Potential of Plasma Technologies for Future Application in Plant-Based Food Production

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Baltisch-Deutsches HOCHSCHULKONTOR

Leibniz Association

FROM IDEA TO PROTOTYPE

Seed Germination and Seed Treatment in Agriculture

Three stages of germination process:

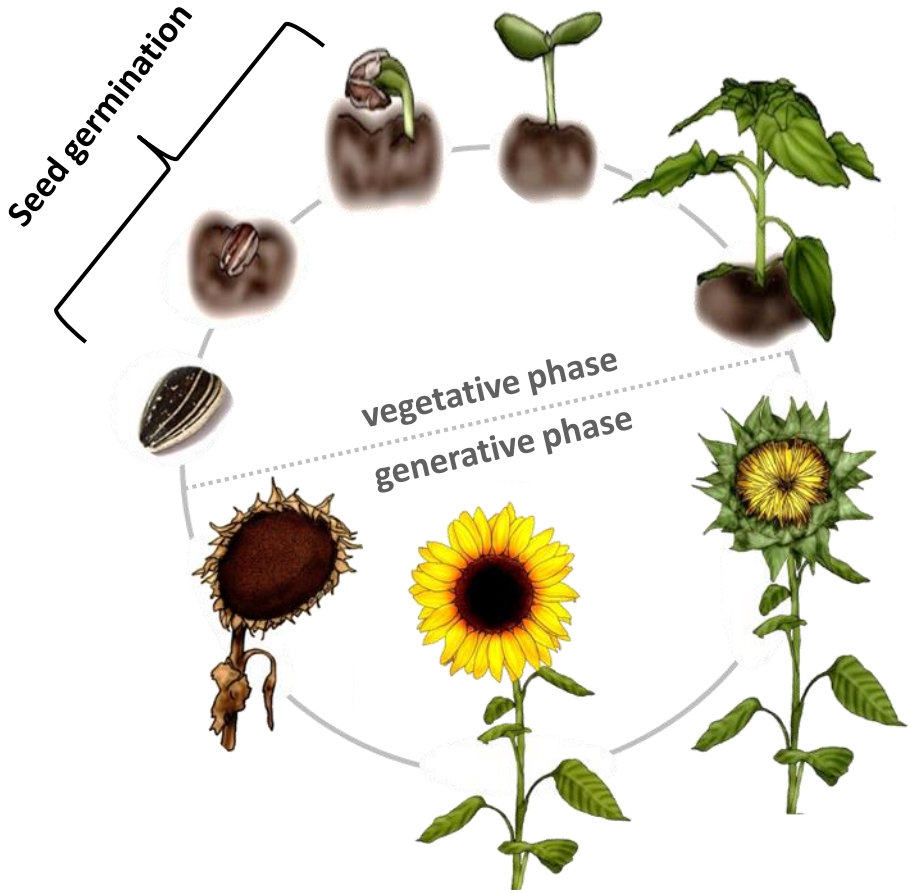
I. Imbibition process
II. Mobilization of storage compounds
III. Differentiation and growth process

Seed germination and seedling development can be affected by:

- Pathogens
- Nutrient deficiency
- Development and growth inhibitors
- Environmental stress

Seed dressing methods in agriculture:

→ Pesticides against plant pathogens
→ Fertilizers (micro- and macro nutrients)
→ Bio-stimulants (e.g. phytohormones)



***Helianthus annuus* L.**

Modifed from http://3.bp.blogspot.com/-3rEVu33Cfnc/U43XcLIna8I/AAAAAAAAJSY/g7ZZbajdIms/s1600/Sonnenblumen_Zyklus.jpg

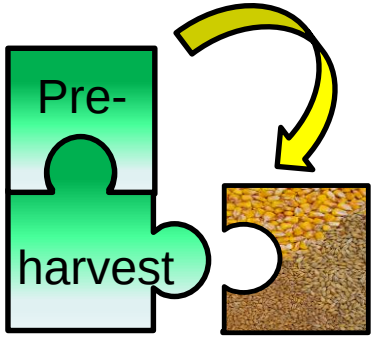
Challenges in Agricultural Practice

https://stock.adobe.com

Undesirable soil conditions

Extensive field use

Diseased seeds



Seed Treatment

Toxicity

- Expose of workers with dust and aerosols
- Accidental poisoning
- Waste disposal
  → dangerous goods
- Harmful for animals
  → e.g. bees
- Accumulation in ecosystem
- Reduction of biodiversity

In Germany
→ use of fungicides (Thiram, Triadimenol) from 2019 onwards for treatment of lupine, rapeseed, maize is forbidden

Plasma in Agriculture – Seed Treatment

Enhance germination and growth.

Improve stress tolerance

Decontaminate and inactivate pathogens on seed surface.

Reduce the use of agrochemicals

Soybean

Pérez-Pizá et al. (2019)

Wheat

Zahoranova et al. (2014)

Quinoa

Gómez-Ramírez et al. (2017)

Rice

Penado et al. (2017)

Tomato

Măgureanu et al. (2018)

Beans

Bormashenko et al. (2015)

Maize

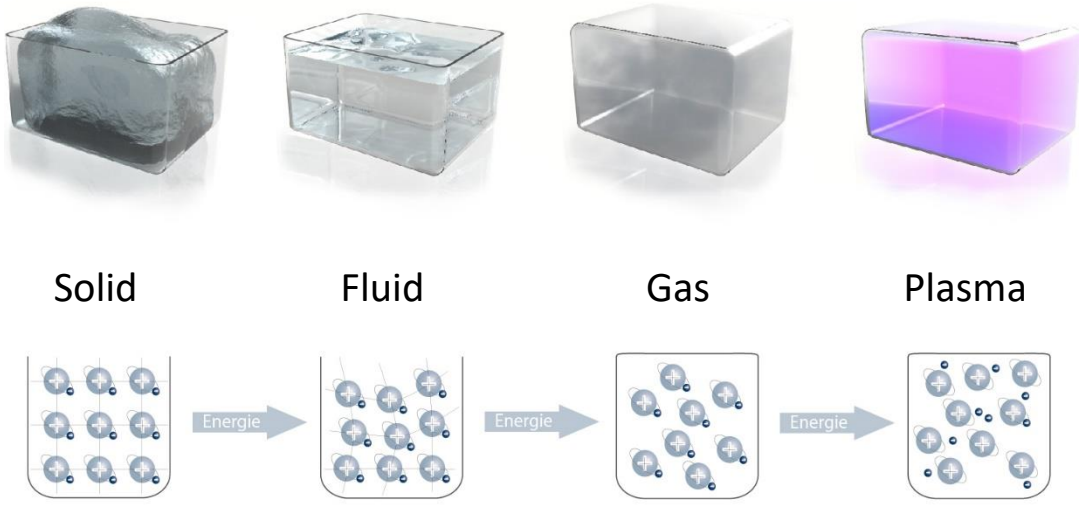
Filatova et al. (2013)

Pepper

Stepánová et al. (2018)

What is Physical Plasma?

- Fourth state of matter
- Ionised gas
- Multicomponent system



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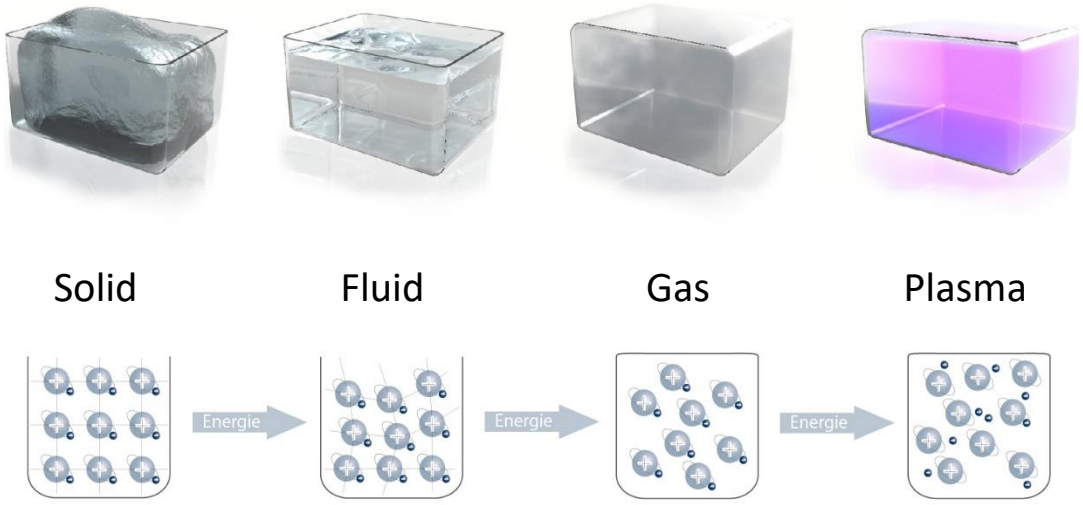
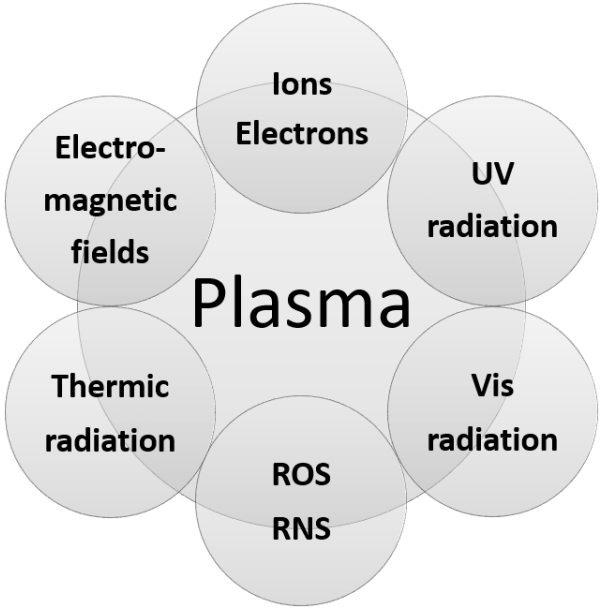




ROS – Reactive Oxygen Species

RNS – Reactive Nitrogen Species

- Generation of plasma needs energy
- Energy is applied to gas or fluid
- Energy to be applied: thermal energy (heat), radiation (microwave), electrical energy (electric fields)
- Generation under atmospheric pressure or under low pressure, with or without noble gases (Ar, He)

Physical Plasma

high temperature plasma (fusion plasma)

10^6 °C – 10^8 °C

https://www.inp-greifswald.de/

→ 99% of the luminous universe is in the plasma state

low-temperature plasma

thermal

> 1000 °C

non-thermal

(cold plasma) approx. room temperature (electron temperature > 10^4 K)

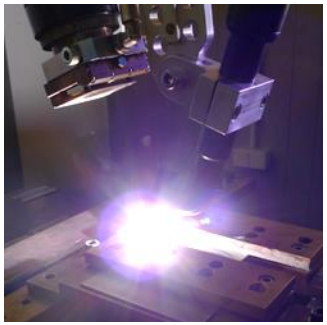
Physical Plasma

low-temperature plasma

thermal

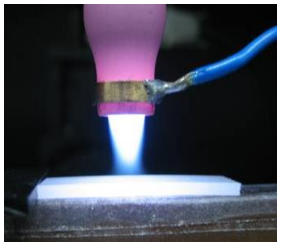
> 1000 °C

welding arcs



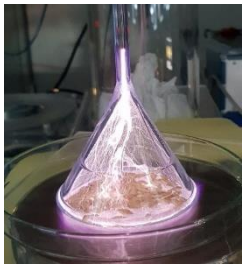
https://www.inp-greifswald.de/

plasma jet

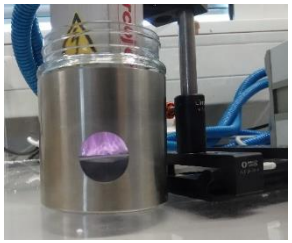


plasma jet

Corona discharge



Gliding Arc

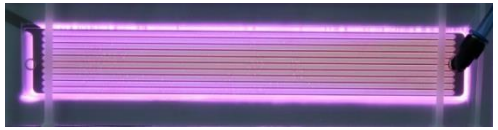


non-thermal

(cold plasma)

surface DBD

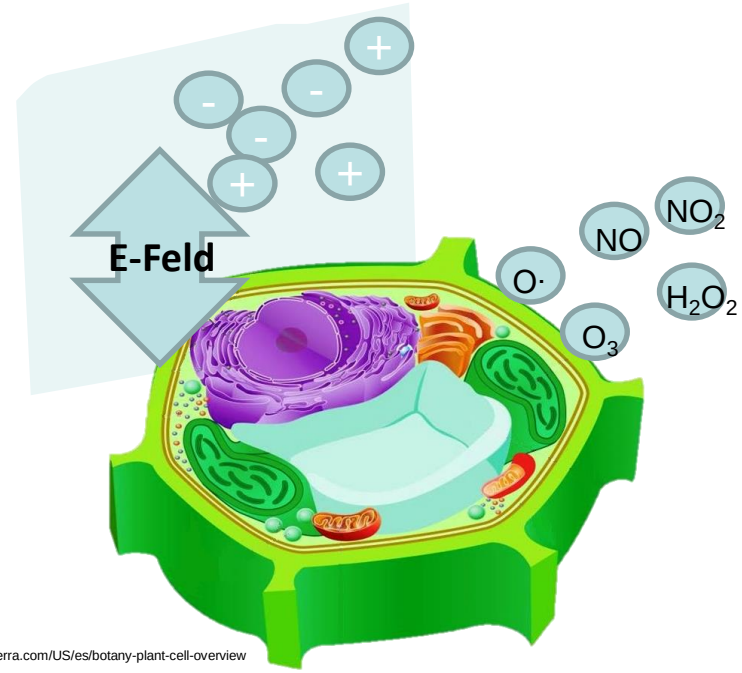
surface dielectric discharge (DBD)



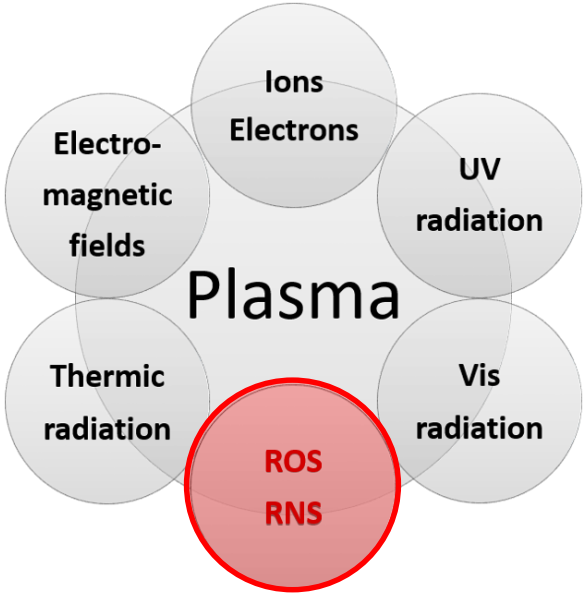
surface DBD

Stacked DBD reactor

Effects of Physical Plasma on Biological Systems



https://www.doterra.com/US/es/botany-plant-cell-overview



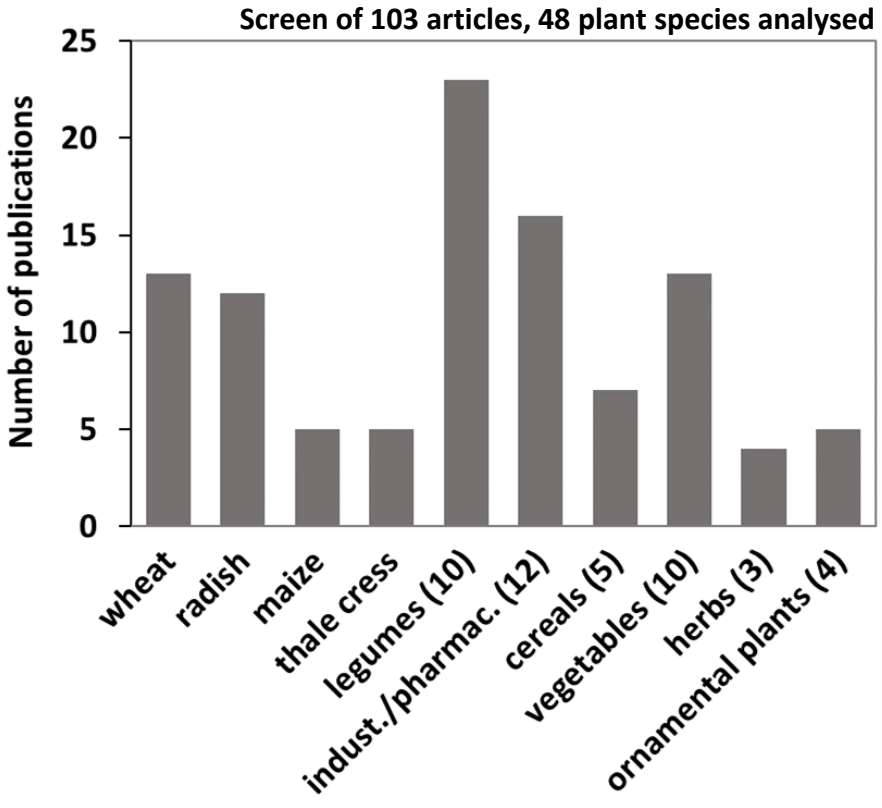
ROS – reactive oxygen species

RNS – reactive nitrogen species

- **Modification of surface properties**
- **Impact on plant/cell metabolism**

- ➢ **Effect on biological systems depended on quality and quantity of plasma**
- ➢ **Stimulating effect → e.g. Wound healing (plasma medicine)**
- ➢ **Destructive effect → e.g. e inactivation of microorganism (plasma medicine)**

Plasma in Agriculture – Seed Treatment

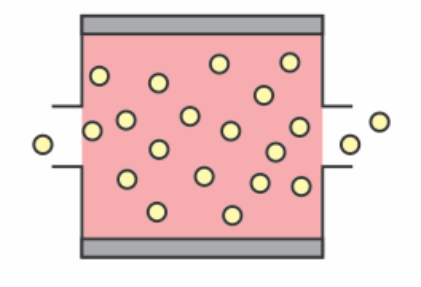


Effects on seed germination and seedling growth

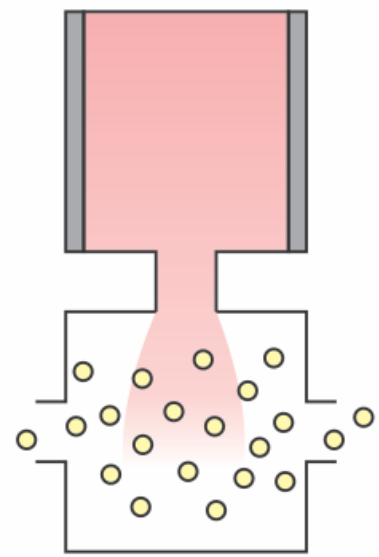
1. **Physico-chemical effects**
   → Seed coat modification
   Porosity and hydrophilicity
2. **Physiological effects**
   → Signalling processes (RONS)
   → Metabolic processes (N fixation)
3. **Reduction of plant pathogens**
   → Decontamination for storage of seeds

Plasma-Treatment Concepts

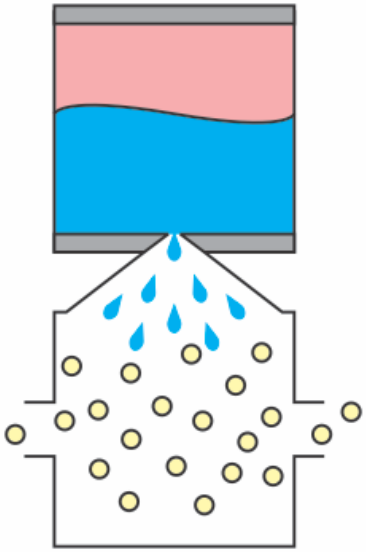
Direct
Plasma-Exposure



Exposure to
Plasma-treated Air

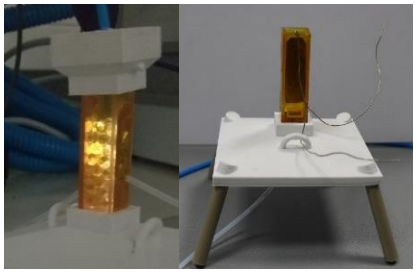


Exposure to
Plasma-treated Water

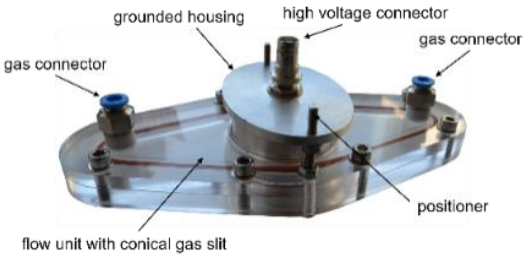


Plasma-Treatment Examples

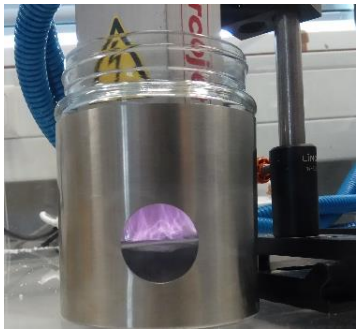
Direct Plasma-Exposure



Exposure to Plasma-treated Air



Exposure to Plasma-treated Water



Plasma-Treatment Examples

Indirect Treatment
Decontamination of seed surface

Exposure to
Plasma-treated Air

Direct Treatment
Stimulation of plant germination

Spiral plasma source

Plasma-Treatment Examples

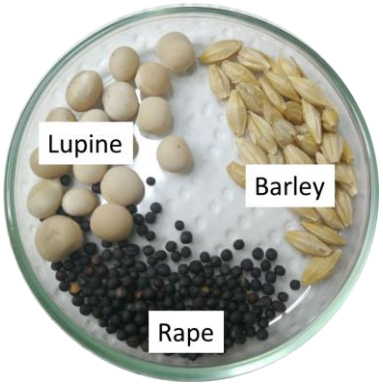
Indirect Treatment
Decontamination of seed surface

Exposure to
Plasma-treated Air

Direct Treatment
Stimulation of plant germination

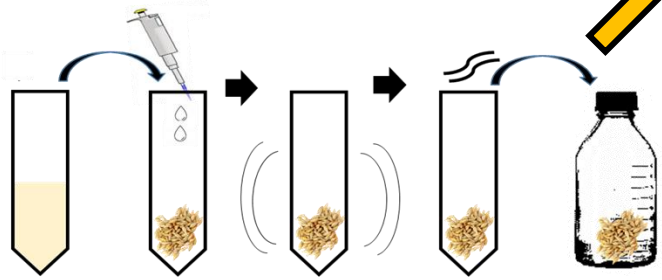
Spiral plasma source

Indirect Treatment with Plasma Processed Air (PPA)

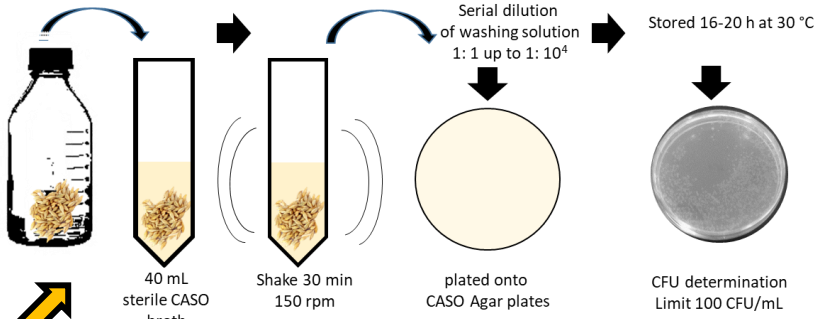


PPA

Model organism
Bacillus atrophaeus spores



Efficiency of Decontamination

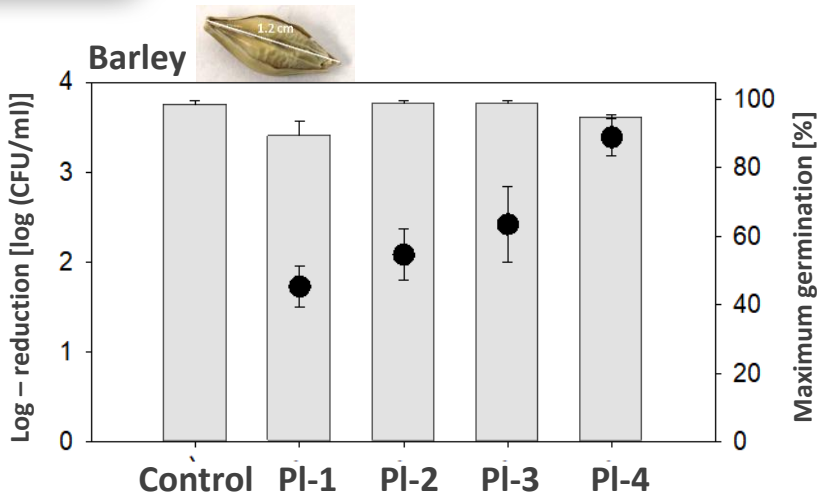


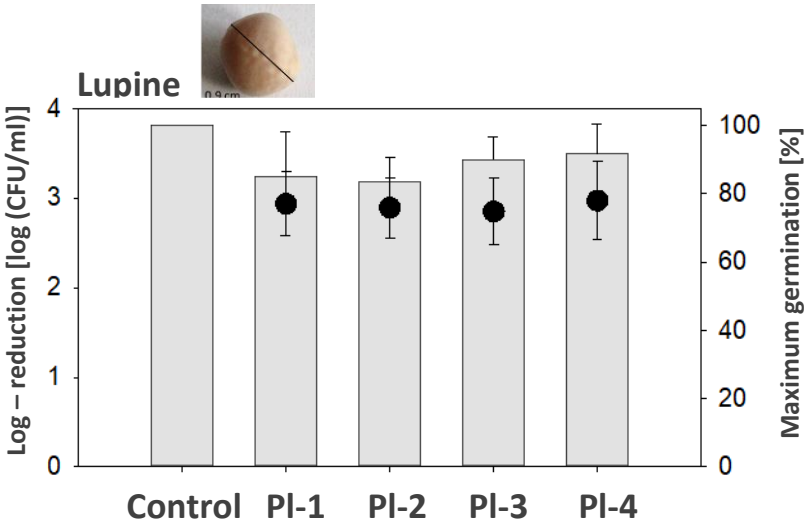
Germination test

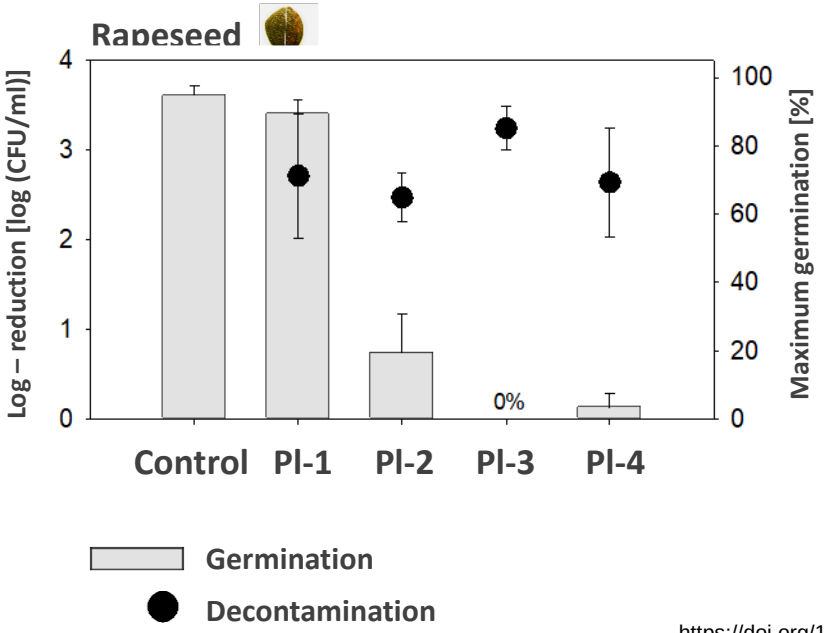
→ Maximum germination monitored after 3 days

https://doi.org/10.1002/ppap.202000207

Indirect Treatment with Plasma Processed Air (PPA)







→ Decontamination efficiency is dependent on plasma parameters and plant species

→ Same plasma parameters have different effects on maximum seed germination of plant species

→ **For future applications** in pre-harvest plasma parameters have to be adjusted for each plant species to sustain seed viability and to guarantee microbial inactivation

https://doi.org/10.1002/ppap.202000207

Plasma-Treatment Examples

Indirect Treatment
Decontamination of seed surface

Exposure to
Plasma-treated Air

Direct Treatment
Stimulation of plant germination

Spiral plasma source

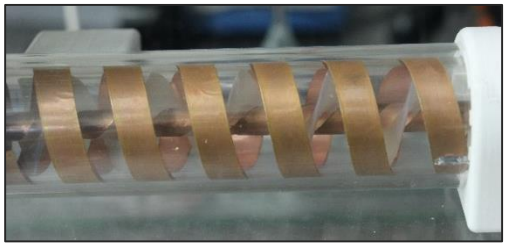
Direct Treatment- Spiral plasma source

spiral plasma device
volume DBD

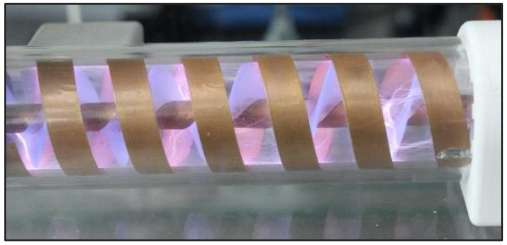
- direct plasma treatment
- Continuous seed treatment
- Treatment from 10 to 60 seconds
- seed treatment barley, wheat, sunflower, lupine and peas

Spiral

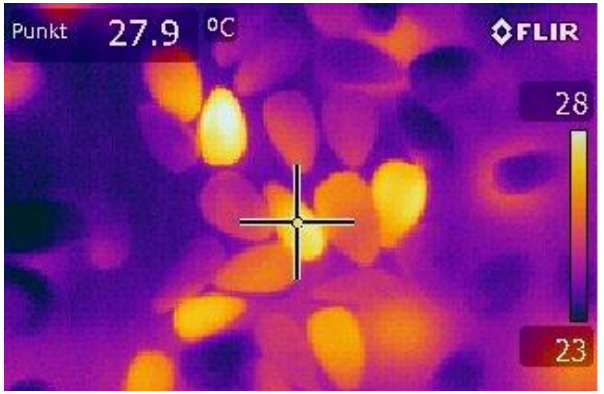
Plasma off



Plasma on



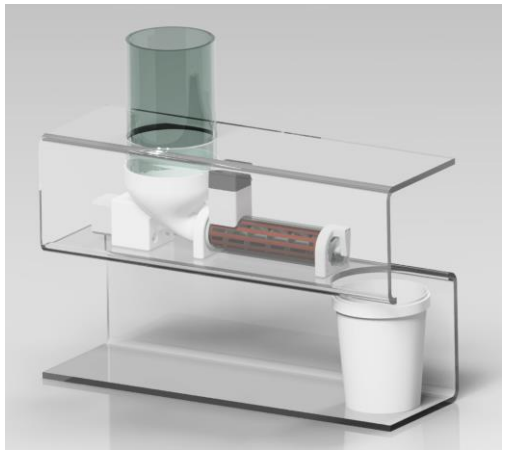
Infrared measurement of temperature



Sunflower seeds directly after treatment

under revision Brust et al.

Direct Treatment- Spiral plasma source- Germination Test



Winter Wheat
Variety Julius

Germination

Observation time:
12h – 48h

Climate cabinet, 22 °C

Checking germination

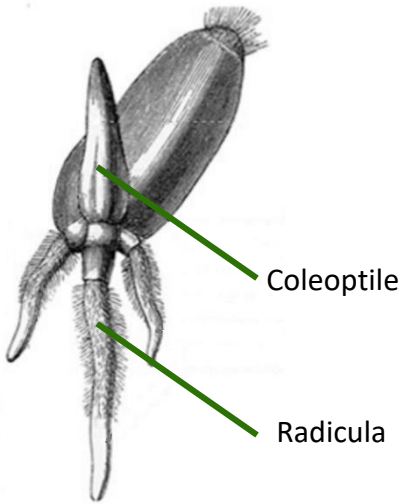
→ 50 seeds per squared petri dish

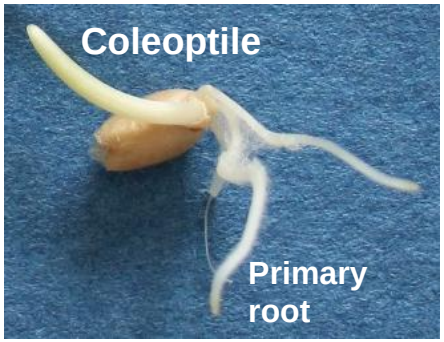
→ Checking for germination for 12-48 hours

→ Counting of germinated seeds

→ Reporting in % (e.g. 50% means that half of all seeds are germinated)

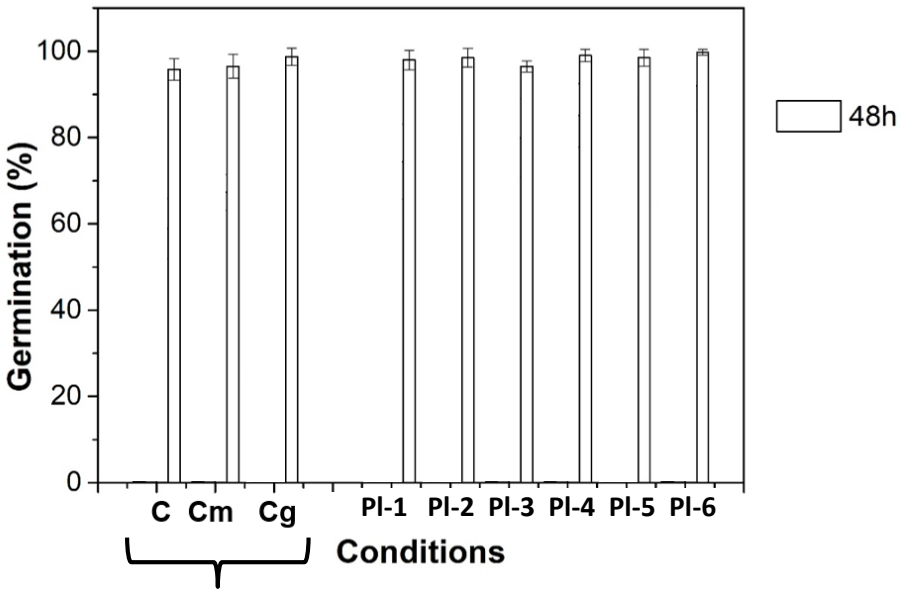
→ Data analysis for germination parameter





under revision Brust et al.

Direct Treatment- Seed Germination



Controls (untreated, mechanical and gas control)

→ Crop plants with high maximum germination >80% and fast germination rate

→ Under laboratory conditions, maximum germination (G_{max}) is reached within 3 days

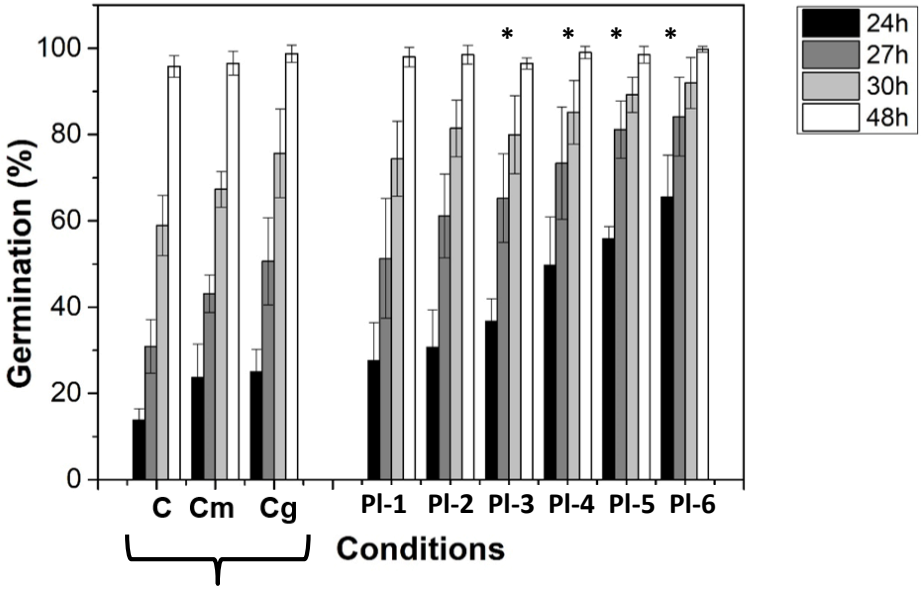
→ G_{max} is not affected

Wheat (*Triticum aestivum* L.)

Wheat (Julius)

under revision Brust et al.

Direct Treatment- Seed Germination

Controls (untreated, mechanical and gas control)

* Significance among T_{50} values against all controls (Student´s t test, $p \leq 0.05$)

n = 8 (50 seeds each)

→ G_{max} is not affected

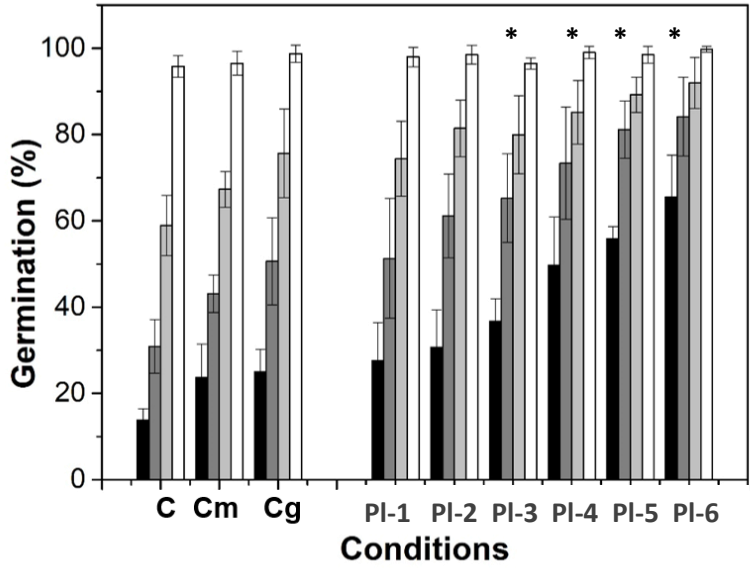
→ Seed germination accelerates with treatment time

Wheat (*Triticum aestivum* L.)

Wheat (Julius)

under revision Brust et al.

Direct Treatment- Seed Germination

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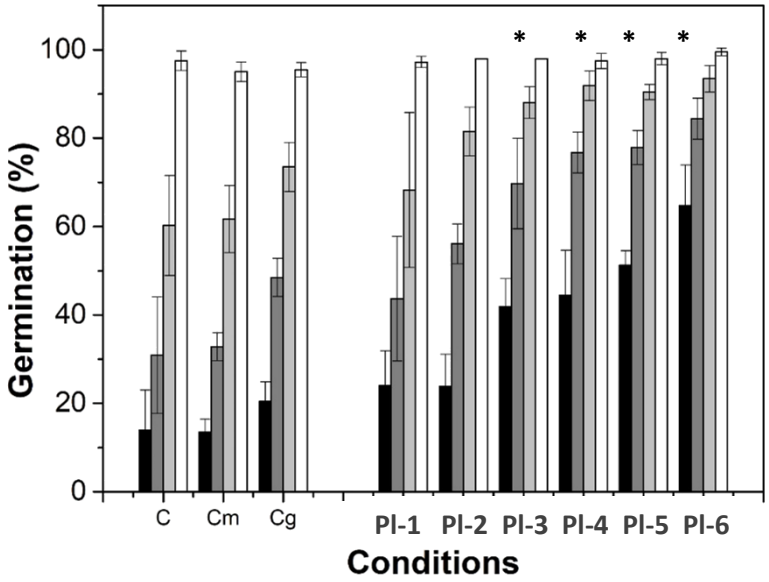


→ **One month stored seeds**

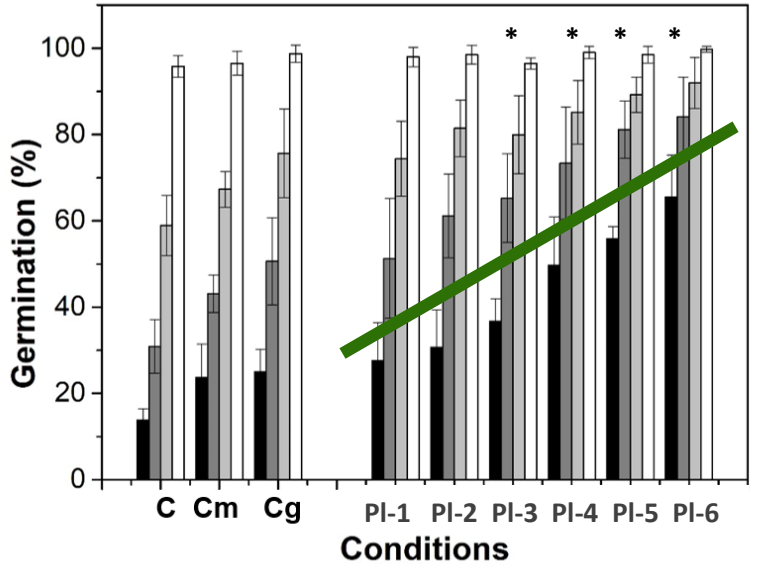
n = 3 (50 seeds each)

Wheat (*Triticum aestivum* L.)

Wheat (Julius)

under revision Brust et al.

Direct Treatment- Seed Germination

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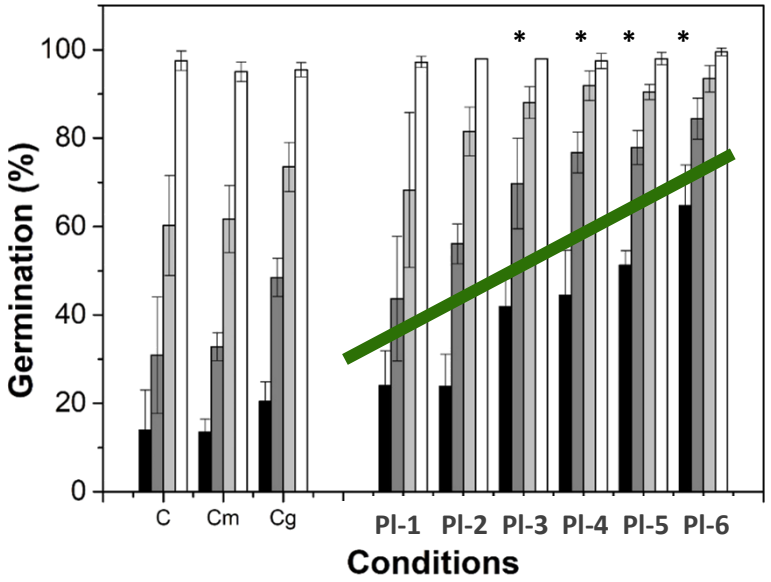

→ **One month stored seeds**

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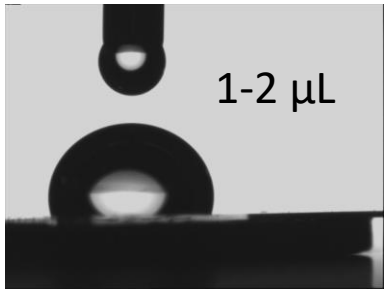
Wheat (*Triticum aestivum* L.)

Wheat (Julius)

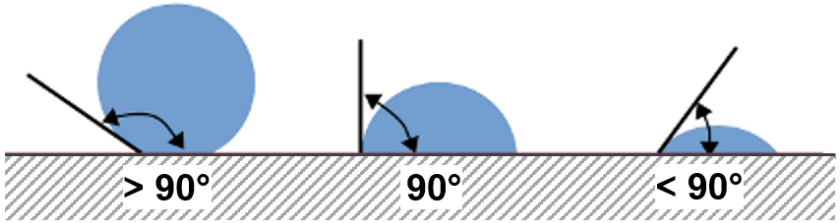
under revision Brust et al.

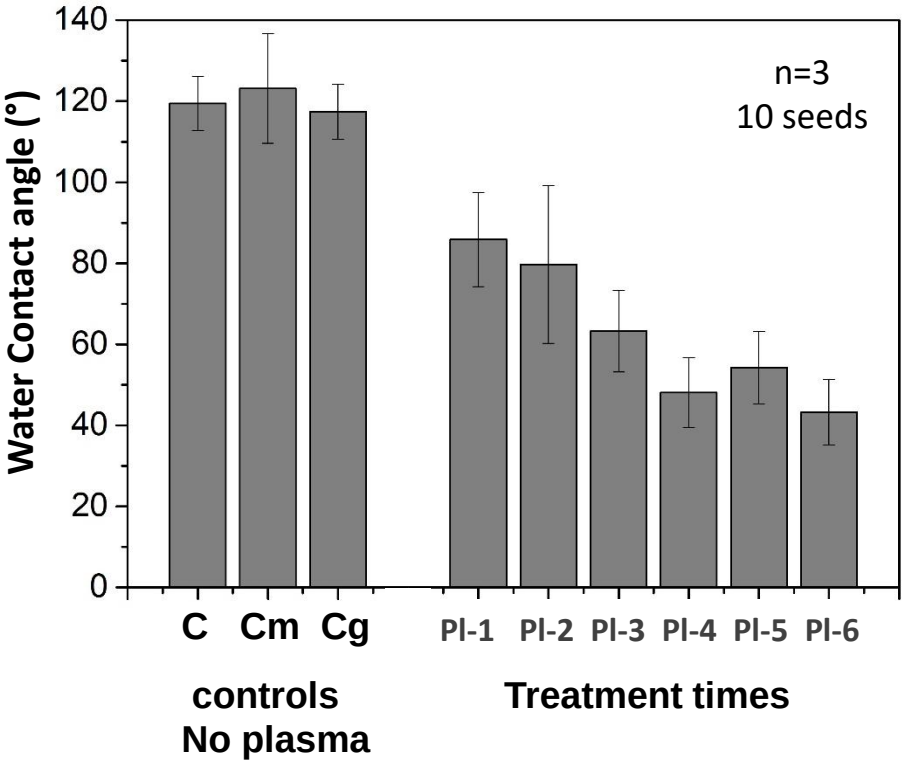
Direct Treatment- Wettability of Seed Surface


Water contact angle
Determination of angle



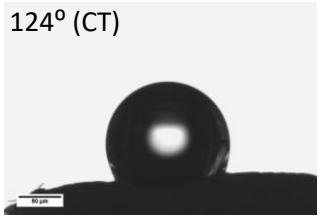
Goniometer (DataPhysics SCA)
software SCA20

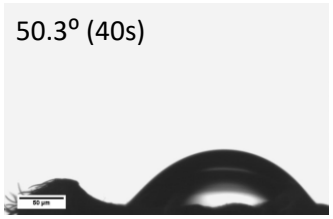




→ Seed surface modified to be more hydrophilic after direct plasma treatment

→ Checking functional groups on seed surface e.g. XPS





Direct Treatment- Element Composition of Seed Surface

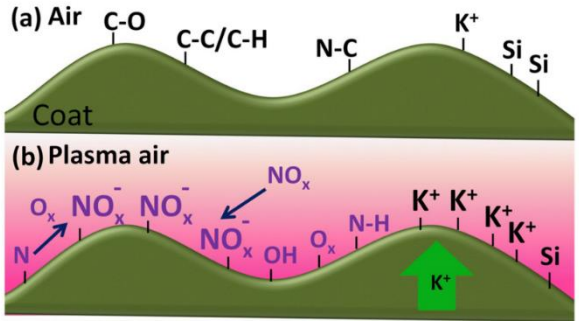
Hypothesis for plasma effects on seed germination

- **Surface functionalization**

→ Better water uptake

- **Physiological changes**

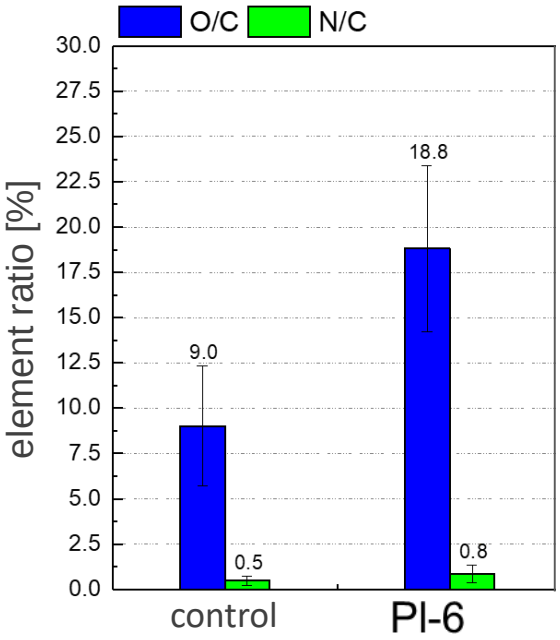
→ RONS are signalling molecules



Gómez-Ramírez et al., 2017

XPS Analysis of wheat seeds treated with Screw PS

Axis Ultra, Kratos



n=9, 3 seeds

wheat

under revision Brust et al.

Seed Treatment – Plant Species

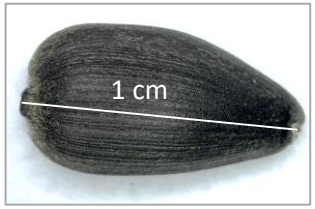
Wheat (*Triticum aestivum* L.)

Wheat (Julius)

Barley (*Hordeum vulgare* L.)

Barley (Kosmos)

Sunflower (*Helianthus annuus* L.)

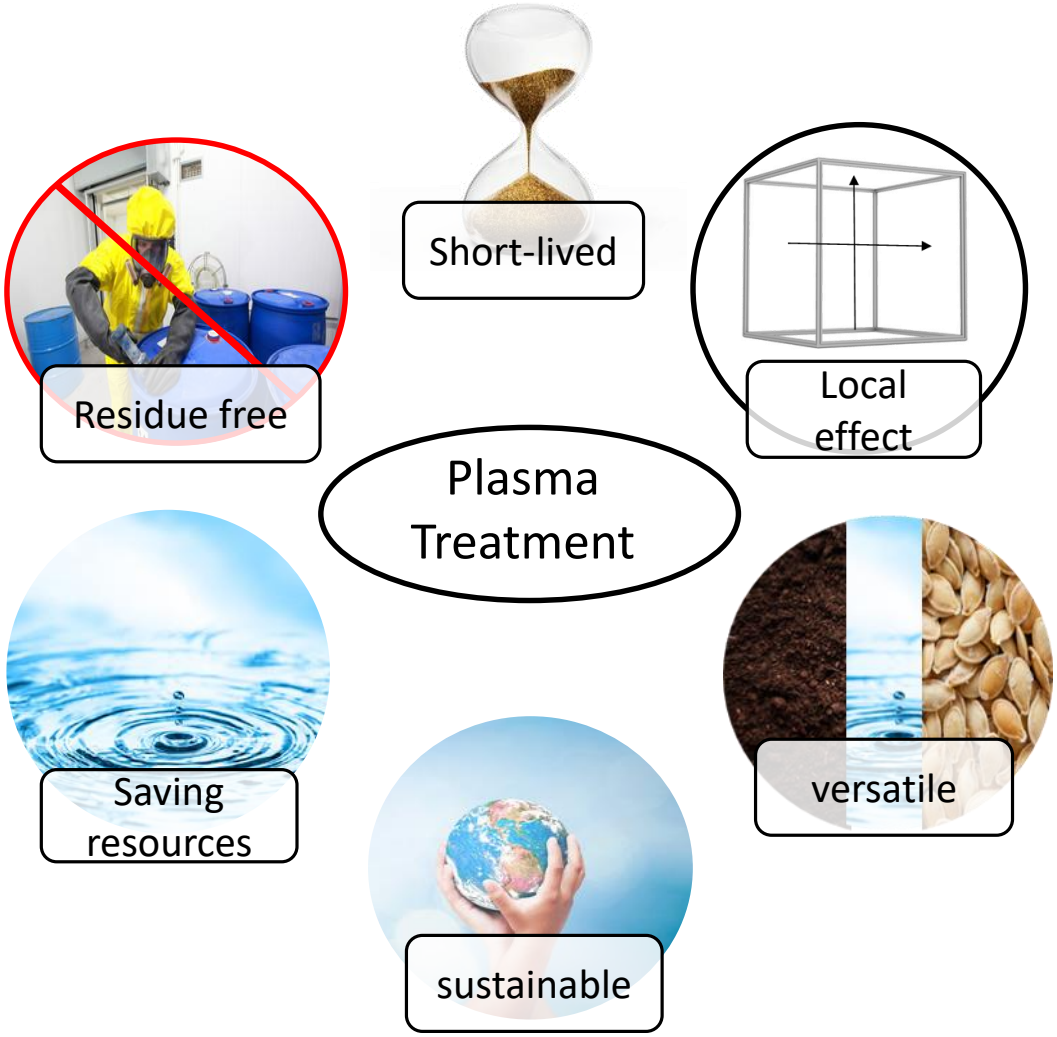


Sunflower (HEL 712/2016)

- Positive Effects on germination rate
- Storage effects
- Improved wettability of seed surface
- Positive trend for improved swelling during water uptake

- Field trials

Potential Advantages of Plasma Technology



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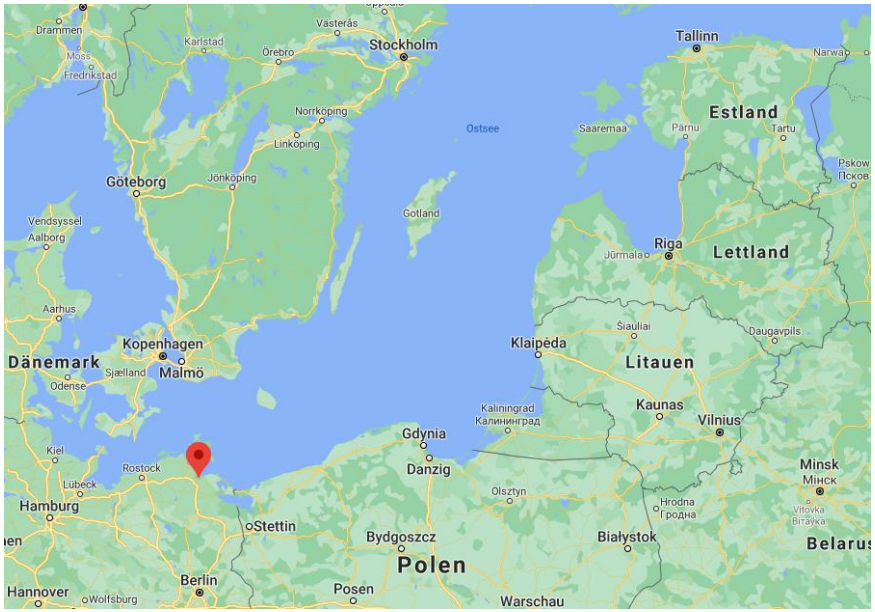
Thank you for your Attention



Research group Plasma Agriculture from Greifswald in Germany

Thank you for your Attention

For further reading:

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- Brandenburg, R., Bogaerts, A., Bongers, W., Fridman, A., Fridman, G., Locke, B. R., ... & Ostrikov, K. (2019). White paper on the future of plasma science in environment, for gas conversion and agriculture. Plasma Processes and Polymers, 16(1), 1700238.
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