EVALUATION OF MICROWAVE ASSISTED FREEZING (MAF) IMPACT ON MEAT

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Technology Synergies in Freezing

- Ultrasound assisted freezing
- Static electric field assisted freezing
- High pressure shift freezing
- Radiofrequency assisted freezing
- Microwave-assisted freezing (?)

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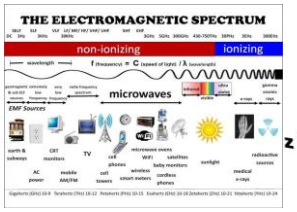
Electromagnetic energy - microwaves



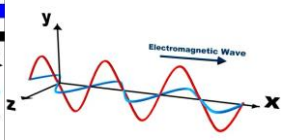


Table 5.1 Frequencies available for industrial, scientific, and medical uses (ISM radio bands).

	Central frequency (MHz)	Frequency range (MHz)
Radiofrequencies	13.560	13.553–13.567
	27.120	26.957–27.283
	40.680	40.660–40.700
Microwaves	915	902–928
	2450	2400–2500

300MHz-300GHz

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Dipolar & Ionic interactions

Dipolar

- When external electric field E of microwave frequency is applied to a dielectric material such as food, the field can cause polarization of the charges in the material.
- The polarization P is related to the applied electric fields according to the equation.

$$P=\varepsilon_o E(\varepsilon-1)$$

- ε: relative permittivity describes the ability of a external field to polarize the material.
- ε_o: vaccum permittivity

TABLE 30.1 Water Content of Several Food Types

Food type	Water content (%)
Fruits	74–92
Vegetables	7–91
Meat and fish	50–77
Milk	86–91
Ice cream	56–62
Breads	26–45
Doughs	5–45

- Water dipole tend to orientate itself in the influence of the changing applied electric field.
- This type of polarization is called dipole polarization
- The movement of the water molecules gives rise to temperature, which also gives rise to convective and conductive heat neighbouring food components

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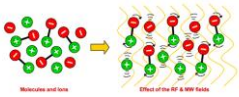
Dipolar and Ionic interactions

Ionic interactions

- Many types of foods contain dissolved salts
- Such dissolved salts are constituted by two charged ions
- When an electric field is applied, these charged moieties tend to displace themselves.
- As a results of this ionic interaction, the ions could then oscillate back and forth, as affected by the applied field and collide with neighbouring molecules and atoms.
- These collisions create heat.



** There are also atomic interactions and Maxwell-Wanger effects

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Dielectric properties

- When a dielectric material is subjected to an electric field, the field causes polarization of atoms and molecules within the material to create electric dipole moments. These moments supplement the electric flux and are related to the material's electrical susceptibility.
- The behaviour of a dielectric material that is influenced by a microwave field is reffered as dielectric property and it is defined as:

$$\varepsilon^*=\varepsilon'-j\varepsilon''_{eff}$$

ε* =relative complexed permitivity

ε': dielectric constant

ε'': relative effective loss factor

ε': dielectric constant

- Is a measure of the food material's ability to store electromagnetic energy

ε'': relative effective loss factor

- Is a materials ability to dissipate electromagnetic energy which results in heating

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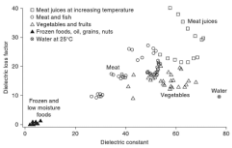
Freezewave

Dielectric properties of food Vs Temperature



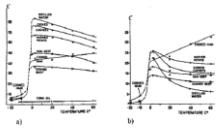


Figure 3. Temperature dependence of the dielectric properties, ε'(a) and ε''(b), for different food substances, measured at 2.8 GHz (Bengtsson and Risman, 1971).

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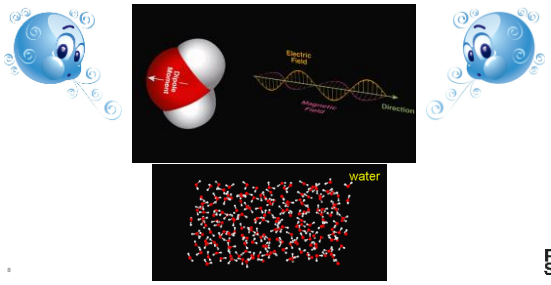
Microwave interactions coupled with freezing



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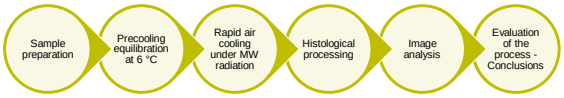
Overview of the experimental process



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Matrices & Samples

Pork Tenderloin (RISE)

RISE

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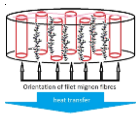
Sample handling



Cylindrical pieces of pork tenderloin were carefully cut parallel to the fibers of the muscle. Each sample was installed into the cylindrical cavity of the sample holder with fibers oriented perpendicular to the refrigerated surface.

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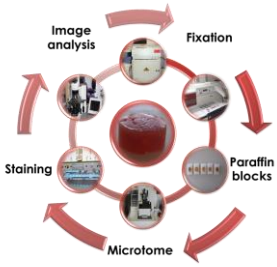
Freeze damage evaluation



- Pore size measurements related with the ice crystal size.
- Average pore size, pore size distribution etc

- Tissue damage
- Homogeneity

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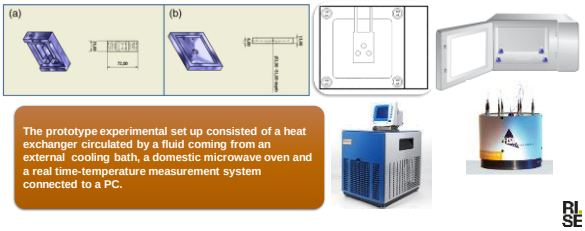
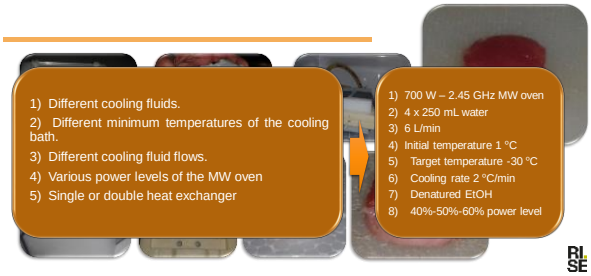
The 1st attempts



The prototype experimental set up consisted of a heat exchanger circulated by a fluid coming from an external cooling bath, a domestic microwave oven and a real time-temperature measurement system connected to a PC.

The first trials…



1) Different cooling fluids.
2) Different minimum temperatures of the cooling bath.
3) Different cooling fluid flows.
4) Various power levels of the MW oven
5) Single or double heat exchanger

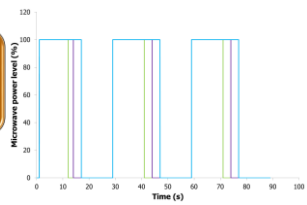
1) 700 W – 2.45 GHz MW oven
2) 4 x 250 mL water
3) 6 L/min
4) Initial temperature 1 °C
5) Target temperature -30 °C
6) Cooling rate 2 °C/min
7) Denatured EtOH
8) 40%-50%-60% power level

Cycle of duty of MW oven

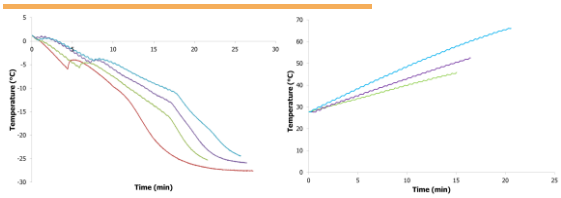
In common domestic microwave ovens the power level doesn't represent the real power of the irradiation but a sequence of time intervals of full power irradiation.

Duty cycling the power ON and OFF adjusts the average power level. The average power level is based on the amount of ON time versus OFF time.

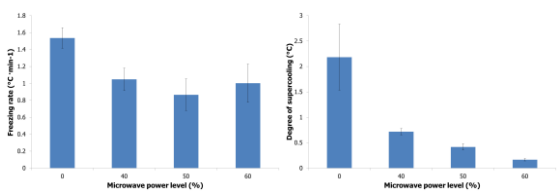
Figure illustrates duty cycle control of 40%, 50% and 60% of power level of the purchased microwave oven.



Time-temperature measurements

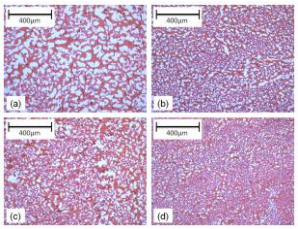


Freezing rates and Degree of Supercooling



Microstructure images

Micrograph images of frozen pork tenderloin transversal cuts under different levels of microwave power irradiation. (a) 0 % (conventional freezing), (b) 40%, (c) 50% and (d) 60%.



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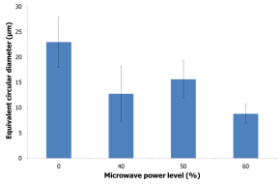
Ice crystal size

The size was characterized with the use of equivalent circular diameter (EqD) which is defined as the diameter of a circle that has the same area with each crystal 2D footprint.



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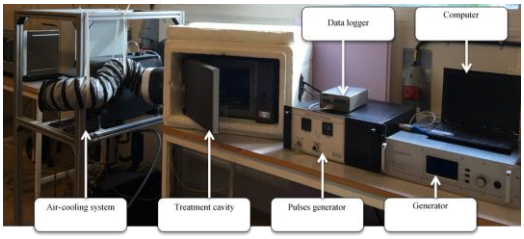
Freezewave

Second Prototype experimental set-up



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Tested conditions of pork freezing

Equilibration of temperature at 6 °C

Pulsed MW → SPHP (4s On/off, 12 W); LPLP (8s On/off, 6 W)

Constant MW → LP (3 W)

Conventional → No P

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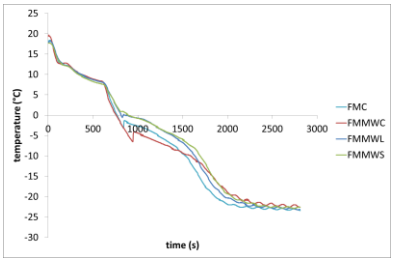
Temperature histories during pork freezing



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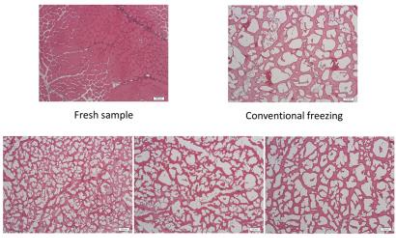
Pork meat microstructure after MW freezing



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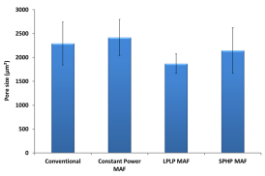
Ice crystal size after freezing of pork



- LPLP MW freezing resulted in the smaller ice crystal size (~25% smaller area)
- SPHP showed lower ice crystal size compared to the conventional
- Freezing under constant microwave irradiation showed slightly higher ice crystal size than the conventional freezing

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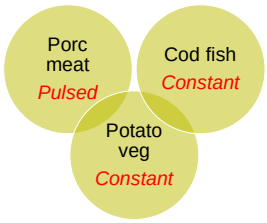
Conclusions

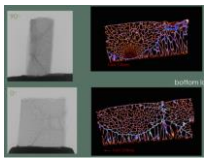
- The application of MW radiation during freezing confirmed the previous results regarding the ice crystal size reduction.
- Pulsed MW irradiation seemed more efficient in ice crystal size reduction
- Tailored conditions should be selected for the successful application of MAF

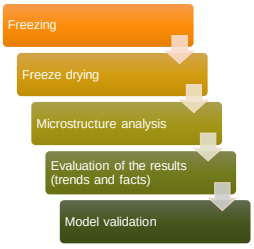


Next steps

- Attempt to identify how the operating conditions influence the ice-crystal growth under MW radiation
- Computer simulation of ice crystal growth under MW radiation and validation
- Cooperation with University of Birmingham

Tylose gels as meat food model system

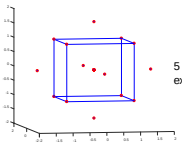




Approach

- 3 factors: pulses (A), power (B), cooling rates (C)
- Quadratic regression models & interactions:

Central Composite Design



5 levels & 20 experiments

Full Central Composite Design

Pulses	Power	Cooling rate
∞ sec on – 0 sec off	0W	0.16°C/min
2sec on – 2 sec off	2W	0.5 °C/min
5sec on – 5 sec off	5W	1.0 °C/min
8 sec on – 8 sec off	8W	1.5 °C/min
10 sec on – 10 sec off	10W	1.84°C/min

A	B	C
-1.682	-1.682	-1.682
-1	-1	-1
0	0	0
1	1	1
1.682	1.682	1.682

run 1	-1	-1	-1
run 2	-1	-1	1
run 3	-1	1	-1
run 4	-1	1	1
run 5	1	-1	-1
run 6	1	-1	1
run 7	1	1	-1
run 8	1	1	1
run 9	-1.682	0	0
run 10	1.682	0	0
run 11	0	-1.682	0
run 12	0	1.682	0
run 13	0	0	-1.682
run 14	0	0	1.682
run 15	0	0	0
run 16	0	0	0
run 17	0	0	0
run 18	0	0	0
run 19	0	0	0
run 20	0	0	0
run 21	0	0	0
run 22	0	0	0
run 23	0	0	0
run 24	0	0	0

Acknowledgements

- *TTZ*
- Julien HUEN,
- Imke MATULLAT
- Marie SHRESTHA

- *RISE – Agrifood & Bioscience*
- Lovisa ELIASSON
- Sven Isaksson

- *ONIRIS*
- Piyush Kumar JHA,
- Alain LE-BAIL

- *University of Birmingham*
- Patricia Andreu Cabedo
- Estefania Lopez Quiroga
- Peter J. Fryer

- *SAIREM*
- Jean Paul Bernard

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Ευχαριστώ πολύ

Freezewave

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