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Plasma activated water: plasma-induced gas-phase and liquid-phase chemistry and applications in biomedicine and food processing

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Water and aqueous solutions treated by cold atmospheric plasmas – so called plasma activated water (PAW) demonstrate antimicrobial or cytotoxic effects that are of great interest for many applications in biomedicine and food processing. Nonequilibrium air plasmas generate various radicals, ions, and reactive molecules commonly called reactive oxygen and nitrogen species (RONS: OH, H₂O₂, NO, NO₂, O₃, O₂⁻). They are transported from the gas phase through the plasma-liquid interface and may induce formation of secondary RONS in the liquid water, such as H₂O₂, nitrites/nitrates NO₂⁻/NO₃⁻, peroxyxynitrites/peroxyxynitrous acid ONOO⁻/ONOOH, superoxide O₂⁻, or OH.

The PAW bio-relevant effects can be enhanced by the efficient mass transfer of plasma-generated RONS into the water, e.g. when air discharges are combined with water electrospray. PAW antimicrobial activity normally decays in a few hours. The fast freezing can preserve it for days and weeks, as tested on various bacteria and yeasts.

The detection of RONS in the PAW is challenging due to the chemical instability of the detected RONS, or possible cross-reactivities of the analytical methods. We tested diagnostic methods for PAW, such as colorimetric detection of H₂O₂, NO₂⁻ and NO₃⁻, fluorescence spectroscopy of ONOO⁻ and OH, and indirect O₂⁻ detection using superoxide dismutase. We showed that established indigo blue assay of dissolved O₃ might be misleading in PAW.

The discharge regime and gas/liquid characteristics determine the PAW composition and the consequent bio-relevant effects. In low power air corona discharges, water electrospray increased O₃ production in both gas and liquid, which enhanced the biocidal effect. When the discharge regime transits to higher power transient spark, gaseous NO_x are dominantly formed, leading to significant NO₂⁻ and NO₃⁻ in the PAW and practically no O₃, and the bactericidal action mainly due to the synergy of H₂O₂, NO₂⁻ and acidic milieu (via ONOOH).

Preliminary results on cold plasma pasteurization of apple juice extending its shelf life up to 4 weeks without changes of its nutrient values demonstrate new potentials in food industry.

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