RI SE

Freezewave

FREEZING ASSISTED BY STATIC ELECTRIC FIELD (SEF)

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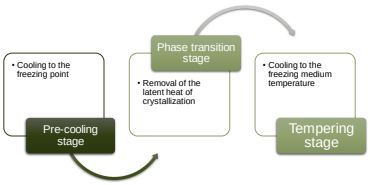
Freezing of water

Freezewave



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Crystallization of water

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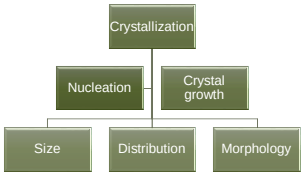
- Crystallization is a term which is used to describe several different phenomena related to the formation of a crystalline lattice structure.
- (Hartel R. (2001). "Crystallization in foods". Gaithersburg, Maryland: Aspen Publishers.)



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Electrofreezing of water

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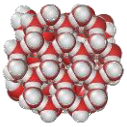
Electric field free liquid water is organized around clusters of water dipole molecules (pentamers)

Application of Static Electric Field (SEF)
✓ Water molecule dipoles are polarized by the application of external DC static electric field
✓Alignment of water molecules with the direction of the electric field vector
✓With high voltage SEF liquid water becomes more ordered and similar to ice like structure
✓The SEF application causes modification of water crystallization thermodynamics



Svishchev & Kusalik,1994; Jung, Yang & Jhon ,1999; Shevkunov & Vegiri, 2002; Vegiri, 2004a, 2004b; Zangi & Mark, 2004; Sun, Chen & Huang 2006; Xiaobin, Hong & Chuanxiang, 2008.

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Electrofreezing aspects

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$$\Delta G_E = 4\pi r^2\gamma - \frac{4}{3}\pi r^3(\Delta G_v + PE) \quad (1)$$

$$\Delta G_0 = 4\pi r^2\gamma - \frac{4}{3}\pi r^3 \Delta G_v \quad (2)$$

ΔG: Gibbs free energy of a spherical formation

r: radious of the sphere

γ: surface free energy of the crystal fluid interface

ΔG_v: free energy change of the transformation per unit volume.

P: permanent polarization

E: electric field

$$\Delta G_0 \Leftrightarrow \Delta G_E$$

Marand, H.L., Stein, R.S., & Stack, G.M. (1988). Isothermal crystallization of poly(vinylidene fluoride) in the presence of high static electric fields. I. Primary nucleation phenomenon. Journal of Polymer Science Part B: Polymer Physics, 26, 1361-1383.
Mullin, J.W. (2001). Crystallization, 4th Edition, Reed Educational and Professional Publishing Ltd.

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Electrofreezing of water samples

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Experimentally determined average values of the nucleation temperature (T_N) together with their standard deviations under different electrostatic field conditions.

Electrostatic field (V/m)	T_N (°C)
0	-12.28 ± 2.19
1.0×10^5	-9.16 ± 0.72
2.5×10^5	-7.36 ± 1.13
5.0×10^5	-6.64 ± 0.95
6.0×10^5	-5.90 ± 1.39

Constant application of high voltage to the samples during their cooling caused increase of the nucleation temperature with the increase of the field strength.

The biggest changes in the degree of supercooling were observed in a range from 0 V/m to 5.0×10^5 V/m.

Further increase of electrostatic field magnitude to 6.0×10^5 V/m was accompanied by smaller temperature shift.

Set of temperature profiles obtained under different electrostatic field conditions during freezing of water.

The underlying mechanism of electrofreezing is related to the decrease of the free energy due to reorientation of water molecules and formation of more ordered cluster structure.

(Orlowska, M., Havet, M., & Le-Bail, A. (2009). Controlled ice nucleation under high voltage DC electrostatic field conditions. *Food Research International, 42*, 879-884)

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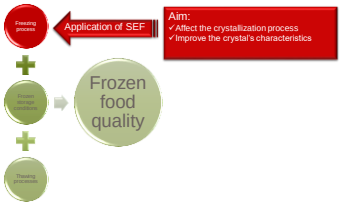
Freezing of food & Electrofreezing



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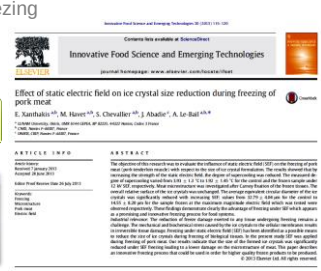
1st study of food electrofreezing

Napoleon & Snowball

Tenderloin muscle of pork

The muscle

The sample



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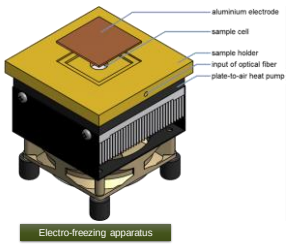
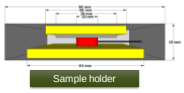
Experimental Set up



Electro-freezing apparatus



Sample holder

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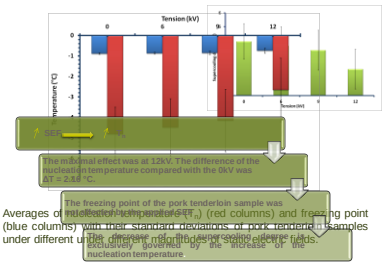
Nucleation temperature



The minimal effect was at 12kV. The difference of the nucleation temperature compared with the 0kV was ΔT = 2.14 °C

The freezing point of the pork tenderloin sample was exclusively governed by the increase of the nucleation temperature

Averages of nucleation temperature (T_n) (red columns) and freezing point (blue columns) with their standard deviations of pork tenderloin samples under different under different magnitudes of static electric fields.

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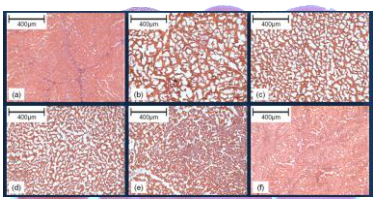
Histological analysis of frozen meat



Micrograph images of frozen pork tenderloin transversal cuts under different magnitude static electric fields. (a) Free magnitude, (b) 0 kV, (c) 3 kV, (d) 6 kV, (e) 9 kV, (f) 12 kV

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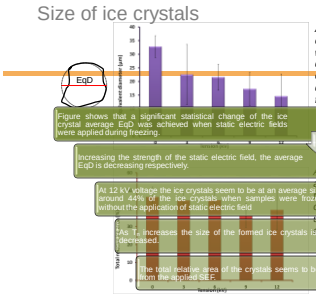
Size of ice crystals



Averages of equivalent circular diameter (EqD) with their standard deviations of the ice crystals voids under different static electric fields

Figure shows that a significant statistical change of the ice crystal average EqD was achieved when static electric fields were applied during freezing.

Increasing the strength of the static electric field, the average EqD is decreasing respectively.

At 12 kV voltage the ice crystals seem to be at an average size around 44% of the ice crystals when samples were frozen without the application of static electric field

As T_n increases the size of the formed ice crystals is getting decreased.

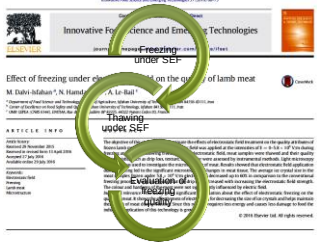
The total relative area of the crystals seems to be not affected from the applied SEF.

Averages of total relative area (%) coverage with their standard deviations of the ice crystals voids under different static fields.

Freezewave

3 years after a second study of food electrofreezing

Objective:



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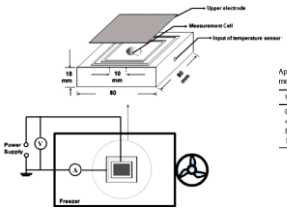
Freezewave

Similar experimental set up



Applied voltage, intensity of the internal electrostatic field and freezing rate (°C/min) of meat samples.

Voltage difference (kV)	Internal electric field (V/m)	Freezing rate (°C/min)
0	0.0E + 00	1.71 ± 0.31
4	1.9E + 04	1.61 ± 0.11
8	3.9E + 04	1.64 ± 0.15
12	5.8E + 04	1.54 ± 0.20

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Freezewave

Microstructure of lamb

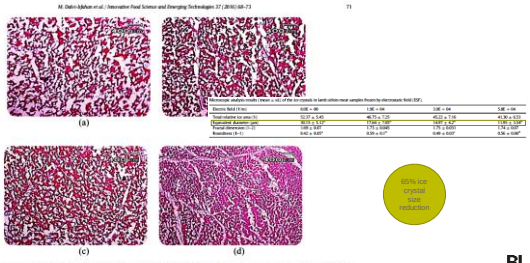

Fig. 3. Light microscopy of cross sections of frozen lamb sirloin under different magnitude electrostatic fields: (a) 0.0E + 00 V/m, (b) 1.9E + 04 V/m, (c) 3.9E + 04 V/m, and (d) 5.8E + 04 V/m.

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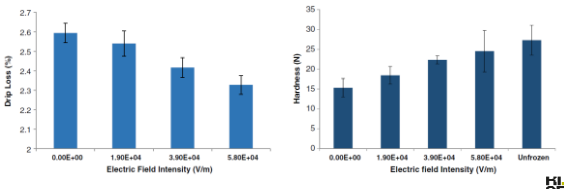
Other quality attributes

Colour:
No significant changes in colour between SEF and the conventional freezing



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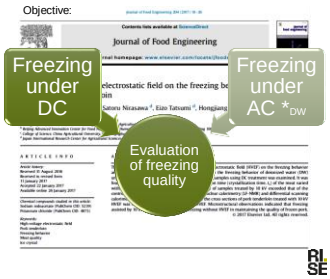
3rd study on SEF freezing of food

Objective:



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Experimental set up

A multiple point-to-plate electrode

The upper electrode contained 81 needles (70 mm long, 1 mm in diameter; 20mm between any two needles)

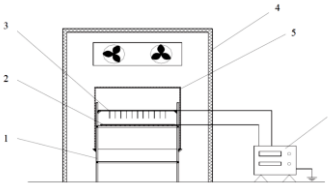

Fig. 1. Scheme of the experimental DC/AC HVEF refrigerator system used in the studies. 1. Treatment chamber. 2. Bottom plate. 3. Prick electrode. 4. Rerigerator body. 5. Cover. 6. Power supply. Sample (deionized water and pork tenderloin) were placed on the stainless steel plate. The voltage was applied between the upper needle-shaped electrode and the lower metallic surface.

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Protein denaturation after SEF freezing and thawing

Myosin denaturation of meat frozen without being subjected to a 10 kV HVEF was more severe than that of HVEF-assisted frozen meat.

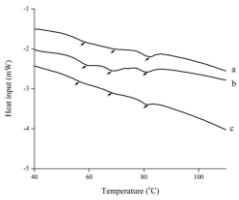

Fig. 4. Typical DSC thermograms from analysis of pork tenderloin. a) frozen pork with 10 kV HVEF treatment, b) fresh pork, c) frozen pork. The arrow represents endothermic peaks.

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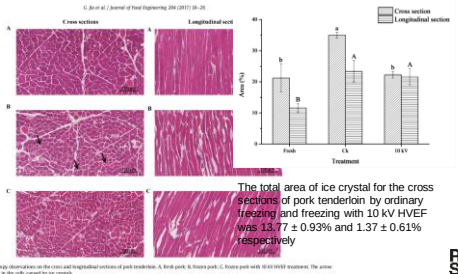
Microstructure of SEF frozen meat



The total area of ice crystal for the cross sections of pork tenderloin by ordinary freezing and freezing with 10 kV HVEF was 13.77 ± 0.93% and 1.37 ± 0.61% respectively

Fig. 6. Light microscopy observations on the cross and longitudinal sections of pork tenderloin. A, fresh pork; B, frozen pork; C, frozen pork with 10 kV HVEF treatment. The arrow represents the voids in the cells caused by ice crystals.

Conclusions

- Limited applications of static electric fields during food freezing
- In all cases SEF freezing showed positive impact on frozen food matrix quality
- Studies for the design of commercial SEF freezers would be relevant
- Potential limitations of the static electric fields and safety issues have to be taken into account

Ευχαριστώ πολύ.

http://freezewave.eu/

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