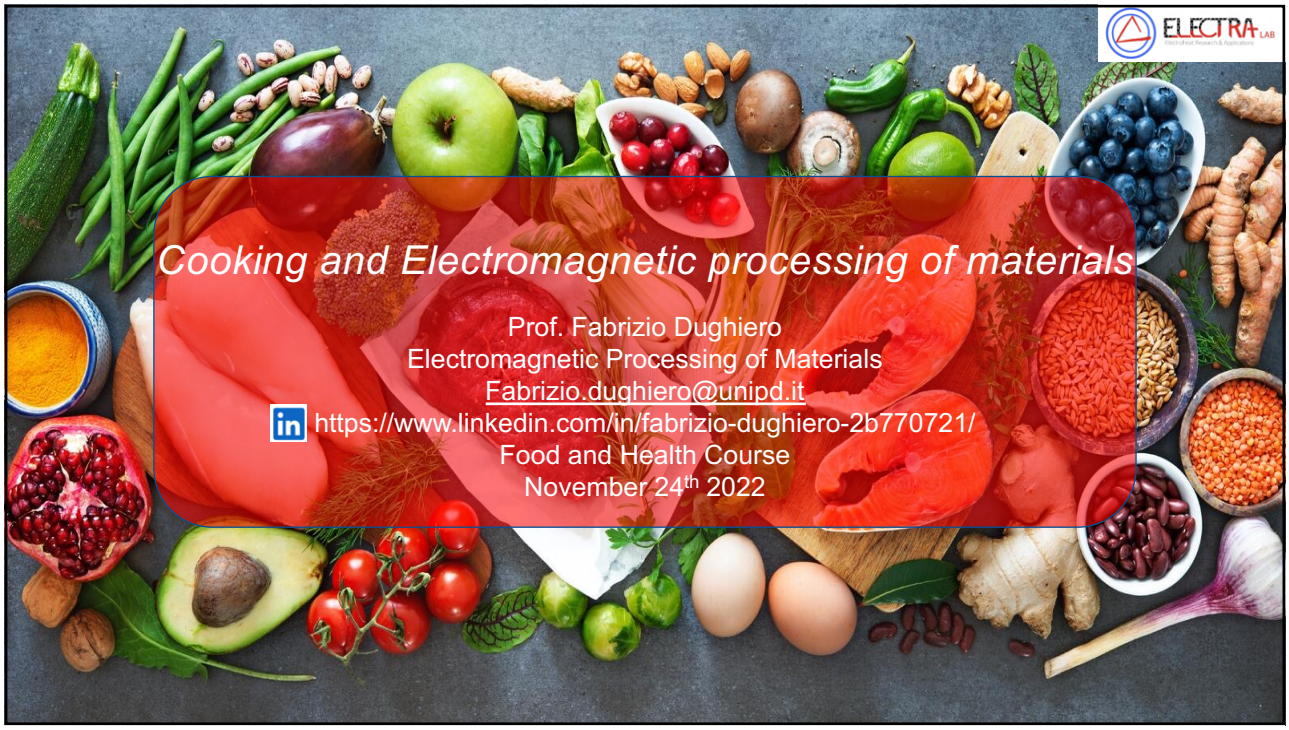

Cooking and Electromagnetic processing of materials

Prof. Fabrizio Dughiero
Electromagnetic Processing of Materials
Fabrizio.dughiero@unipd.it
https://www.linkedin.com/in/fabrizio-dughiero-2b770721/

Food and Health Course
November 24th 2022

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Outline

- The Electralab Laboratory
- Introduction
- Reasons for cooking food
- Heat Transfer mechanisms
- The technology available for cooking
- Perspectives and dreams about future of food and cooking
- Conclusion

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50+ YEARS OF HISTORY

From LEP to ELECTRALAB

The Laboratory for Electroheat of Padua University, LEP, is the only Italian academic group that researches about electroheating. LEP was founded about 40 years ago by prof. Di Pieri, it was leaded for many years by prof. Lupi and now it is directed by prof. Dughiero. Actually, about 7 people are working in the group. It is also the organizer of the conference 'HES', Heating by Electromagnetic Sources.

3

3

PEOPLE

Fabrizio Dughiero
Full Professor

Michele Forzan
Associate Professor

Nicola Trivellin
Associate Professor

Anna Maria Cavazzini
PhD Student

Matteo Lazzarin
PhD Student

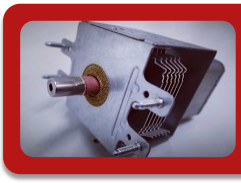
Matteo Ciofani
PhD Student

Alberto Gerometta
Research Assistant

4

4

Heating Technologies



Microwave & Radiofrequency

Electromagnetic Induction

Resistive Heating

5

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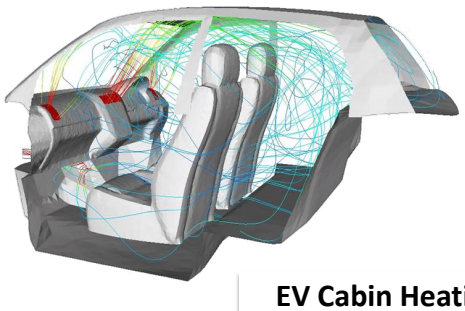
Research Topics

Food flavour enhancement

MW heating
Combined ovens
Colorimetry and texture analysis
Optimal cooking (homogeneity, browning)
Health



EV Cabin Heating and Thermal Comfort

Resistive heating
Improving thermal sensation for the passengers
Energy saving to improve vehicle range

6

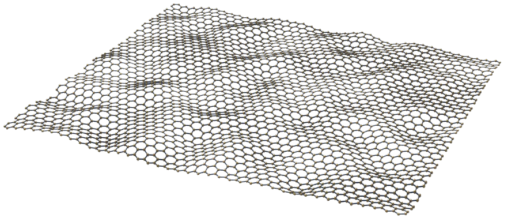
6

ELECTRA LAB

Research Topics

Innovative materials processes

MW & IH Graphene Production
Nanomaterials
Efficiency Improvement
Faster Production Processes



Applied Machine Learning

Computer Vision for Food Analysis
Algorithms for Cooking Processes
Neural Network Algorithms for EMP Optimization

7

7

Introduction

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EVOLUTION

Food for Thought: Was Cooking a Pivotal Step in Human Evolution?

The dietary practice coincided with increases in brain size, evidence suggests

By Alexandra Rosati on February 26, 2018

Scientific American – Feb 2018

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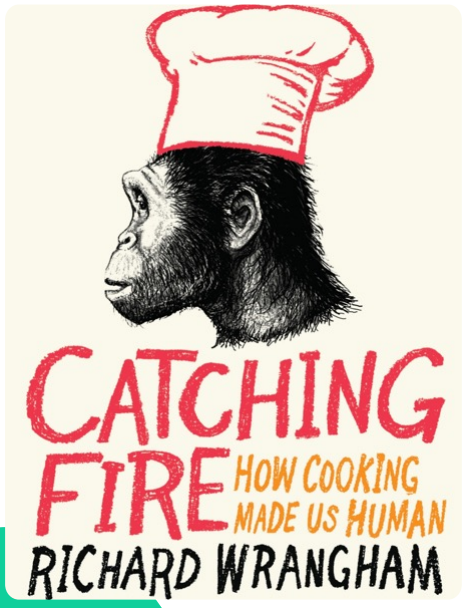

What is the connection between cooking and brains?

- «Understanding how and why our brains got so big has been a major puzzle because such a brain is metabolically expensive. In fact, the brain needs more energy for its size than any other organ. Although it might seem being smarter is always better, having a big brain exerts a high toll. Ancestral humans may have compensated for this energy cost by cooking food».

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Definitions

- **Cooking** or **cookery** is the art of **preparing food** for consumption with the **use of heat**.
- **Electroheat Technologies** are different techniques which convert electricity into heat for industrial, household and biomedical applications

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Reasons for cooking food

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Physical and chemical trasformations

The cooking's method and parameters influence final texture, appearance and volatile molecules, which have an impact on health and flavour. Cooking creates the conditions of temperature and humidity that permit food's evolution as consequence of chemical reactions and physical transformations. Maillard reaction is an example which shows that cooking can enhance food flavour and appreciability but can also damage food from the nutritional point of view if its parameters aren't set in a proper way.

Bread changes during cooking: formation of porous an open structure, volume expansion, water evaporation, starch gelatinization, protein denaturation, carbon dioxide production, crust formation and browning.

Changing cooking condition changes the final result even if the ingredients and the preparation are the same.

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Browning reactions and flavour development

During Maillard reaction and Caramelisation, there is the formation of flavouring compounds, also responsible for colour formation. These reactions are also called «browning reactions». The level of umidity has to be low, and temperature higher than 140-160°C depending on the type of food. Also the amount of volatile molecules perceived with the sense of smell before and after tasting depends on the temperature reached during cooking and on cooking time.

Maillard reaction takes place when reducing surgars and amino acids, proteins or nitrogen-containing compounds are heated together, and the level of humidity is low. It happens during meat cooking.

Caramelisation indicates a group of reactions that happens when carbohydrates are heated. Proteins are not reagents of these reactions which therefore occurs also during veggies cooking.

During baking, the **browning effect** is due to both the **Maillard** reaction and the **caramelisation**'s ones. This is due to the composition of the dough, the ingredients used to made it.

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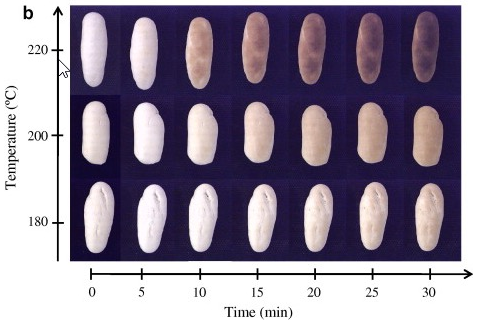
Acrylamide formation

Even if some products of browning reactions are health promoting substances, because of their antioxidative activity, Maillard reaction is also associated with the formation of **acrylamide**, a probably carcinogenic compound (group 2A). High levels of acrylamide can be found in bakery products, coffee, potato products and their formation is associated with high temperatures or excessive cooking time.

Darker the surface colour, higher the acrylamide content: this is the easier way to identify this characteristic in a qualitative way.



Modeling the browning of bread during baking. E. Paulis and Viviana O. Salvadori. Food Research International 42 (2009) 865-870.

Cooking can also favors the formation of dangerous compound

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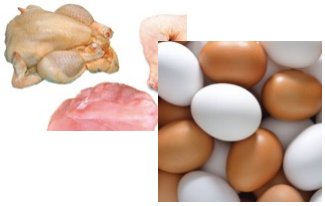
Cooking as guarantee of safe

Cooking permits also to destroy most of the phatogens making safe many type of food.

Salmonella is destroyed at temperature higher than 70°C; it can be found in chicken, eggs, meat.



Staphylococcus is a family of bacteria that can be found in fish, milk, ready-meals not preserved in a proper way.

Botulinum can be found in meat or vegetables conserved immersed in oil. Its spores can be destroyed at temperature higher than 100°C if maintained for at least 10/15 minutes.

Sicurezza e igiene degli alimenti, Servizio sanitario regionale

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Heat transfer mechanisms

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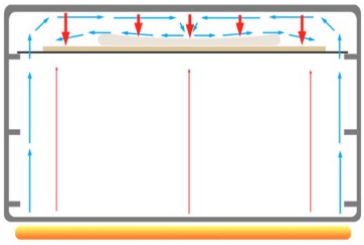
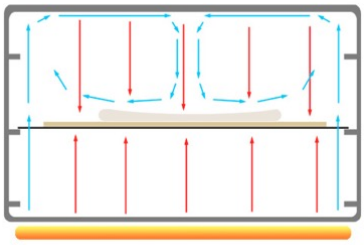
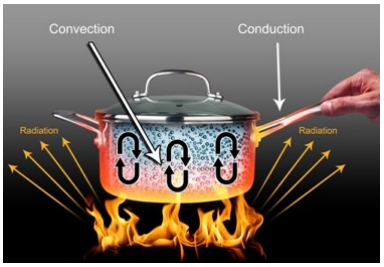
Heat transfer mechanisms

- **Radiation**
- **Convection**
- **Conduction**







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Heating by internal sources

- Traditionally people use external heating methods for cooking. Only in the last years MW has been considered as an internal cooking method reliable for fast and quality cooking
- In order to be sure that the temperature inside food reaches a proper value, we need to wait for a certain time due to the conductivity of the material. Heat flux depends on temperature gradient.
- Volumetric or "internal heating" has a completely different heat transfer mechanism in comparison with external heating

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Volumetric heating

- Microwave, Radio Frequency, Conduction and Induction are all internal heating techniques.
- Microwave and Radiofrequency work on dielectric (non conductive) materials like most of foodstuff.
- Induction and conduction work on conductive materials like pans and pots and on special food (hot dogs).
- The main advantages of these techniques are:
  - Fast (high values of power density)
  - Precise (the electromagnetic field can be controlled in space and time)
  - Efficient (most of these techniques deliver heat inside the workpiece – this means low heat losses)
  - Controllable (all these techniques are supplied by electricity)
  - Clean (no pollution for combustion process)
  - Safe (non free flames, no high temperatures)

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Cooking methods
Dry heat cooking
Broiling
Drilling
Roasting
Baking
Sauteing
Moist heat cooking
Poaching
Simmering
Boiling
Steaming
Combined cooking
Braising
Stewing
Basic methods of French Cooking from the spruce
Sautéing
Poaching

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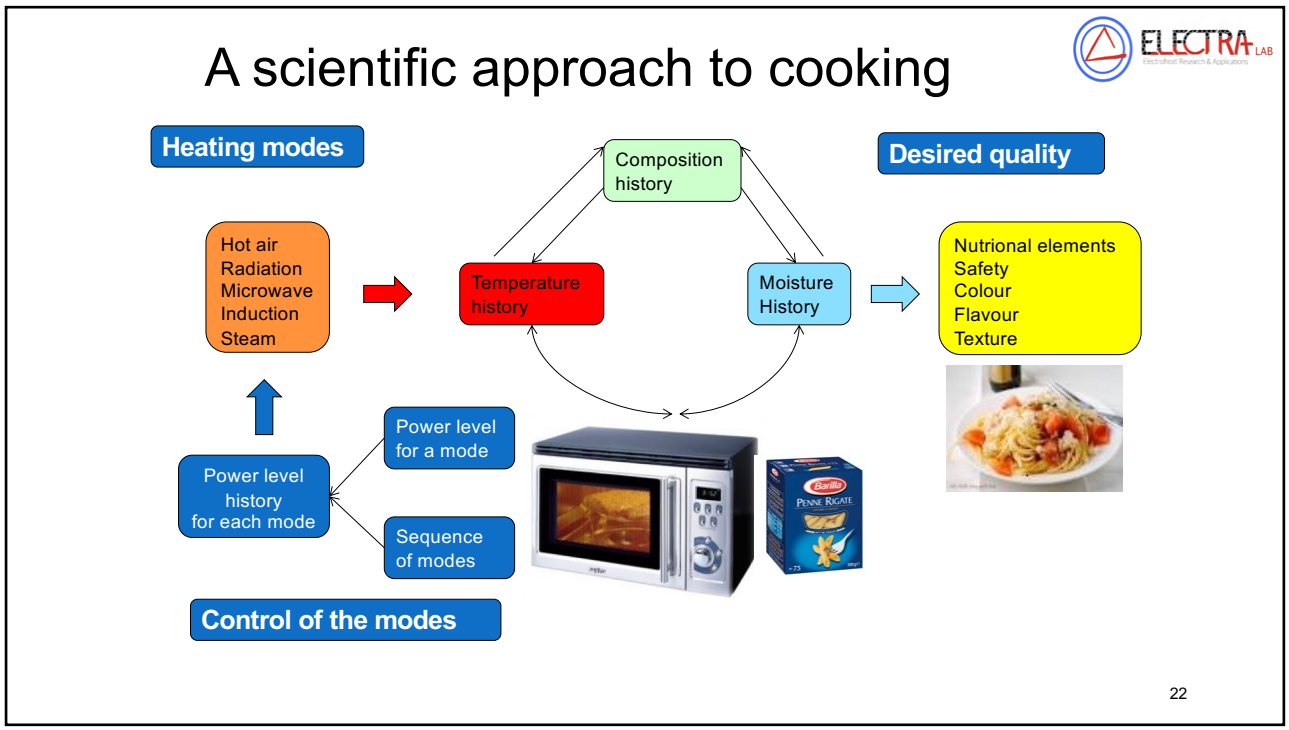
A scientific approach to cooking
Heating modes
Hot air
Radiation
Microwave
Induction
Steam
Composition history
Temperature history
Moisture History
Desired quality
Nutrional elements
Safety
Colour
Flavour
Texture
Power level history for each mode
Power level for a mode
Sequence of modes
Control of the modes
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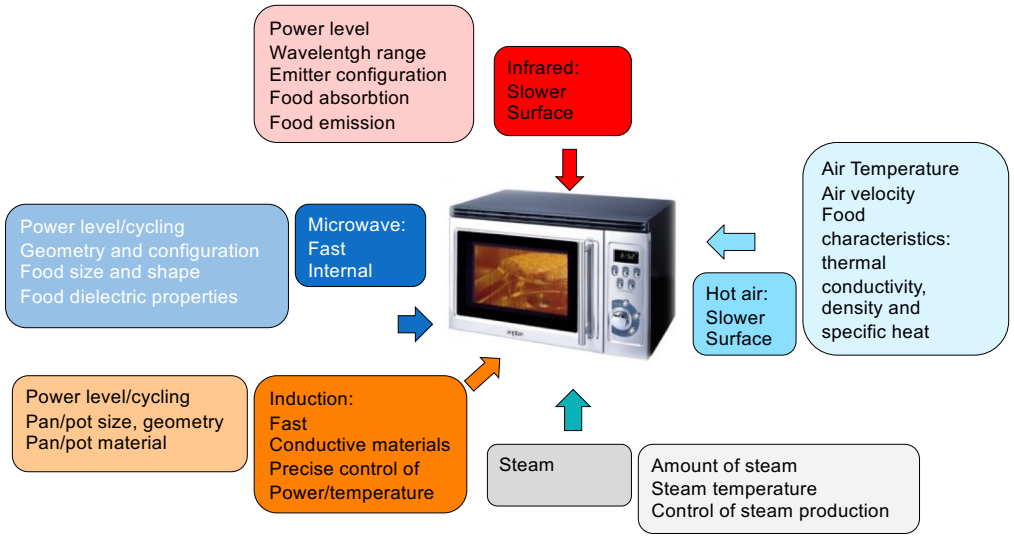
Combination of several heating technologies



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Available technologies for cooking and heating

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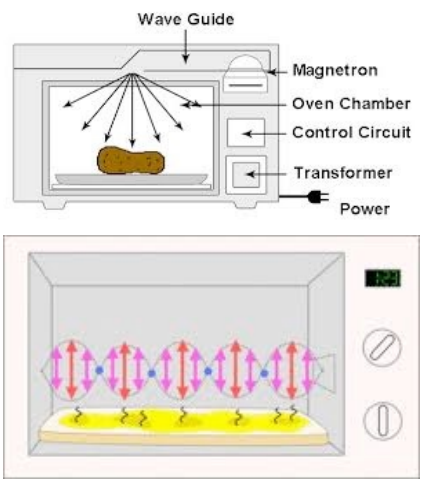

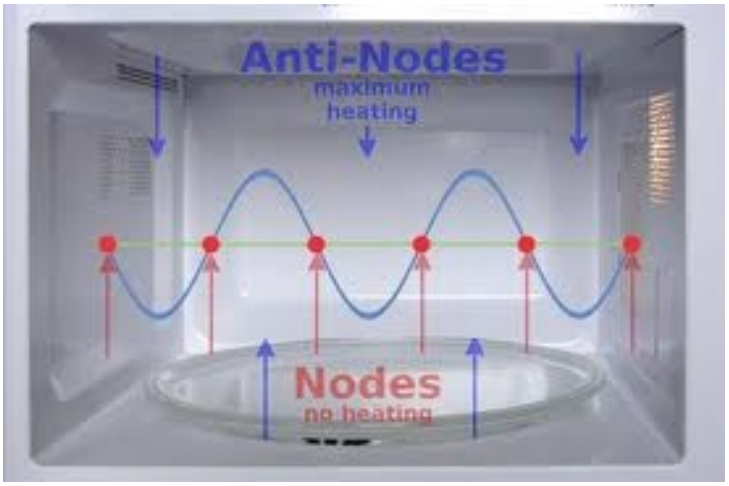

Microwave oven: how it works

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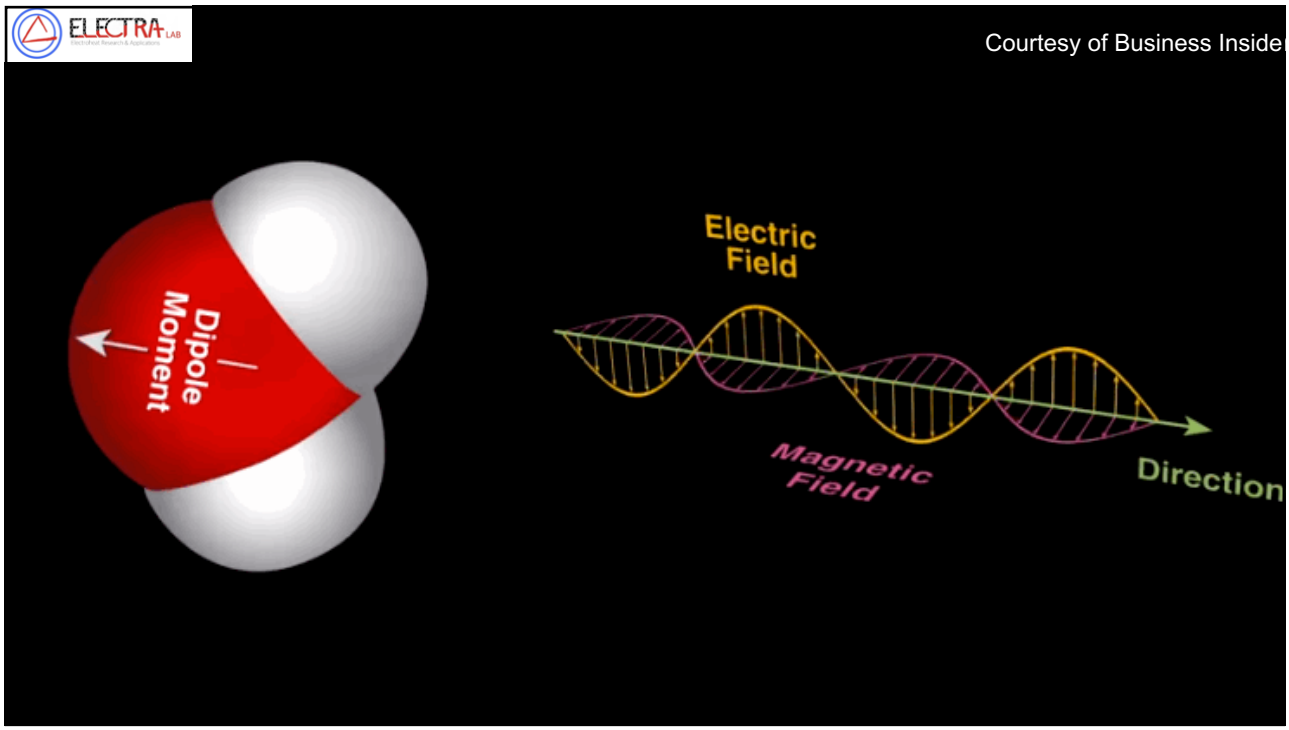

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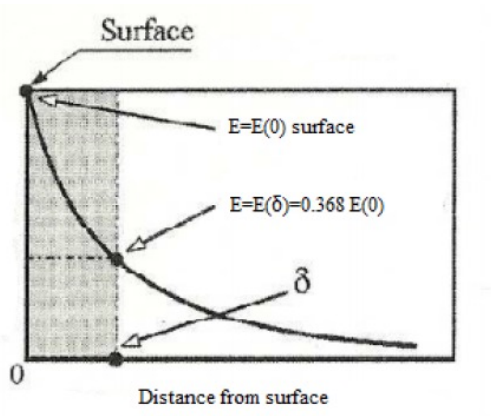
Penetration Depth in foods



$$d_p = \frac{1}{\alpha} = \frac{1}{\pi f \sqrt{2\mu\varepsilon\left[\sqrt{1+\left(\frac{\sigma}{\omega\epsilon}\right)^2}-1\right]}}$$

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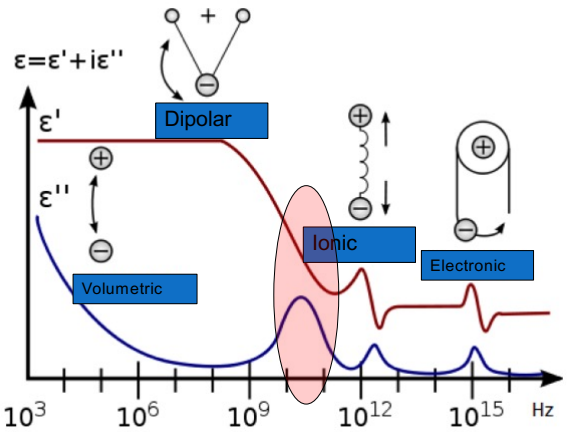
Food characteristics for MW heating



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How the food influences the heating process

Behaviour of MW heating @2450 MHz

Material	Dielectric constant ($F\,m^{-1}$)	Loss factor	Penetration depth (cm)
Banana (raw)	62	17	0.93
Beef (raw)	51	16	0.87
Bread	4	0.005	1170
Brine (5%)	67	71	0.25
Butter	3	0.1	30.5
Carrot (cooked)	71	18	0.93
Cooking oil	2.6	0.2	19.5
Distilled water	77	9.2	1.7
Fish (cooked)	46.5	12	1.1
Glass	6	0.1	40
Ham	85	67	0.3
Ice	3.2	0.003	1162
Paper	4	0.1	50
Polyester tray	4	0.02	195
Potato (raw)	62	16.7	0.93

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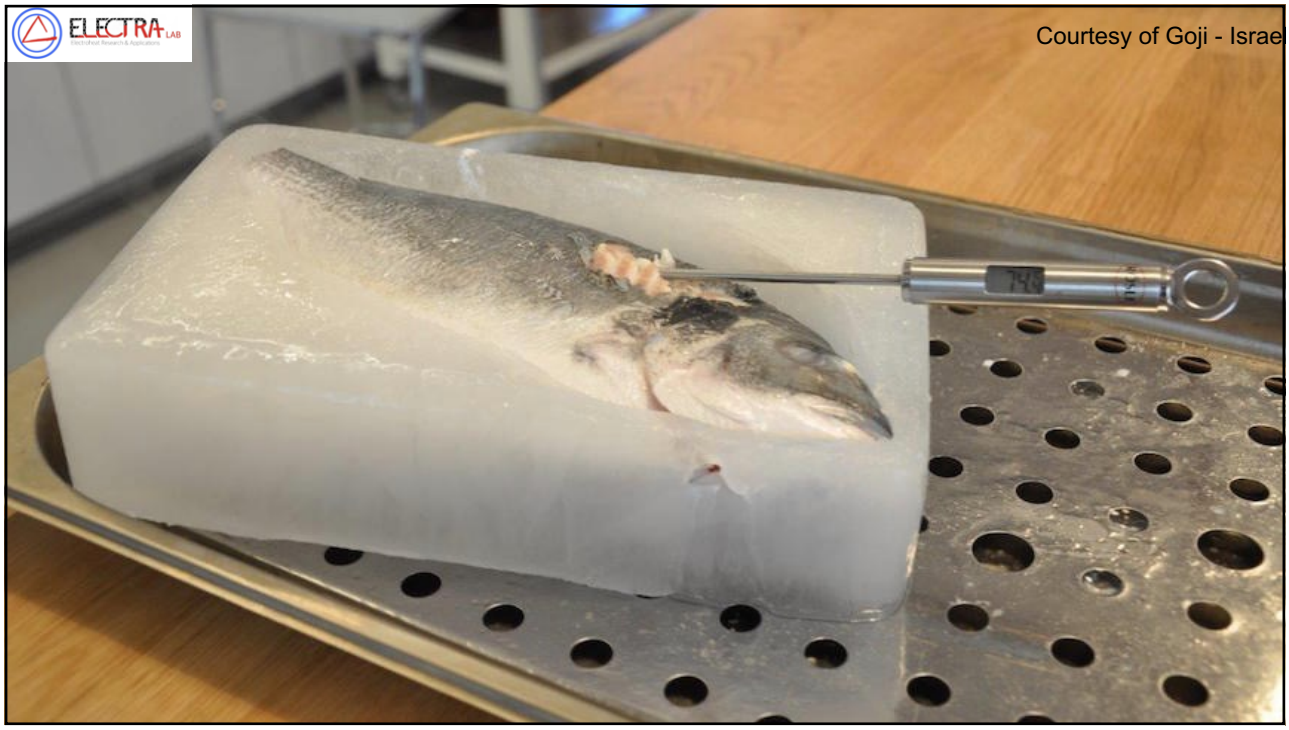

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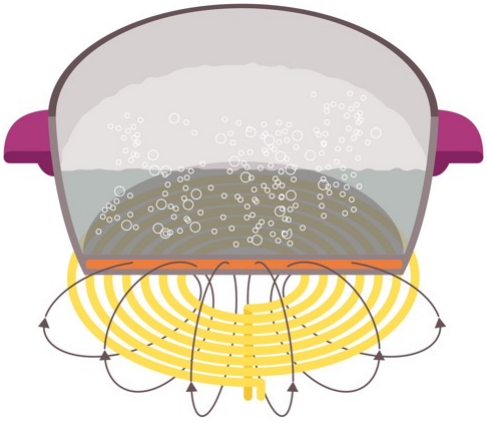
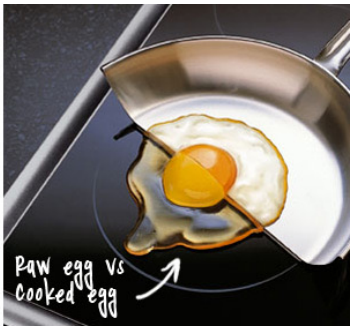
Physical principle of an induction cooktop





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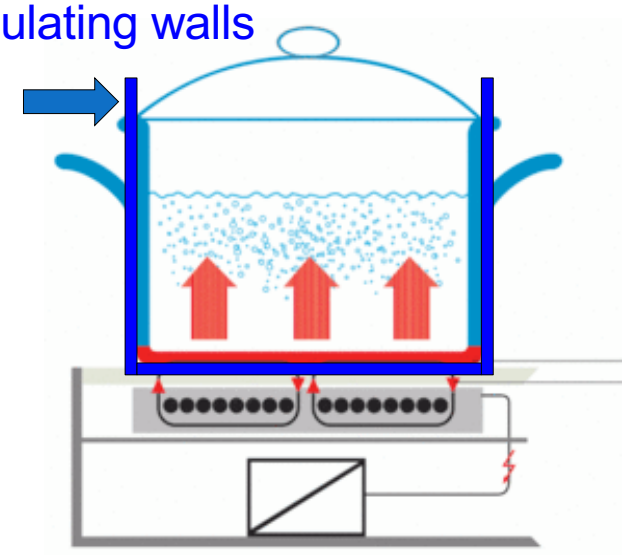
Induction cooktop with a special high efficiency and “smart”pot

- Induction use electromagnetic fields for heating conductive magnetic materials with very high efficiency.
- The pots generally used have a thin bottom of magnetic steel.
- The use of insulating materials (ceramic for example as shown in figure) provide a high efficiency cooking because of the limited thermal losses.
- EM fields produced by induction cooktops can be used as a “witricity” supplying pots for “smart” functions (stirring, browning, etc.) or sensors.

Insulating walls



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An example: 6 th sense induction oven

Induction heating is based on **magnetic field** generation through a tray inside the oven coupled with a magnetic material pan.
The induction cooking process is a combination of the heating process activated through the induction tray and the pot provided and the grill.
This cooking process is **less energy consuming** than a traditional cooking process.

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Induction Teppanyaki

- There are already some examples of induction heating used for teppanyaki but this technology has a lot of capabilities to create a real smart and innovative product (materials, temperature control, design...)

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Steam heating/cooking

- Cooking at a temperature of about 100 °C (212 °F) in steam, with the food and cooking liquid completely separated.
- The main feature of steam cooking is the maintainance of the moisture inside the food. At the same time a lot of nutrients aren't lost in the cooking medium.
- A drawback is the lackness of browning. This means that steam cooking alone is well suited for vegetables and fish.

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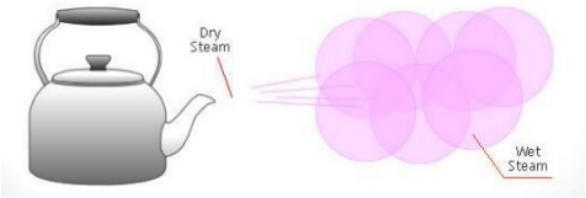
Types of steam

- **Wet steam**: a portion of its water molecules have given up their energy (latent heat) and condense to form tiny water droplets. It is known as saturated steam (water in the liquid state and gaseous state).
- **Dry steam**: all its water molecules remain in gaseous state. It is known as superheaetd steam. It doesn't contain any water molecules and it's completely transparent.



Wet Steam	Dry Steam
Rapid even heating with latent heat transfer	Low heat transfer coefficient
High heat transfer coefficient	Temperature may be exremely high
Originates from water	Sensible heat to transfer heat
Used for heating, cooking, drying	Exclusively used in turbines

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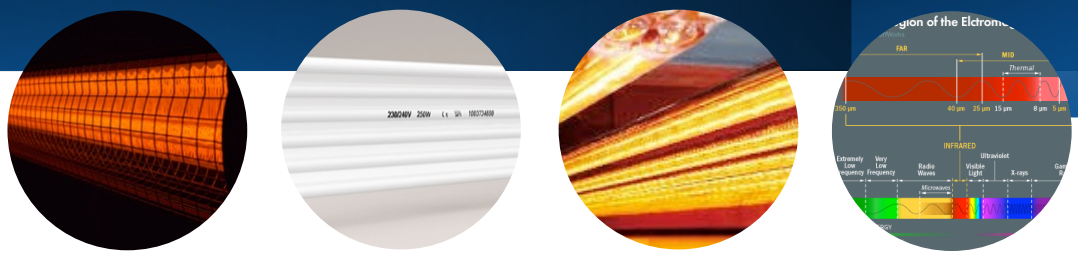
Infrared heating



- Infrared heating is the mechanism under which a source at high temperature delivers heat to a work-piece (food) at lower temperature by means of electromagnetic radiation.

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Infrared cooking

- Infrared cooking is mainly used for browning but it can be used also for cooking.
- Radiation can penetrate the food depending on the wavelength (short wavelength high penetration) and depending on absorbtion coefficient and emissivity of food.
- Infrared is very rapid (short wavelength lamps)
- It's easy to control (voltage is the main control quantities)
- Life time of lamps is sometimes limited
- Pollution (steam, fats, oils) inside a oven can deteriorate the performances of lamps and the reflections of walls

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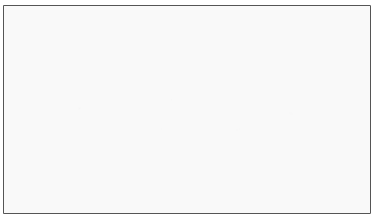

InfraRed Heating

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Conduction heating

- Conduction heating is based on a very simple physical principle: the ohm and Joule law
- We apply a voltage between two terminals of the food and a current will flow in it.
- The current will produce heat inside the food

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Perspectives and dreams about future of food and cooking

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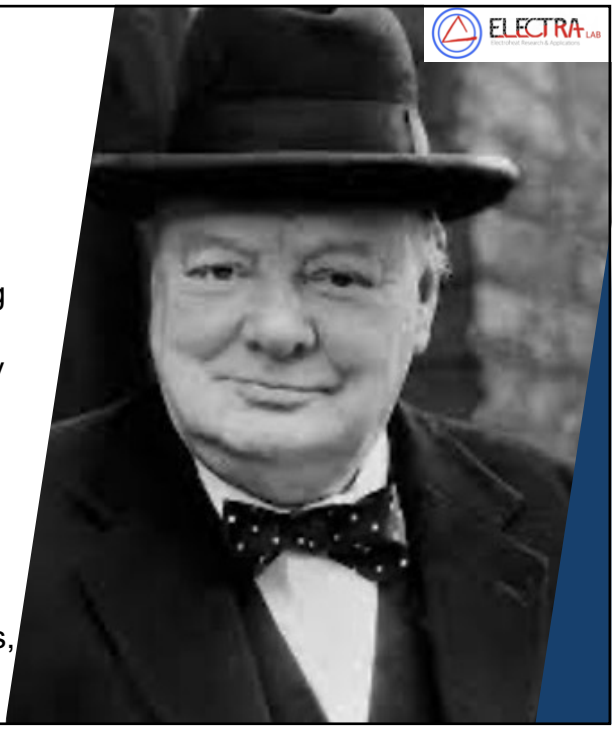
«Many people, of course, prefer food in what the vegetarians call 'the secondhand form', i.e. after it has been digested and converted into meat for us by domestic animals kept for this purpose. In all these processes, however, ninety-nine parts of the solar energy are wasted for every part used.»

«We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium. Synthetic food will, of course, also be used in the future. Nor need the pleasures of the table be banished. That gloomy Utopia of tabloid meals need never be invaded. The new foods will from the outset be practically indistinguishable from the natural products, and any changes will be so gradual as to escape observation.»



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3D printing of the food of the future
"Additive manufacturing" will also enter the professional kitchen

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The robot and AI in the kitchen to make food safer and more personalized in terms of doses and ingredients

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The fully automatic production of increasingly sophisticated foods that simulate the experience of starred cuisine
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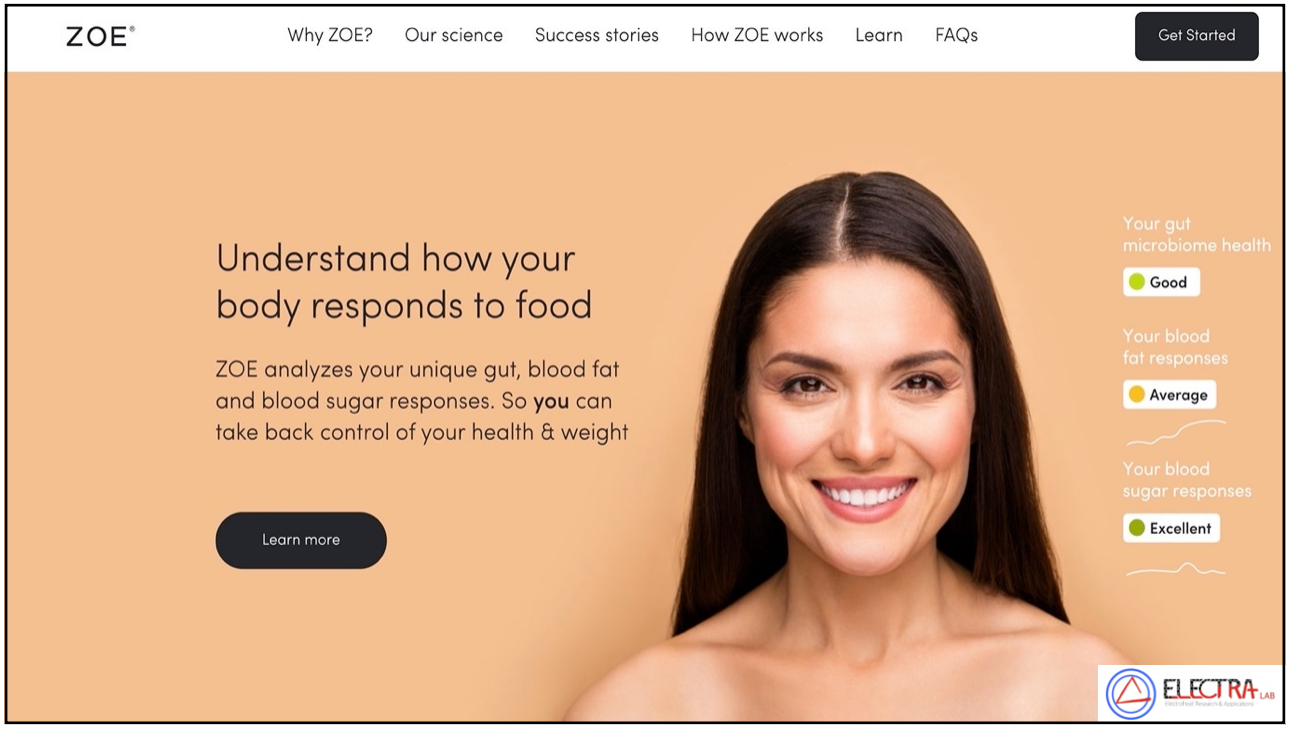
ZOE
Why ZOE?
Our science
Success stories
How ZOE works
Learn
FAQs
Get Started
Understand how your body responds to food
ZOE analyzes your unique gut, blood fat and blood sugar responses. So you can take back control of your health & weight
Learn more
Your gut microbiome health
Good
Your blood fat responses
Average
Your blood sugar responses
Excellent
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Conclusion

- Electroheat technologies have an important role in cooking/heating of foods
- Each technology has a different behaviour and acts on different zones in the food producing different effects on it
- A combination of some heating technologies can improve cooking **velocity and quality preserving the nutritional elements of food**.
- The choice of the combination in terms of duration, powers, modes is very difficult and challenging
- A deep understanding of **physical characteristics** of each technology is the first step in order to combine them properly
- Proper **control algorithm based on AI** able to drive the potentiality of different heating sources is mandatory in order to have a **high quality food**.

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Research topics

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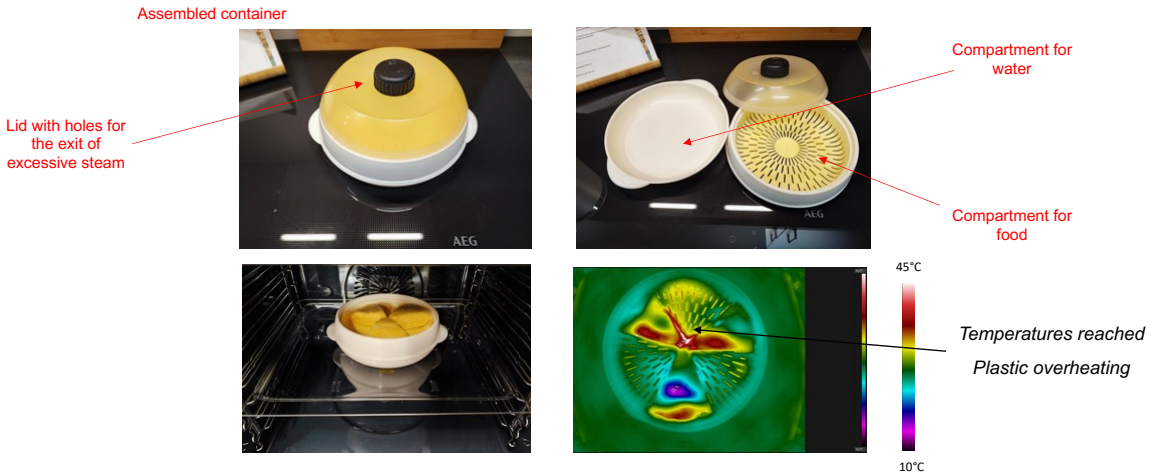
Research topic 1

Cooking with Microwave & Steam: a scientific analysis to identify problems concerning human health and the main consequence on food nutritional values and flavour.



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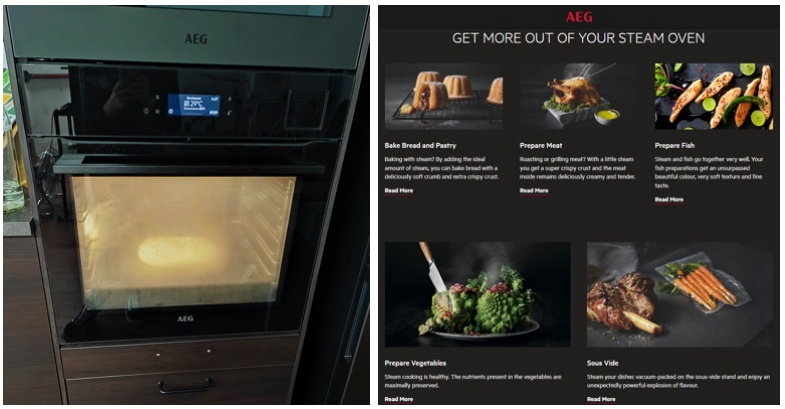
Research topic 2

Cooking with steam: many ovens have the possibility to generate steam inside the cavity and cook using moist air instead of dry air. The cooking time is reduced in a significant way using steam. The aim of this research topic is to understand if the reduced cooking time can have a positive effect on nutritional value of veggies after cooking.



AEG Steam Oven in our laboratory

From AEG website; everything can be cooked with steam.

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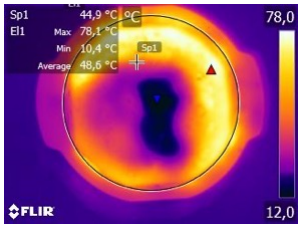
Research topic 3

Solid-State microwave thawing: there a two types of microwaves generators, the magnetron and the solid state. Nowadays the magnetron is the most used in commercial microwave ovens, but some prototypes with a solid-state generator are under test. The high cost of this technology is a limit, but the many advantages due to the possibility to control many parameters (frequency, phase, power) motivate the research on its performance during heating and cooking. A comparison between magnetron and solid-state thawing is the focus of this research topic.

Solid-state microwave oven prototype



The main problem of microwave thawing is the non-uniform result.