3rd TRAINING SCHOOL PIAGRI COST ACTION CA19110

"Plasma applications for smart and sustainable agriculture"

PLASMAS FOR PLANT AND FOOD PROCESSING

11-14 June 2024, Faculty of Natural Sciences, Vytautas Magnus university, Kaunas, Lithuania

COST EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY · CA19110 COST · VYTAUTAS MAGNUS UNIVERSITY MCMXXII · LITHUANIAN ENERGY INSTITUTE · LITHUANIAN RESEARCH CENTRE FOR AGRICULTURE AND FORESTRY

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

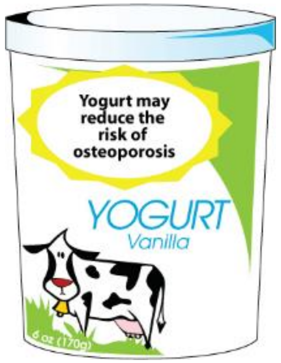
'Cold plasma application for food stability and functionality'

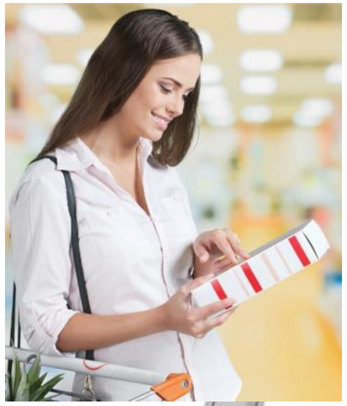
Prof. Silvia Tappi

DISTAL – Department of Agricultural and Food Sciences – *Alma Mater Studiorum*, University of Bologna

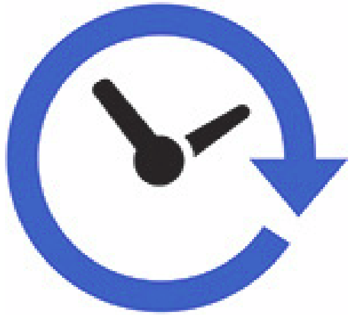
silvia.tappi2@unibo.it

Motivation for emerging technologies in the food sector





- New products /consumer expectation
- Quality
  - ➢ Health benefits
  - ➢ Sensory attributes
- Food safety
- Economic advantage
  - ➢ cost (energy)
  - ➢ time
  - ➢ efficiency
- Waste reduction/reuse, sustainability



Application of cold plasma in the food sector

Presentation structure:

- Research on Cold Plasma in the Food Sector
- Main applications:
  - Food decontamination
    - microrganisms
    - viruses
    - mycotoxins
    - pesticides
    - allergens
  - Modification of enzymatic activity
  - Functionalization of food components (proteins, starches)
- Secondary effects: effects on quality and nutritional properties, lipid oxidation
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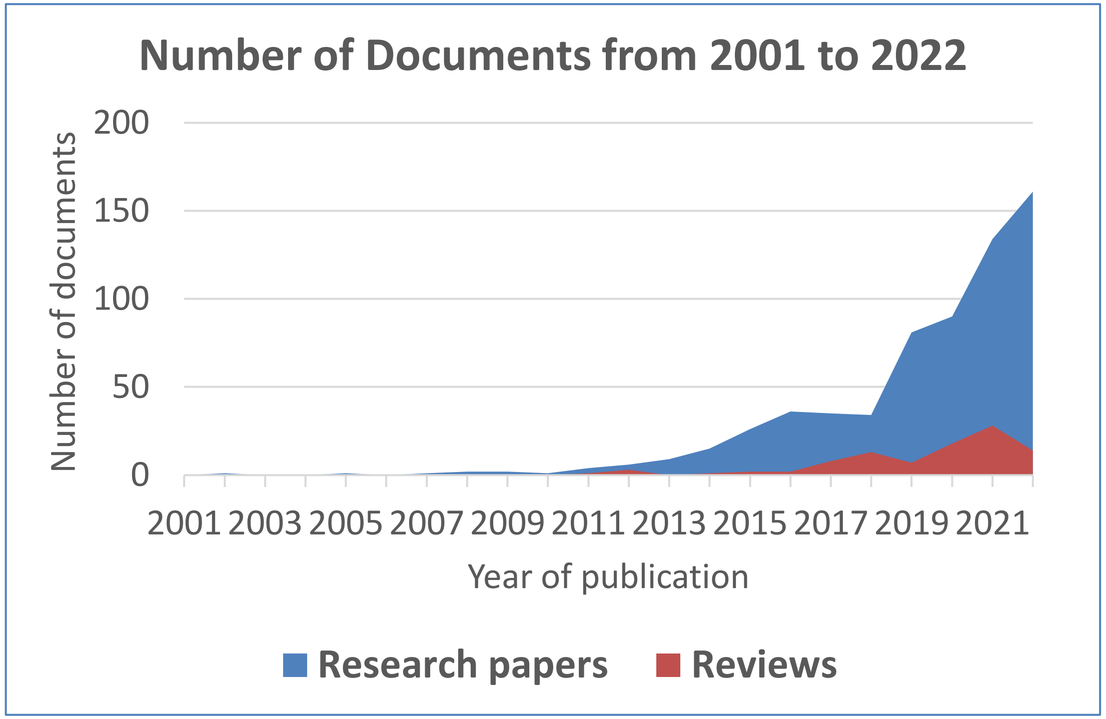
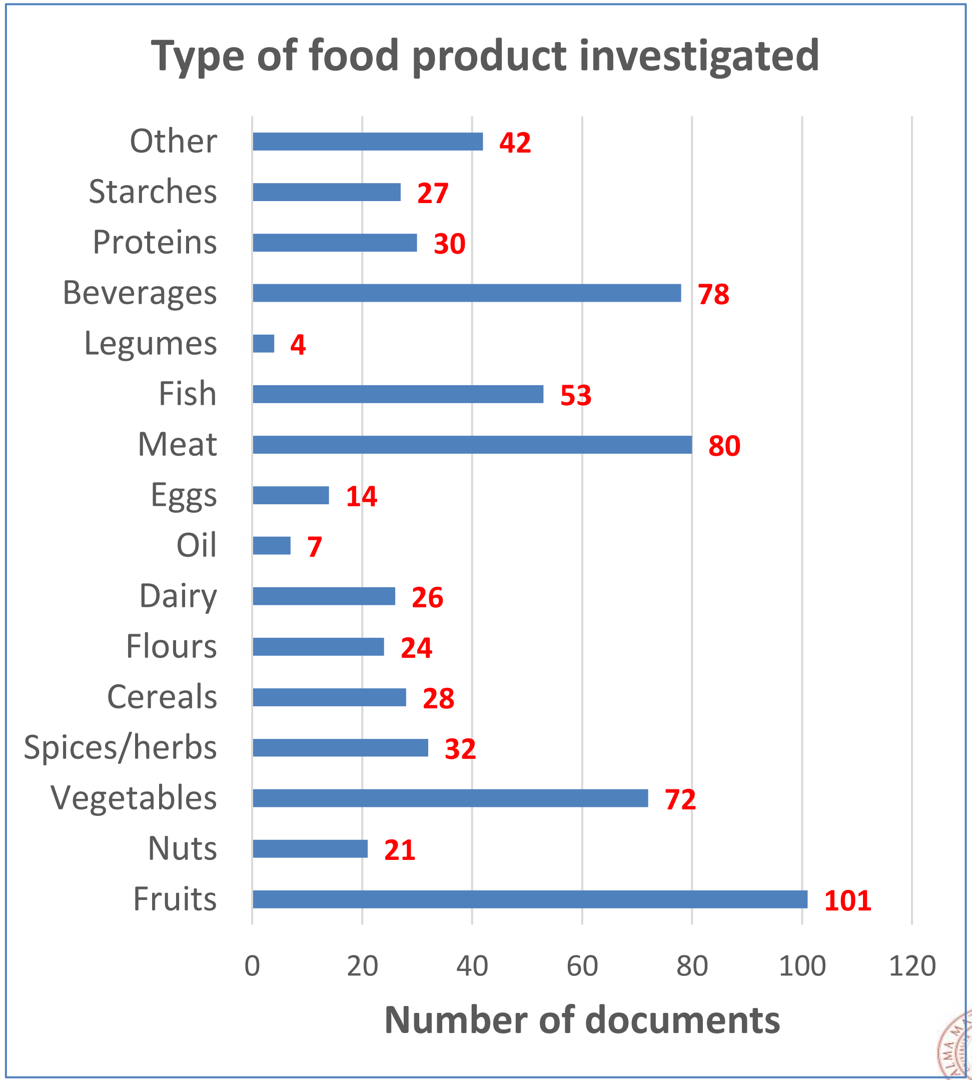
Research on Cold Plasma in the Food Sector

Virtual Mobility Grant
Plasma effect on safety and quality of foods
08/08/2023 to 20/10/2023

Source: Scopus
738 bibliographic records (after pre-processing)





cost
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Plasma applications for smart and sustainable agriculture

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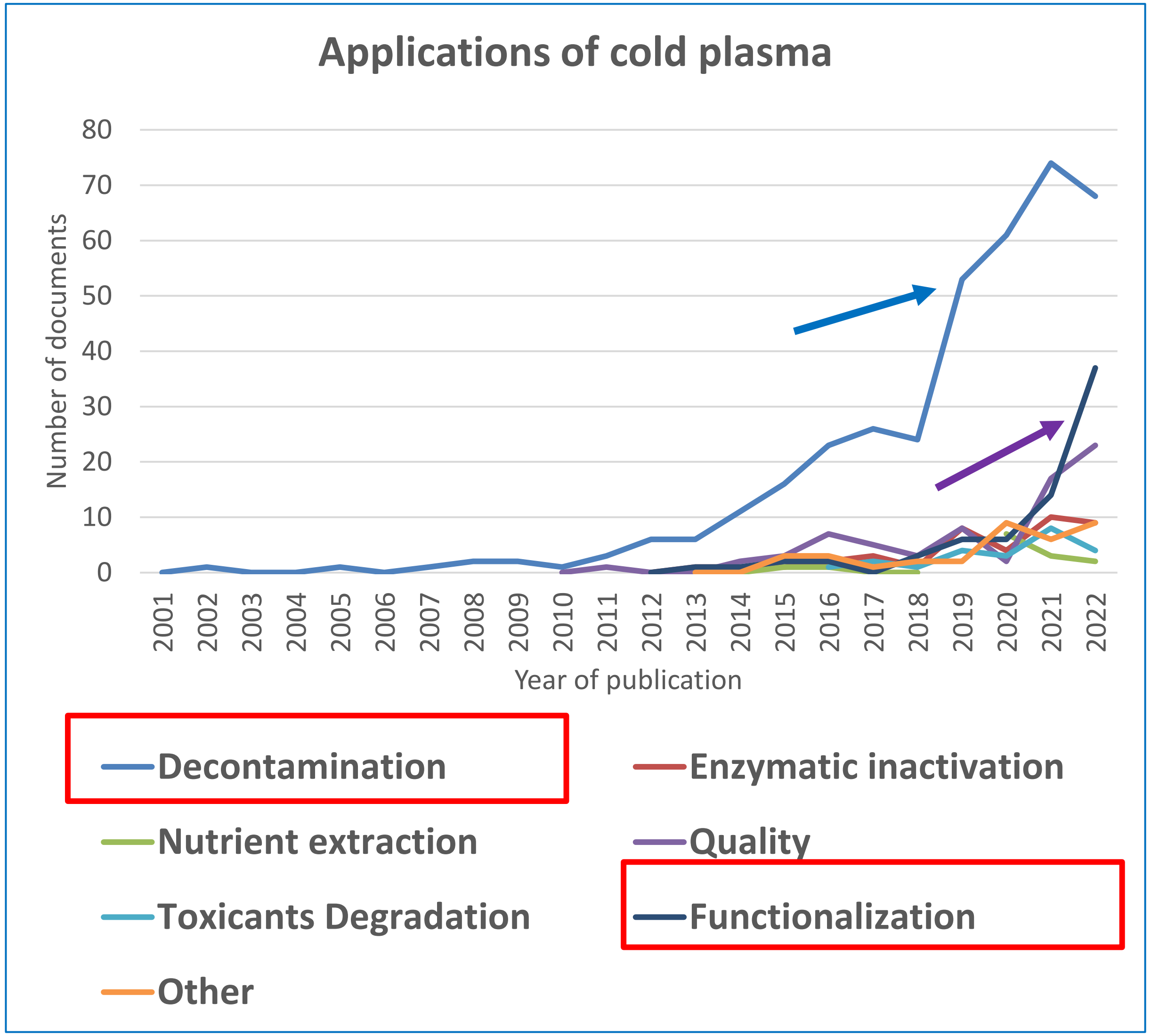
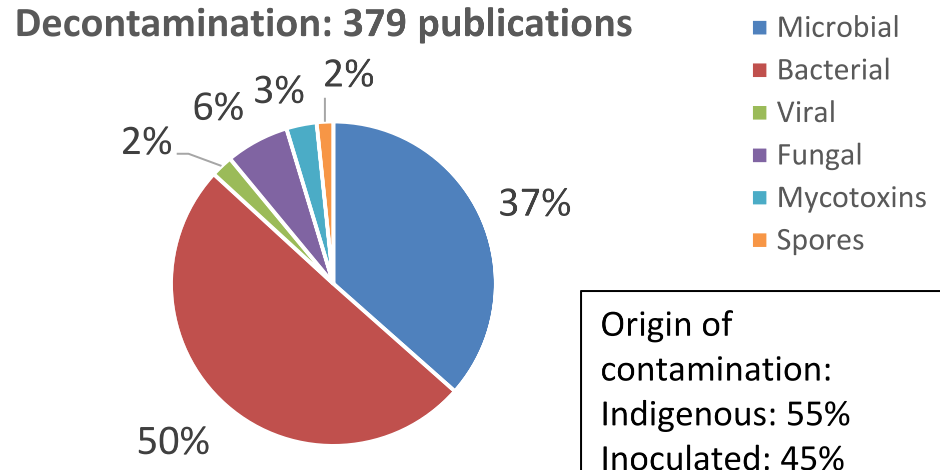
Research on Cold Plasma in the Food Sector

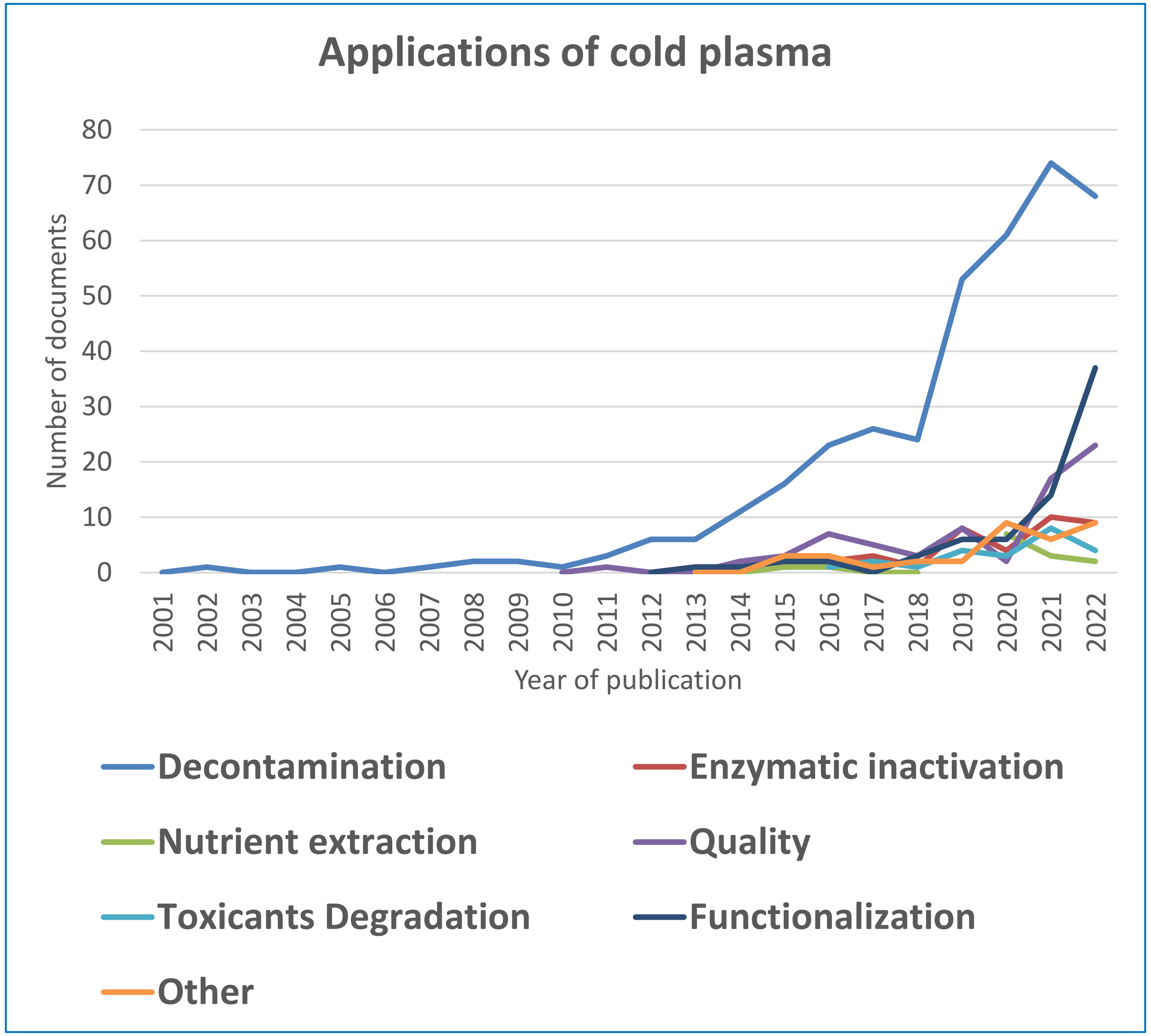


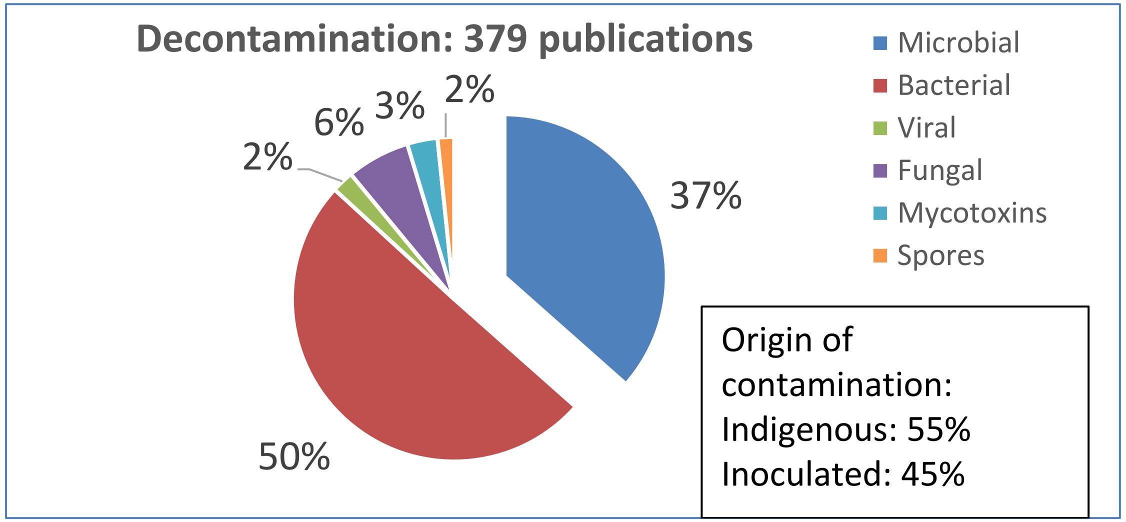


Origin of contamination:
Indigenous: 55%
Inoculated: 45%

Total documents	379	
Contamination agents	Number of documents	%
Total viable/mesophilic count	148	39.1
Yeast and moulds	59	15.6
Escherichia coli	95	25.1
Listeria	61	16.1
Salmonella spp	124	31
Saccharomyces cerevisiae	10	2.6
Aspergillus	31	9.2
Mycotoxins	20	3.1
Norovirus	10	2.0
HAV	2	0.5
Parasites	1	0.2

Research on Cold Plasma in the Food Sector





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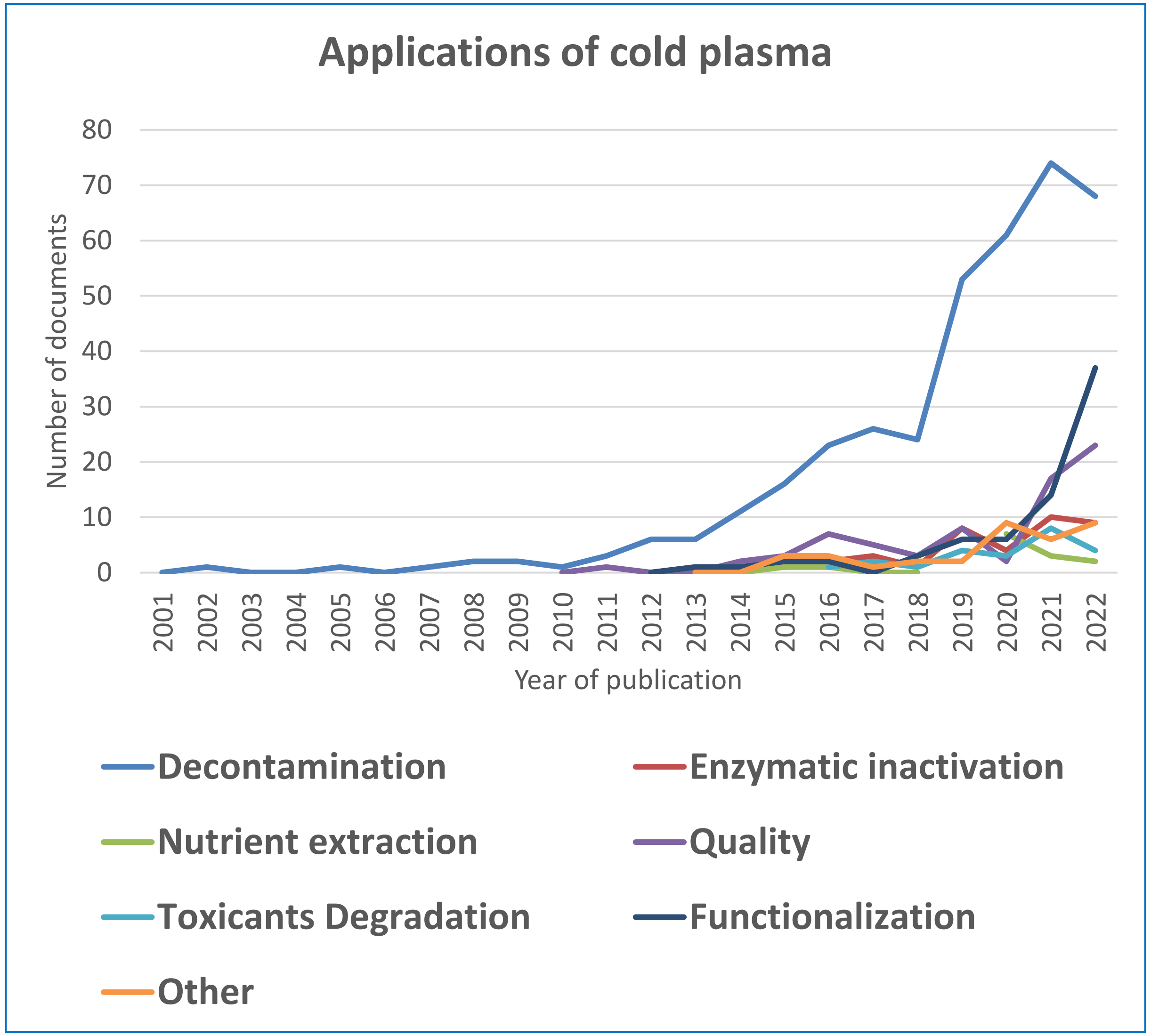

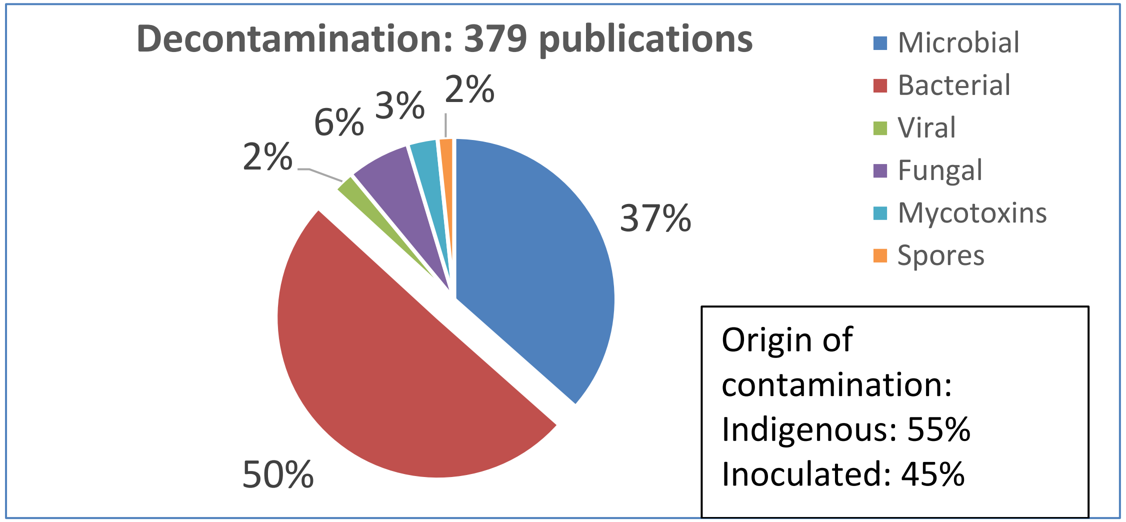

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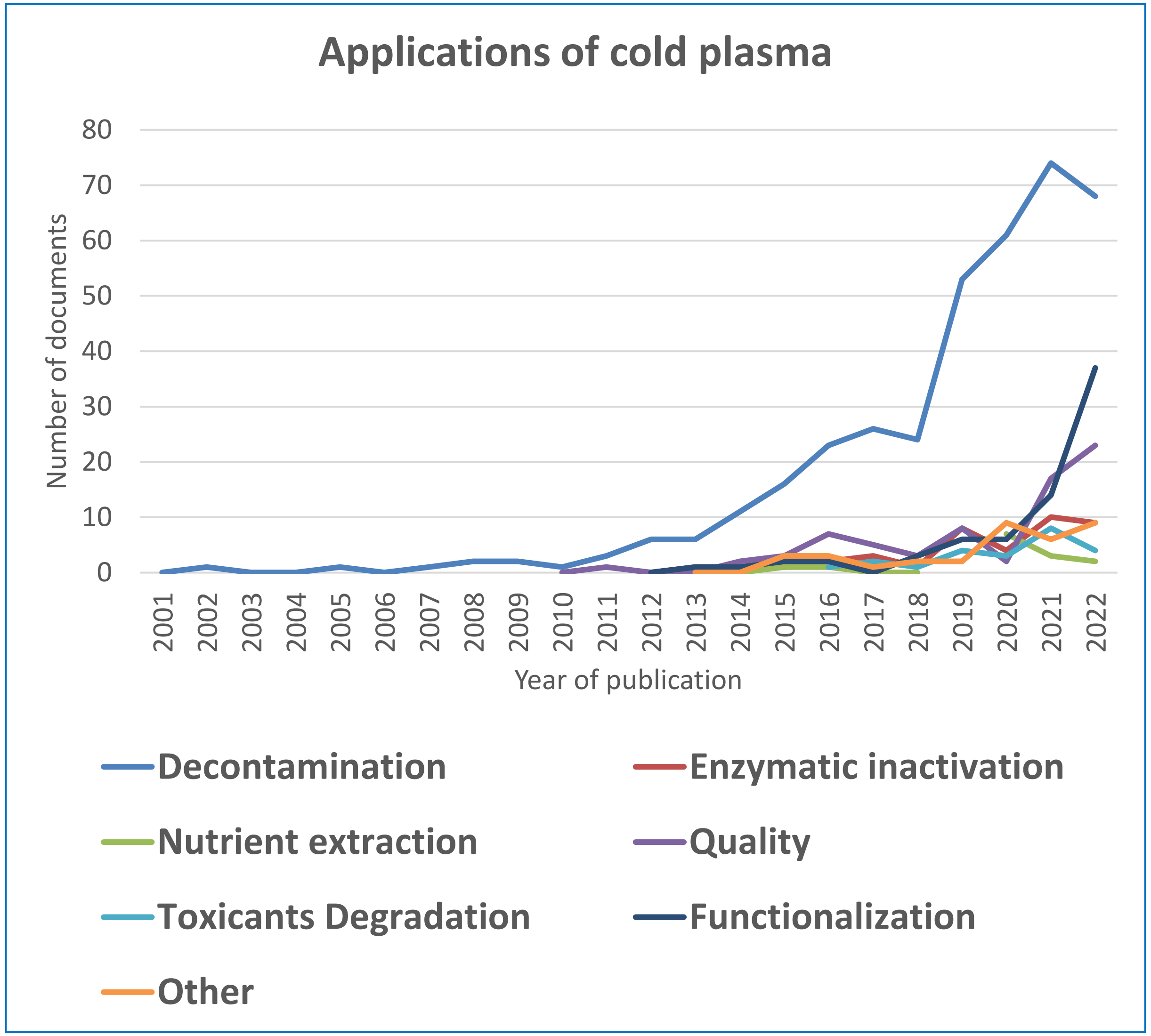

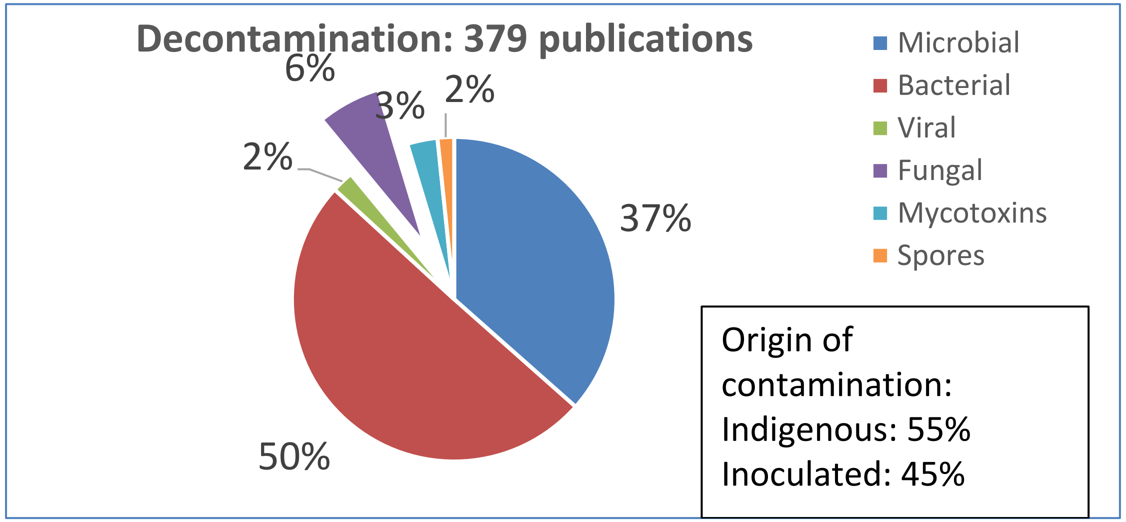

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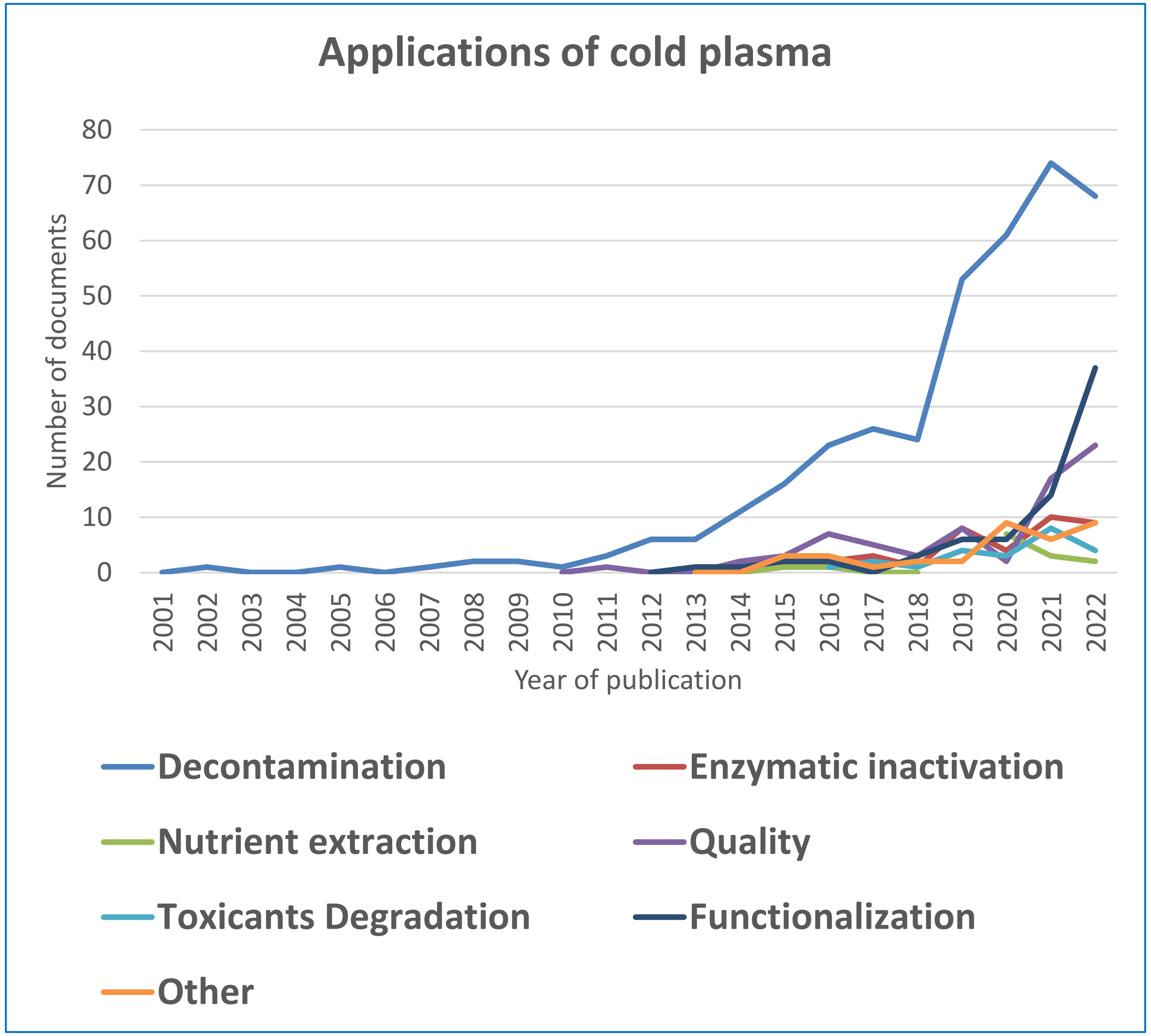

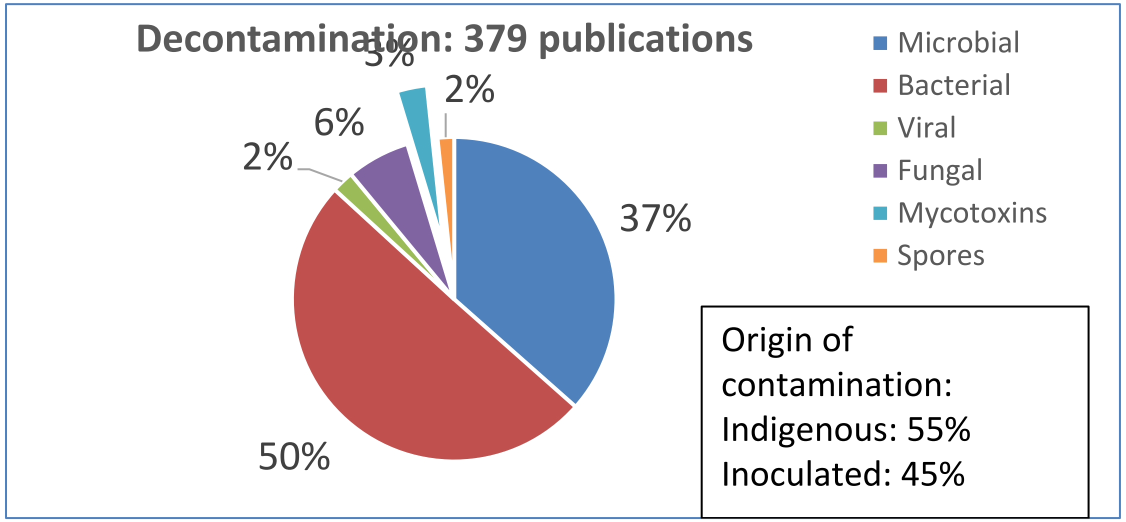

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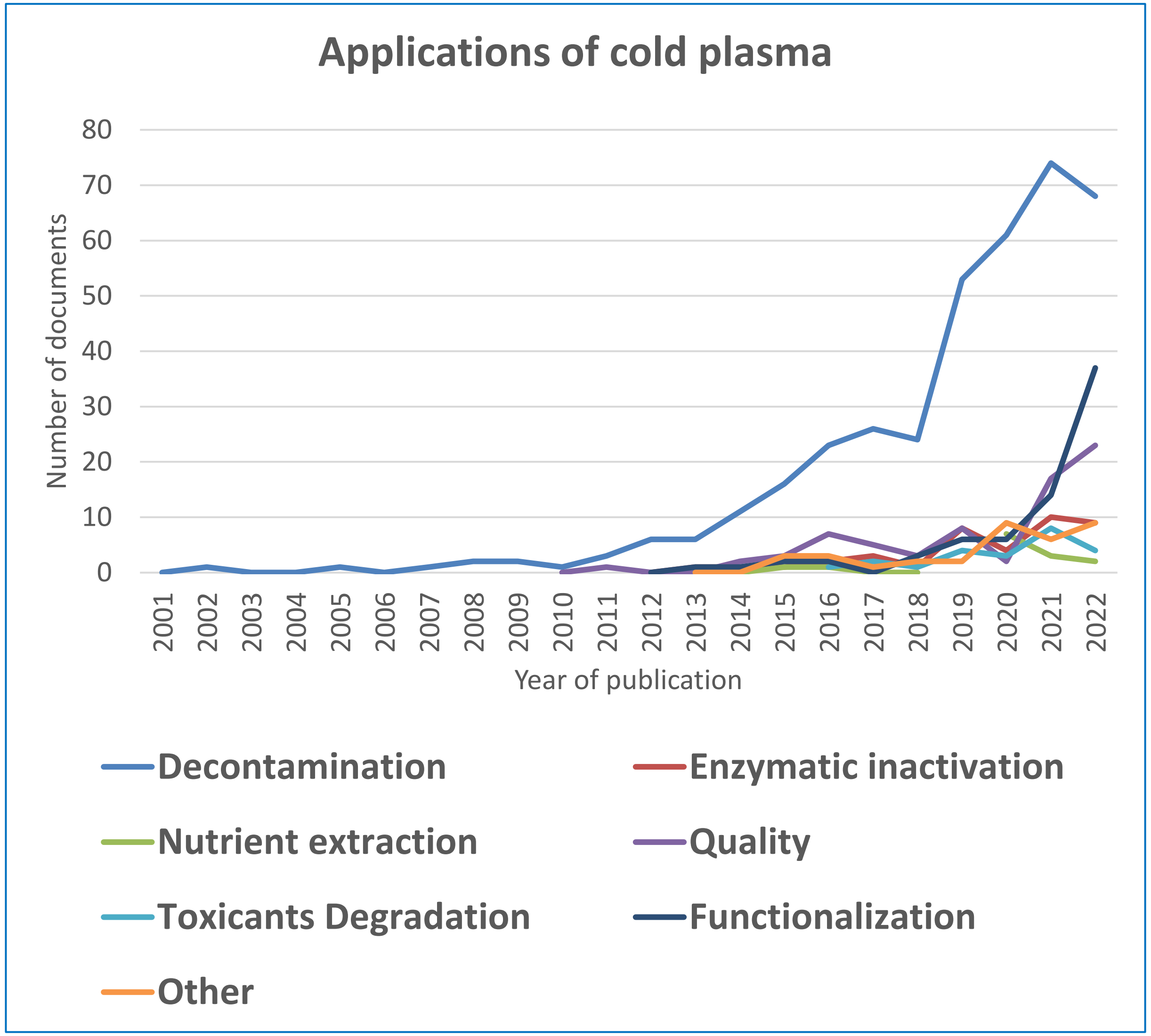

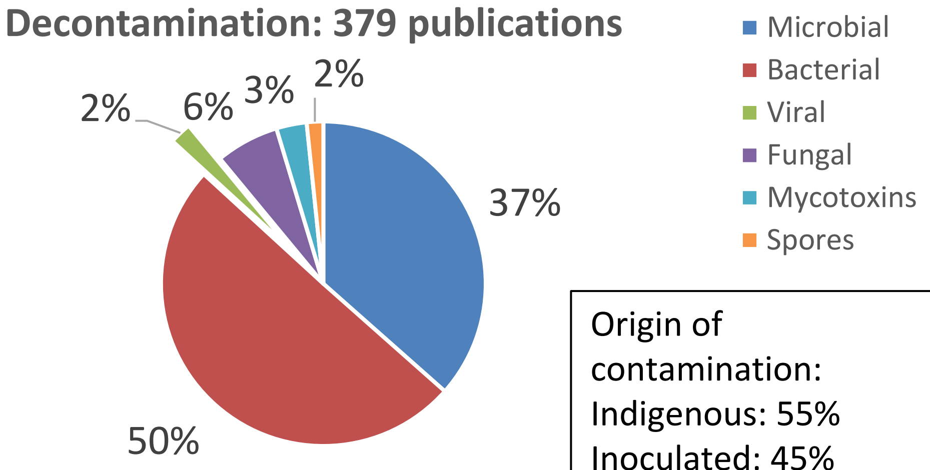

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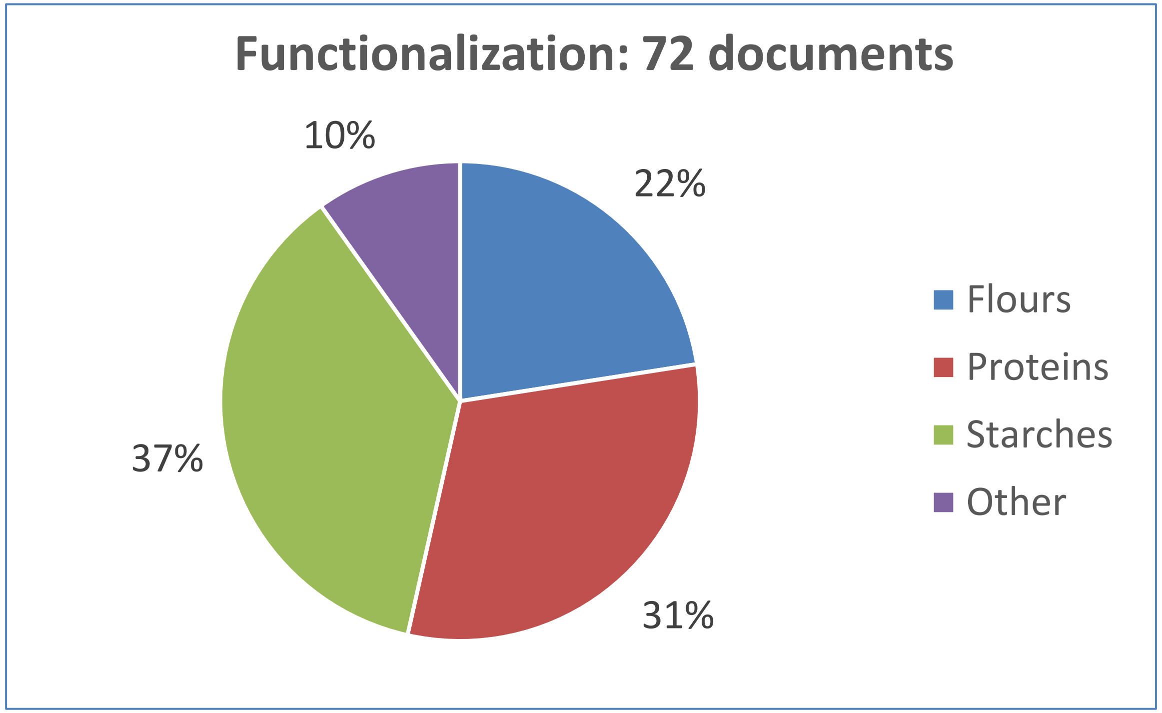
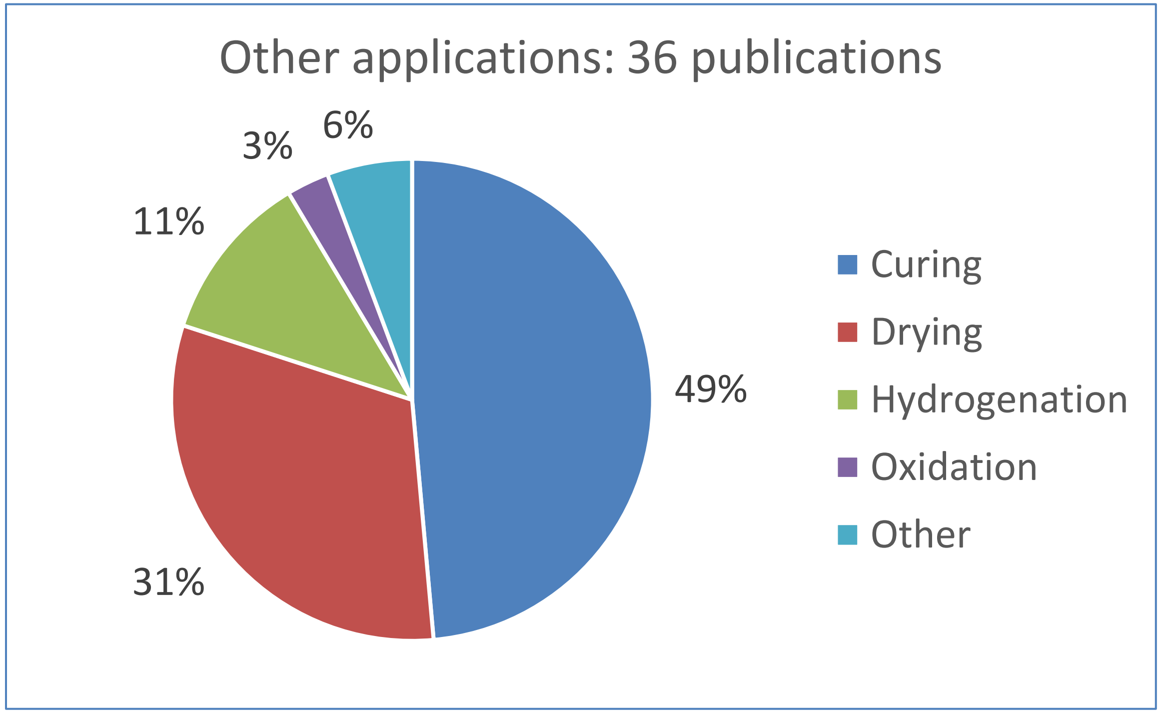
Research on Cold Plasma in the Food Sector

Emerging applications





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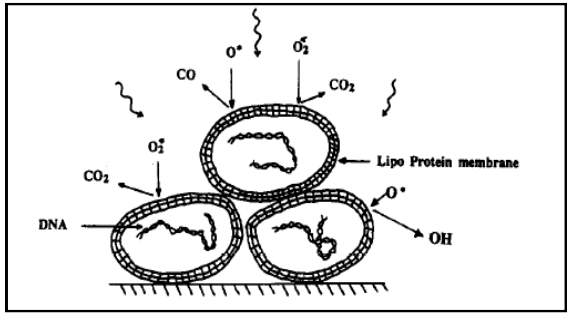
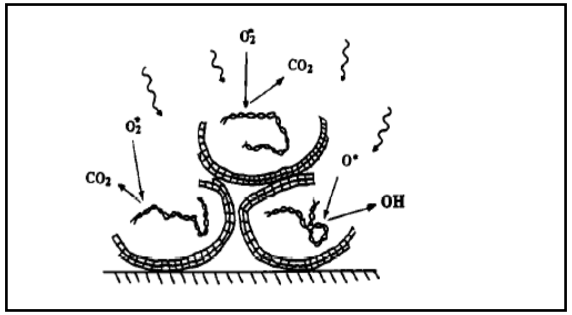
Hypothesis on the mechanism of microbial inactivation of plasma

DIRECT DESTRUCTION OF DNA CAUSED BY UV RAYS

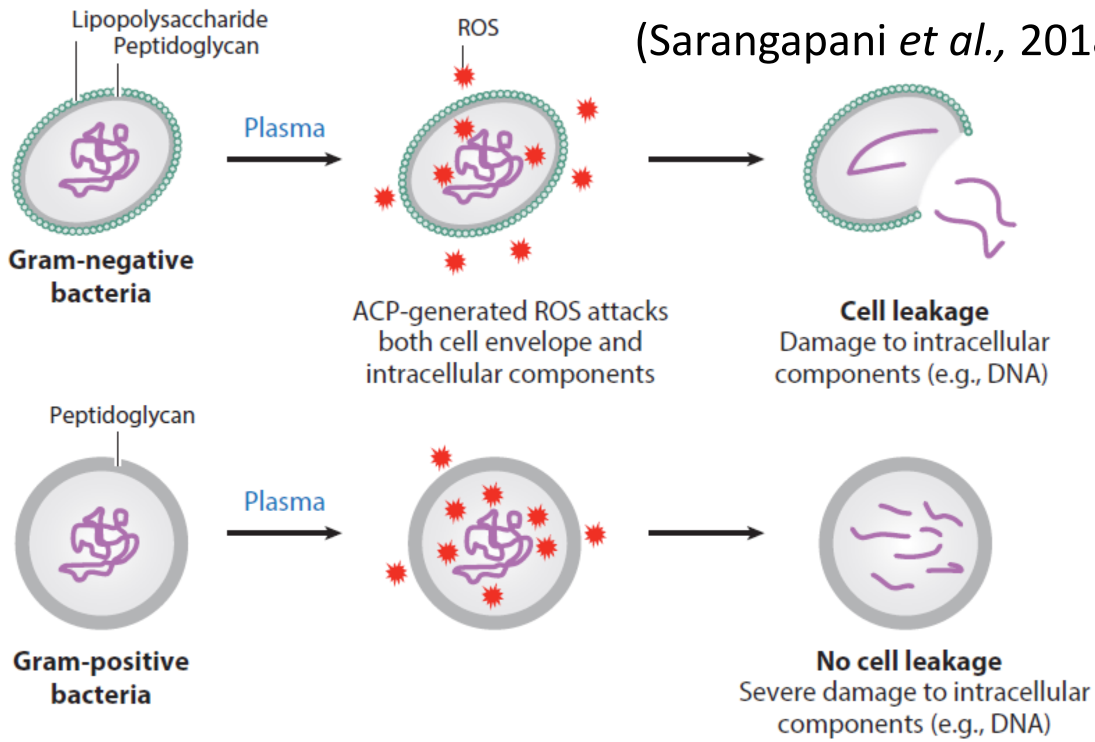
DEGRADATION OF CELL MEMBRANES



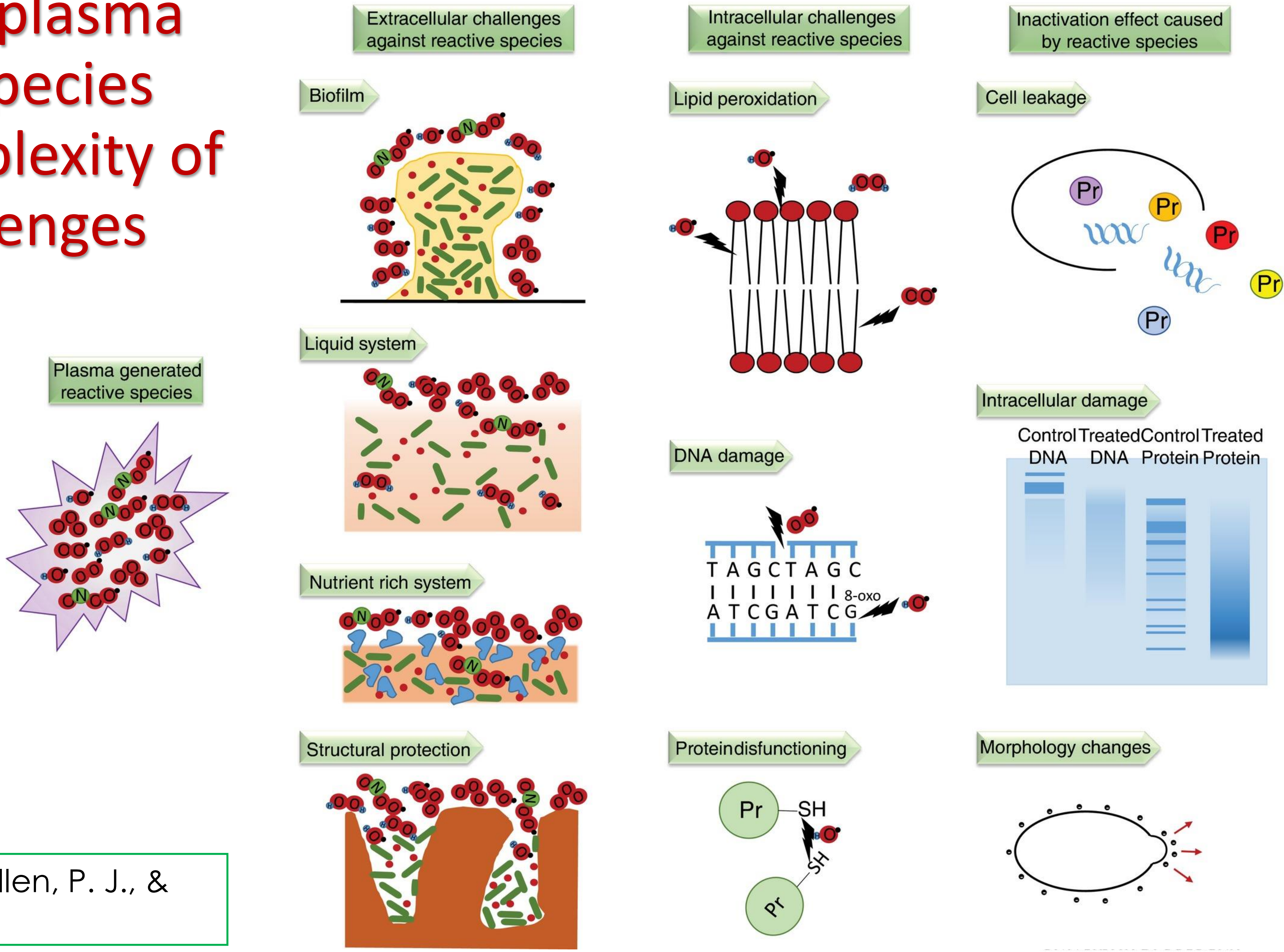


(Laroussi *et al.*, 2002)

(Sarangapani *et al.*, 2018)



Mechanisms of cold plasma generated reactive species with respect to complexity of microbiological challenges



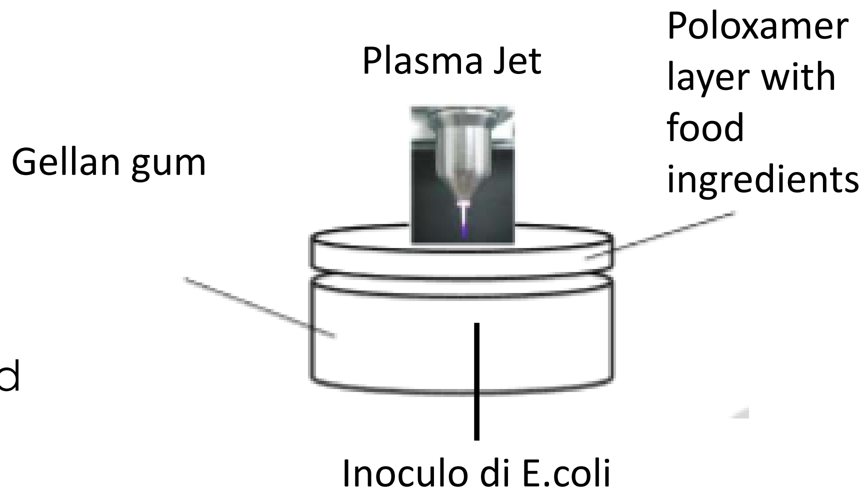
Bourke, P., Ziuzina, D., Han, L., Cullen, P. J., & Gilmore, B. F. (2017).

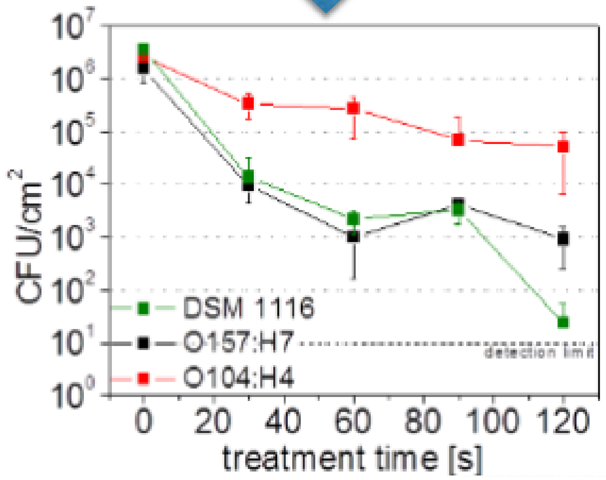
Studies on the mechanisms of microbial inactivation of plasma

Use of model systems

- useful aids for exploring efficient process parameters and efficacy limits for a single plasma device to be tested
- allow for homogeneous treatments and convenient extraction and provide reproducible results;
- As a simplified model system, large numbers of samples can be analyzed in the absence of drying stress, competing indigenous microflora or other inhibitory factors
- Generally consisting of a polysaccharide gel plate which contains some of the food ingredients, with a suitable pH at aw

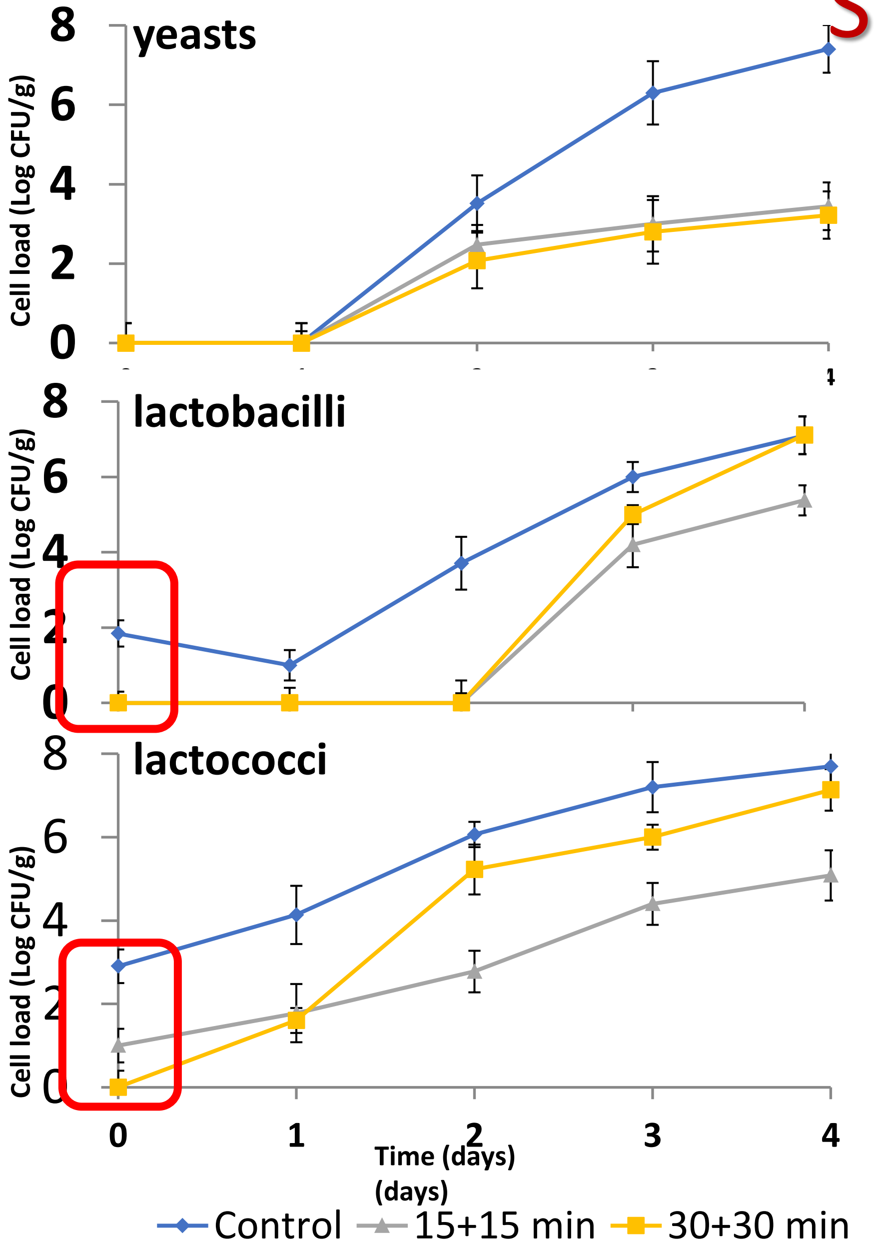
ATTENTION: THE RESULTS ON REAL MATRICES COULD BE VERY DIFFERENT!!
MATRIX EFFECT





Plasma treatments for the decontamination of fresh-cut melon

Shelf-life study



Microbial group	Treatment time (min)	Shelf-life (giorni)**
Mesophiles	Control	2.3
	15+15 min	>4
	30+30 min	2.9
Psycrothrophes	Control	2.9
	15+15 min	>4
	30+30 min	2.6

**Time necessary to attain a cell count of 6 Log CFU g^{-1}, calculated using the predicted Gompertz parameters.

Microflora naturally present on the fruit pulp

Tappi et al., 2016

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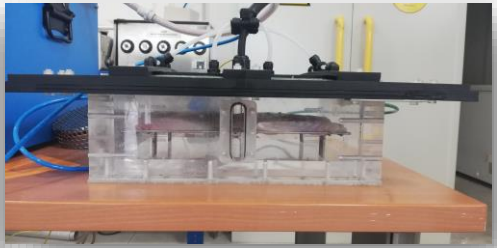
Cold plasma treatment to increase the shelf life of sea bream fillets

FUTURE EUAQUA

Seabreams from Kefalonia



PLASMA TREATMENT

- **A** (Air)80% Nitrogen + 20% O_2
- **B** 80% Argon + 20% O_2

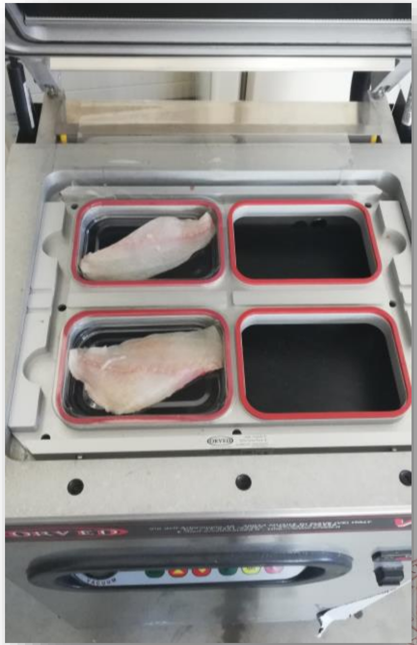
Current 20mA
Voltage 18 kV
Frequency 5 kHz
Time 20 min

- **C** Control

PACKAGING AND STORAGE

- Polypropilene (PP) trays and film
- Modified Atmosphere (MAP) 80% N_2 e 20% CO_2
- Refrigerated storage (4±1°) for 14 days

Sea bream



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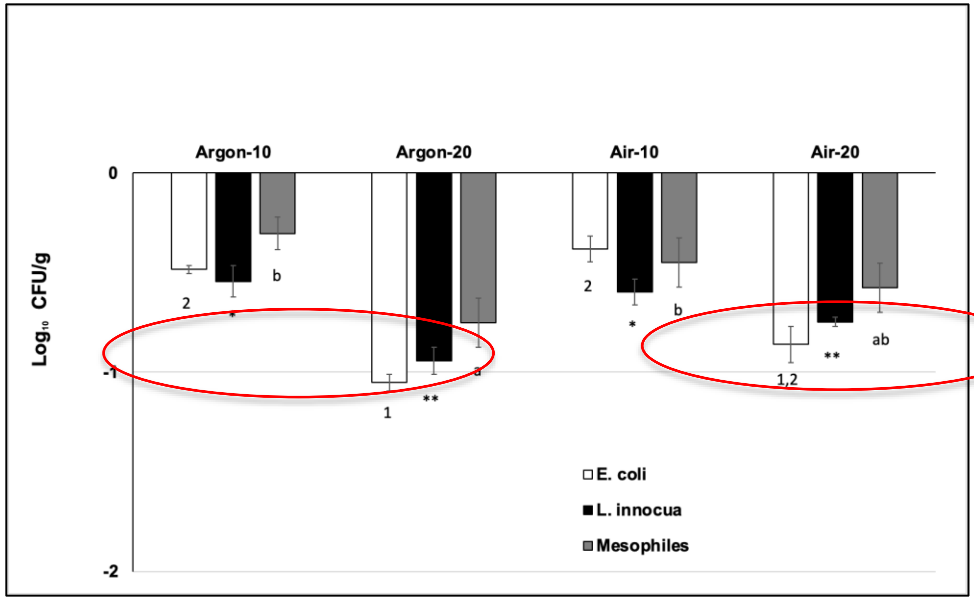
Cold plasma treatment to increase the shelf life of sea bream fillets

Inactivation of degradative and pathogenic bacteria



Latest acceptable data point

Sea bream

Storage day	Control	Plasma Air
0	3.08	3.05
2	3.11	3.09
5	3.50	3.78
6	3.88	3.91
8	5.07	4.84
9	5.10	5.56
10	6.36	5.80
12	6.78	5.87
13	6.93	5.94
14	7.29	6.62

Tappi, S., Nissen, L., Casciano, F., Antonelli, G., Chiarello, E., Picone, G., ... & Rocculi, P. (2023).

Increase of 4 days!

Gaseous plasma treatment on shredded carrots and sliced apples inoculated with Arcobacter spp. or E. coli

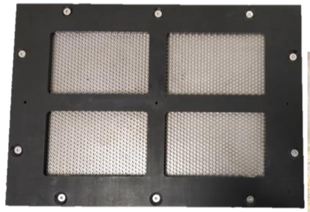
Arcobacter spp.: Campylobacteriaceae family
emerging animal and human pathogen, underestimated global prevalence
most likely source of Arcobacter spp. to fruits and vegetables include irrigation water and contaminated soil

1-cm sliced apple

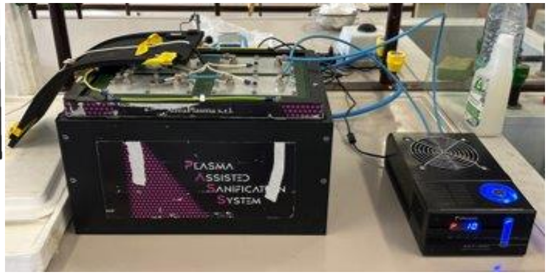
Shredded carrots

Teasted strains
E.coli 555
Arcobacter spp. (BZs 206) – strain 12 *Arcobacter spp. (BZG 74) - strain 28*

Prototype: PASS
Surface Dielectric Barrier Discharge (SDBD)
Treatment times:
2, 5, 10, 20, 30 minutes
Gas regime: NOx



SDBD

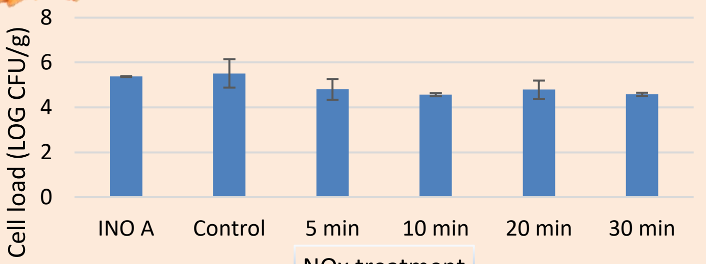


Gaseous plasma treatment on shredded carrots and sliced apples inoculated with Arcobacter spp. or E. coli

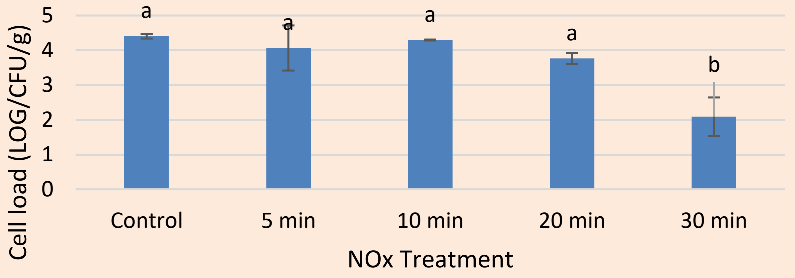
TECH4path PRIN2022

(Unpublished data)

Shredded carrots inoculated with ***E.coli* 555**

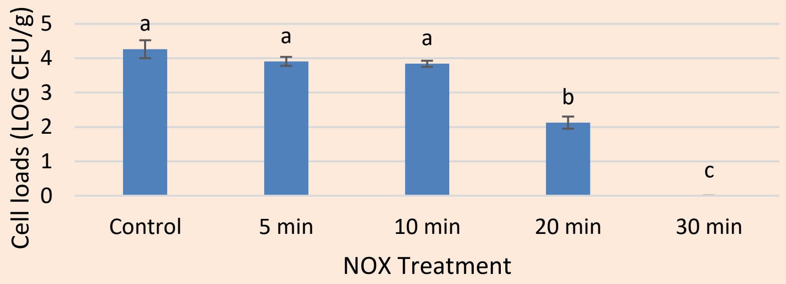


Shredded carrots inoculated with ***Arcobacter spp.* BZS206 (strain12)**

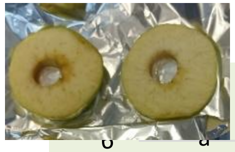


reduced by < 2.5 Log after 30 min

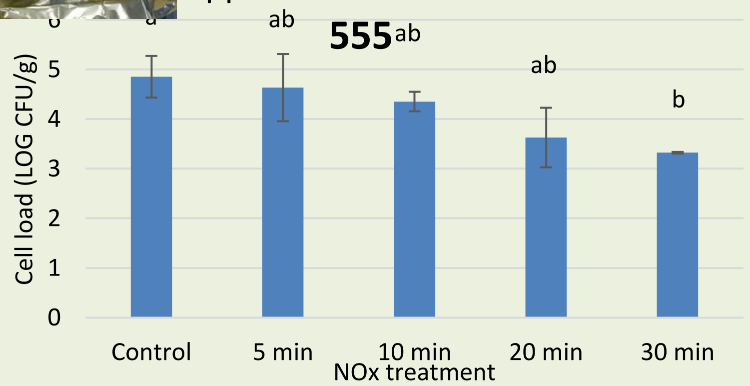
Shredded carrots inoculated with ***Arcobacter* spp. BZS74 (strain 28)**



reduced by < 2 Log after 20 min

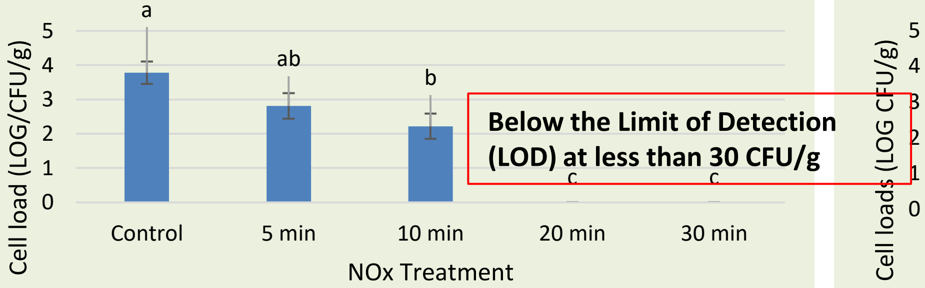


apples inoculated with ***E.coli* 555**



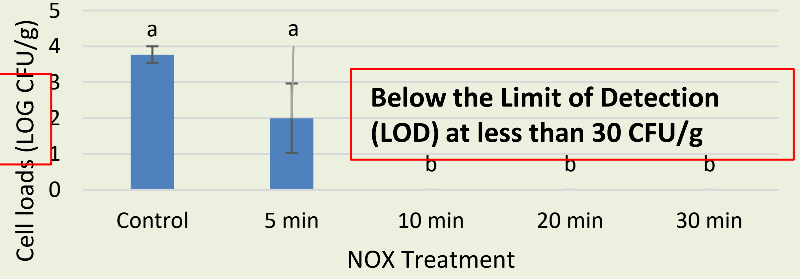
reduction of approx. 1.5 Log after 30 min

Sliced apples inoculated with ***Arcobacter* BZS206 (strain 12)**



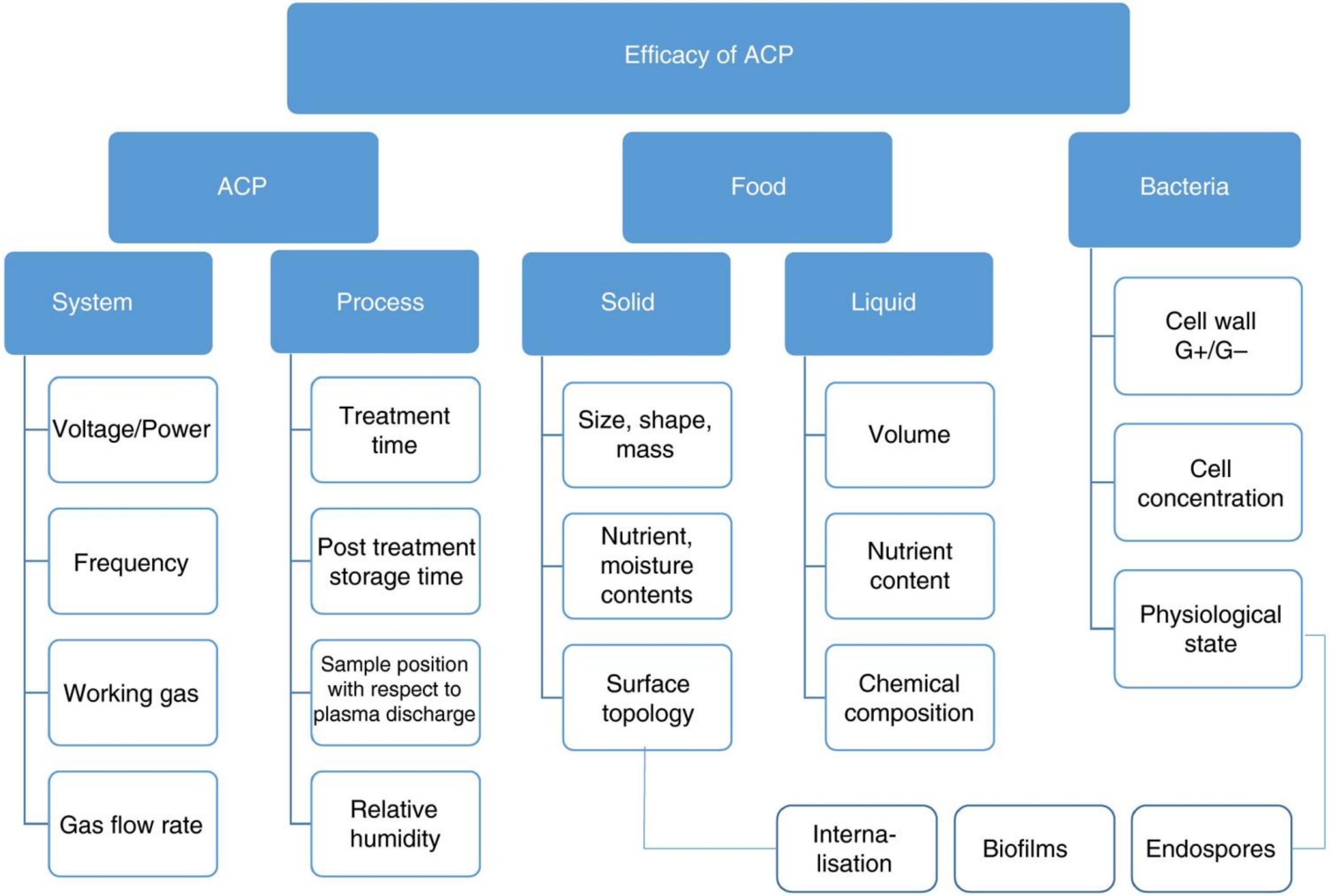
reduced after 5 min of treatment (1 Log), max reduction after 30 min

Sliced apples inoculated with ***Arcobacter spp.* BZS74 (strain 28)**



reduced after 5 min, reduction under LOD after 10, 20 and 30 min

Parameters influencing plasma treatment decontamination efficacy



Necessary to 'tailor' the treatment to each specific situation, considering all variables!

Bourke, P., Ziuzina, D., Han, L., Cullen, P. J., & Gilmore, B. F. (2017). Microbiological interactions with cold plasma. *Journal of applied microbiology*, *123*(2), 308-324.

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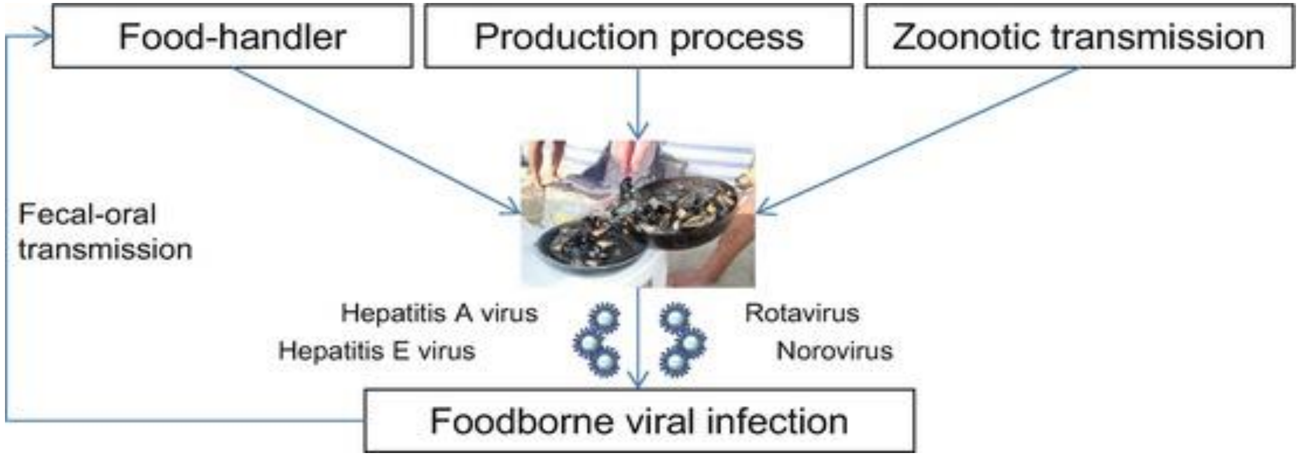
Foodborne viruses

Although viruses, unlike bacteria, cannot grow in or on foods, foodborne illnesses are associated with viruses due to contamination of fresh produce or processed foods by fecal matter containing viruses.

Commonly Reported Major Foodborne Illnesses Due to:

- Norovirus,
- hepatitis A and E virus,
- rotavirus and
- astrovirus.



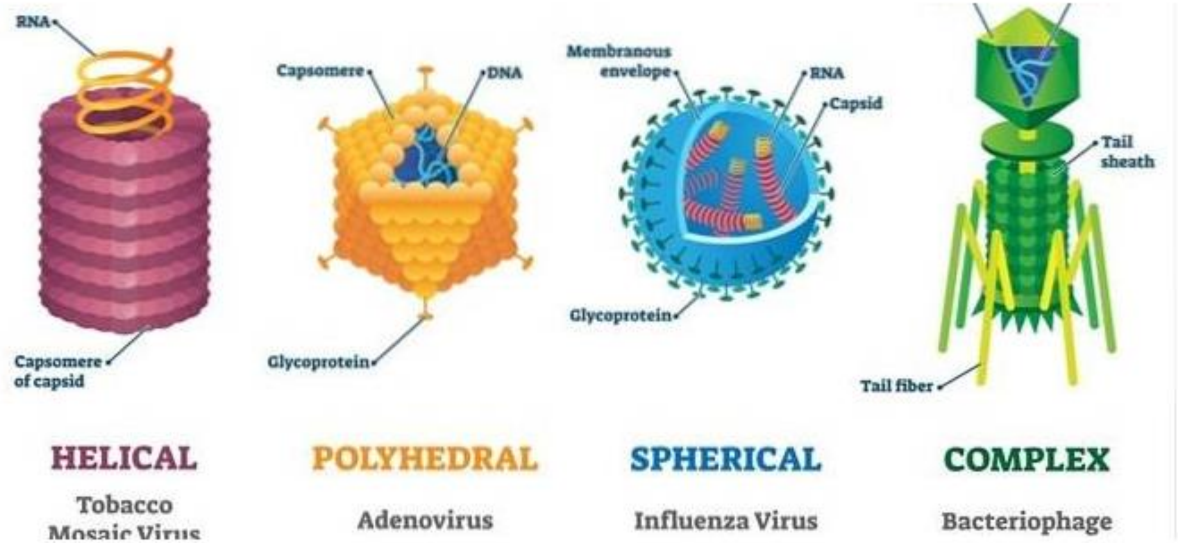
Characteristics: highly infectious nature and survival in drastic conditions such as high acid pH and low temperatures

Structural elements of viruses

A complete virus particle, known as a ***virion***, consists of **nucleic acid** surrounded by a protective coat of protein called a **capsid**. These are formed from protein subunits called capsomeres. Viruses can have a **lipid "envelope"** derived from the host cell membrane.

Some of the morphological types:

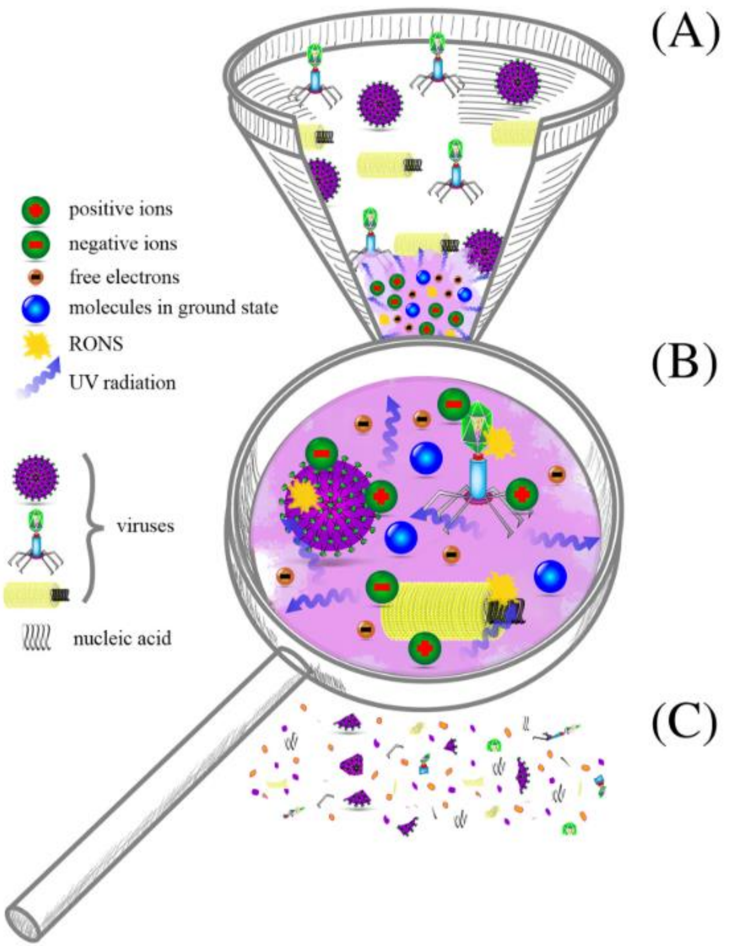
1. Helical
2. Icosahedrical
3. Enveloped (SARS-CoV-2)
4. Complex



Plasma viral inactivation

Modes of virus inactivation

- Changes in lipid components from the envelope
- Degradation of the capsid proteins, which precedes the degradation of nucleic acids
- Disruption of virus integrity at both the structural and genomic levels by affecting both proteins and nucleic acids



Filipić, A., Gutierrez-Aguirre, I., Primc, G., Mozetič, M., & Dobnik, D. (2020).

(A) Morphologically different viruses treated with CP
(B) Close-up of CP properties responsible for virus inactivation
(C) Residual virus particles and nucleic acids after CP treatment,

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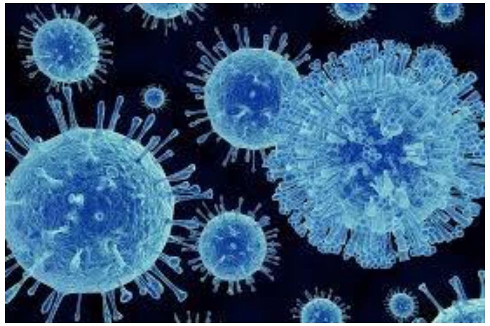
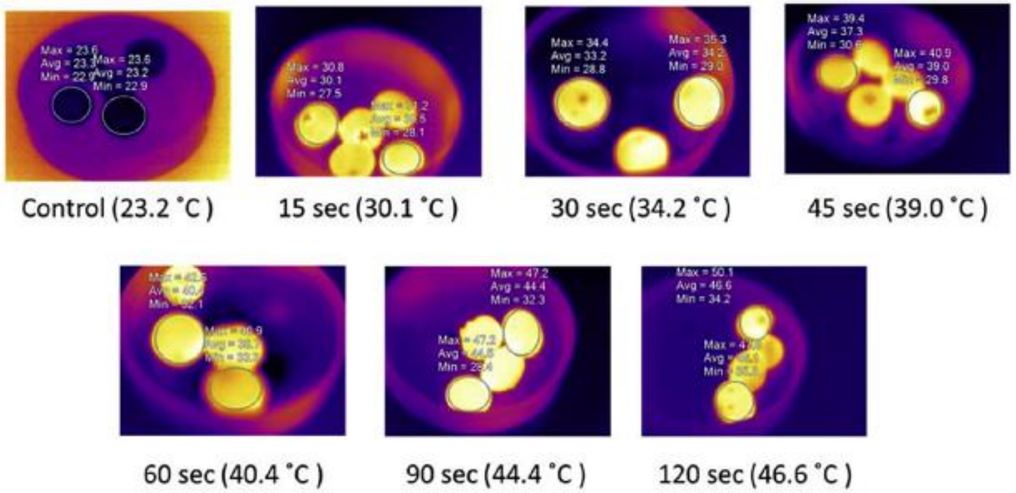
Plasma treatments for the decontamination of viruses

Lacombe et al. (2017)

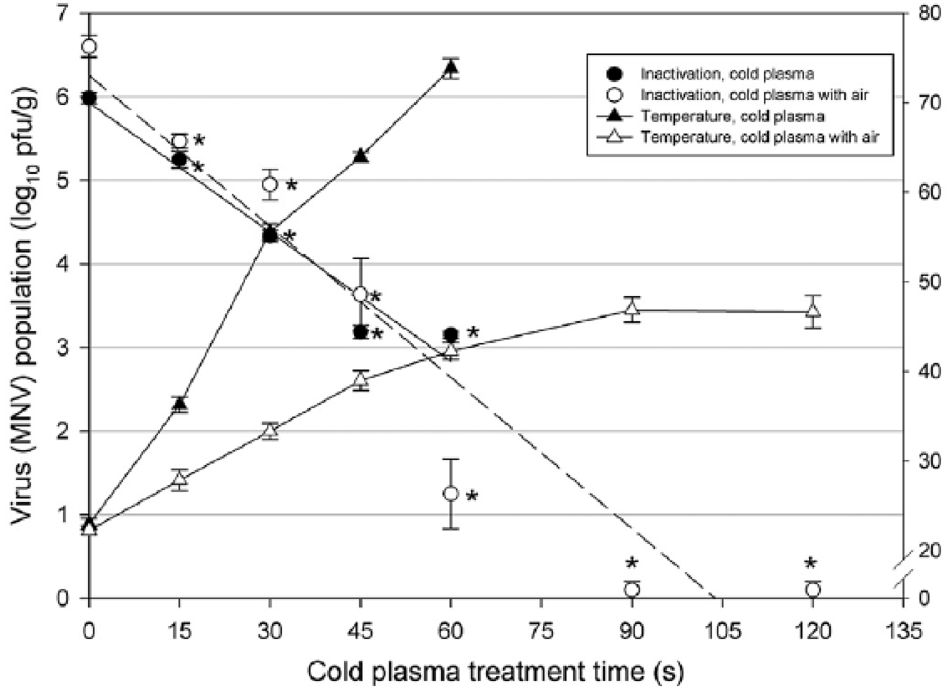
Inoculus of Tulane virus and Norovirus on bluberries

plasma jet
pulse frequency: 47 kHz
power consumption: 549W.





Thermal images of cold plasma treatment: 4 cfm plasma jet plus 7 cfm air.



Proposed mechanism:
ozone and ROS inactivate viruses first damaging the polypeptide chains causing a perforation in the viral capsid

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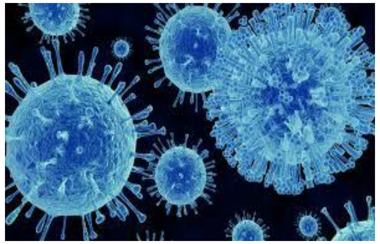
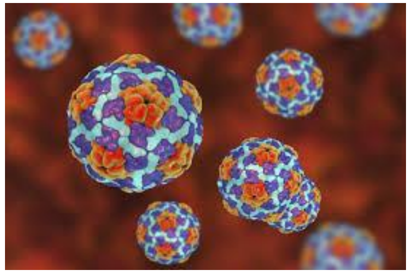
Plasma treatments for the decontamination of viruses

DIPARTIMENTO
SICUREZZA ALIMENTARE, NUTRIZIONE
E SANITÀ PUBBLICA VETERINARIA

PLASMA FOOD
PRIN 2017



NOROVIRUS
(MNV – strain MNV-1
3.5 log $TCID_{50}$/ml)

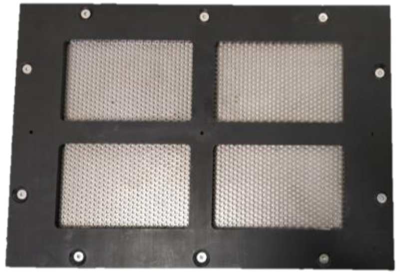


HEPATITIS A VIRUS
(HAV – strain HM 175
3.6 log $TCID_{50}$/ml)

Artificial inoculum

Strawberries

SDBD



Surface Dielectric Barrier Discharge (SDBD),

4 rectangular high-voltage electrodes (115 cm^2 each)
Mica dielectric layer over 2 mm thick

Sinusoidal waveform, 6 kV, 23 kHz.

NOx-mode=332,9 W up to 30 min

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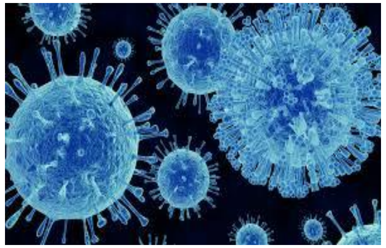
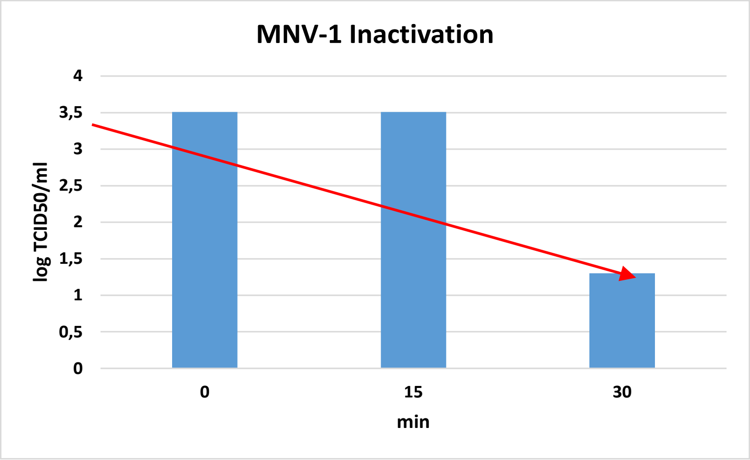
Plasma treatments for the decontamination of viruses

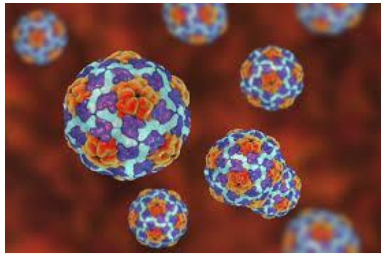
(Unpublished data)

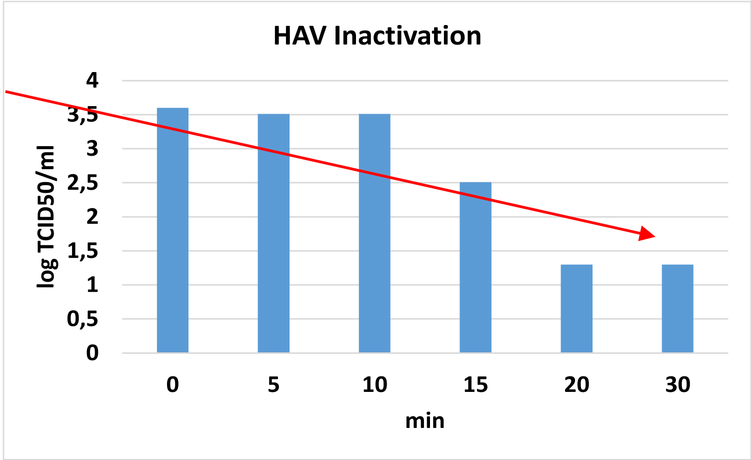
NOROVIRUS





HEPATITIS A VIRUS





Reduction below the detection level (20 TCID50/ml) was achieved corresponding to 1.2 log for MNV and to 2.3 log for HAV

Application of cold plasma in the food sector

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    - viruses
    - mycotoxins
    - pesticides
    - allergens
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- Legislative aspects

Plasma treatments for the decontamination of mycotoxins

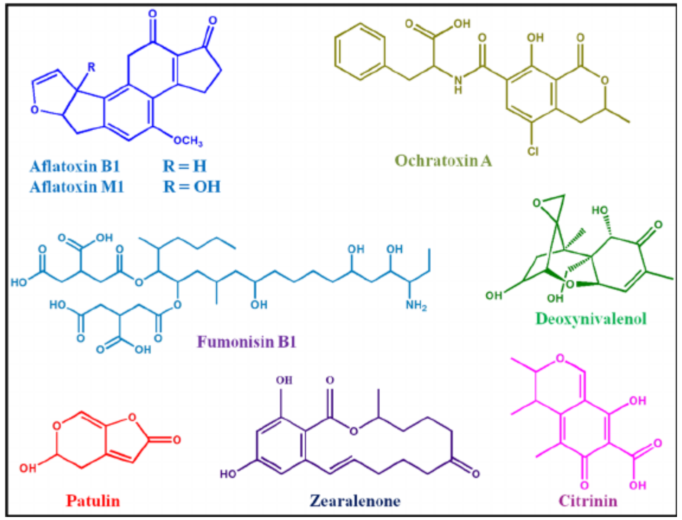
Many species of filamentous fungi have the ability to produce **toxic secondary metabolites** known as mycotoxins. The term mycotoxins is used only for toxic substances produced by fungi related to **food and feed products**; it does not include toxins produced by mushrooms

Today about **400 structurally different mycotoxins** have been discovered divided into the following main groups:

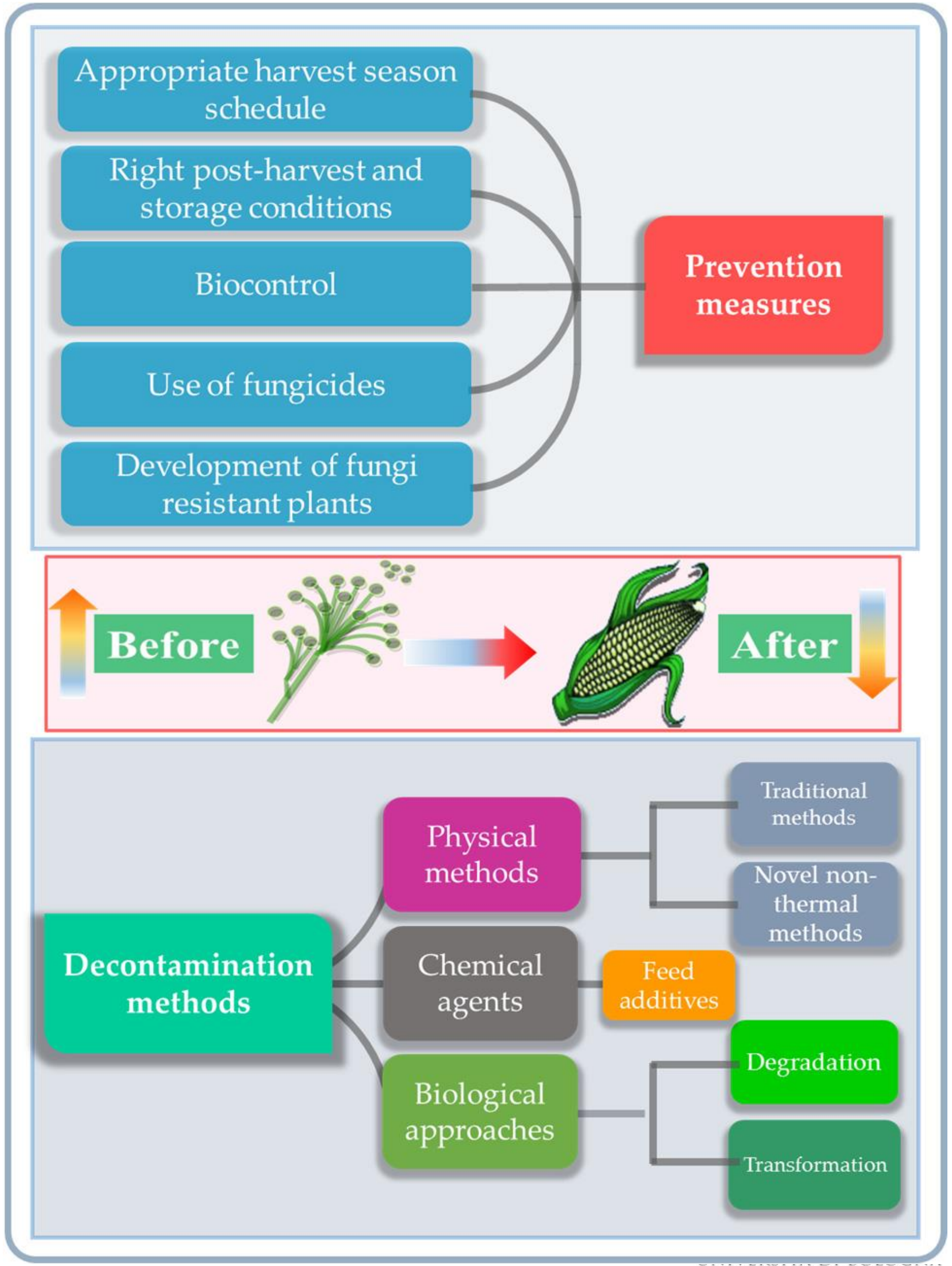
(i) **aflatoxins** produced by Aspergillus species and **ochratoxins** produced by both Aspergillus and Penicillium species;
(ii) **trichothecenes, zearalenone** and **fumonisins** produced by Fusarium species;
(iii) and ergot **alkaloids**, produced by Claviceps and other species

In favorable environmental conditions the Aspergillus spores germinate and subsequently colonize various types of foods, such as **grains, corn, peanuts and other oil seeds.**

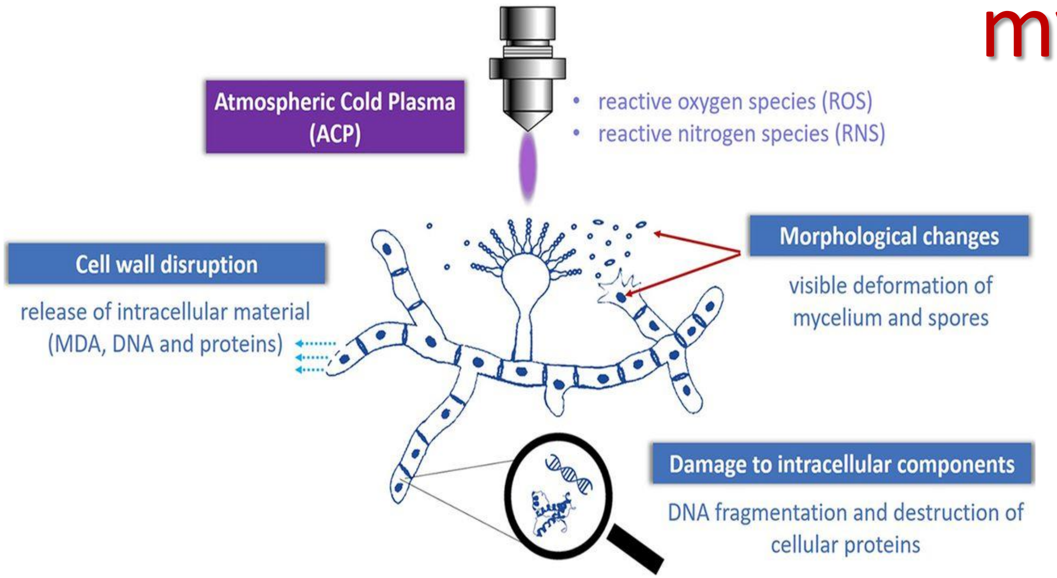
High levels of aflatoxins induce acute hepatic necrosis, liver carcinoma, and are classified as mutagenic and carcinogenic, being able to intercalate with DNA and being able to alkylate its bases through its more oxidized metabolites.



Overview of currently available mycotoxin prevention and decontamination measures taken before and after contamination of food by fungi and mycotoxins.



Plasma treatments for the decontamination of mycotoxins



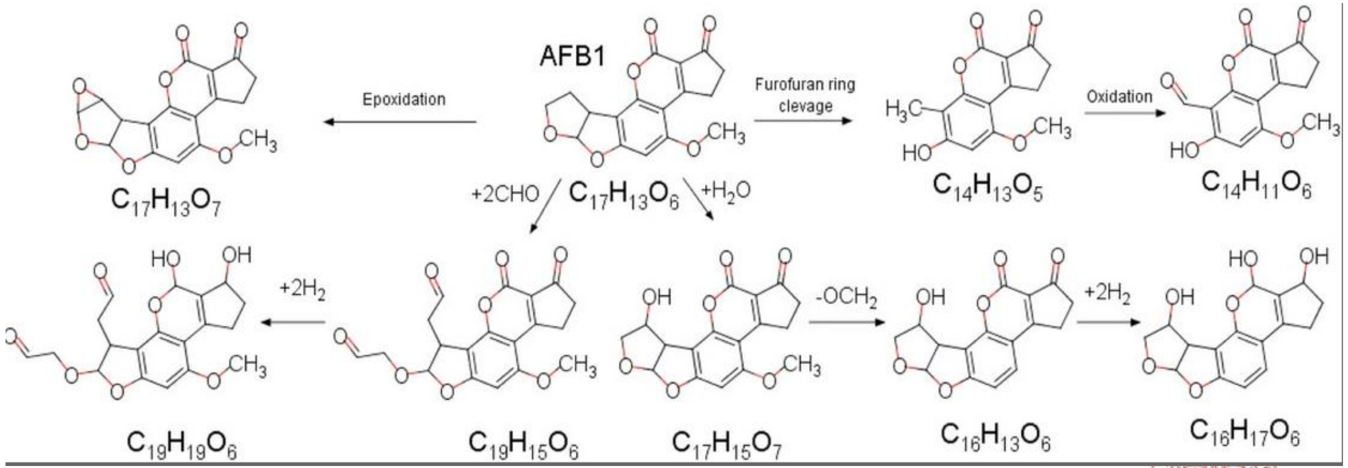
Approach 1: inactivation of fungal species

Various mechanisms related to structural and metabolic changes

Approach 2: chemical degradation of mycotoxins

Structure modification during plasma treatment: related to the presence of UV photons, ozone or reactive ions and electrons.

Possible significant contributions of different reactive species or to the synergistic action of these species ➔ the effectiveness of mycotoxin degradation of cold plasma technology is greater than that of ozone or UV treatments only



Degradation pathways of aflatoxin (AFB1) on exposure to high voltage atmospheric cold plasma. Adapted from Shi et al. (2017).

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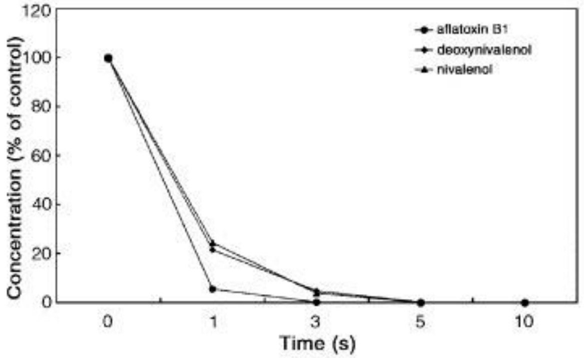
Plasma treatments for the decontamination of mycotoxins

Reduction of 97 and 99% in the growth of Aspergillus parasiticus and Aspergillus flavus.
40 W 15 min and 60 W 12 min plasma treated samples: more than 70% and 90% reduction in aflatoxin B1

Devi et al. 2017

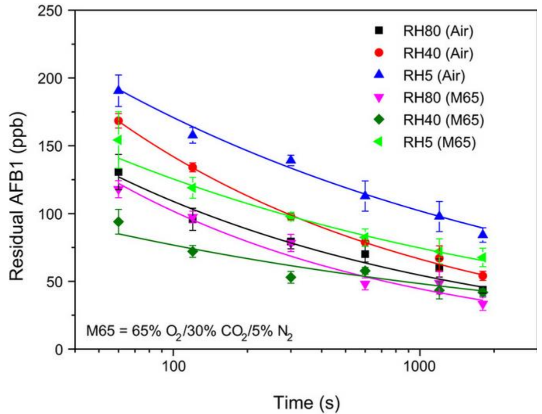
Reduction of 3-log for both Aspergillus spp. and Penicillum spp. 15 min of SF6 plasma on dry legumes

Selcuk et al. 2015



Complete inactivation of aflatoxin B1 (AFB1), deoxynivalenol (DON) and nivalenol (NIV) with a mocorwave plasma using Argon at atmospheric pressure

Park et al. 2007



Degradation of aflatoxin in contaminated corn kernels subjected to atmospheric pressure cold plasma DBD working a t90 kV, discharge gap 44 mm

Shi et al (2017)

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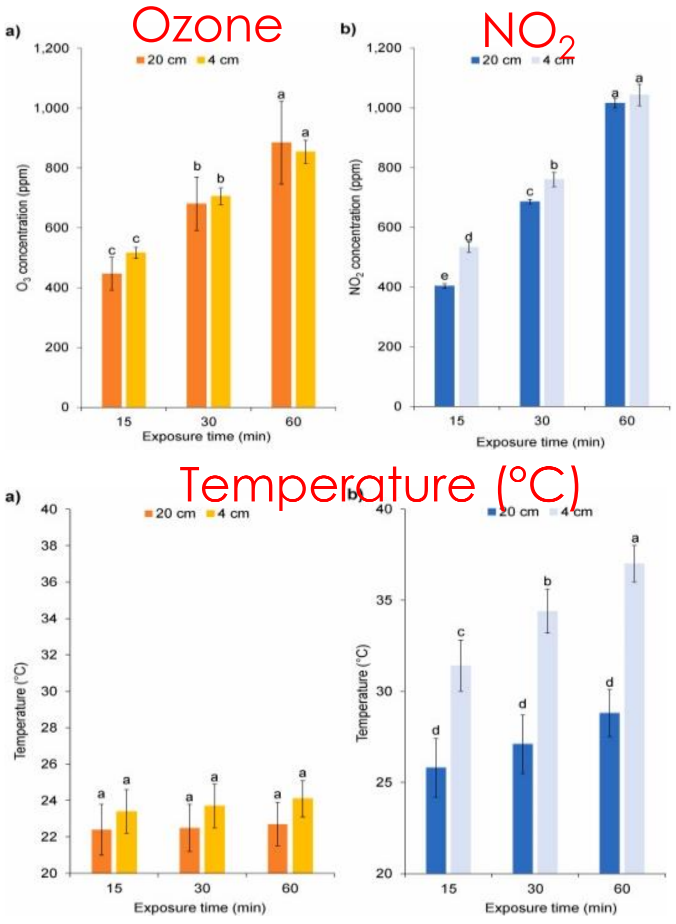
Degradation of mycotoxins in pistachio kernels

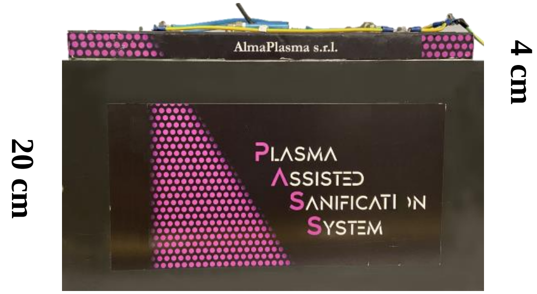


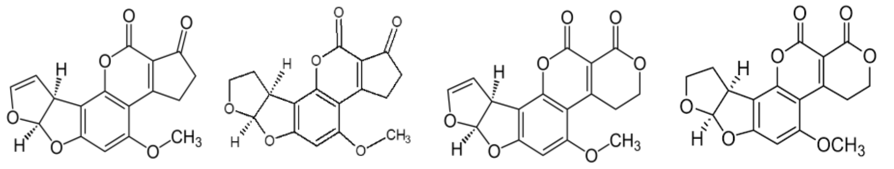
- Surface Dielectric Barrier Discharge (SDBD)
- sinusoidal waveform,
- peak voltage: 6 kV
- fixed frequency: 23 kHz

NOx regime: duty cycle equal to 100% (425.35 ± 25.79 W), **O3 regime**: duty cycle equal to 10% (42.54 ± 2.58 W)

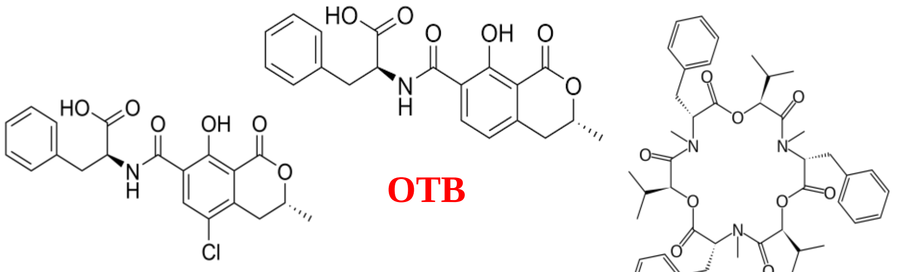
Exposure time: 15, 30, 60 min

Distance from source: 4 cm, 20 cm





AFB1 AFB2 AFG1 AFG2

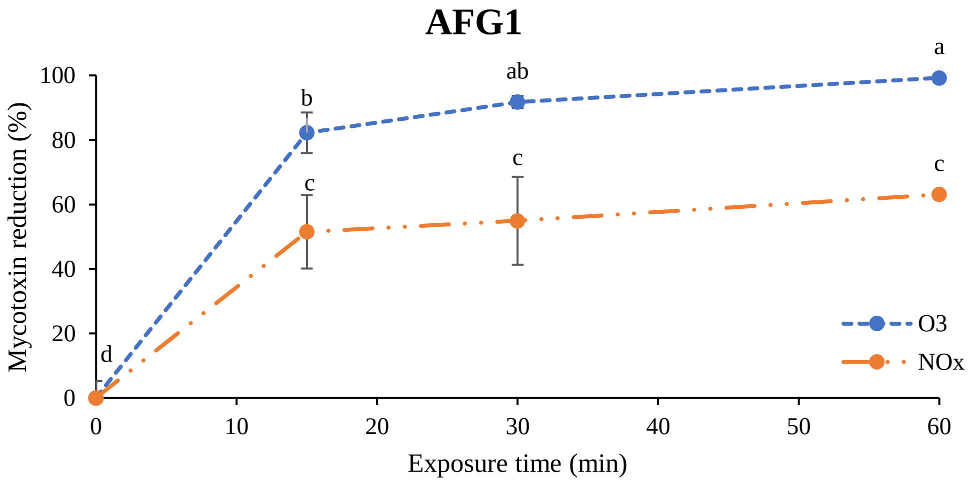


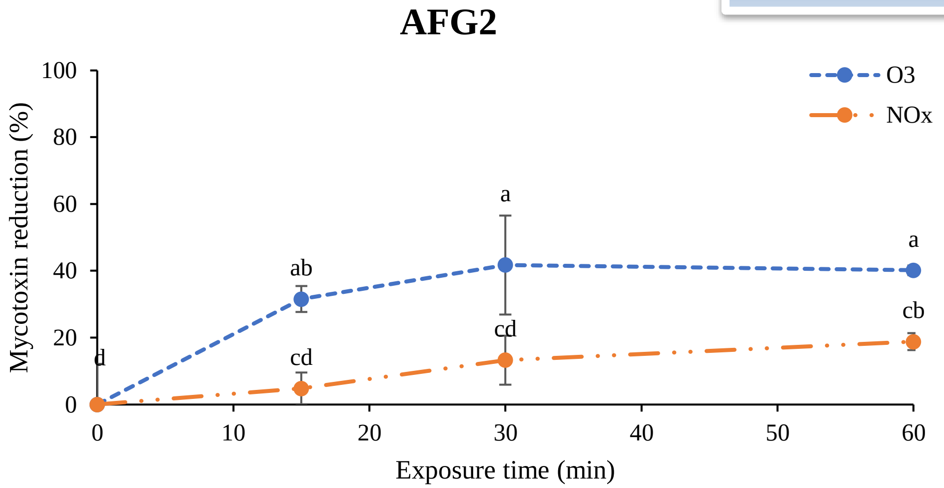
OTA OTB BEA

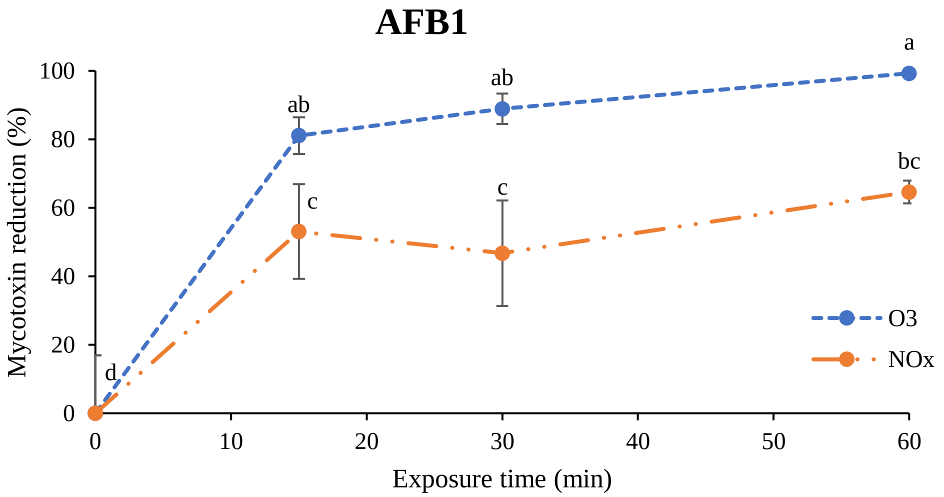
Laika, J., Viteritti, E., Molina-Hernandez, J. B., Sergi, M., Neri, L., Laurita, R., Tappi, S., Ricci, A. & Chaves-López, C. (2024).

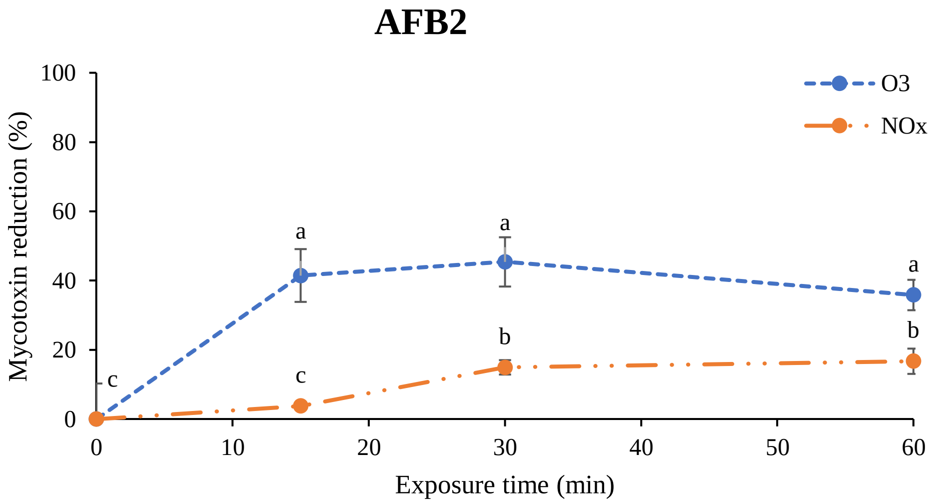
Degradation of mycotoxins in pistachio kernels
Effect of the plasma regime

O_3 – REGIME MORE EFFICIENT









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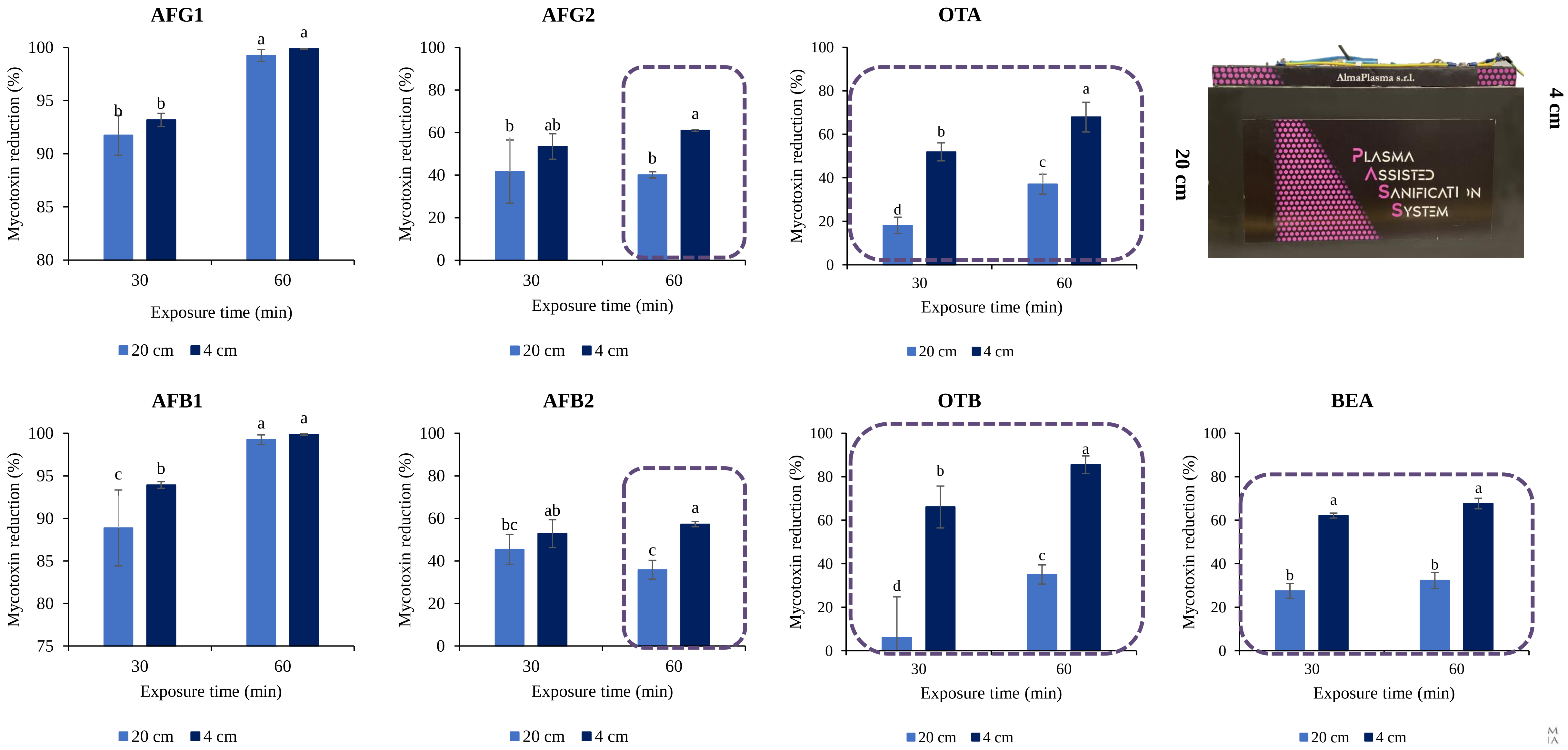
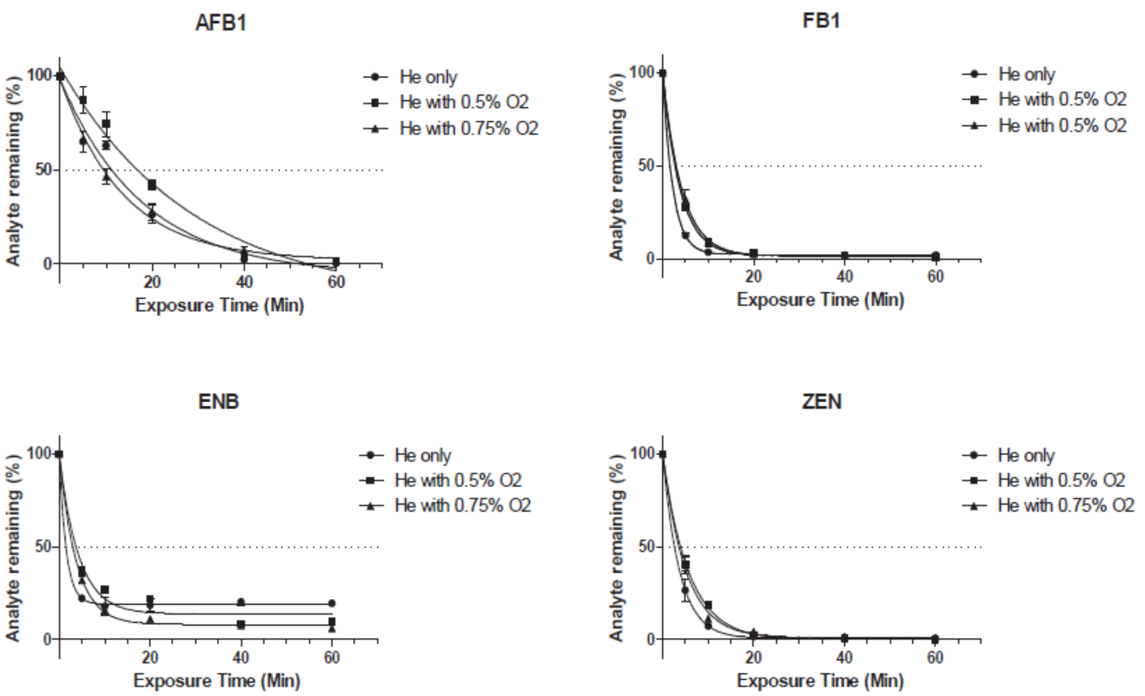
Degradation of mycotoxins in pistachio kernels
Effect of distance from source



Plasma treatments for the decontamination of mycotoxins



Degradation products
untargeted UPLC-HRMS analysis

Cytotoxicity
human hepatocarcinoma (HepG2)

Wielogorska et al. (2019).

Results
no increase in cellular toxicity in HepG2 cell line after CAPP treatment, possible increased toxicity should still be investigated in other cell assays or in vivo to fully confirm CAPP safety, especially in produce destined for human consumption.

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Application of cold plasma in the food sector

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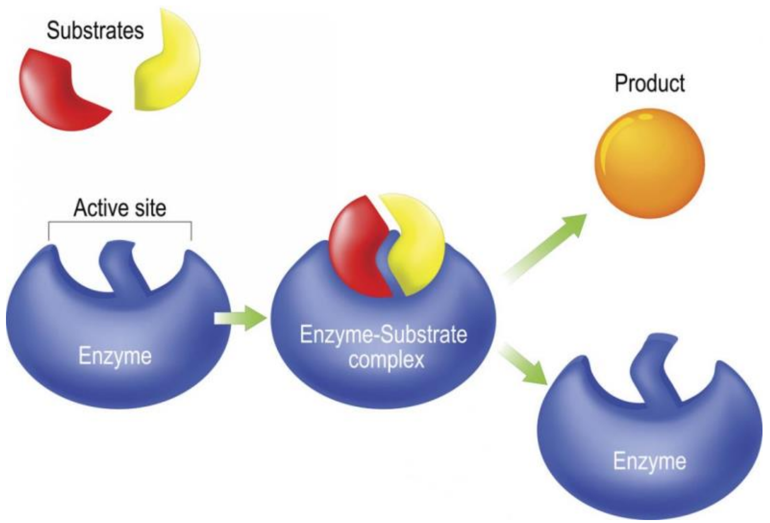
Enzymes

Enzymes are ***protein*** molecules that are present in all living things.

They speed up and target **chemical reactions**, in many cases increasing the rate of reaction millions of times.

For example, they aid digestion, metabolise and eliminate waste in humans and animals, and play a crucial role in muscle contraction.

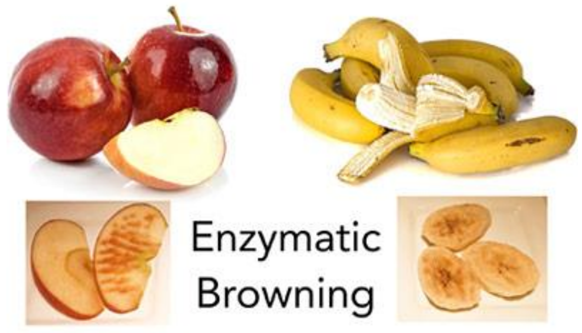


Enzymes in food

Enzymes can be **favourably exploited** by the food industry.

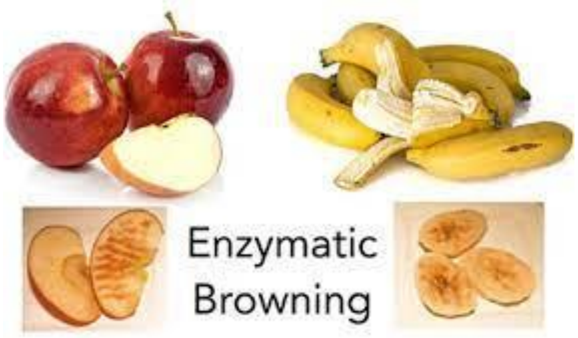
However, the **residual activity** of many enzymes is **detrimental to the quality** of foods, resulting in effects such as **browning**, **off-flavour** and **loss of vitamins**.

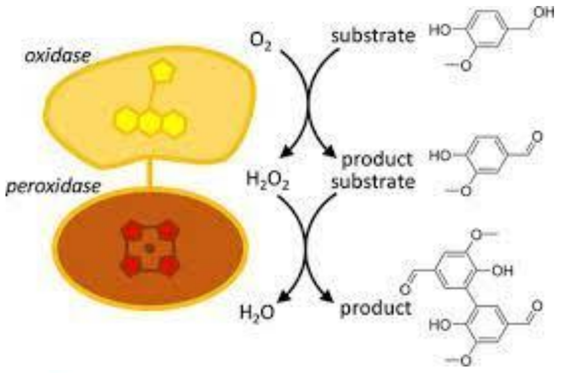
In certain cases, validation of processing conditions can only be achieved when the critical parameters of plasma processes assure inactivation of not only micro-organisms but also enzymes



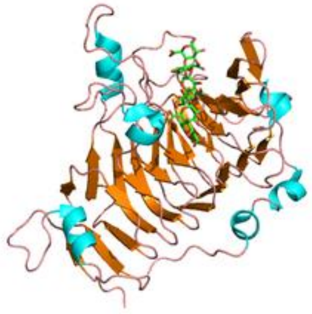
Examples of degradative enzymes

Polyphenol oxidase (**PPO**; also **polyphenol oxidase i, chloroplastic**), an enzyme involved in fruit browning, PPO catalyses the rapid polymerization of *o*-quinones to produce black, brown or red pigments (polyphenols).





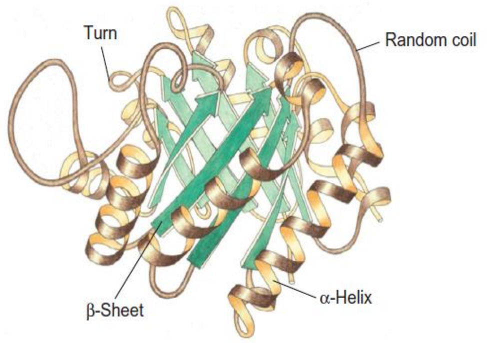
Peroxidase is a common, heat stable enzyme that is found in plants and plant products, including fruits, vegetables and grains. There is a direct relationship between the peroxidase activity and the development of off-flavours, off-odours and off-colours in food



Pectinesterase is a ubiquitous cell-wall-associated enzyme that presents several isoforms that facilitate plant cell wall modification and subsequent breakdown.

Effect on enzymatic activity

PLASMA TREATMENT
ROS, RNS



PPO
POD
Lisozime
…

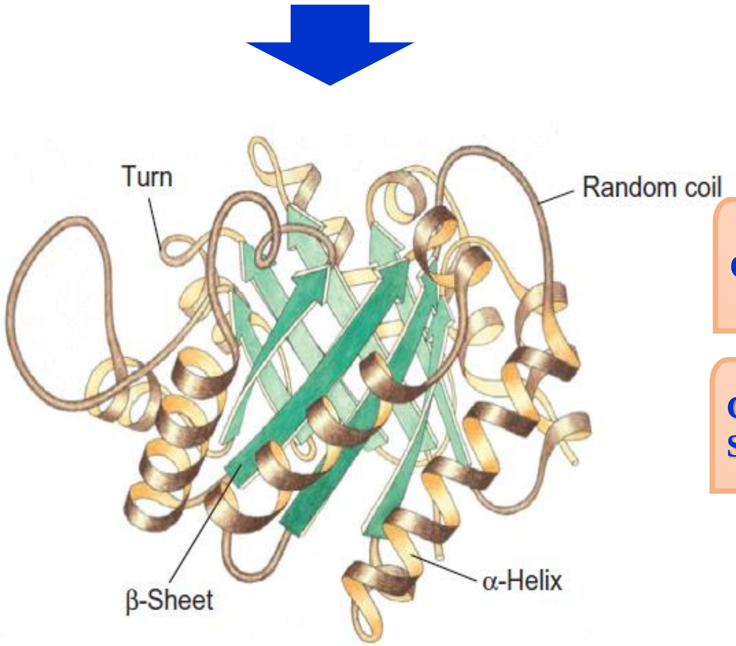
Catalase
Lipase
PAL
SOD
…

Reduction of quality degradation

This contrary effect can thus be utilized to achieve different purposes during food processing.

Increased seed germination, Production of polyphenols

ROS, RNS



Hypothesis on the enzymatic inactivation mechanism

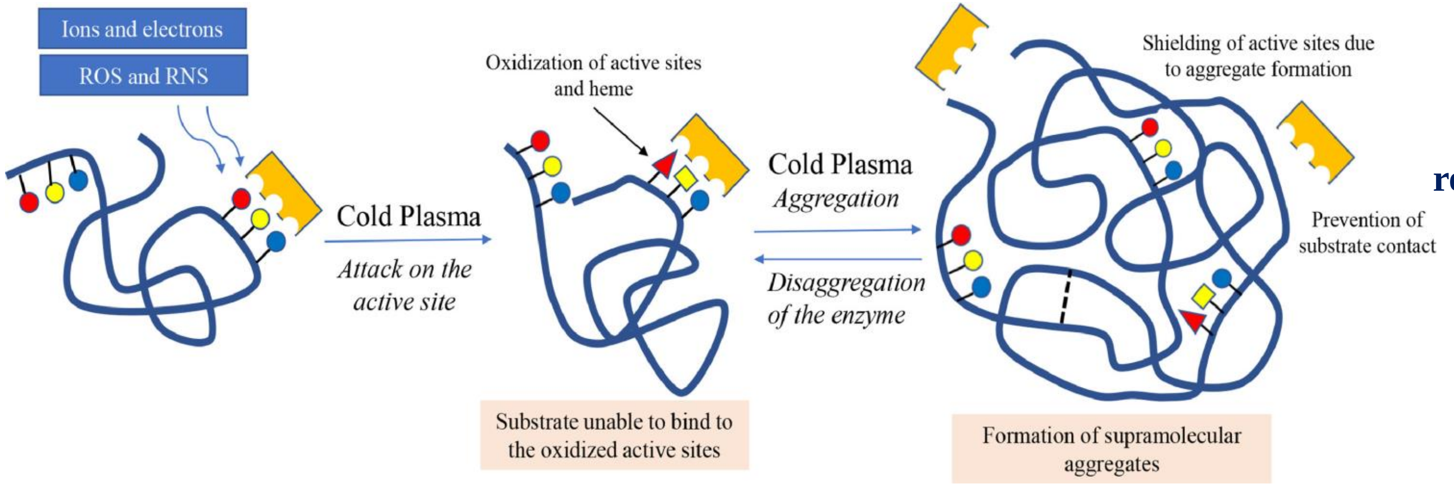
(Misra et al., 2016)

OXIDATION OF LATERAL AMINO ACIDS

CHANGES OR LOSS OF THE TERTIARY STRUCTURE

hydroxyl radicals (OH), superoxide anionic radicals (O2), hydroperoxy radicals (HOO) and nitric oxide (NO) ➔ chemical modifications of the most reactive amino acids in the side chains of the protein (cysteine, aromatic rings of phenylalanine, tyrosine and tryptophan) ➔ alteration of the structure ➔ loss of enzymatic activity

(Takai et al., 2012)



decomposition of C-H, C-N and N-H bonds in proteins resulting from oxidation by reactive oxygen-containing species ➔ loss of structure *β*

(Misra et al. 2016)

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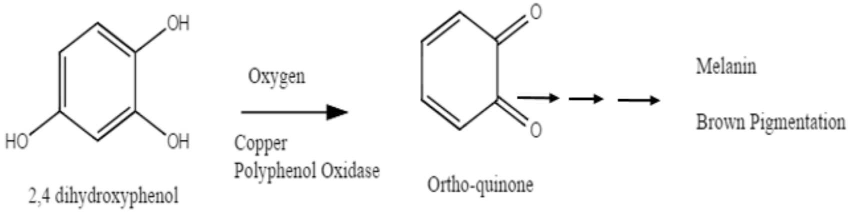
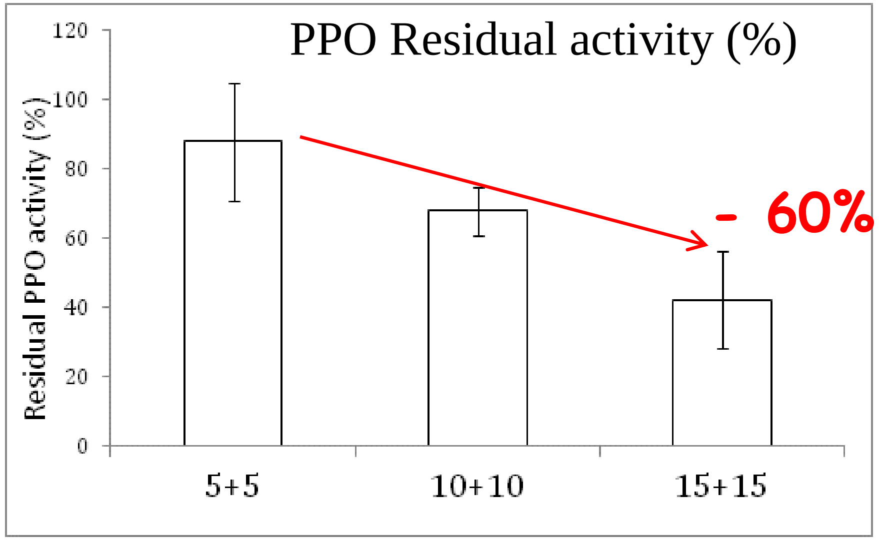
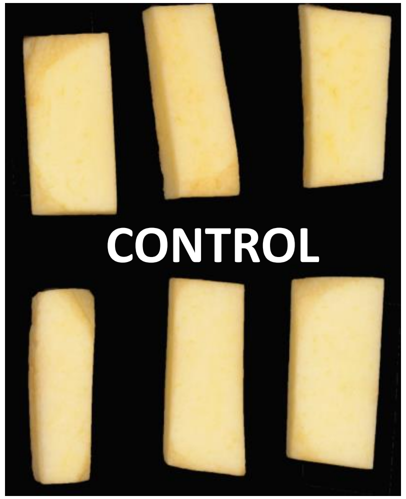
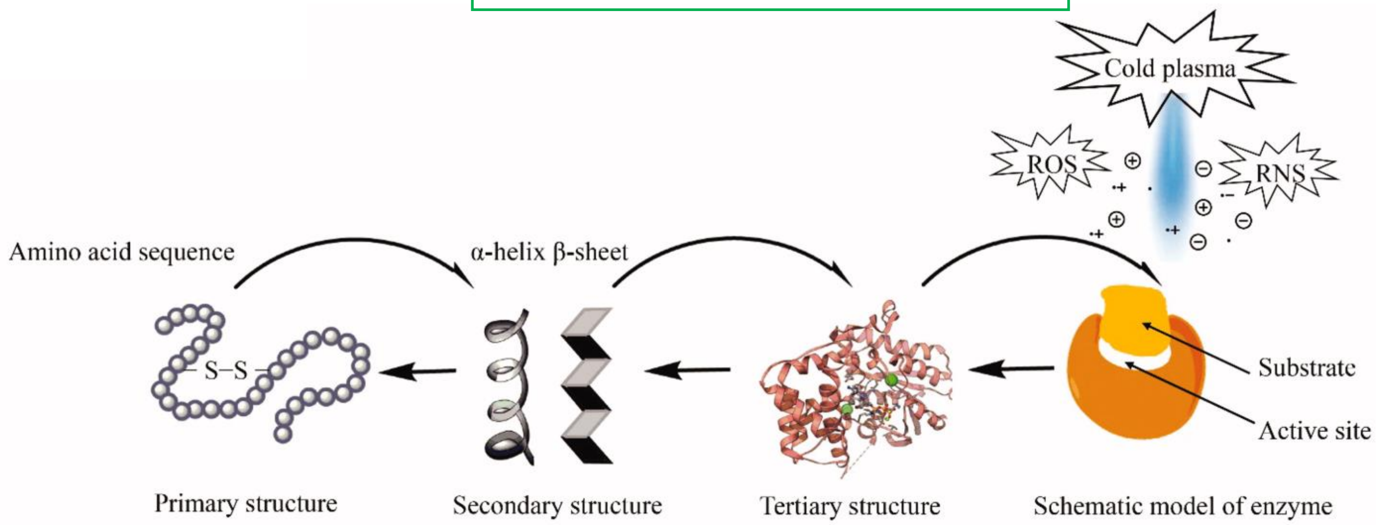
Inhibition of enzymatic browning





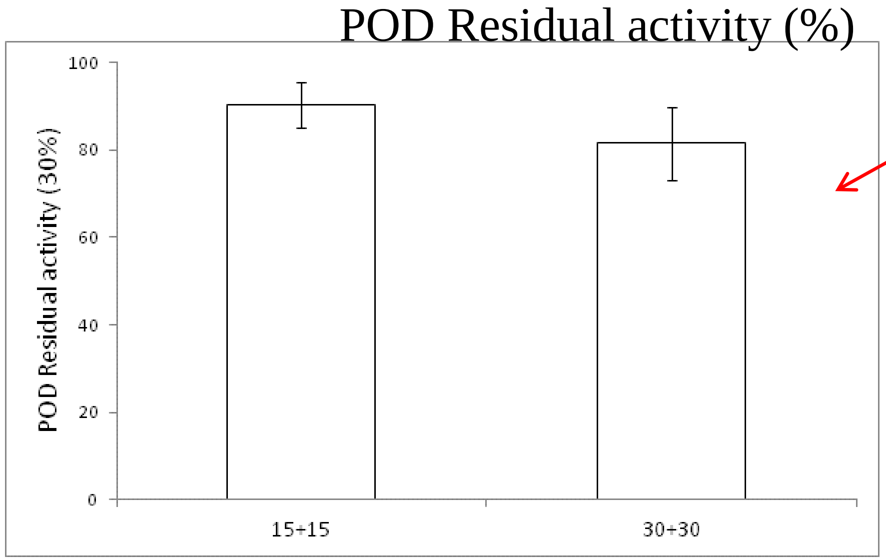
Tappi et al., 2014



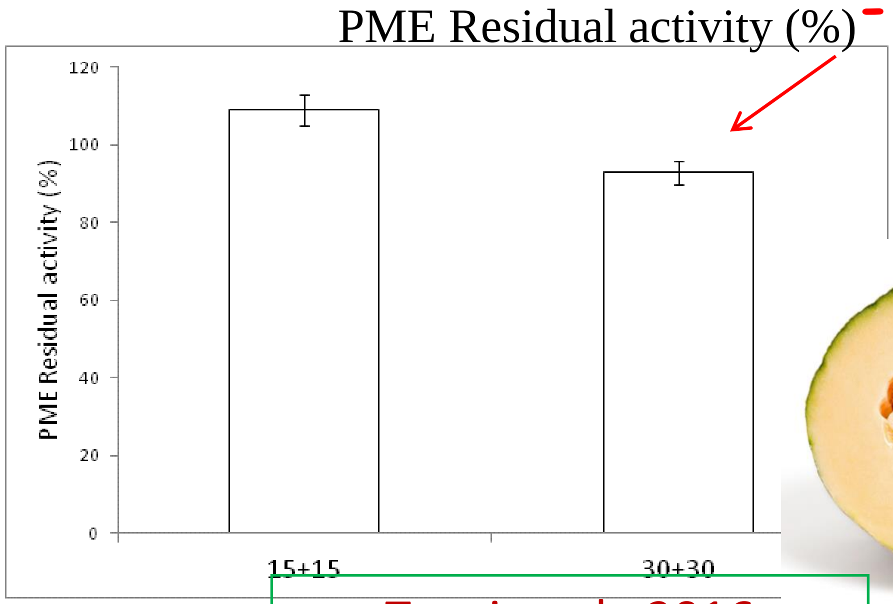


From Han, Y., Cheng, J. H., & Sun, D. W. (2019)

Inhibition of enzymatic activity in fruit



- 17,4%

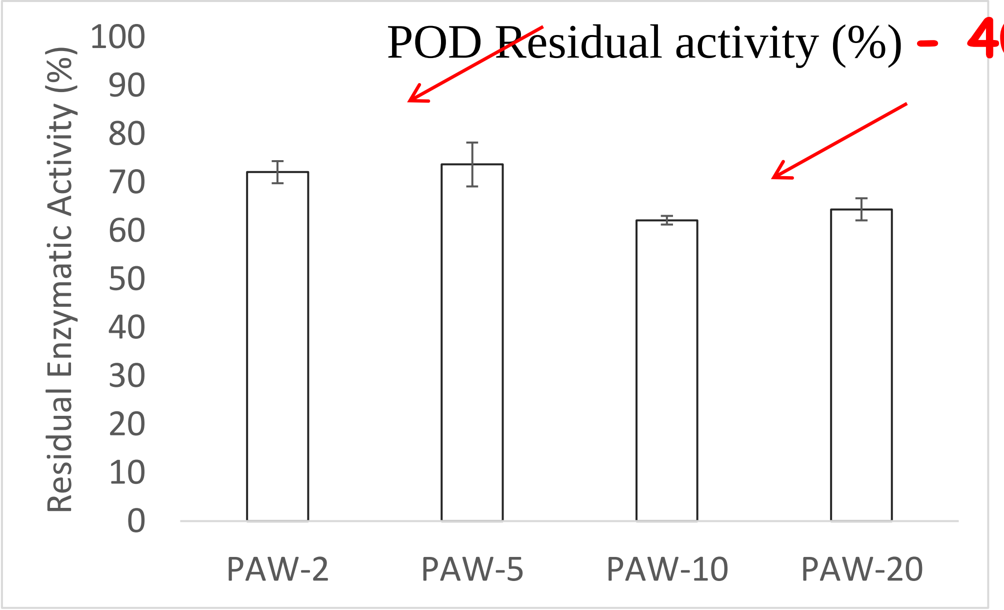


- 6%

Tappi et al., 2016

- 30%

- 40%



High variability depending on type of enzyme and on the matrix!!

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Role of the matrix on enzymatic inactivation

Laika, J., Sacchetti, G., Sabatucci, A., Molina-Hernandez, J. B., Ricci, A., Laurita, R., ... & Neri, L. (2023).

effect of different CAP exposures on the activity of **horseradish peroxidase (HRP)**

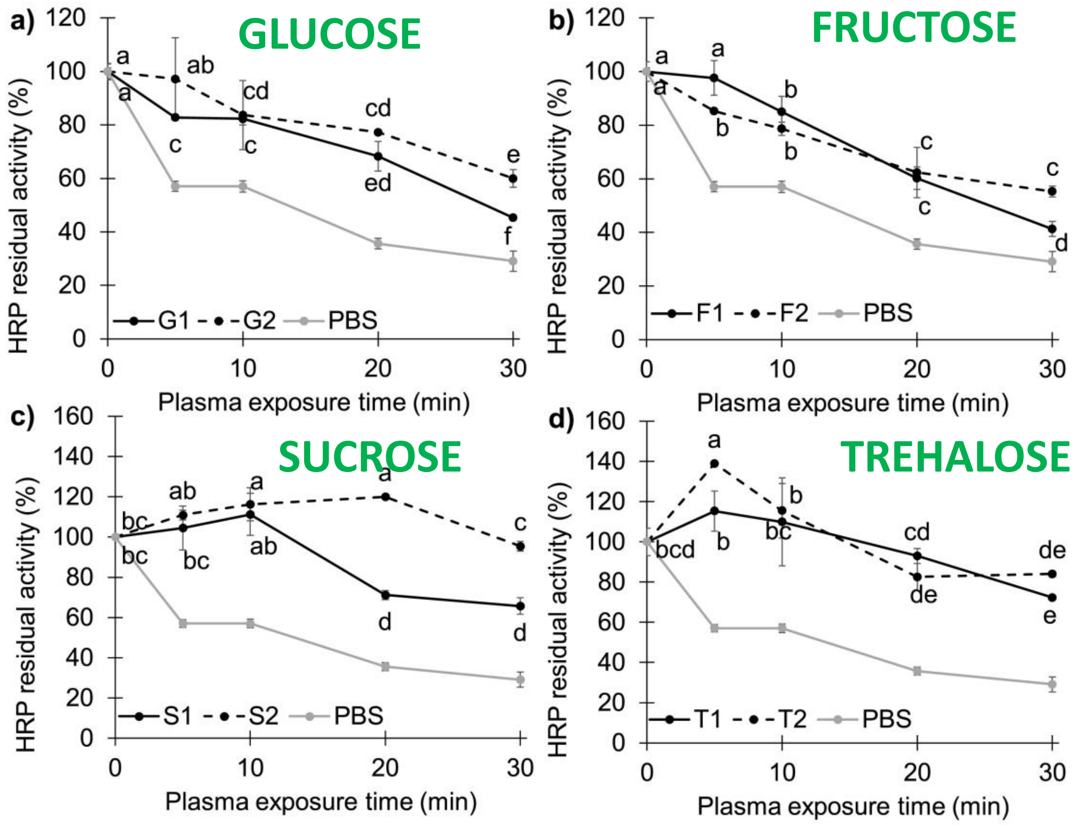
- phosphate buffer and in model systems
- with different concentrations of monosaccharides and disaccharides

<u>mono and disaccharides</u>: naturally found in fruits and vegetables and widely employed in food and beverage industries

diverse protective effects of sugars on HRP

- ability of sugars, and especially of disaccharides, to scavenge free radicals with a concentration-dependent effect
- prevent denaturation phenomena through the suppression of perturbation of the hydration structure of the protein

HRP inactivation kinetic in PBS system and sugar model systems.



Enhancement of enzymatic activity

Reactive species (ROS and/or RNS) can be generated and interact with the surfaces of foods.

In this condition, a **physiological response** occurs.

A **complex antioxidant enzymatic system** converts these reactive species into less harmful compounds for vegetable cells.

significant increase in the activity and genes expression of

- ascorbate peroxidase,
- Catalase (CAT) , and
- superoxide dismutase (SOD)
- phenylalanine ammoniumlyase (PAL)

← **activation of the physiological antioxidant system**

during storage of different fruits treated with plasma

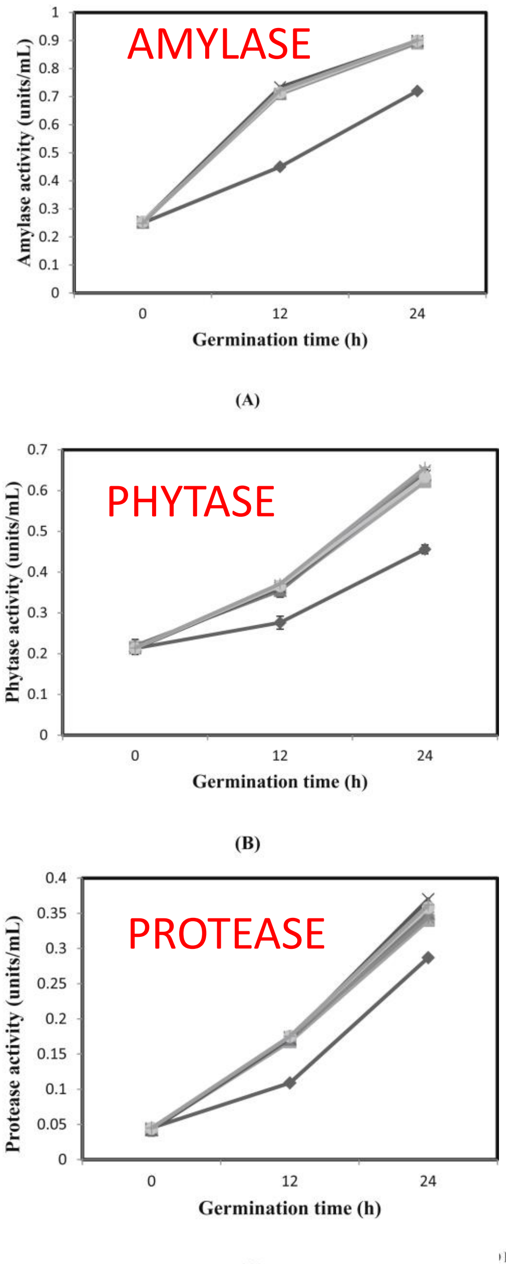
Increased seed germination

Cold atmospheric plasma treatment for 1 min showed a strongly improved chickpea seed germination (89.2%) and speed of germination
(Mitra et al., 2014)

Cold plasma enhance the seed germination and seedling growth
(Bormashenko et al., 2012, Sera et al., 2008, Zhou et al., 2011)

Plasma enhanced the seed germination and seedling growth rates which might be associated with the increased water uptake of seeds
(Ling et al., 2014)

The plasma treatment can increase the roughness of the seed surface, and finally lead to increase in the hydrophilicity of the seed by changing the chemical structure, which may account for the increase in water uptake of seed
(Bormashenko et al., 2012)



(A)

(B)

(C)

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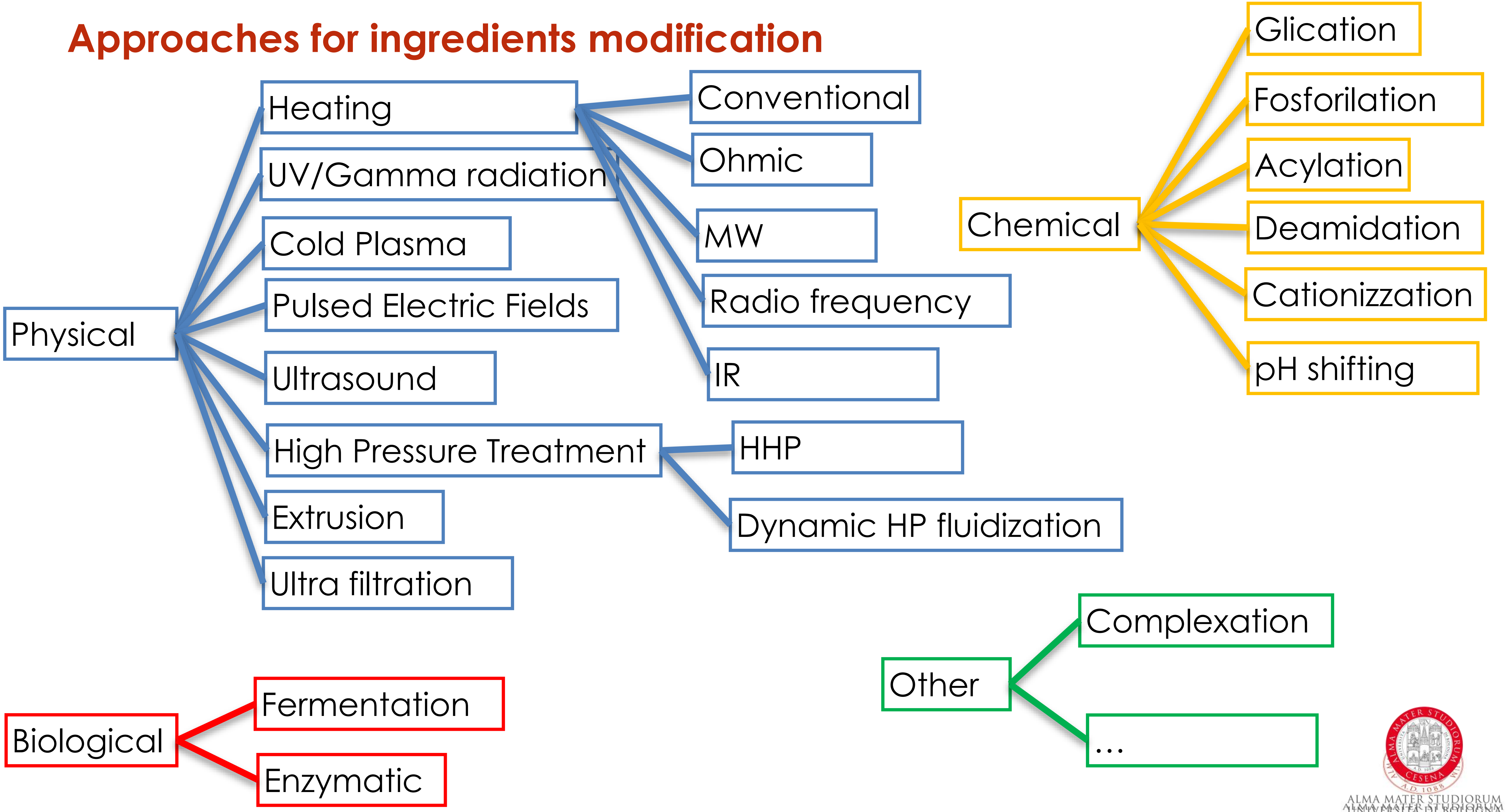
Approaches for ingredients modification



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CAMPUS DI CESENA

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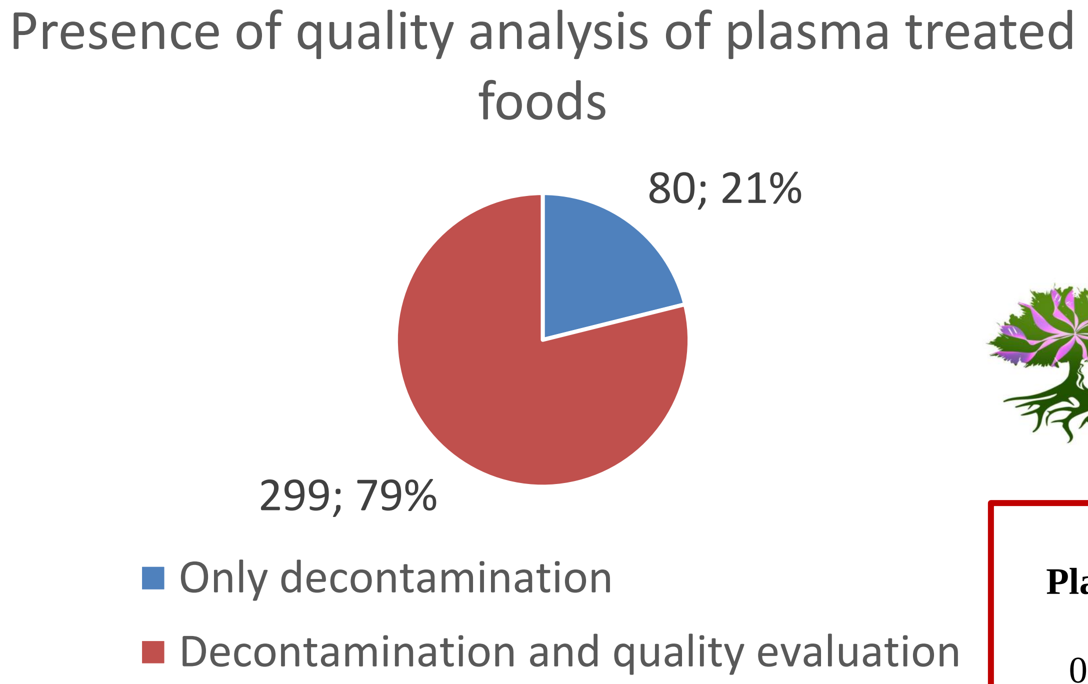
Effect of cold plasma on food quality

Quality of foods:

- Organoleptic properties
- Nutritional value
- Techno-functional properties
- Physico-chemical properties



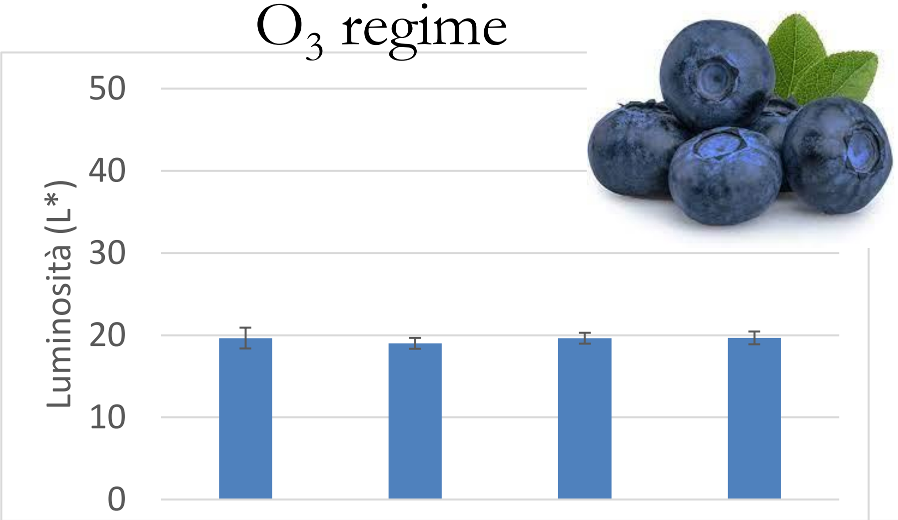
CA19110
Plasma applications for smart and sustainable agriculture

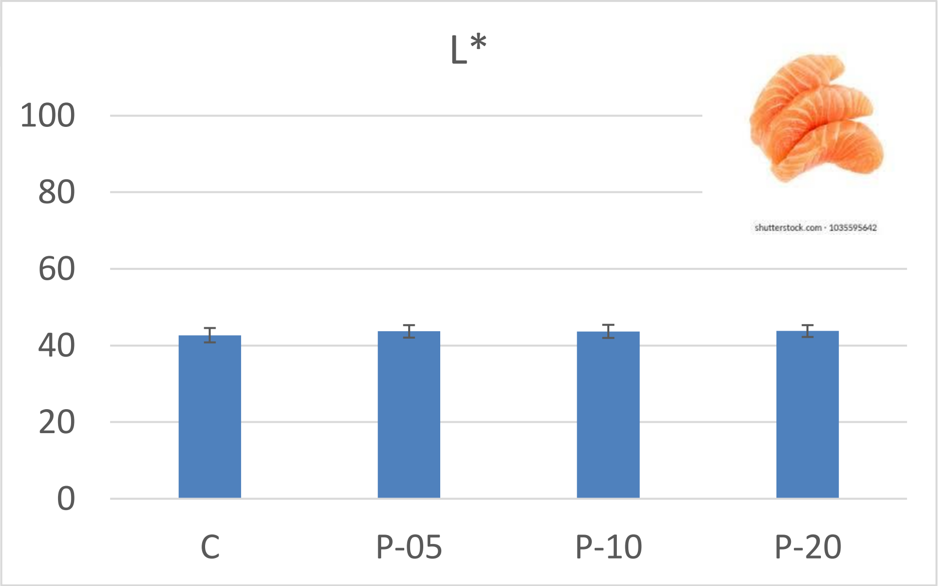
cost
European Cooperation in Science and Technology

Virtual Mobility Grant
Plasma effect on safety and quality of foods
08/08/2023 to 20/10/2023

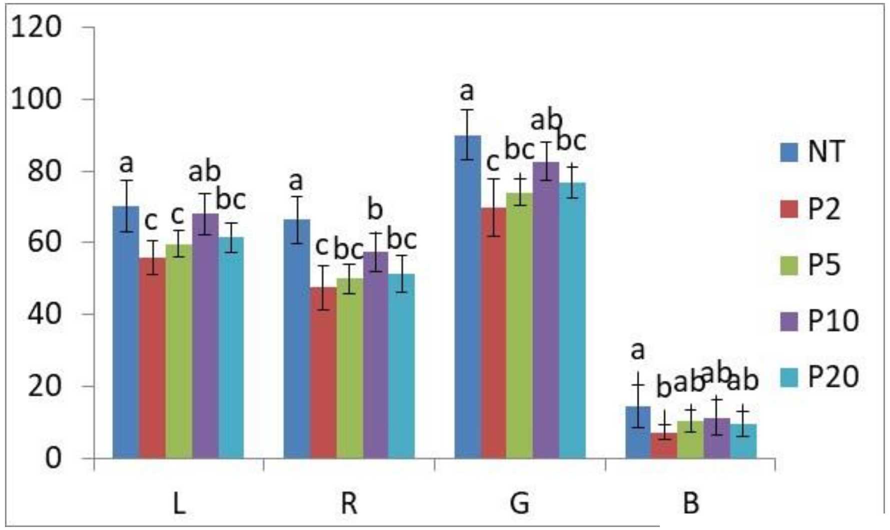
Effect of plasma on colour of food products

PASS prototype
O_3 regime





PAW immersion

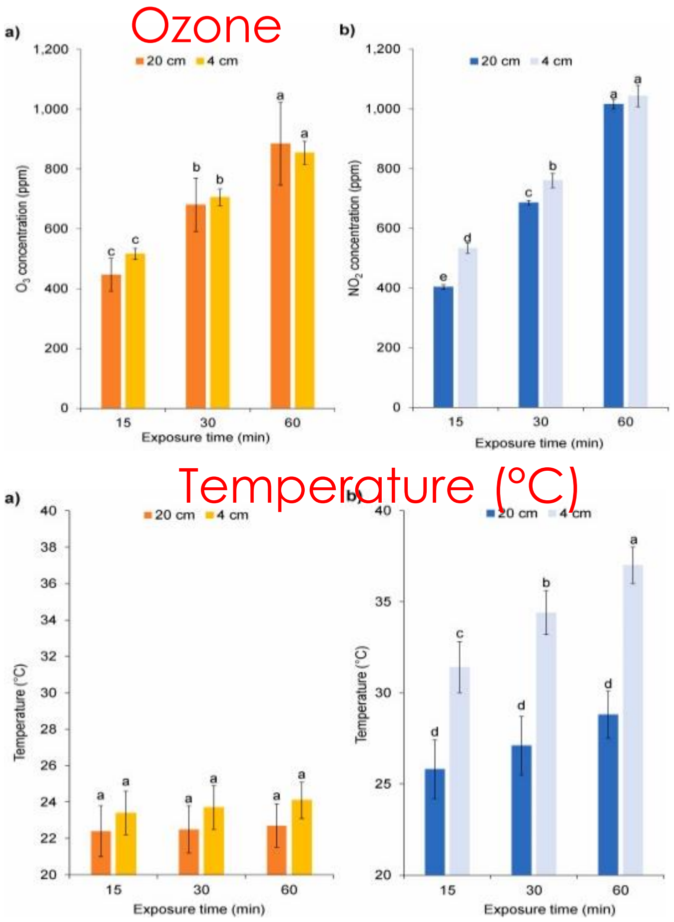


Significant changes in colour coordinates

Laurita et al., 2021

Perceptible by human senses?

Effect of plasma on visual quality of food products

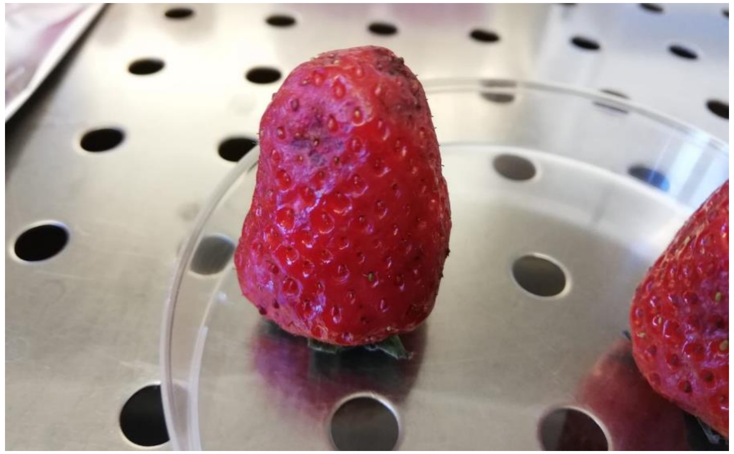


- Surface Dielectric Barrier Discharge (SDBD)
- sinusoidal waveform,
- peak voltage: 6 kV
- fixed frequency: 23 kHz

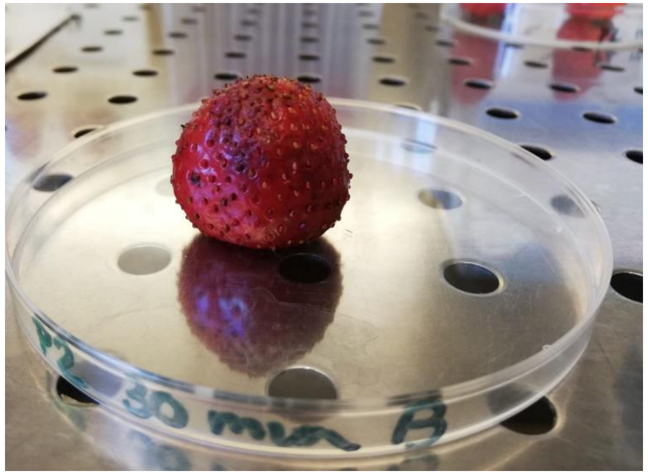
NOx regime: duty cycle equal to 100% (425.35 ± 25.79 W), **O3 regime**: duty cycle equal to 10% (42.54 ± 2.58 W)

Distance from source: **20 cm**

Untreated sample



60 min of O_3 treatment



60 min of Nox treatment

Effect on visual quality of baby leaves treated with PAW during storage

Appearances of salads treated and untreated during storage period
(4 °C until day 4, and 15 °C until day 12)

CO-FRESH

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101000852

(Unpublished data)

Control t_0

Control t_{12}

IPO2 t_{12}

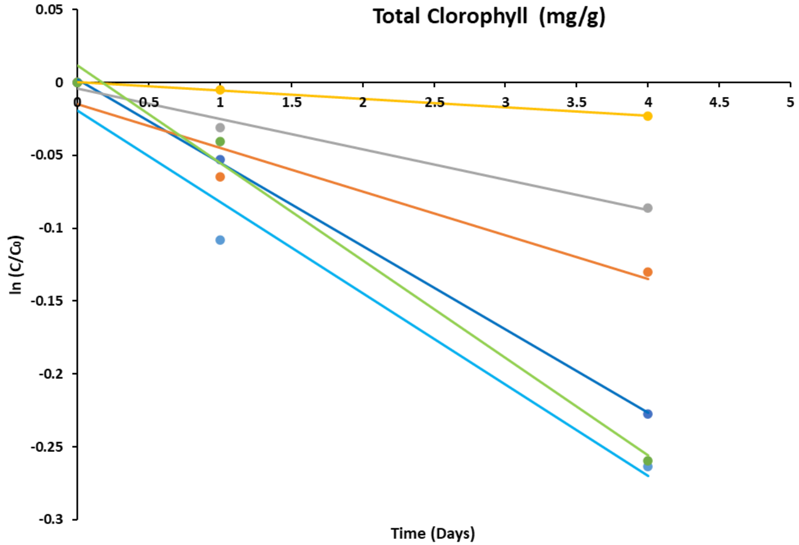
IPO10 t_{12}

P2 t_{12}

P10 t_{12}

P20 t_{12}

P2, and P10 had less effect in visual quality compared to NaOCL after 12 days



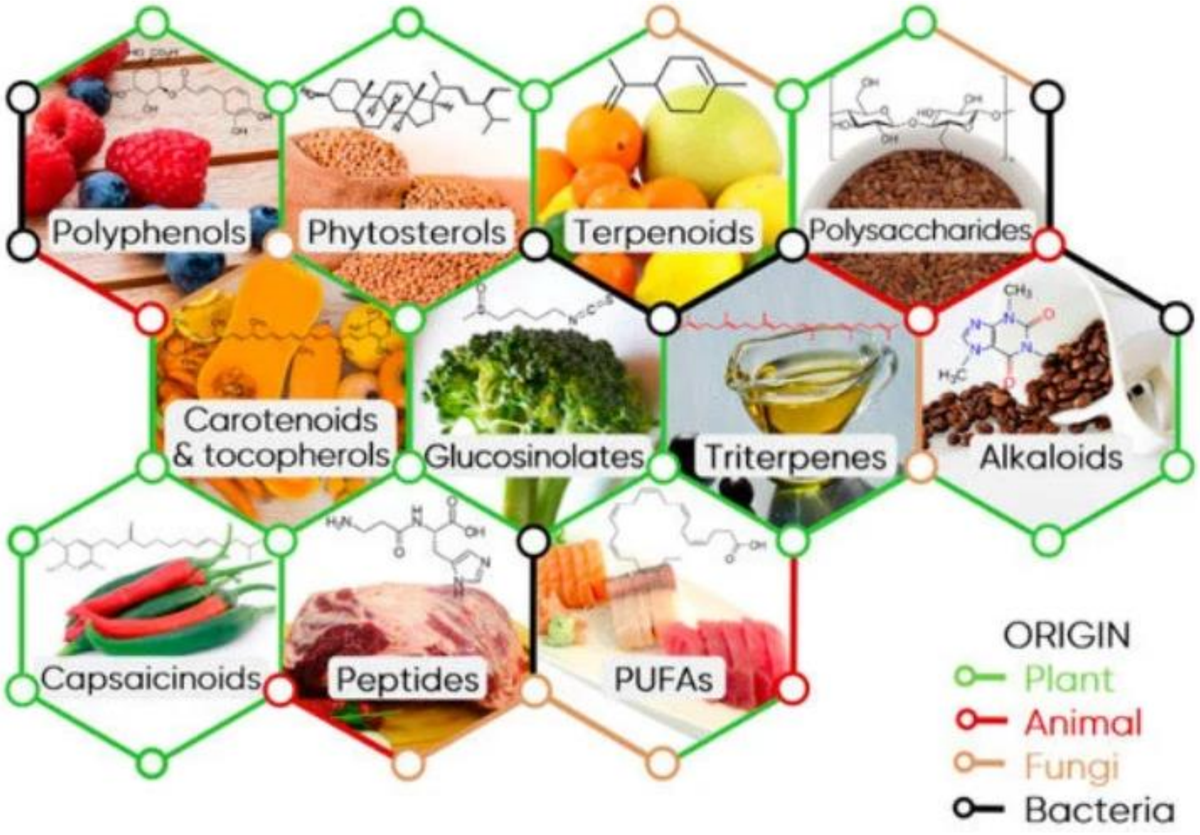
Total Clorophyll degradation

Treatment	k/day-1	R^2
Control	0.051	0.9997
IPO2	0.9234	0.9234
IPO10	0.0208	0.9861
P2	0.0057	0.9999
P10	0.0626	0.9904
P20	0.0668	0.9691

Green color degradation

Treatment	k/day-1	R^2
Control	0.0026	0.994
IPO2	0.0046	0.9715
IPO10	0.0053	0.999
P2	0.0019	0.9994
P10	0.0046	0.9715
P20	0.0033	0.9906

Bioactive compounds in foods

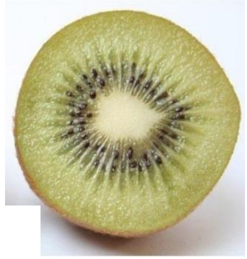


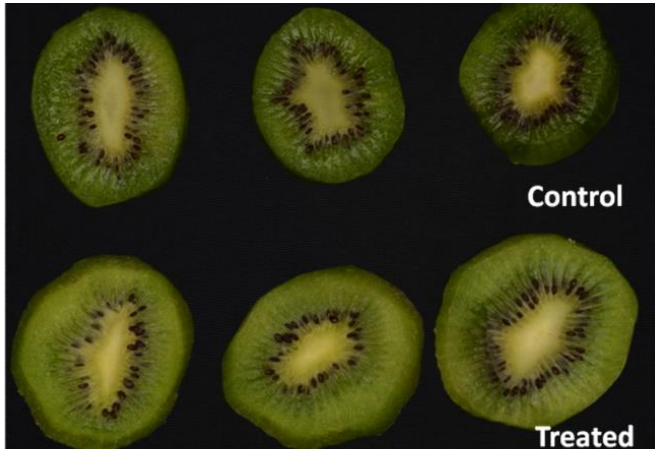
Challenge: improve products shelf life preserving of bioactive compounds

Many compounds are sensitive to oxidation

TREATMENT OPTIMIZATION

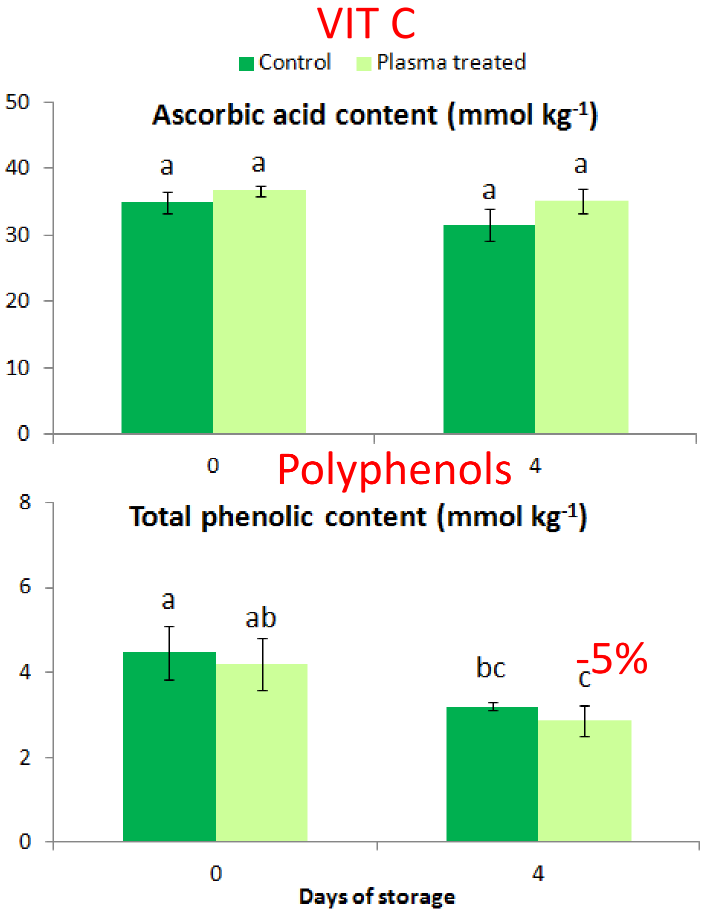
Bioactive compounds in kiwifruit treated with DBD plasma

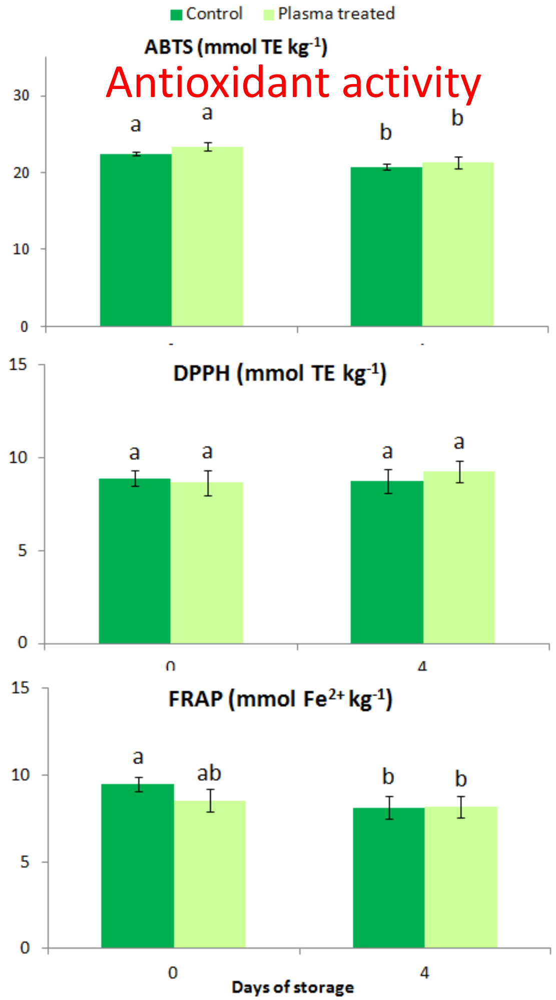




Kiwifruit slices subjected to 20 + 20 min DBD gas plasma treatment and control ones after 4 days of storage in controlled conditions.

Ramazzina et al., 2015





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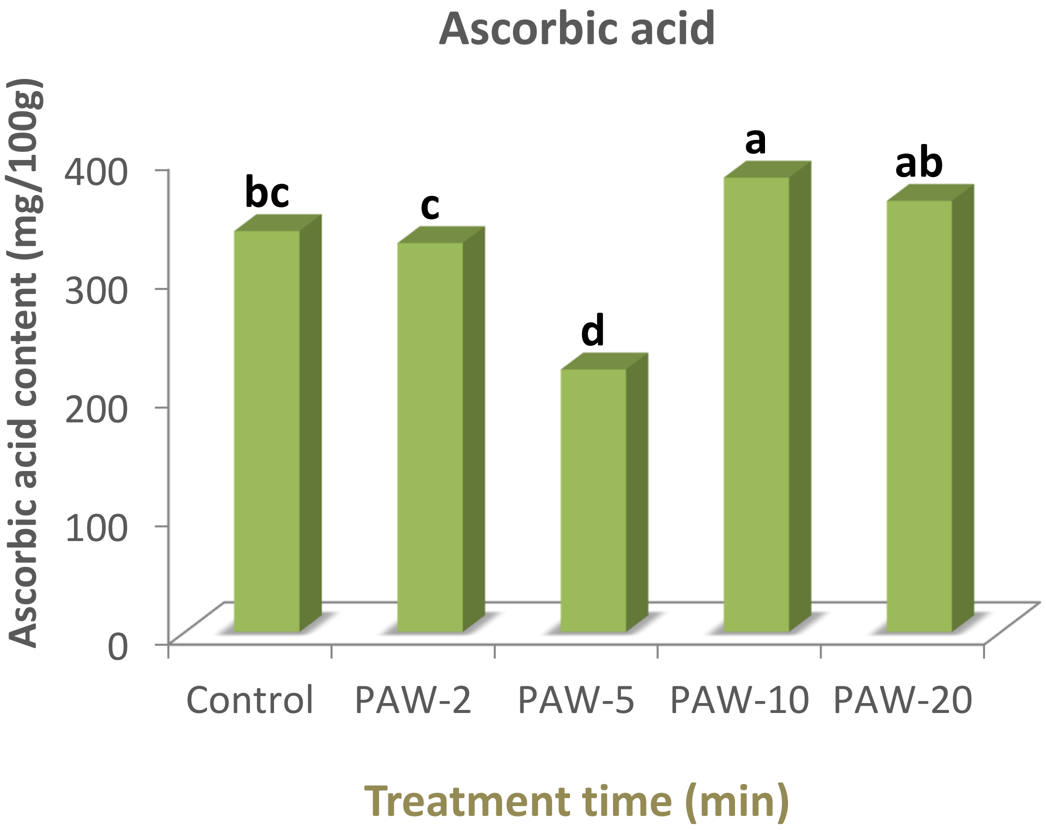
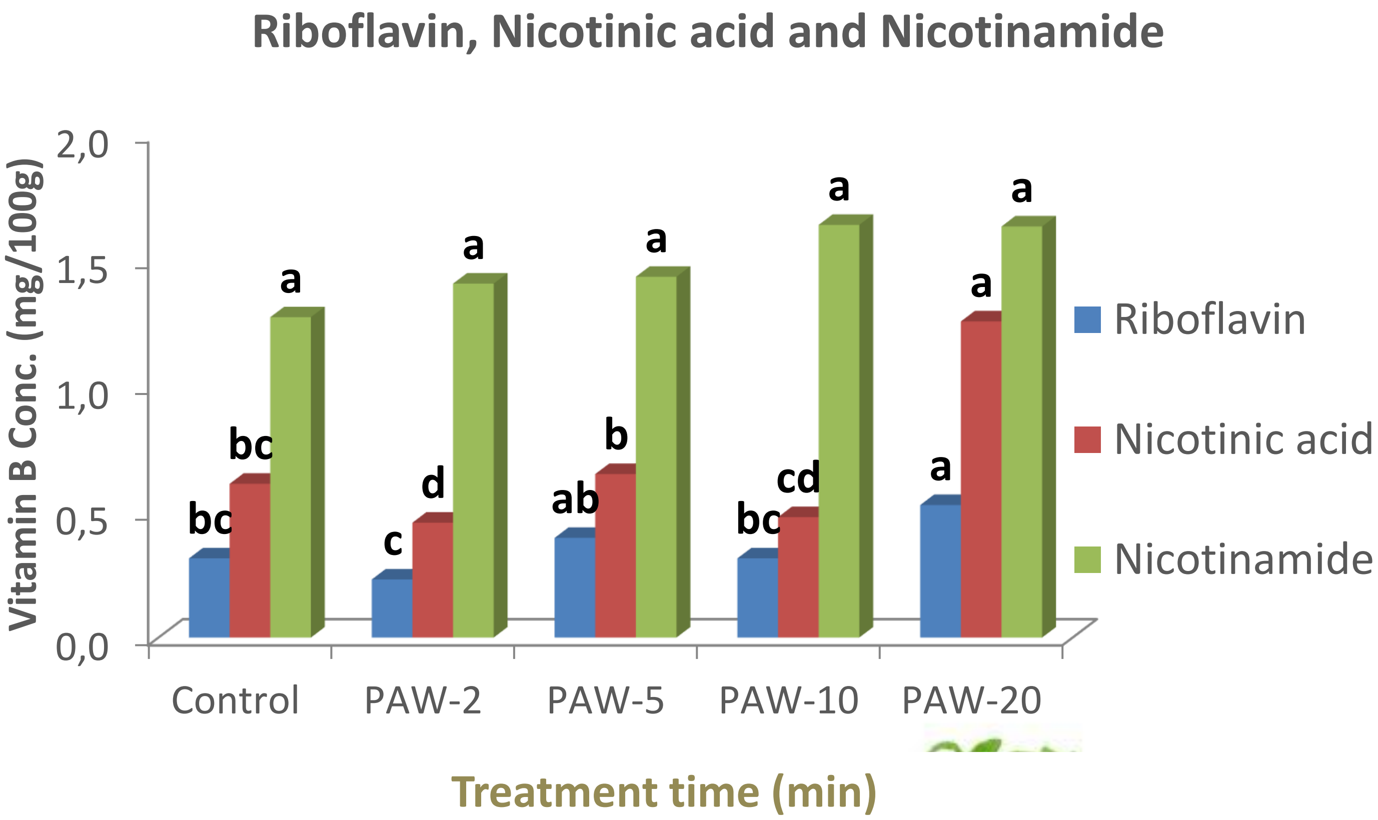
Bioactive compounds in rocket treated with PAW

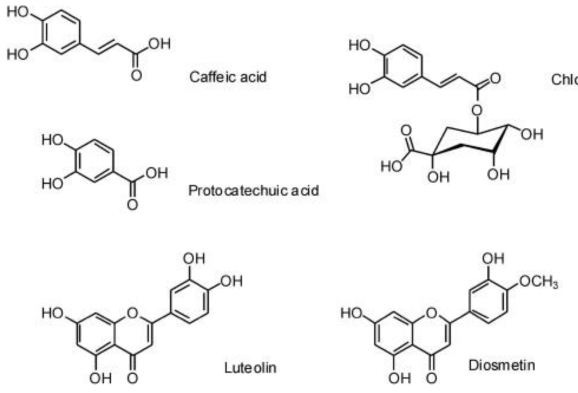


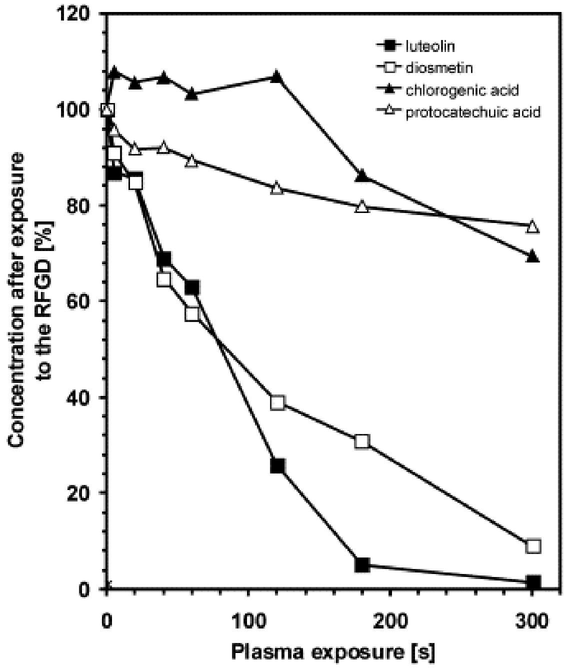


Laurita, R., Gozzi, G., Tappi, S., Capelli, F., Bisag, A., Laghi, G., ... & Vannini, L. (2021).

Polyphenols in lamb's lettuce

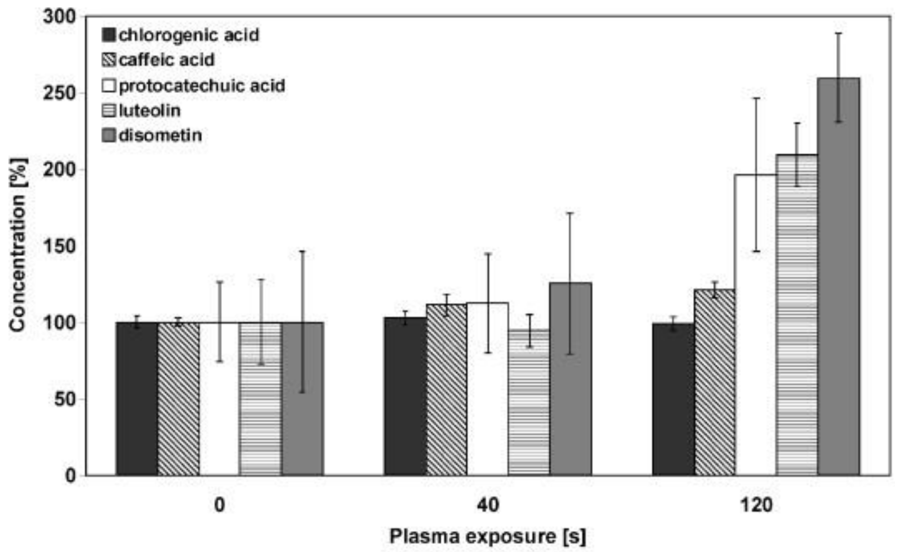
Grzegorzewski, et al. (2010)

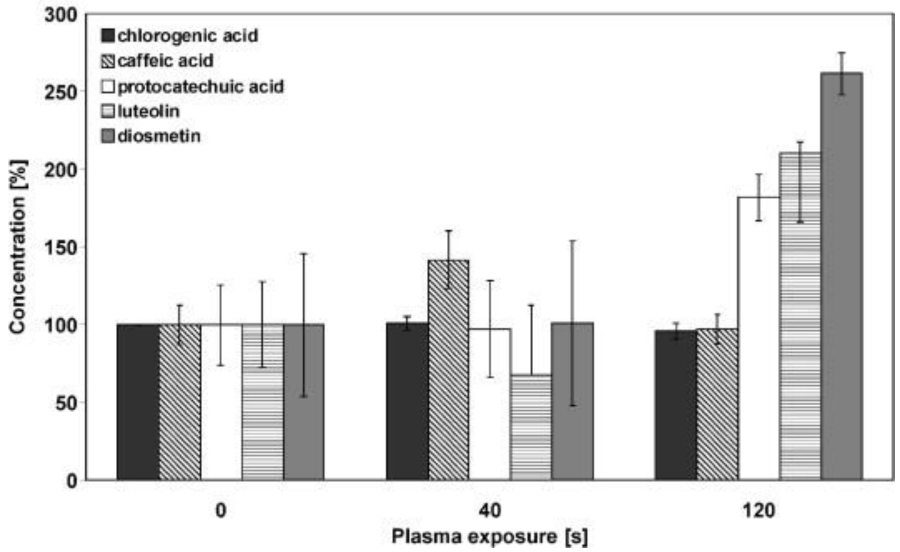




Degradation of **pure compounds** upon exposure to a RFGD plasma (75 W, $p(O_2)$ = 0.5 mbar).

MATRIX EFFECT! PRODUCTION OF NEW POLYPHENOLS/HIGHER EXTRACTION?





Contents of phenolic acids and flavonoids in freeze-dried **lettuce leaves** after exposure to the RFGD plasma (p(O2) = 0.5 mbar) at 75 W (top), at 150 W (bottom)

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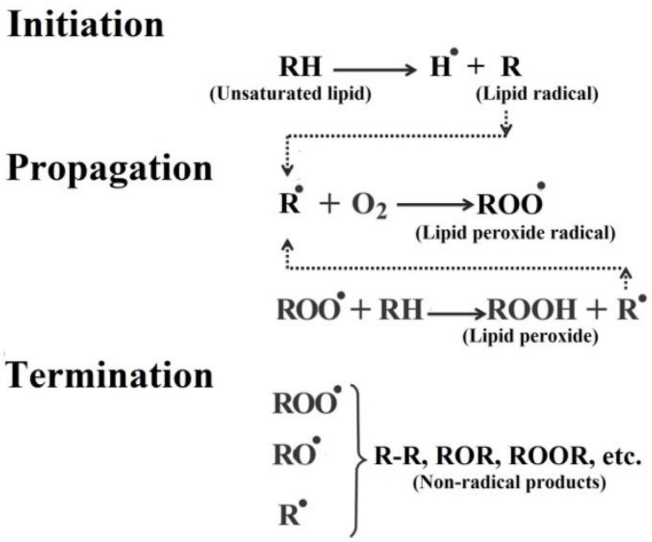
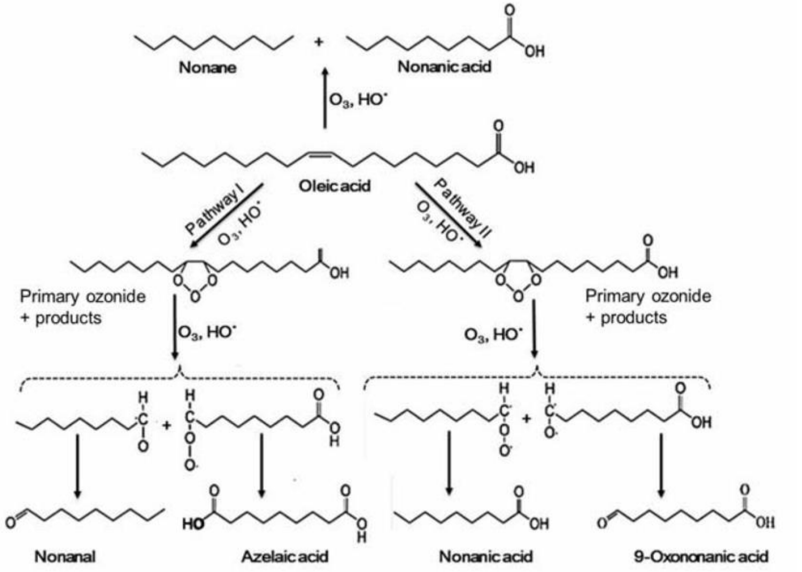
Effect on Lipid oxidation



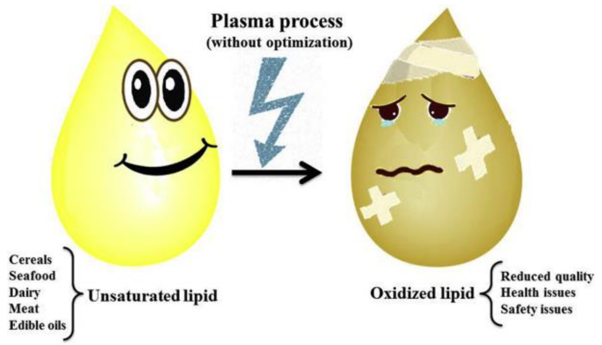
COLD PLASMA IS COMPOSED BY HIGHLY OXIDATIVE SPECIES ➔ INDUCTION OF LIPID OXIDATION IS EXPECTED



The mechanisms of plasma induced oxidation for oleic acid (Sarangapani et al., 2017).

Effects of lipid oxidation in foods:

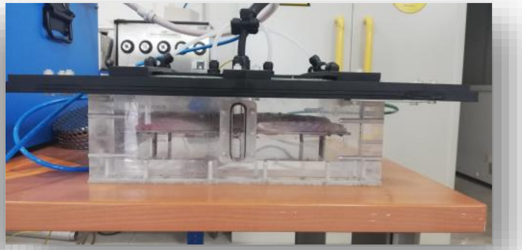
- Modification of colour
- Development of off-odours (rancid)
- Decrease in nutritional value
- Formation of toxic compounds



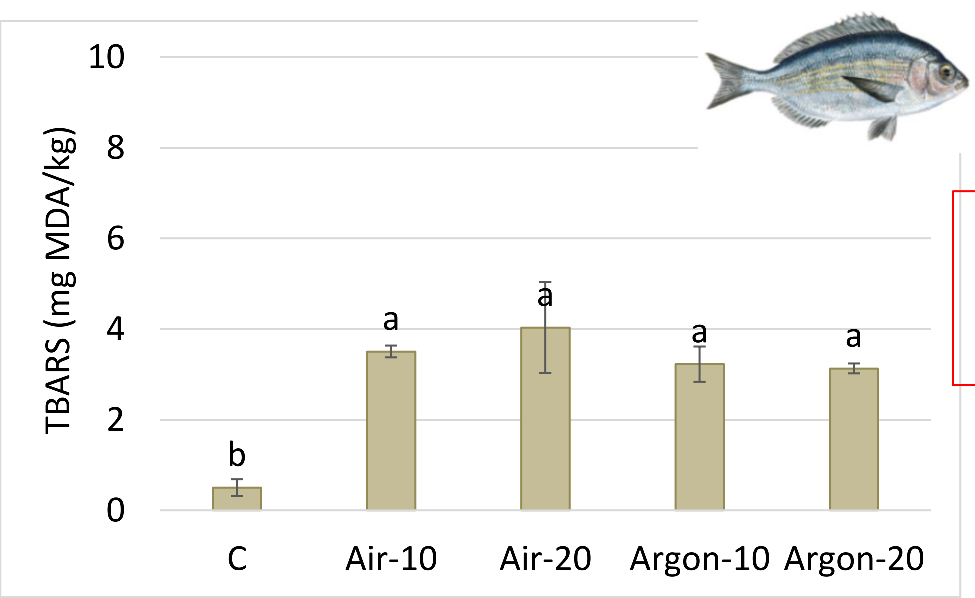
Effect on lipid oxidation in food matrices

Seabreams from Kefalonia

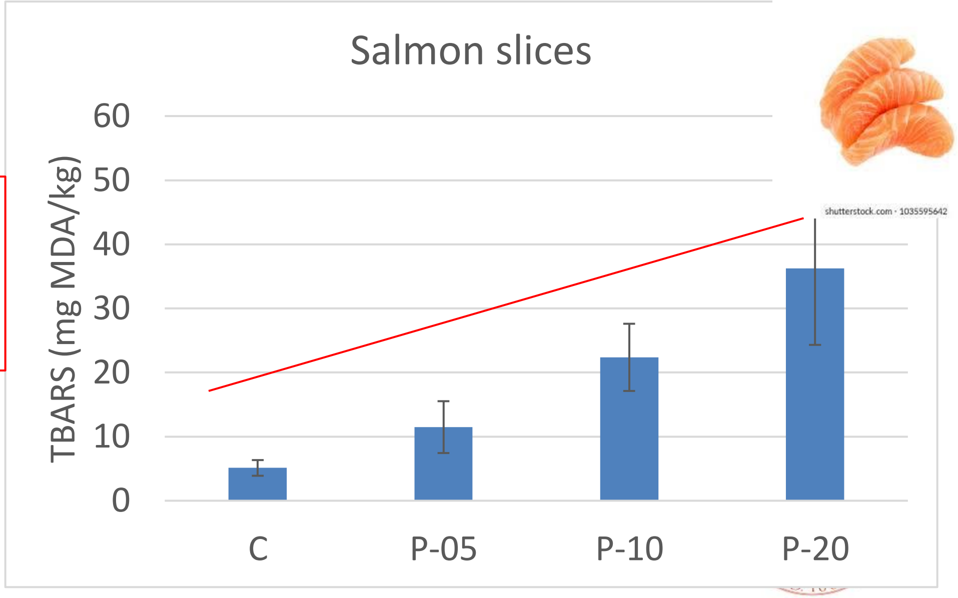
FUTURE EU AQUA



Current 20mA
Voltage 18 kV
Frequency 5 kHz
Time 20 min
2 Atmospheres:
Air: 20% O_2/80% N_2
Argon: 20% O_2/80% Argon



Increase ol lipid oxidation in PUFA rich matrix



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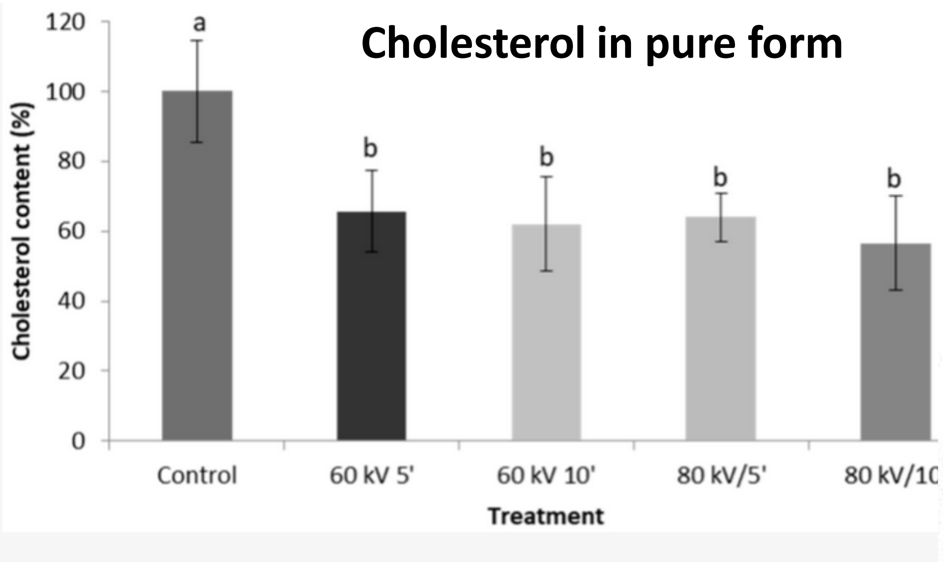
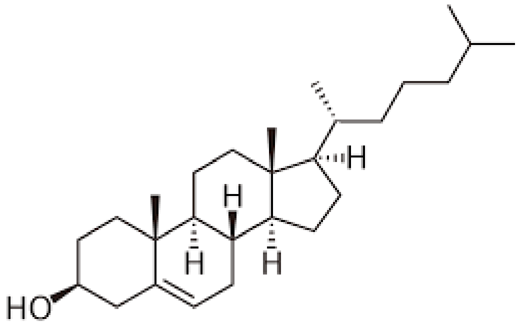
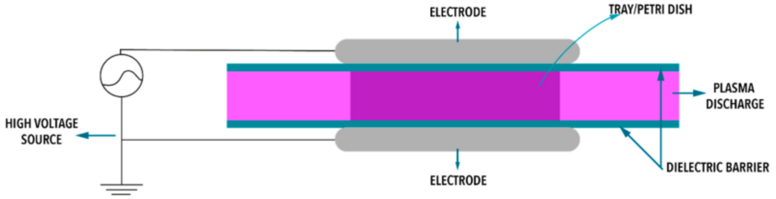
Effect on cholesterol

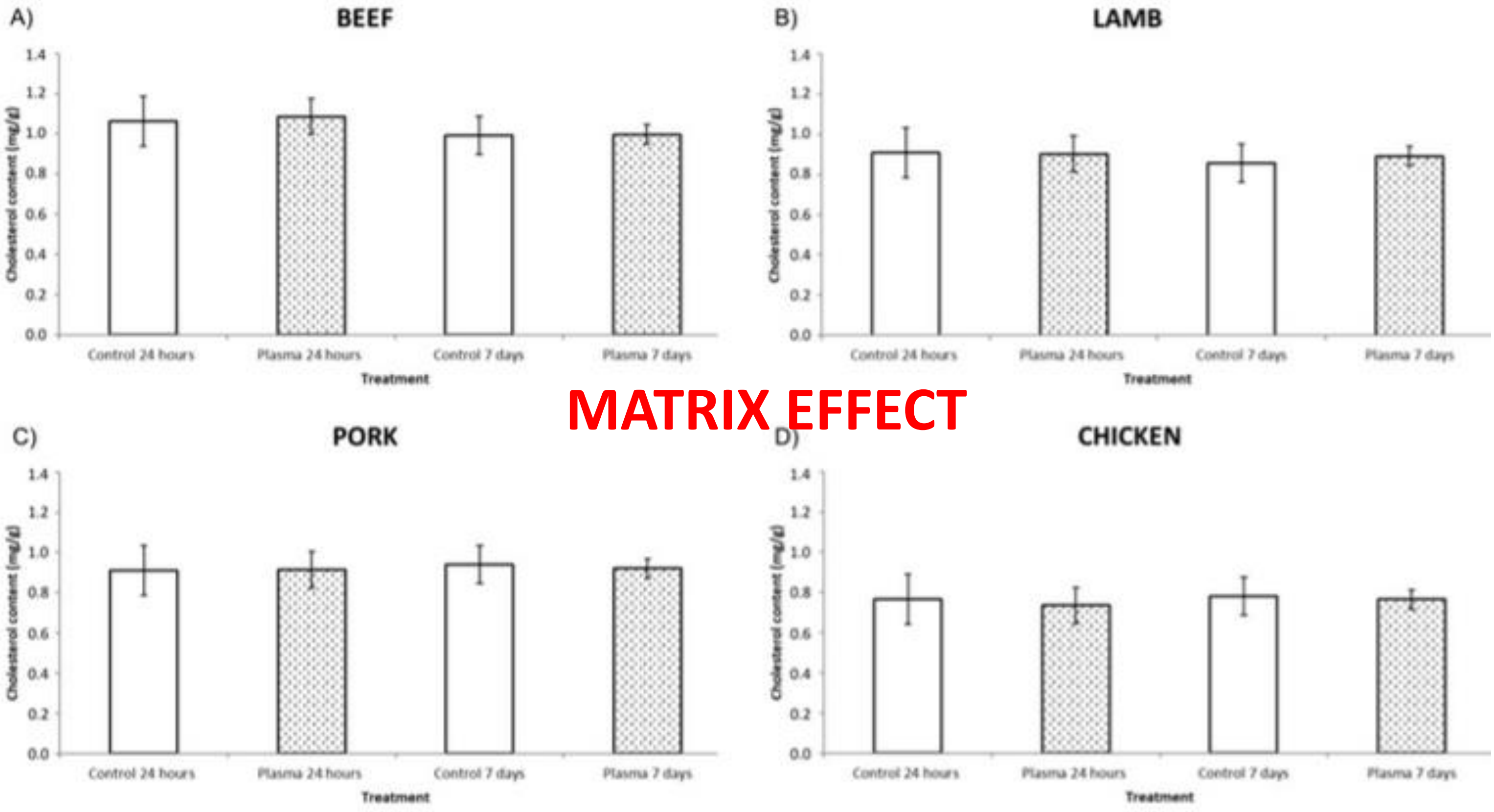






Two polypropylene (PP) dielectric layers
(2 mm thickness)
60 kV and 80 kV
5 and 10 min

Cholesterol in food matrix



MATRIX EFFECT

Cholesterol oxidation products (COPs)
?
Toxic compounds!!

Pérez-Andrés et al. (2020)

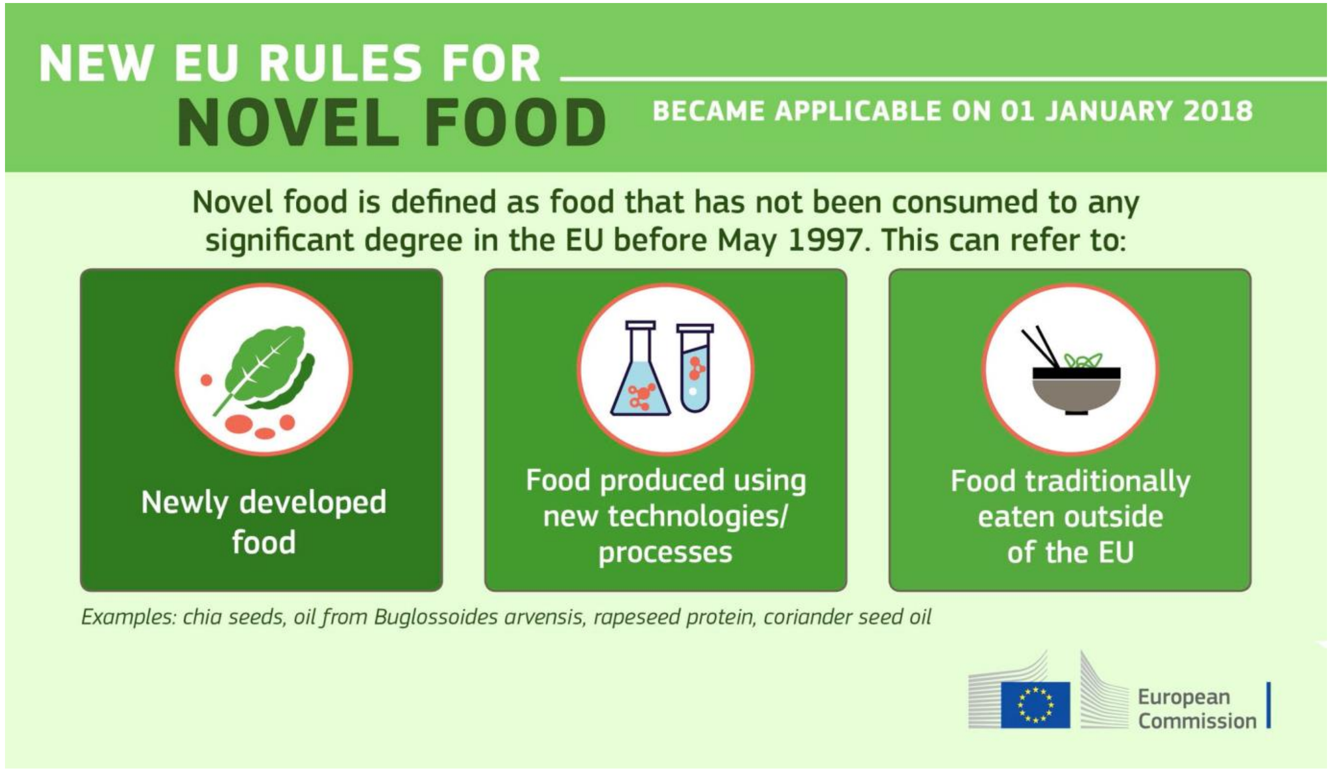
Application of cold plasma in the food sector

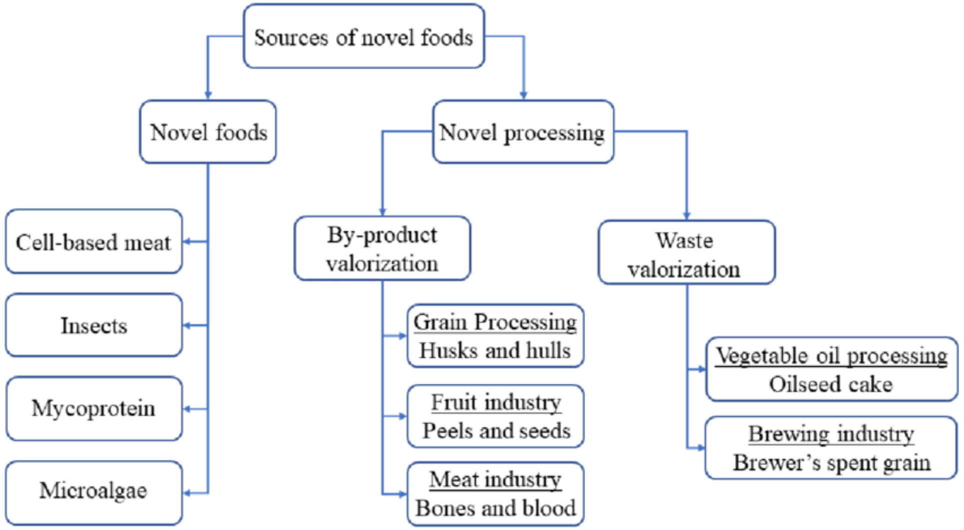
Presentation structure:

- Research on Cold Plasma in the Food Sector
- Main applications:
  - Food decontamination
    - microrganisms
    - viruses
    - mycotoxins
    - pesticides
    - allergens
  - Modification of enzymatic activity
  - Functionalization of food components (proteins, starches)
- Secondary effects: effects on quality and nutritional properties, lipid oxidation
- Legislative aspects

Novel Foods Legislation

Established to demonstrate to the consumer that foods that had not been consumed to a significant degree within the European Union prior to 1997, had undergone a stringent and independent safety assessment (labelled to not mislead)





Novel Foods Legislation

https://ec.europa.eu/food/safety/novel-food_en

'Novel Food' can be newly developed, innovative food, **food produced using new technologies** and production processes, as well as food which is or has been traditionally eaten outside of the EU.

The underlying principles underpinning Novel Food in the European Union are that Novel Foods must be:

- **Safe** for consumers
- Properly **labelled**, so as not to mislead consumers
- If novel food is intended to replace another food, it must not differ in a way that the consumption of the Novel Food would be **nutritionally disadvantageous** for the consumer.

Pre-market authorisation of Novel Foods on the basis of an evaluation in line with the above principles is necessary.

…Foods resulting from a production process not used for food production within the Union before 15 May 1997, which gives rise to significant changes in the composition or structure of a food, affecting its nutritional value, metabolism or level of undesirable substances

Novel Foods Legislation

First step: '**scientific assessment prior to authorisation to ensure their safety**'.

Performed by the European Food Safety Authority (EFSA)

The EFSA convenes an **expert scientific panel**, collects **relevant information** and then develops an **expert report** on the benefits and risks of the technology resulting from a 'novel food' designation. Those novel food applications that receive 'authorisation' can then be sold in the EU.

The 'authorisation' sets out the **conditions for the novel food use, their designation as a food/food ingredient and labeling requirements**.

Among the *novel food ingredient approvals*, only a small percentage involve **new technology**:

UV (technology) treatment of mushrooms, bread, baker's yeast, and milk

HPP for fruit preparations

Where are we on Plasma Processing?

Currently, **uncertainty** remains in the EC regulatory approval process for cold plasma technologies due to the lack of definition within the evaluation criteria (e.g., ‘risk to public health’, ‘nutritionally disadvantageous’ and ‘not misleading to the consumer’) (Bourke et al., 2018).

Does cold plasma treatment lead to residuals that are harmful to health
?

In depth investigations of the safety of plasma for food applications remain lacking.
Different results highlighted:

- the **complexity** resulting from the range of diverse plasma devices, treatment regimens, and target substances;
- the need for a better understanding of the effect of plasma-treated substances, studies focused more directly on **food-related toxicity** are needed;
- need for evaluations of the persistence of **cytotoxic effect** in food overtime, their concentration and their oral toxicity;
- Need to address and contextualize **potential of adverse effects** resulting from plasma-induced changes to food constituents

- Need to evaluate **consumer acceptance!!**

Take home messagge

Many promising applications for food stabilization and innovation

But

Processing optimization is necessary based on the characteristics of the raw material!!

Concluding remarks

<u>Most studied applications</u>:

- Microbial/viral/mycotoxins inactivation

<u>Newer trends</u>:

- Functionalization of components (foods and packaging)
- Enhancement of drying

<u>Need for</u>:

- In depth safety assessment → Novel food regulation

CA19110
Plasma applications for smart and sustainable agriculture

Plasma applications for smart and sustainable agriculture – PlAgri

https://plagri.eu/

The scientific community is making a multidisciplinary effort to make plasma applicable also for direct food processing!

Our researches on cold plasma

- **TECH4PATH – PRIN 2022** Non-thermal TECHnologies FOR the inactivation of emerging viral, bacterial and protozoan PATHogens on fruit and vegetable products

OBJECTIVE: Optimize non thermal processing for the inactivation of emerging pathogens and evaluate the effect on quality and environmental impact

- **PLASMAFOOD – PRIN 2017** Study and optimization of cold atmospheric plasma treatment for food safety and quality improvement

OBJECTIVE: Learn more about the effects of cold plasma on various aspects (microbiological, qualitative, chemical and nutritional)

- **PASS – EIT** "Plasma assisted sanitation systems" for the inactivation of SARS-CoV-2 on food contact materials

OBJECTIVE : use plasma as a strategy to inactivate the virus on food packaging materials

- **FuturEUAqua** Future growth in sustainable, resilient and climate friendly organic and conventional European aquaculture. Horizon 2020 Call: H2020-BG-2018-2020

OBJECTIVE : Apply cold plasma to increase the shelf life of seafood

TECH4path PRIN2022

PLASMA FOOD PRIN 2017

PASS Plasma Assisted Sanitation System

eit Food supported by the EIT he European Union

FUTURE EUAQUA

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Research Group for Food Technology

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

DEPARTMENT OF AGRICULTURAL AND FOOD SCIENCES

CIRI AGROALIMENTARE














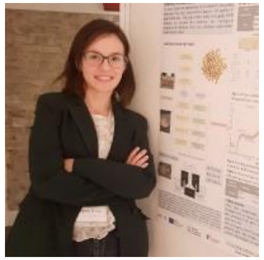

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Research Group for Industrial Applications of Plasmas (IAP Group)

DEPARTMENT
INDUSTRIAL ENGINEERING

CIRI
ADVANCED APPLICATIONS IN MECHANICAL ENGINEERING AND MATERIALS TECHNOLOGY

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cost
EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

PlasTHER
THERAPEUTICAL APPLICATIONS OF COLD PLASMAS

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IPCS
International Plasma Chemistry Society

sib
Società Italiana Biomateriali

ISPM
INTERNATIONAL SOCIETY FOR • PLASMA • MEDICINE

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Thank you!!

Questions?

Meet the presenter

Bibliographic references

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