $\times$ 3 replicates $\times$ 4 HVEF intensities ($n=48$) for control (0 kV/cm) and 4 pieces $\times$ 3 replicates ($n=12$) for each HVEF intensity (1.25, 1.875, 2.5 and 3.125 kV/cm), were measured in longitudinal and transverse fiber muscle directions.

Table 2 Texture of cooked chicken breasts from freezing under HVEF process measured in direction of longitudinal fiber muscles.

I _{HVEF} (kV/cm)	Hardness (N)	Springiness (mm)	Cohesiveness	Chewiness (mJ)
0	32.24 $\pm$ 7.34 ^b	0.61 $\pm$ 0.06 ^b	0.37 $\pm$ 0.06 ^a	7.23 $\pm$ 2.49 ^b
1.25	24.63 $\pm$ 2.98 ^a	0.59 $\pm$ 0.06 ^{ab}	0.34 $\pm$ 0.03 ^a	5.04 $\pm$ 1.06 ^a
1.875	28.50 $\pm$ 3.81 ^{ab}	0.57 $\pm$ 0.04 ^a	0.35 $\pm$ 0.05 ^a	5.71 $\pm$ 1.44 ^a
2.5	31.90 $\pm$ 5.56 ^b	0.61 $\pm$ 0.04 ^b	0.38 $\pm$ 0.06 ^a	7.47 $\pm$ 2.24 ^b
3.125	27.17 $\pm$ 3.23 ^a	0.57 $\pm$ 0.05 ^{ab}	0.35 $\pm$ 0.06 ^a	5.40 $\pm$ 1.30 ^a

Note: ^{a, b} Means $\pm$ Standard deviation with different superscripts are significantly different ($P < 0.05$) in the same column.

Table 2 showed the texture of cooked meats, measured in longitudinal fiber muscle direction, while the texture detected in direction of transverse fiber muscles were presented in Table 3. The results showed that the effect of HVEF on texture properties of both directions was a similar tendency. The cooked meats, frozen with HVEF, were more tender than the control, frozen with no HVEF.

Table 3 Texture of cooked chicken breasts from freezing under HVEF process in direction of transverse fiber muscles.

I _{HVEF} (kV/cm)	Hardness (N)	Springiness (mm)	Cohesiveness	Chewiness (mJ)
0	28.31 ± 5.07 ^b	0.625 ± 0.08 ^a	0.375 ± 0.04 ^a	6.630 ± 1.73 ^{bc}
1.25	23.11 ± 2.01 ^a	0.655 ± 0.05 ^a	0.373 ± 0.03 ^a	5.657 ± 0.88 ^{ab}
1.875	23.12 ± 2.47 ^a	0.625 ± 0.04 ^a	0.370 ± 0.03 ^a	5.366 ± 1.03 ^a
2.5	28.31 ± 5.77 ^b	0.662 ± 0.08 ^a	0.377 ± 0.05 ^a	7.148 ± 2.33 ^a
3.125	25.16 ± 4.57 ^a	0.626 ± 0.06 ^a	0.383 ± 0.04 ^a	6.120 ± 1.81 ^{abc}

Note: ^{a, b, c} Means ± Standard deviation with different superscripts are significantly different (P<0.05) in the same column.

By increasing HVEF intensities assisted freezing process, the changing trends in hardness and chewiness properties were quite similar. Their values of cooked chicken breasts, frozen with HVEF, were lower than those of non-HVEF in both longitudinal and transverse fiber directions. While the springiness and cohesiveness had no effect from the HVEF intensities, there were no significant differences from the control treatment for both directions. These results were in agreement with the reports of Jia *et al.* (2017). Jia *et al.* (2018) revealed that during freezing process, HVEF can reduce myosin denaturation while sarcoplasmic proteins and actin were less sensitive. Myofibrillar proteins including myosin are associated with water holding capacity, while myofibrillar proteins were also denatured during the thermal process (Bowker and Zhuang, 2015; Rahbari *et al.*, 2018; Zhang and Ding, 2020). Therefore, texture of frozen meat treated by HVEF had lower hardness and higher moisture content than non-HVEF because of smaller ice crystal size leading to less cell damage (Dalvi-Isfahan *et al.*, 2018; Jha *et al.*, 2017) and less protein denaturation (Jia *et al.*, 2017).

4. Conclusion

In this study, the freezing of chicken breast samples under HVEF system using 4 different intensities (1.25, 1.875, 2.5 and 3.125 kV/cm) was investigated. The results showed that freezing under all HVEF intensities significantly reduced drip loss and cooking loss. Texture properties, measured from both fiber muscle directions, changed in the same trends. There was no effect of HVEF intensities on springiness and cohesiveness of cooked samples, but HVEF, at intensity 1.25 kV/cm, affected to their hardness and chewiness. Therefore, freezing under HVEF could improve the physical characteristics of chicken breast.

Acknowledgement

The authors thank Suranaree University of Technology for providing instruments.

References

- Abedini, S., Kaku, M., Kawata, T., Koseki, H., Kojima, S., Sumi, H., Motokawa, M., Fujita, T., Otani, J., Ohwada, N. and Tanne, K. 2011. Effects of cryopreservation with a newly developed magnetic field programmed freezer on periodontal ligament cells and pulp tissues. *Cryobiology*. 62(3): 81-187.

- Amiri A., Mousakhani-Ganjeh A., Shafiekhani S., Mandal R., Singh A. P. and Kenari R. E. 2019. Effect of high voltage electrostatic field thawing on the functional and physicochemical properties of myofibrillar proteins. *Innovative Food Science and Emerging Technologies*. 56: 102191.
- Anese, M., Manzocco, L., Panozzo, A., Beraldo, P., Foschia, M. and Nicoli, M. C. 2012. Effect of radiofrequency assisted freezing on meat microstructure and quality. *Food Research International*. 46(1): 50-54.
- Bowker, B., and Zhuang, H. 2015. Relationship between water-holding capacity and protein denaturation in broiler breast meat. *Poultry Science*. 94(7): 1657-1664.
- Cheng, X., Zhang, M., Xu, B., Adhikari, B. and Sun, J. 2015. The principles of ultrasound and its application in freezing related processes of food materials: A review. *Ultrasonics Sonochemistry*. 27: 576-585.
- Bowker, B. and Zhuang, H. 2015. Relationship between water-holding capacity and protein denaturation in broiler breast meat. *Poultry Science*. 94(7): 1657-1664.
- Cheng, X., Zhang, M., Xu, B., Adhikari, B. and Sun, J. 2015. The principles of ultrasound and its application in freezing related processes of food materials: A review. *Ultrasonics Sonochemistry*. 27: 576-585.
- Chevalier, D., Le-Bail, A. and Ghoul, M. 2000. Freezing and ice crystals formed in a cylindrical food model: Part II. Comparison between freezing at atmospheric pressure and pressure-shift freezing. *Journal of Food Engineering*. 46(4): 287-293.
- Dalvi-Isfahan, M., Hamdami N. and Le-Bail A. 2016. Effect of freezing under electrostatic field on the quality of lamb meat. *Innovative Food Science and Emerging Technologies*. 37: 68-73.
- Dalvi-Isfahan, M., Hamdami, N. and Le-Bail, A. 2017. Effect of freezing under electrostatic field on selected properties of an agar gel. *Innovative Food Science and Emerging Technologies*. 42: 151-156.
- Dalvi-Isfahan, M., Hamdami N. and Le-Bail A. 2018. Effect of combined high voltage electrostatic with air blast freezing on quality attributes of lamb meat. *Journal of Food Process Engineering*. 41(6): 1-6.
- Delgado, A.E. and Sun, D.W. 2001. Heat and mass transfer models for predicting freezing processes – A review. *Journal of Food Engineering*. 47(3): 157-174.
- Gomes, C. L., Silva, T. J., Pflanzner, S. B. and Bolini, H. M. A. 2021. Impact of frozen temperature and thawing methods on the Brazilian sensory profile of Nellore beef. *Scientia Agricola*. (78)6: e20200067.
- Hu, R., Zhang, M. and Mujumdar, A. S. 2022. Novel assistive technologies for efficient freezing of pork based on high voltage electric field and static magnetic field: A comparative study. *Innovative Food Science and Emerging Technologies*. 80: 103087.
- Irwin, J. D. and Nelms, R. M. 2020. Voltage divider in: *Basic engineering circuit analysis* (12 Eds). John Wiley and Sons, Inc. USA. pp. 33-37.
- Jha, P. K., Sadot, M., Vino, S. A., Jury, V., Curet-Ploquin, S., Rouaud, O. and Le-Bail, A. 2017. A review on effect of DC voltage on crystallization process in food systems. *Innovative Food Science and Emerging Technologies*. 42: 204-209.

- Jia, G., He, X., Nirasawa, S., Tatsumi, E., Liu, H. J. and Liu, H. 2017. Effects of high-voltage electrostatic field on the freezing behavior and quality of pork tenderloin. *Journal of Food Engineering*. 204: 18-26.
- Jia, G., Nirasawa, S., Ji, X., Luo, Y. and Liu, H. 2018. Physicochemical changes in myofibrillar proteins extracted from pork tenderloin thawed by a high-voltage electrostatic field. *Journal of Food Chemistry*. 240: 910-917.
- Kiani, H., Zhang, Z., Delgado, A. and Sun, D.W. 2011. Ultrasound assisted nucleation of some liquid and solid model foods during freezing. *Food Research International*. 44(9): 2915-2921.
- Le-Bail, A., Orłowska, M. and Havet, M. 2011. Electrostatic field assisted food freezing. In D.-W. Sun (Ed.) *Handbook of frozen food processing and packaging* (2nd ed). CRC Press, Taylor and Francis Group, Florida. pp. 685-692.
- Lee, S., Jo, K., Jeong, H.G., Choi, Y-S., Kyoung, H. and Jung, S. 2022. Freezing-induced denaturation of myofibrillar proteins in frozen meat. *Critical Reviews in Food Science and Nutrition*. 2: 1-18.
- Liu, J., Wang, Y., Zhu, F., Yang, J., Ma, X., Lou, Y. and Li, Y. 2022. The effects of freezing under a high-voltage electrostatic field on ice crystals formation, physicochemical indices, and bacterial communities of shrimp (*Solenocera melanthero*). *Food Control*. 142: 109238.
- Mohanty, P. 2001. Magnetic resonance freezing system. *Australian Refrigeration, Air Conditioning and Heating*. 55(6): 28-29.
- Morrison, C.R. 1993. Fish and Shellfish. In C.P. Mallett (ed) *Frozen Food Technology*. Blackie Academic and Professional, London. pp. 196-236.
- Orłowska, M., Havet, M. and Le-Bail, A. 2009. Controlled ice nucleation under high voltage DC electrostatic field conditions. *Food Research International*. 42(7): 879-884.
- Rahbari, M., Hamdami, N., Mirzaei, H., Jafari, S. M., Kashaninejad, M. and Khomeiri, M. 2018. Effects of high voltage electric field thawing on the characteristics of chicken breast protein. *Journal of Food Engineering*. 216: 98-106.
- Reid, D.S. 1993. Basic physical phenomena in freezing and thawing of plant and animal tissues. In C.P. Mallett (ed) *Frozen food technology*. Blackie academic and professional. Glasgow, Scotland. pp. 1-19.
- Su, G., Ramaswamy, H.S., Zhu, S., Yu, Y., Hu, F. and Xu, M. 2014. Thermal characterization and ice crystal analysis in pressure shift freezing of different muscle (shrimp and porcine liver) versus conventional freezing method. *Innovative Food Science and Emerging Technologies*. 26: 40-50.
- Wang, Q., Li, Y., Sun, D-W. and Zhu, Z. 2019. Effects of high-voltage electric field produced by an improved electrode system on freezing behaviors and selected properties of agarose gel. *Journal of Food Engineering*. 254: 25-33.
- Wei, S., Xiaobin, X., Hong, Z. and Chuanxiang, X. 2008. Effects of dipole polarization of water molecules on ice formation under an electrostatic field. *Cryobiology*. 56: 93-99.
- Xanthakis, E., Havet M., Chevallier S., Abadie J. and Le-Bail A. 2013. Effect of static electric field on ice crystal size reduction during freezing of pork meat. *Innovative Food Science and Emerging Technologies*. 20: 115-120.

- Xia, X., Kong, B., Liu, Q. and Liu, J. 2009. Physicochemical change and protein oxidation in porcine longissimus dorsi as influenced by different freeze-thaw cycles. *Meat Science*. 83: 239-245.
- Xu, B., Chen, J., Yuan, J., Roknul Azam., S. M. and Zhang, M. 2021. Effect of different thawing methods on the efficiency and quality attributes of frozen red radish. *Journal of the Science of Food and Agriculture*. 101: 3237-3245.
- Zhang, Y. and Ding, C. 2020. Study of Thawing Characteristics and Mechanism of Frozen Beef in High voltage electric fields. *IEEE Access*. 8: 134630-134639.
- Zhang, Y., Zhang, D., Huang, Y., Chen, L., Bao, P., Fang, H., Xu, B. and Zhou, C. 2020. Effects of basic amino acid on the tenderness, water binding capacity and texture of cooked marinated chicken breast. *LWT - Food Science and Technology*. 129: 109524.