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Atmospheric Air Plasma Discharges and Plasma Activated Water for Plasma Medicine and Agriculture

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Atmospheric pressure air discharges generate cold plasmas rich in production of *reactive oxygen and nitrogen species* (RONS) that play crucial roles in multiple biomedical, food processing and agriculture applications, such as disinfection, induction of cell proliferation, antitumor effects, stimulation of seed germination or plant growth. *Plasma activated water (PAW)*, i.e. water or aqueous solutions treated by such plasmas, also demonstrate antimicrobial or cytotoxic effects. The plasma-generated RONS are transported from the gas phase through to the liquid and induce formation of secondary RONS in water. This is typically accompanied by acidification and antimicrobial effects that can last in the PAW for several hours/days after plasma treatment [1].

We tested various self-pulsing DC-driven air discharges regimes: positive and negative streamer corona and transient spark (TS) in various configurations and gas mixtures. Water was activated either indirectly or by a discharge directly into the water surface. The water electrospray was even more efficient, allowing for very efficient mass transfer of plasma-generated RONS into water [1-2]. The production of RONS in PAW can be controlled by the physical discharge properties and gas mixtures, which determine the PAW chemical and antibacterial properties.

The antibacterial effects were tested on *E. coli* in water and correlated with the RONS generation and time evolutions. They are stronger with direct than indirect plasma treatment when bacteria are only incubated in PAW. Antibacterial properties of PAW decay within hours but can be prolonged when cooled or frozen. PAW showed a great potential for some medical therapies e.g. of periodontal biofilms, endodontics, urinary tract infections, or open wounds. Direct TS treatment of various biomolecules (e.g. protein or DNA) show efficient denaturation and changes in their secondary structure. Indirect TS treatment of cell culture media decreased viability of cancer cell (HeLa, A375 melanoma) without recovery, while normal cells (Vero, HEK293T) partly recovered after initial inhibition, which opens new potential for cancer therapies [2].

TS air discharge was successfully tested to induce antimicrobial effects in food products, such as fruit juices and significantly extended shelf-life time of the juice without a negative impact on its chemical (pH change, contents of organic acids, polyphenols, sugars) and sensory properties. RONS in the PAW may act like signal molecules inducing the seed germination and also as the essential nutrients for plant growth. We measured the increase of germination rate of wheat seeds and dry weight of seedlings. Enhanced plant growth was tested on several plant species (lettuce, radish, tomato, wheat): the growth parameters, photosynthetic pigments, net photosynthesis rate, and activity of antioxidative enzymes were analyzed. We observed different responses to PAW in dependence on plant species. PAW can be used in certain conditions as an environmentally friendly fertilizer.

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[1] Z. Machala et al.: *Plasma Process. Polym.* 10, 649, 2013

[2] K. Hensel et al.: *Biointerphases* 10, 029515, 2015