Electrical discharge plasma for seed sterilization and quality enhancement

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Challenges / Research problems

Electrical discharge plasma

- Low-cost, Low power and Scalable nonthermal plasma operated under atmospheric pressure under air-based ambient conditions without the need for a vacuum.
- Gas, Liquid, Liquid-air interfacial Plasma

Seed sterilization and quality enhancement

- Seed sterilization from microorganism infestation
- Seed surface modification and wettability enhancement
- Seed vigor improvement
- Seed storability factors (hydration, hygroscopicity and aging test)

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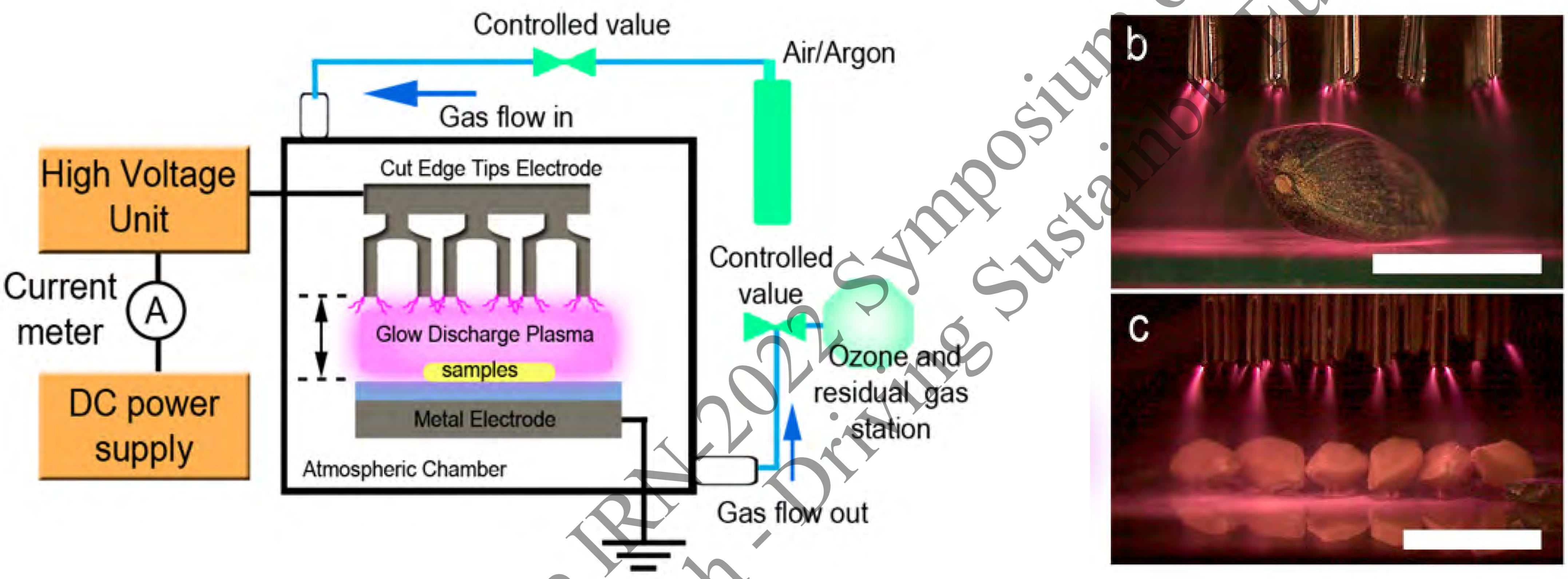
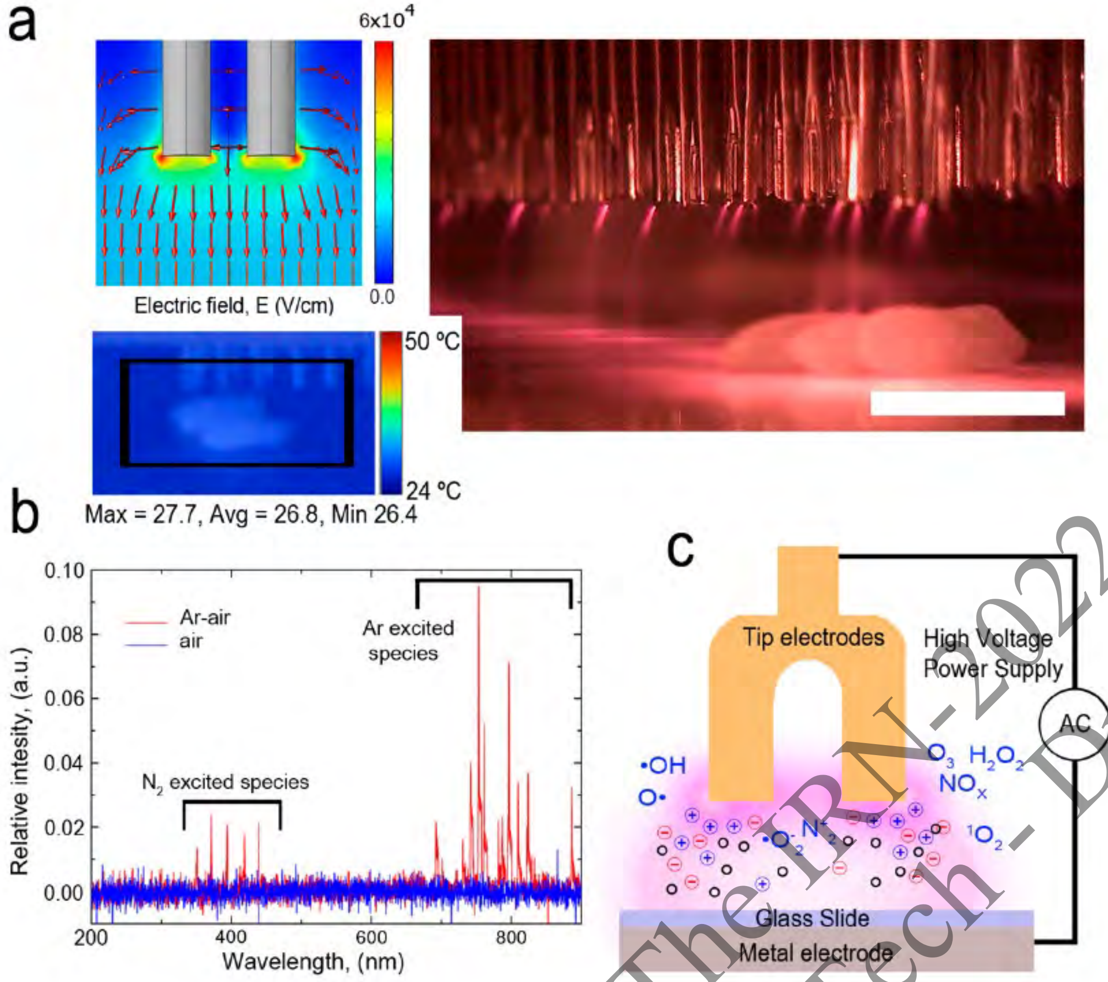
Hybrid cold discharge-plasma system configuration for sterilizing and modifying the surface of rice seeds.



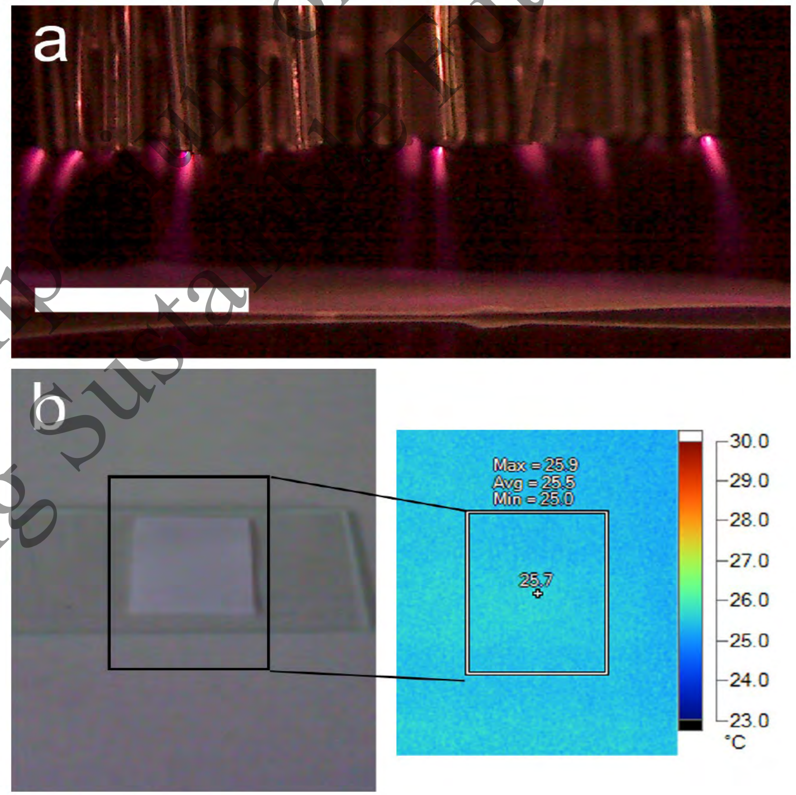
The hybrid cold discharge-plasma system. (Left) schematic of the microcorona discharge on the single dielectric barrier, (Right) The hybrid cold discharge-plasma mechanism

Khamsen, N.; Onwimol, D.; Teerakawanich, N.; Dechanupaprittha, S.; Kanokbannakorn, W.; Hongesombut, K.; **Srisonphan, S.,** Rice (Oryza sativa L.) seed sterilization and germination enhancement via atmospheric hybrid nonthermal discharge plasma. *ACS applied materials & interfaces* **2016,** *8* (30), 19268-19275.

Hybrid cold discharge-plasma system configuration for sterilizing and modifving the surface of rice seeds.



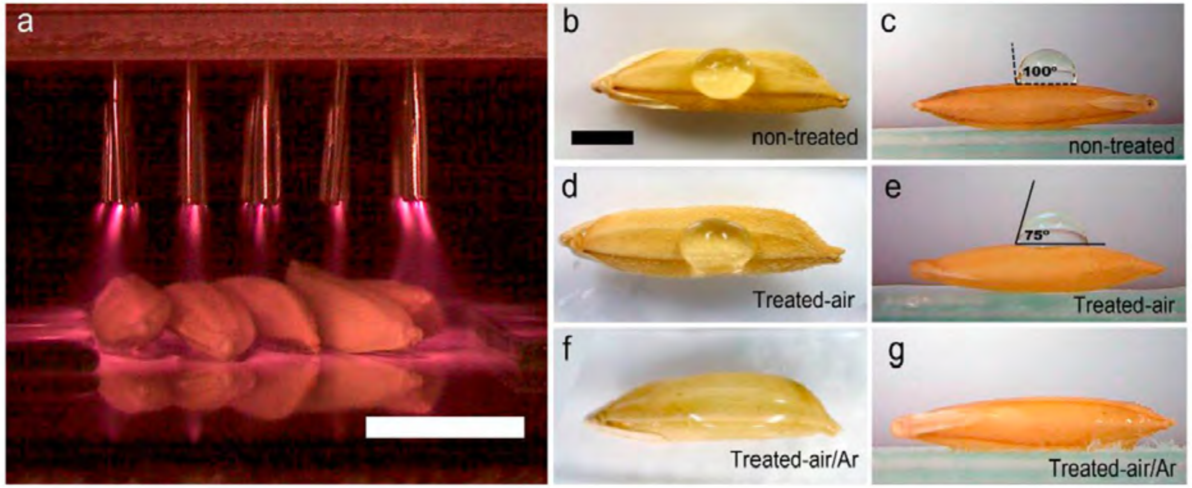
Hybrid cold plasma-discharge mechanism. (a) the large-scale plasma treatment of rice grains with corresponding temperature. (b) Optical emission spectra (OES) of plasma generated under the mixture of Ar-air (red line) and air ambient (blue line). (c) A diagram of the plasma mixture comprising UV and related reactive species composition.



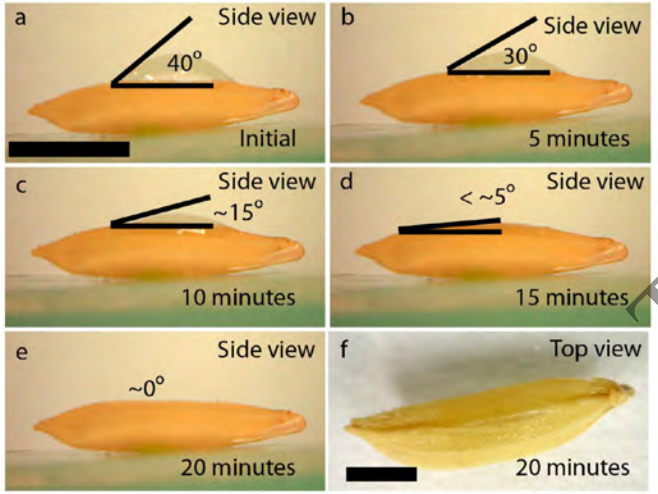
Non-thermal hybrid plasma treatment on white paper. (a) Optical micrograph of an atmospheric hybrid cold plasma treated on white paper (scale bar ~5 mm). (b), a white paper after ten mins of plasma operation (scale bar ~2 cm). Inset is the corresponding temperature of paper right after plasma process.

Khamsen, N.; Onwimol, D.; Teerakawanich, N.; Dechanupaprittha, S.; Kanokbannakorn, W.; Hongesombut, K.; **Srisonphan, S.,** Rice (Oryza sativa L.) seed sterilization and germination enhancement via atmospheric hybrid nonthermal discharge plasma. *ACS applied materials & interfaces* **2016,** *8* (30), 19268-19275.

Cold plasma-mediated hydrophilic surface modification and enhancement of water imbibition of rice seed

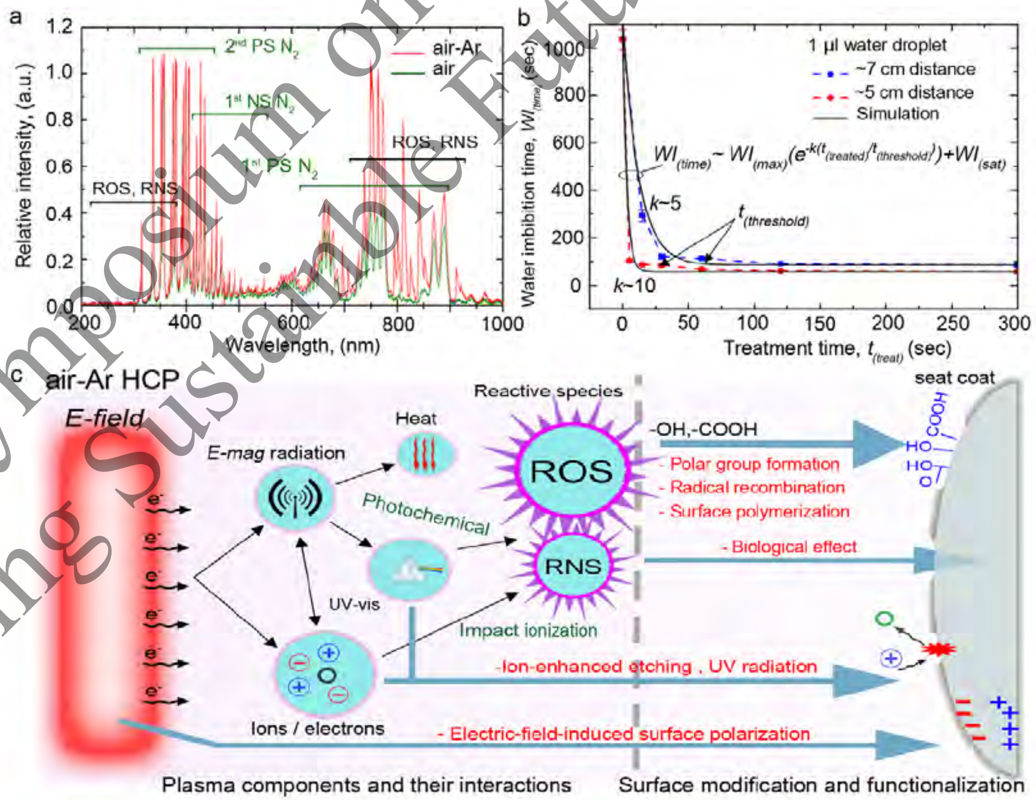


Cold plasma-mediated hydrophilic surface modification and enhancement of water imbibition.
(a) Operation of hybrid cold-discharge plasma on rice seeds (scale bar ~7 mm). (b, d, f) Water-droplet morphology and imbibition enhancement of nontreated, pure air-treated, and air/Ar-treated seeds, respectively. (c, e, g) Apparent contact-angle measurements of nontreated (~100°), pure air-treated (~75°), and air/Ar-treated (~0°) seeds, respectively (scale bar ~4 mm)



The apparent contact angle of scarification seeds rice seed. (a) the immediately contact angle of scribed seed (~40°) (scale bar ~ 5 mm), and the contact angle of scribed seed after (b) 5 mins (~30°), (c) 15 mins (~ 15°) and (e) 20 mins (~0°). (f) the top view of rice seed. Note that in this figure water was not fully absorb and need ~25 mins for fully absorption. (scale bar ~4 mm)

Khamsen, N.; Onwimol, D.; Teerakawanich, N.; Dechanupaprittha, S.; Kanokbannakorn, W.; Hongesombut, K.; **Srisonphan, S.,** Rice (Oryza sativa L.) seed sterilization and germination enhancement via atmospheric hybrid nonthermal discharge plasma. *ACS applied materials & interfaces* **2016,** *8* (30), 19268-19275.



Surface modification mechanisms and models.
(a) Optical emission spectrum of air and air−Ar HCP used to shower the seed surface. (b) Modeling WI(time) as a function of t(treat) at electrode distances of ~5 and ~7 cm. (c) Interactions between the fundamental components of NAP. The circle dimensions correspond to levels of interaction.

Srisonphan, S., Tuning surface wettability through hot carrier initiated impact ionization in cold plasma. *ACS applied materials & interfaces* **2018,** *10* (13), 11297-11304.

Rice (Oryza sativa L.) seed sterilization and germination.

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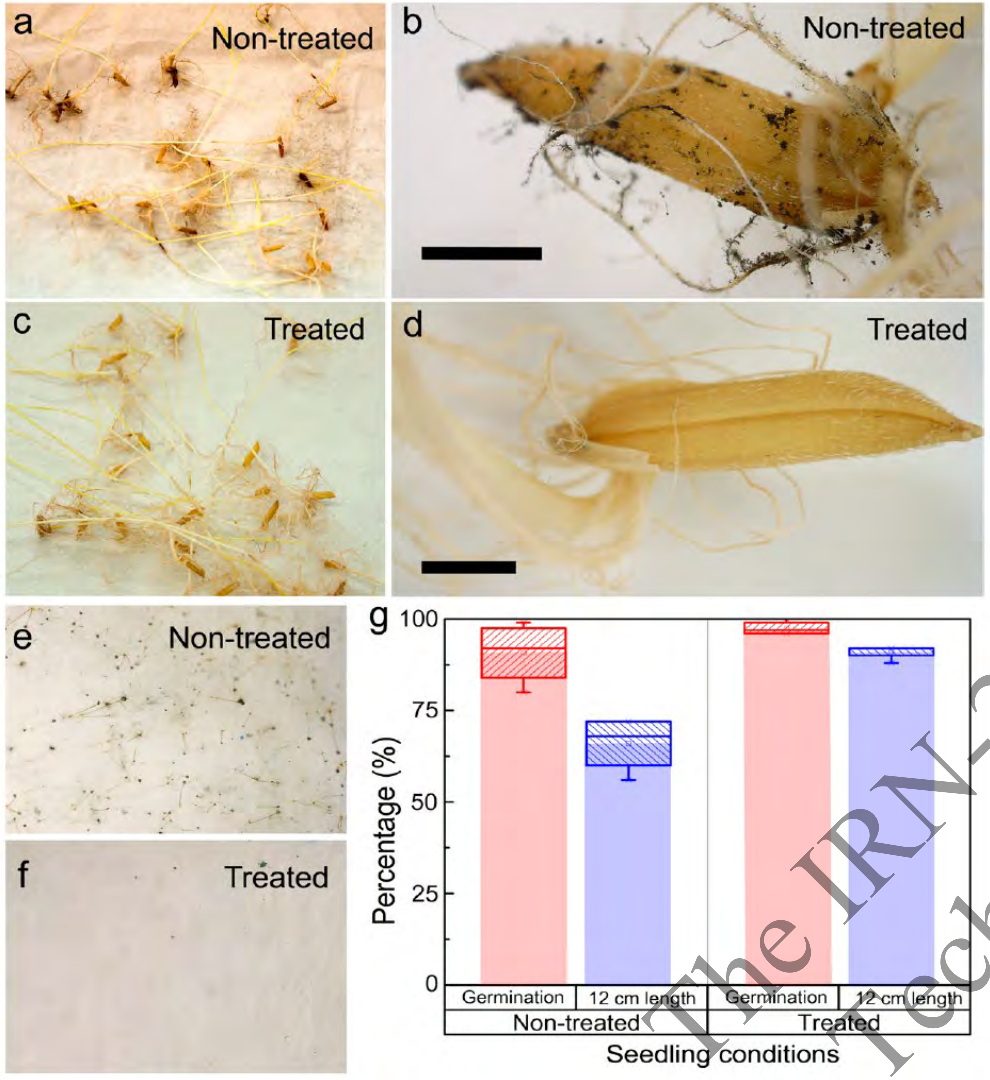
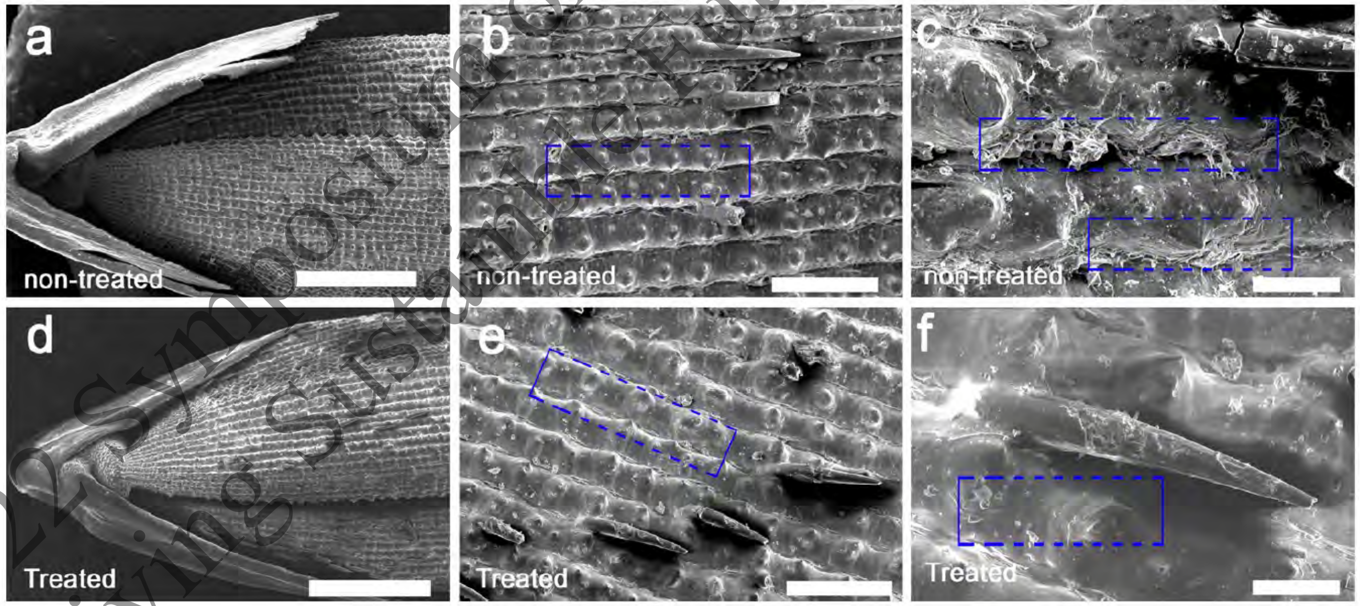


(a, b) Day 14 rice seedlings that did not experience cold plasma before planting. All the seedlings show poor germination due to pathogenic fungi and seed-transmitted diseases (Scale bar ~3.5 mm). (c, d) Day 14 rice seedlings that experienced cold plasma before planting. All the seedlings appear healthy and without pathogenic fungi. (e, f) Blotter paper used to incubate the seedlings after the day 14 (g) Statistical variation of germination rate and seed quality on day 14 of nontreated and treated samples.



SEM micrographs of rice seeds, including the seed coat−lemma and palea−in untreated control and cold plasma-treated KDML105 rice. (a−c) Nontreated rice seeds with scale bars ~500, 200, and 50 μm, respectively. (d−f) Treated rice seeds with scale bars ~500, 200, and 50 μm, respectively. The blue dashed line windows demonstrated (b, c) the microorganism living along the trench and (e, f) fragments of microorganisms.

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Effect of atmospheric DBD plasma treatment on the hydration characteristics of rice seeds.

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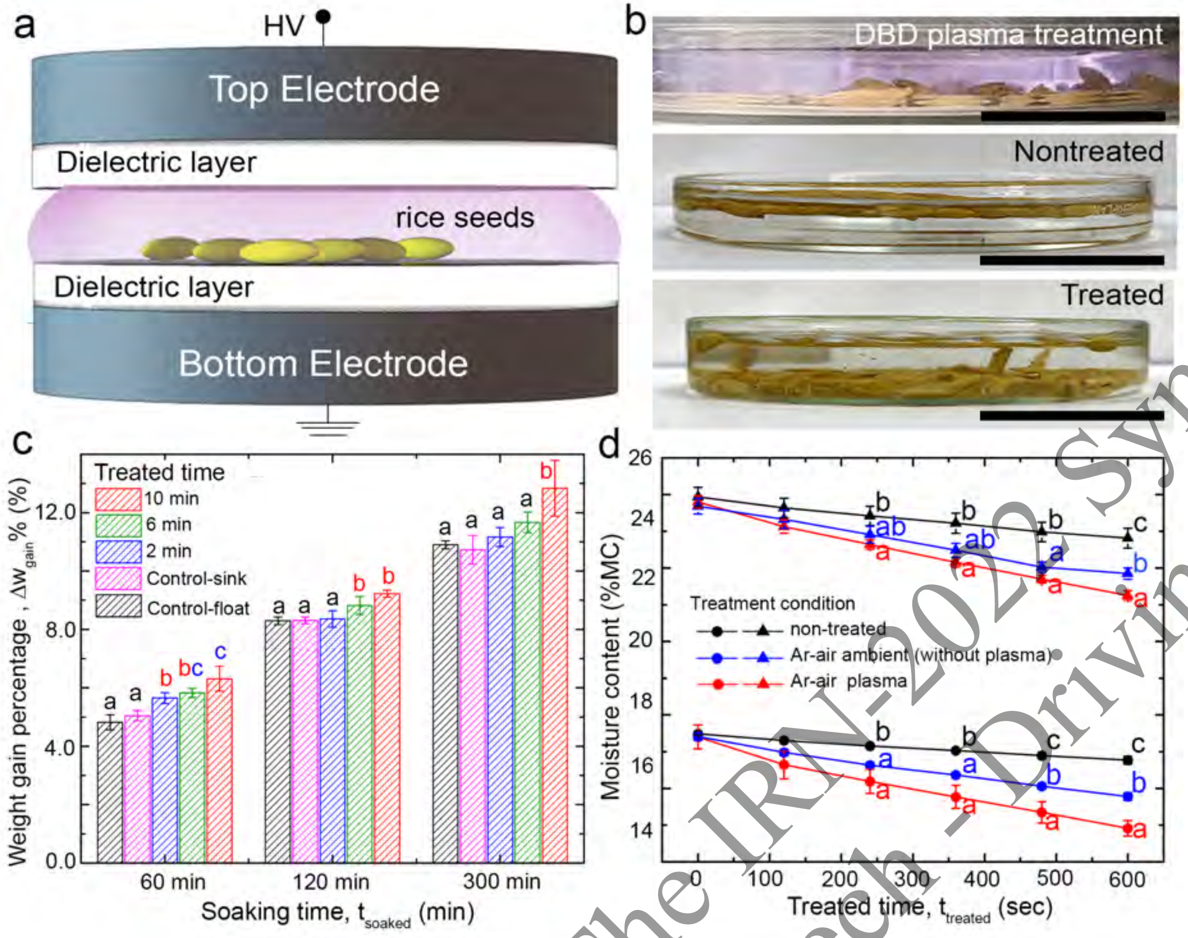
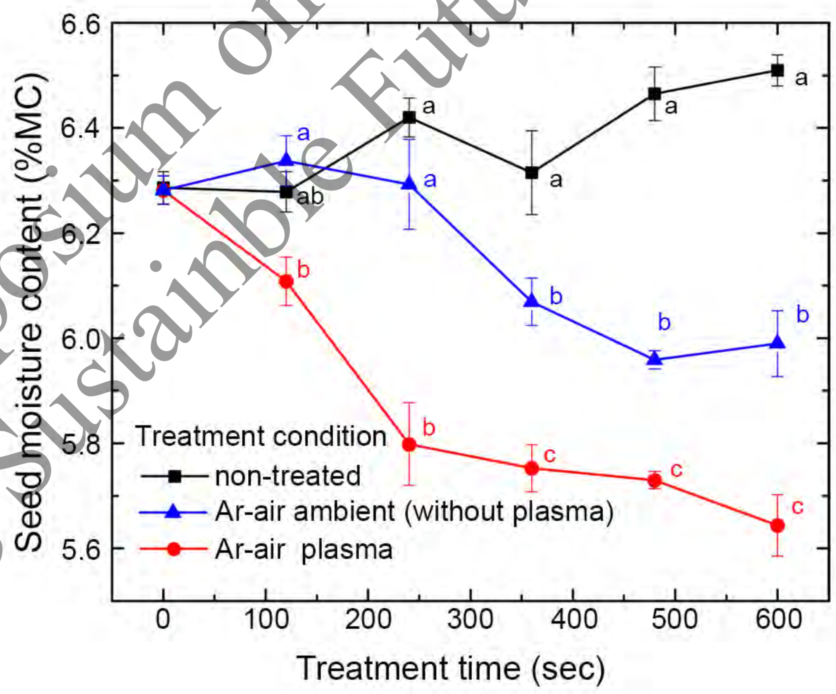


(a) Schematic diagram and ((b), top) optical image of rice seeds treated with DBD plasma (scale bar 3 cm). The comparison of seed surface wettability of nontreated ((b), middle) and treated ((b), bottom) seed in a flotation test (scale bar 4 cm). (c) The weight gain percentage (Δ*wgain*%) of nontreated and treated rice seeds after soaking for 1, 2, and 5 h. (d) The plasma treatment on the relatively high moisture content of rice seeds; the seed moisture content for nontreatment (black-line), Ar-air plasma treatment (red-line), and only Ar-air treatment without plasma activation (blue line) at different treatment times. The data shows the mean ±2SE using different letters to denote a statistically significant difference ($p < 0.05$) between the different treatment conditions at each treatment time.



Plasma treatment of seeds with a very low MC

S. Srisonphan et al., "Effect of dielectric barrier discharge plasma on rice (Oryza sativa L.) seed hydration and hygroscopicity," *Journal of Physics D: Applied Physics*, vol. 55, no. 36, p. 365201, 2022/06/24 2022, doi: 10.1088/1361-6463/ac791d.

Effect of plasma on rice seed hygroscopicity and the interactions on the seed's surface

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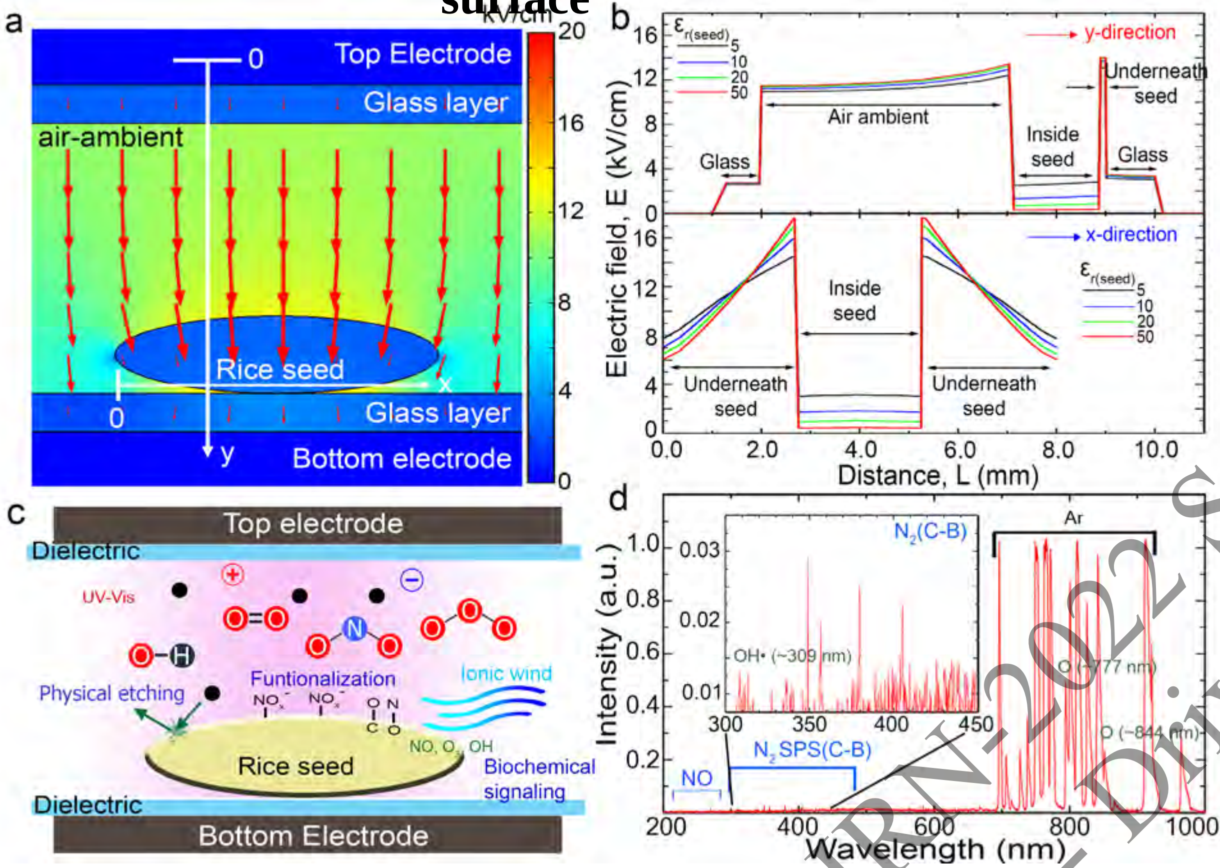
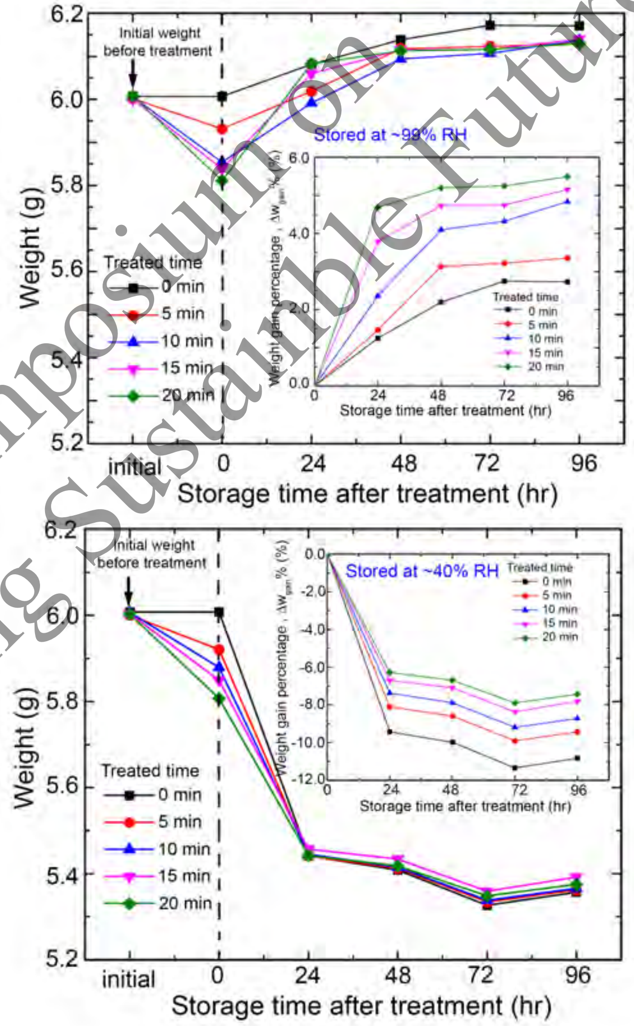


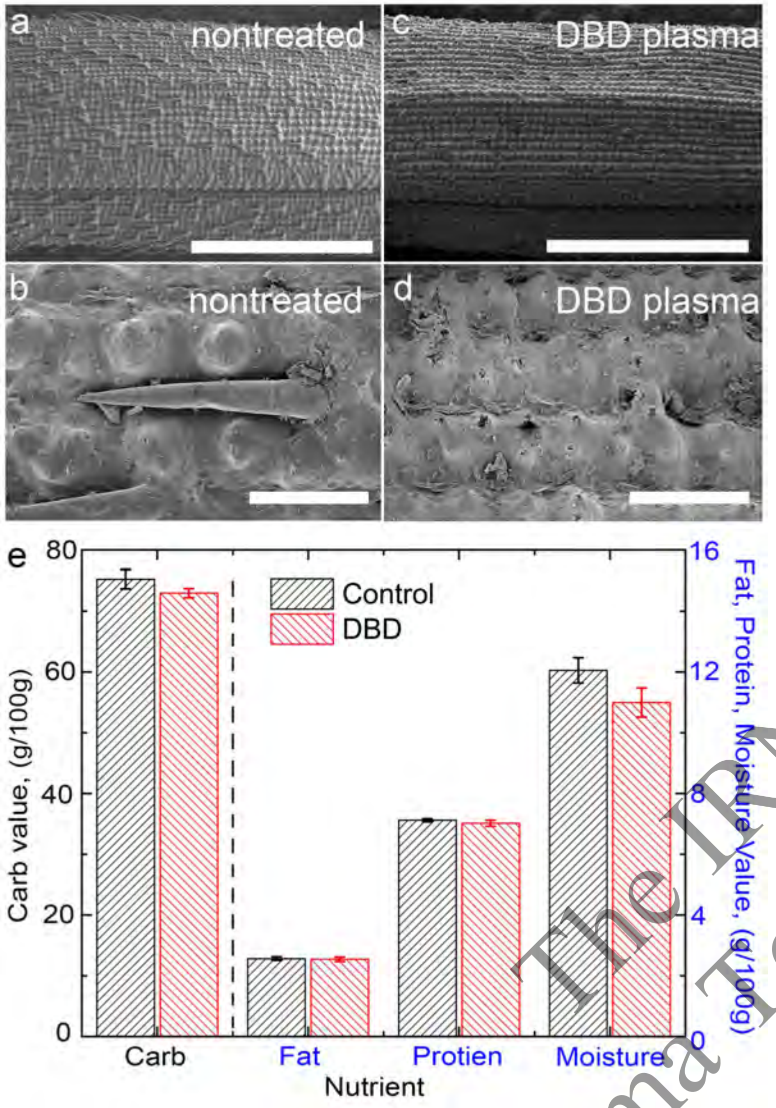
DBD plasma mechanism and interactions on the seed's surface:
(a) the two-dimensional E-field distribution during operation of the DBD plasma treatment and (b) the corresponding E-field along the vertical direction from the top electrode to the bottom electrode (top) and horizontal direction beneath the rice seed (bottom) for varying dielectric permittivity. (c) Plasma treatment of seeds and the associated effects on the seedling's physiology. Ions, electrons, and reactive species interact with a microbiological surface via etching or the introduction of functional groups such as –COOH, –OH, and –NH2 change the surface energy and composition. (d) Optical emission spectroscopy (OES) was used to determine the radical composition of the plasma.



Effect of plasma on rice seed hygroscopicity.
Weight of plasma-treated rice seed after being kept in (a) ~99% RH and (b) room humidity ~40% RH ambient. The corresponding weight gain percentage (Δ*w*gain%) of rice seed at a given time of storage (inset). The data represents the mean of five different measurements for each seed treatment.

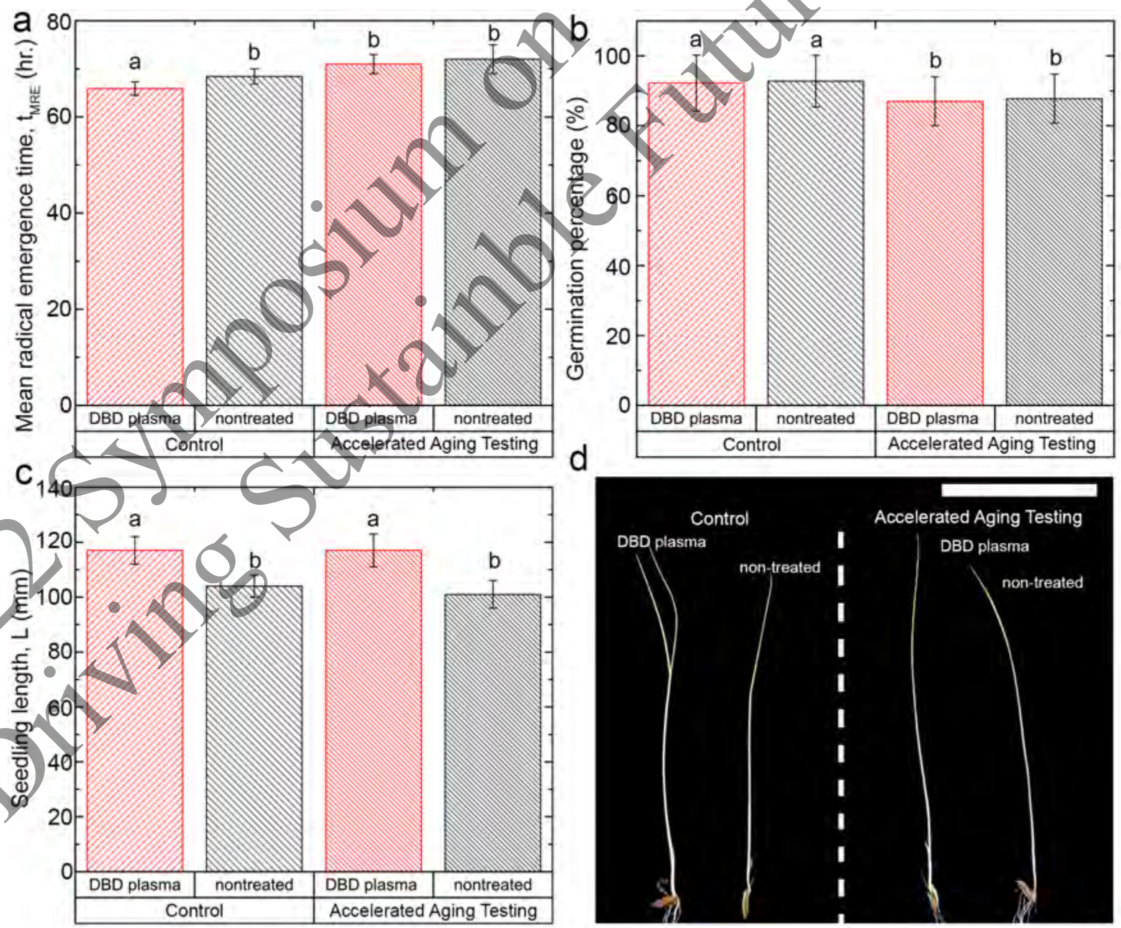
S. Srisonphan et al., "Effect of dielectric barrier discharge plasma on rice (Oryza sativa L.) seed hydration and hygroscopicity," *Journal of Physics D: Applied Physics*, vol. 55, no. 36, p. 365201, 2022/06/24 2022, doi: 10.1088/1361-6463/ac791d.

Plasma effect on the morphology and nutrition of rice seeds.



S. Srisonphan et al., "Effect of dielectric barrier discharge plasma on rice (Oryza sativa L.) seed hydration and hygroscopicity," *Journal of Physics D: Applied Physics*, vol. 55, no. 36, p. 365201, 2022/06/24 2022, doi: 10.1088/1361-6463/ac791d.

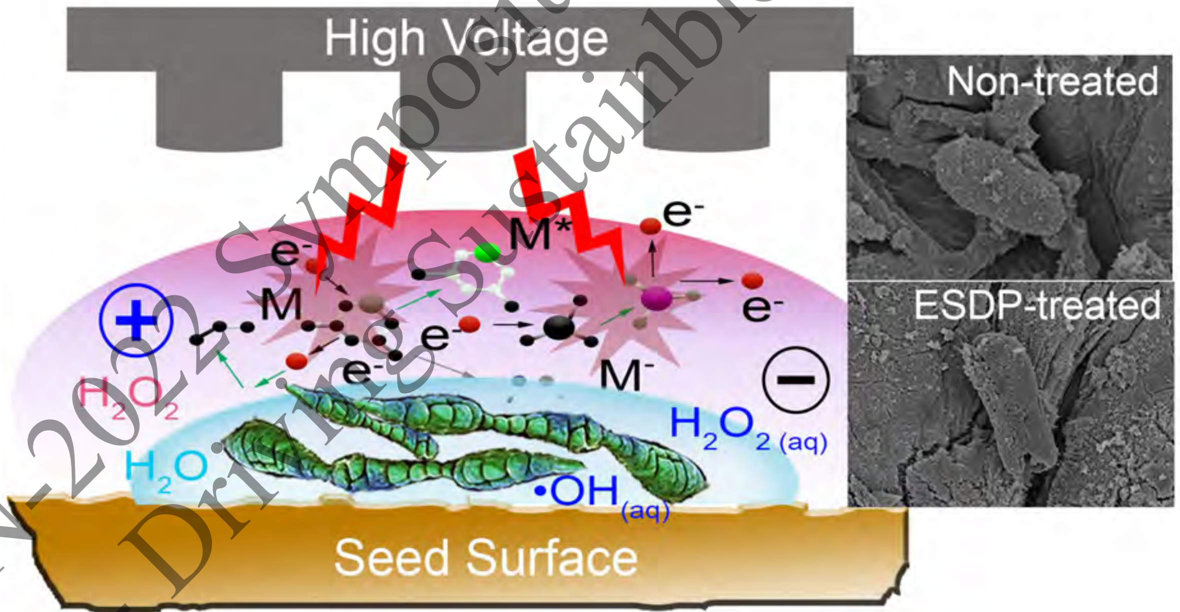
Plasma effect on germination parameter before and after artificial aging.



The effects of cold plasma on (a) mean radical emergence time, (b) germination percentage, and (c) seedling length. Each result is the average of four replications, with each sample containing 100 seeds. Error bars indicate two standard errors ($n = 4$) using different lowercase letters to denote a statistically significant difference ($p < 0.05$). (d) A representative optical image of a seedling on day 14 of germination.

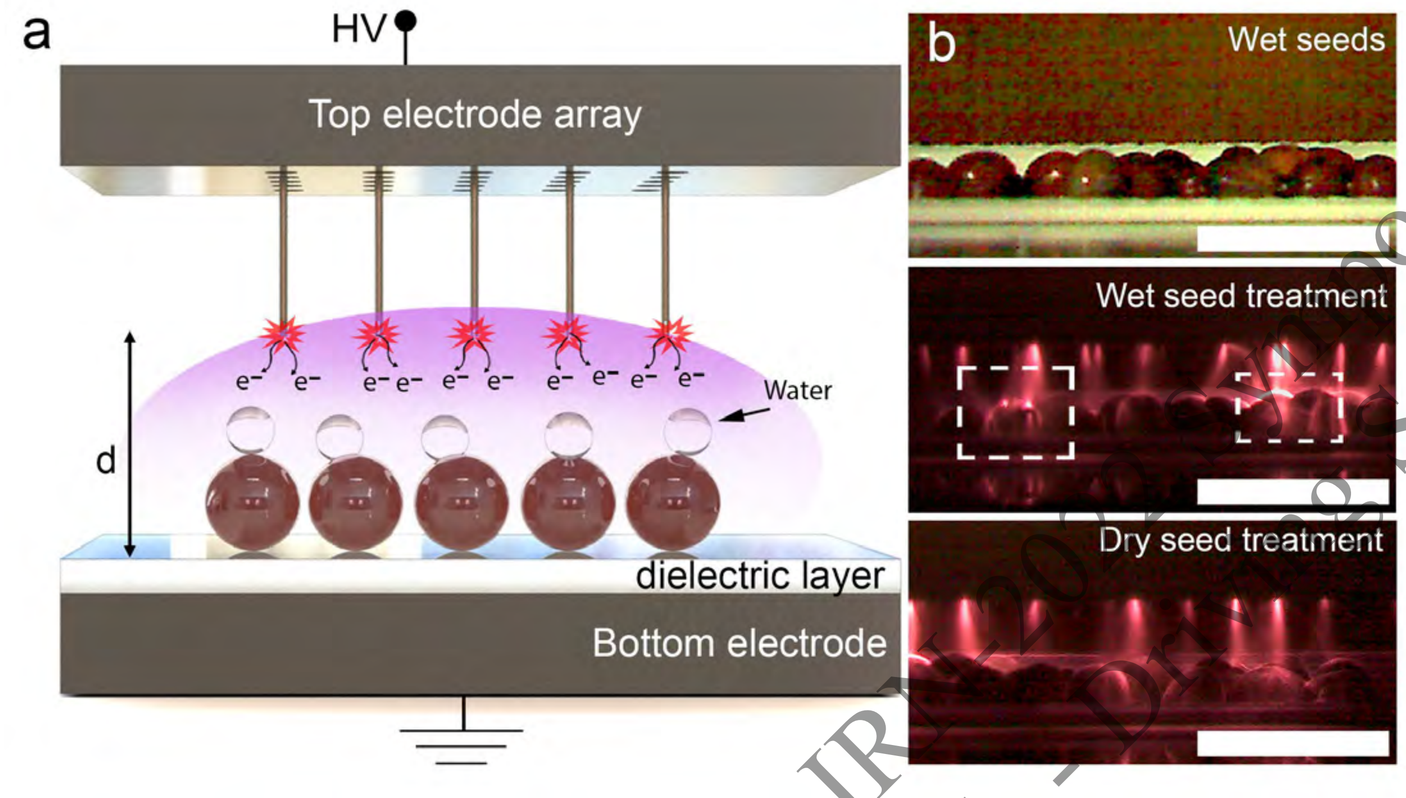
Electrohydraulic Streamer Discharge Plasma-Enhanced *Alternaria brassicicola* Disinfection in Seed Sterilization

https://commons.wikimedia.org/wiki/File:Alternaria_brassicicola_host_symtoms5.jpg

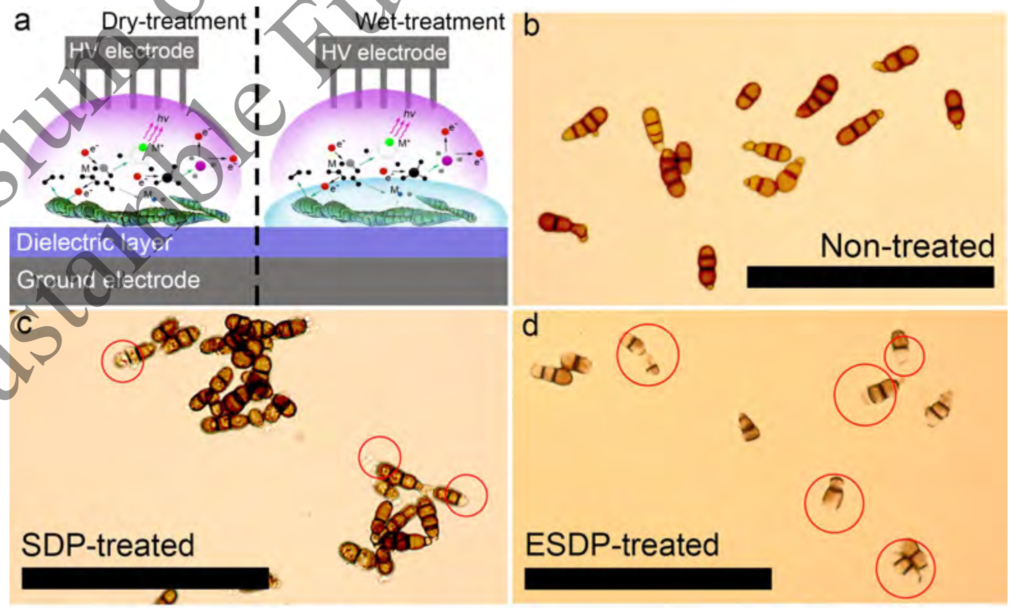


Suwannarat, S.; Thammaniphit, C.; **Srisonphan, S.,** Electrohydraulic Streamer Discharge Plasma-Enhanced Alternaria brassicicola Disinfection in Seed Sterilization. *ACS Applied Materials & Interfaces* **2021,** *13* (37), 43975-43983.

Electrohydraulic streamer discharge plasma treatment on Chinese kale seeds and the *A. brassicicola.*



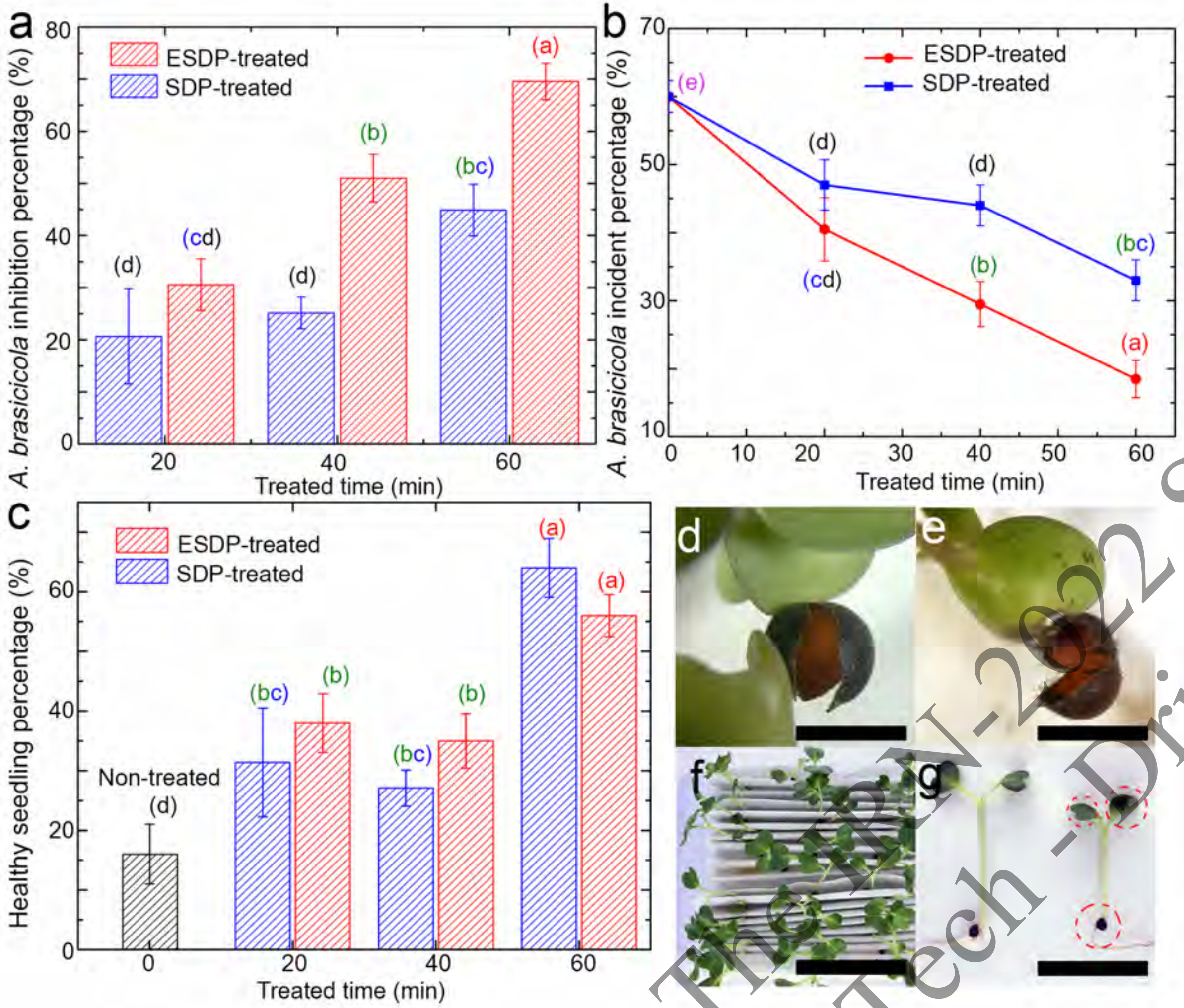
Electrohydraulic streamer discharge plasma treatment on Chinese kale seeds.
(a) Schematic diagram of the ESDP treatment of Chinese kale seeds. (b) Optical images of nontreated wet seeds (top), SDP-treated wet seeds (middle), and SDP-treated dry seeds (bottom) (scale bar ∼1 cm).



Effects of ESDP and SDP on the fungal morphology and viability of *A. brassicicola.*
(a) Schematics of A. brassicicola spores treated with SDP in dry conditions (left) and wet conditions (right). (b−d) Optical images of the A. brassicicola spores (b) before plasma treatment, (c) after SCP treatment, and (d) after ESDP treatment. The red circles indicate abnormalities such as distorted structures, swellings, leakage of membranes, and loss of pigmentation in spores. (Scale bars ∼100 μm). This experiment was performed twice with at least 100 spores.

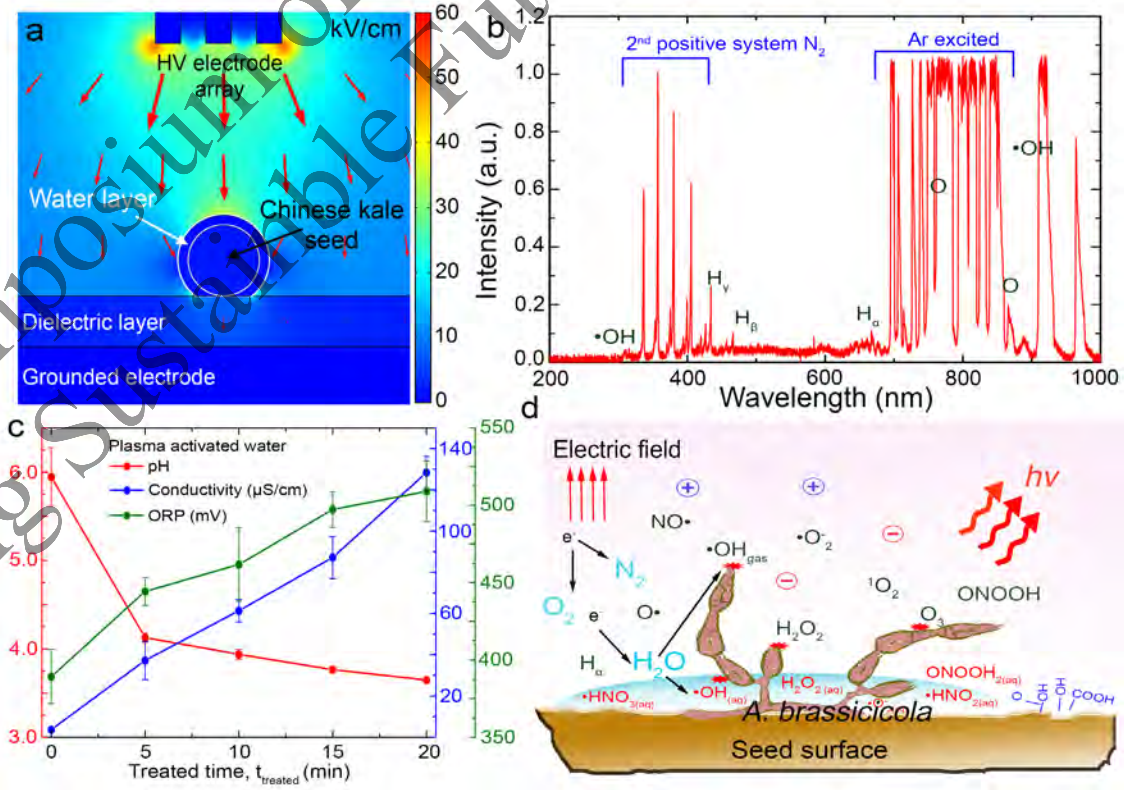
Suwannarat, S.; Thammaniphit, C.; **Srisonphan, S.,** Electrohydraulic Streamer Discharge Plasma-Enhanced Alternaria brassicicola Disinfection in Seed Sterilization. *ACS Applied Materials & Interfaces* **2021,** *13* (37), 43975-43983.

ESDP sterilization of *A. brassicicola*-inoculated Chinese kale seeds.



(a) A. brassicicola inhibition percentage of the germinated seeds on day 7 after incubation. (b) A. brassicicola incident percentage of the germinated seeds on day 7 after incubation. (c) Germination percentage of the healthy seedlings after the germination test on day 14. Optical images of the (d) healthy and (e) infected germinated seeds (scale bar ~0.4 cm). (f) Germination test of the blotter paper showing the disease-free seedlings (g-left) and infected seedlings (g-right) (scale bar ~3 cm).

Gas−liquid interfacial interaction of ESDP and the microbial deactivation mechanism.



(a) E-field distribution during the wet treatment process. (b) Optical emission spectroscopy (OES) measured electrohydraulic streamer discharge plasma in the Ar−air ambient mixture. (c) Physicochemical properties (PH, conductivity, and ORP) of PAW at different treatment times. (d) Mechanism of the liquid−gas interfacial plasma interacting on the A. brassicicola attached to the seed surfaces due to RONS and its physiochemical properties.

Suwannarat, S.; Thammaniphit, C.; **Srisonphan, S.,** Electrohydraulic Streamer Discharge Plasma-Enhanced Alternaria brassicicola Disinfection in Seed Sterilization. *ACS Applied Materials & Interfaces* **2021,** *13* (37), 43975-43983.

SEM images of the *A. brassicicola* spores attached to the Chinese kale seed before and after plasma treatment.

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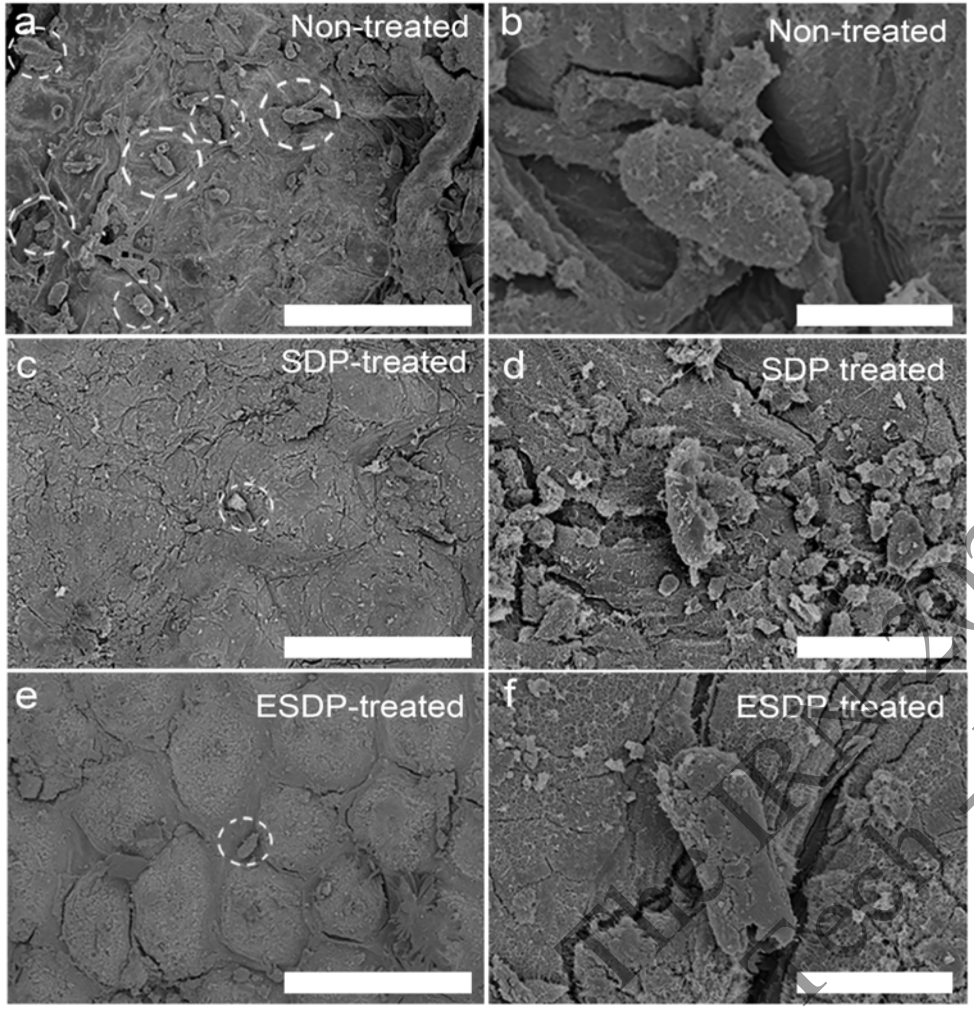
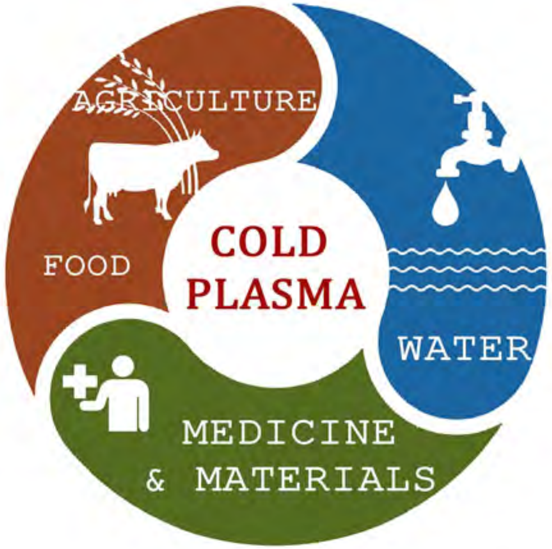
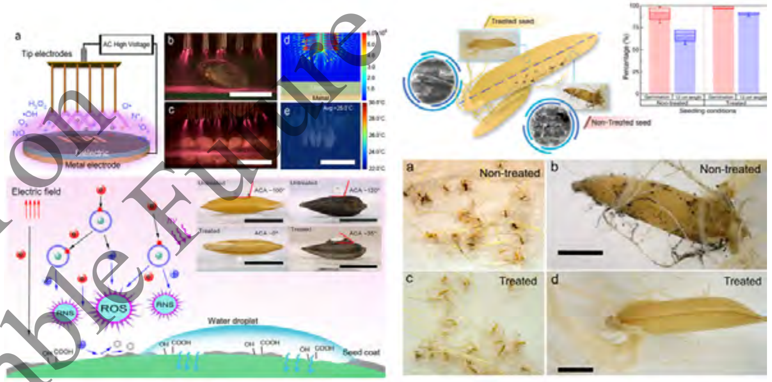


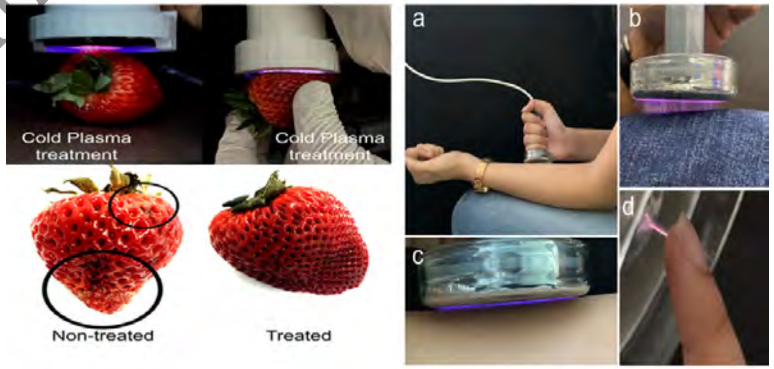
Suwannarat, S.; Thammaniphit, C.; **Srisonphan, S.,** Electrohydraulic Streamer Discharge Plasma-Enhanced Alternaria brassicicola Disinfection in Seed Sterilization. *ACS Applied Materials & Interfaces* **2021,** *13* (37), 43975-43983.

(a, b) Control of the Chinese kale seeds after inoculation with A. brassicicola for ∼7 days. (c−f) Inoculated Chinese kale seed surface after passing (c, d) SDP and (e, f) ESDP treatments for ∼60 min (left scale bar ∼100 μm and right scale bar ∼10 μm).

Conclusion







Test organism	Number of bacteria on pool of 5 carriers: Untreated carriers (Control carriers) (CFU/pool of 5 carriers)	Number of bacteria on pool of 5 carriers: Survivor on product treated carriers (Test carriers) (CFU/pool of 5 carriers)	Killing activity: Log reduction	Killing activity: % Reduction	Average killing activity, Geometric mean: Log reduction	Average killing activity, Geometric mean: % Reduction
Staphylococcus aureus (ATCC 6538)						
Replicate 1	1.3 X 10^7 (7.14 log)	1.0 X 10^3 (3.00 log)	4.14	99.9	3.99 log	99.9 %
Replicate 2		9.8 X 10^2 (2.99 log)	4.15	99.9		
Replicate 3		2.4 X 10^3 (3.38 log)	3.76	99.9		
Replicate 4		1.2 X 10^3 (3.08 log)	4.06	99.9		
Salmonella choleraesuis (ATCC 10708)						
Replicate 1	1.4 X 10^7 (7.16 log)	$0 \leq 10$ ($\leq$ 1.00 log)	≥ 6	≥ 99.9	≥ 6 log	≥ 99.9 %
Replicate 2		$0 \leq 10$ ($\leq$ 1.00 log)	≥ 6	≥ 99.9		
Replicate 3		$0 \leq 10$ ($\leq$ 1.00 log)	≥ 6	≥ 99.9		
Replicate 4		$0 \leq 10$ ($\leq$ 1.00 log)	≥ 6	≥ 99.9		

Thank you