Plasma wet and dry approaches for agriculture: limitations, challenges and opportunities

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Abstract: Cold atmospheric plasma processes are routinely investigated in regard of their ability to induce relevant biological effects like improving seeds germination, promoting stems length or increasing crops yields. If research works have already demonstrated how plasma processes can successfully drive to such agronomical benefits, few of them are focused on the underlying energetical costs. This parameter, although at the interface of science and economy, is of major importance to make plasma agriculture a sustainable model.

Keywords: wet/dry plasma processes, plasma agriculture, energetic costs, molar production rates, energetic yields

1. Introduction

The assessment of physical processes to respond agricultural issues is the subject of research works for more than a century. Hence Shear *et al.* investigated in 1927 the effects of selective radiation on the germinative properties of seeds [1] while Stadler quantified the effects of X-rays radiation on plants growth in 1930 [2]. If the first use of cold plasmas to respond the same issues is mentioned in the early 2000s [3], [4], "plasma agriculture" as a transdisciplinary and foundational research area appears only a decade later [5]. Surprisingly, from 2000 to 2019 in a context where research is carried out at international level, no plasma technology has properly "emerged". Indeed, no phytosanitary company or industry professional has capitalized and raised funds to promote this technology or engineer large-scale plasma facilities, as they have done in the past with other technologies. In this presentation, we discuss the strengths and weaknesses of plasma processes dedicated to agriculture at the light of our research works but also considering current alternatives, deeply anchored in agriculture practices.

2. Plasma dry approach

A versatile flowing DBD device has been engineered to directly treat seeds either in discharge or in post-discharge regions, with the ability to control the volumetric seed filling rate, as shown in Fig. 1. Seeds of alfalfa, sunflower, radish, corn and barley have been directly exposed to plasma considering different plasma chemical strategies, e.g. carrier gas mixed with various O_2-N_2 contents. The energetic costs have been measured in terms of electrical consumption for a given treatment time while biological effects have been highlighted through the usual prism of germination and vigor rates but also in a perspective of seeds decontamination. In that latter case, it appears that the admixture of only 2 sccm of oxygen to a 2 L/min helium flow rate can drive to significant decontamination effects of seeds presenting fungi.

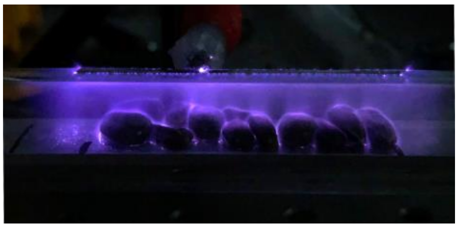

Fig 1. Treatment of radish seeds following dry plasma approach in DBD (interelectrode region).

Voltages and currents have been measured at different points of the experimental setup using high voltage and Rogowsky coil probes respectively. Then, Lissajous curves have been plotted following [6] to estimate the electrical power at every point of the electrical circuit. As an example, in our DBD supplied in helium and operating at 8 kV (600 Hz), plasma power is estimated to 2.8 W while the electrical power of the "environment" devices is as high as 288W due to the operation of the HV power supply (function generator & power amplifier) and mass flow controller. If plasma power is low and may falsely lead to consider that such DBD process subscribes to a sustainable development strategy, one must keep in mind that the real energetic cost must include "environment" devices. If so, the power consumed by the HV generator is 100 times higher than plasma power itself.

3. Plasma wet approach

Several wet plasma processes have been investigated and benchmarked to activate aqueous liquids subsequently utilized for seeds imbibition and plants irrigation. As illustrated in Fig. 2, these processes are based on He plasma jet (Fig. 2a), He plasma spark (Fig. 2b) and multiple electrodes DBD operating in ambient air without any plasmagen gas (Fig. 2c).

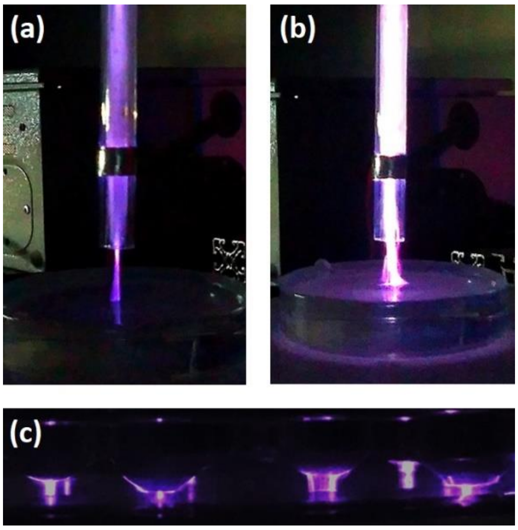

Fig. 2. (a) He plasma jet device, (b) He plasma spark device, (c) air multiple electrodes DBD. All three sources are dedicated to water activation.

At same energetic cost, the concentrations of long life time reactive species have been measured, including nitrites, nitrates, hydrogen peroxide and hydrogenocarbonates. The biological effects enhanced by these higher reactive species concentrations have been assessed in terms of germination and vigor rates as well as stems length enhancement. Since hydrogen peroxide appears as one of the most determinant species in inducing strong growing effects, it can be considered as a relevant marker to bridge biological effects with economic issues.

As shown in Fig. 3, depending on the type of plasma process utilized, [H_2O_2] production can vary between 30 µM and 1900 µM after 30 min of water treatment and for water volumes typically tens of cm^3. So far, since [H_2O_2] as high as 2 mM show beneficial effects on seedlings growth, it seems appropriate to plasma-activate water samples with the aim to reach higher [H_2O_2]. However such strategy would be at the price of longer treatment times and therefore of higher energetic costs. The corresponding H_2O_2 production rates and energetic yields of the 3 processes are given in Table 1. If the multiple electrode DBD seems the most interesting approach in terms of H_2O_2 production rate, the energetic yield appears more attractive using He plasma spark process.

	Plasma power (mW)	Production Rate of H_2O_2 (nmol/s)	H_2O_2 energetic yield (nmol/J)
Air multiple DBD	6000	52	10
He plasma spark	335	12	35
He plasma jet	140	1	7

Table 1. Comparison of the 3 plasma processes to activate water considering H2O2 production rate and energetic yield

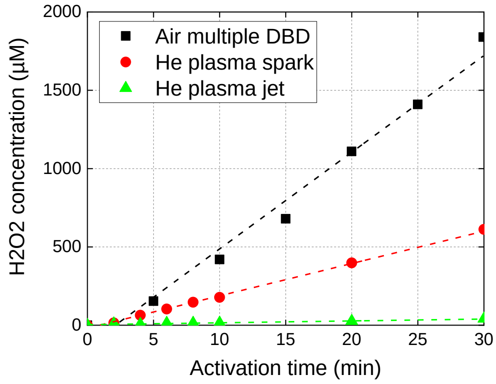

Fig. 3. [H_2O_2] measured in plasma-activated water considering air multiple DBD, He plasma spark and He plasma jet (volumes of 50 cm^3).

Although these plasma sources are undersized with respect to the performance requirements of current agricultural facilities, it is possible to (i) calculate their electrical consumption, (ii) evaluate the energy cost to produce defined quantities of radicals in the liquid phase and (iii) extrapolate these energy costs to greenhouses or priming facilities to compare the viability of plasma paradigms with existing solutions.

4. Plasma approaches vs marketed technologies

Overall, if no technical constraint prevents the plasma-production of high concentrations of hydrogen peroxide (typically 2 mM) in small volumes of water (typically 50 cm^3), the challenge is quite different to meet agriculture stakes by treating larger volumes at – furthermore – lower energetic costs. This issue will be debated in regard of the current means to produce H_2O_2 like processes relying on the hydrolysis of the ammonium peroxydisulfate [7]. Both plasma wet and dry approaches will be compared to more conventional techniques and marketed solutions in terms of biological effects and energetic-financial costs. We will conclude on plasma processes limitations in regard of specific agronomical stakes and where new opportunities should arise.

5. References

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