Controlled generation of air plasma-derived reactive nitrogen species and its agricultural applications

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Atmospheric-pressure plasmas (APPs) have been of great interest and are widely used in medical, agricultural, and environmental applications. In particular, air APP can convert nitrogen (N_2), oxygen (O_2), and water (H_2O) molecules on-site into gaseous reactive species $H_xN_yO_z$ [for example, ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), and hydroxyl radicals (OH)]. Air APP directly or remotely interacting with liquids can also activate reactive oxygen and nitrogen species (RONS) chemistry in the liquid phase. These gas- and liquid-phase species play a key role in various applications. However, understanding the generation pathways and control of these species remains challenging.

For nearly 10 years, our intention has been to understand and control air plasma-induced chemistry, especially focusing on its effective utilization in the agricultural field [1]. In particular, we have focused on investigating the question: "How is the chemical composition of APP-generated species determined?" by combining the quantitative diagnostics of gas-phase reactive species with numerical simulations based on simple kinetic models. Understanding the chemical reaction pathways in the afterglow region has led to the development of new APP systems for the selective generation of dinitrogen pentoxide (N_2O_5) [2].

This on-site N_2O_5 generation system requires only air as the raw material and less than 100 W of electric power, providing opportunities for various applications. We investigated the effects of APP-generated N_2O_5 gas on plants for sustainable agriculture. We recently found that plasma-generated N_2O_5 gas has many beneficial effects in agriculture, as summarized in figure 1 (*e.g.*, bactericidal/virus-inactivating [1], activation of plant immunity [3, 4], increased production of highly functional secondary metabolites [5], and nitrogen fertilization [6, 7]).

There are two primary methods for N_2O_{5gas} treatment; direct N_2O_{5gas} exposure and indirect N_2O_{5gas} exposure (using N_2O_5 gas-bubbled solutions). When gaseous N_2O_5 is transported to moist surfaces, it temporarily forms a highly reactive intermediate, $[NO_2^+{\cdot}NO_3^-]_{aq}$, which is quickly converted into nitrate ions ($NO_3^-{}_{aq}$). Therefore, in direct treatment, $[NO_2^+{\cdot}NO_3^-]_{aq}$ can potentially stimulate plant cells and be a key factor for the N_2O_{5gas} induced beneficial effects. On the other hand, $NO_3^-{}_{aq}$ is known as a major nitrogen source for plants. Thus, it is considered that N_2O_{5gas}-derived $NO_3^-{}_{aq}$ can be responsible for many of the N_2O_{5gas}-induced nitrogen fertilization effects. Moreover, the water solubility of N_2O_{5gas} is extremely higher than those of NO_{gas} and NO_{2gas}. Thus, the conversion efficiency to $NO_3^-{}_{aq}$ is also

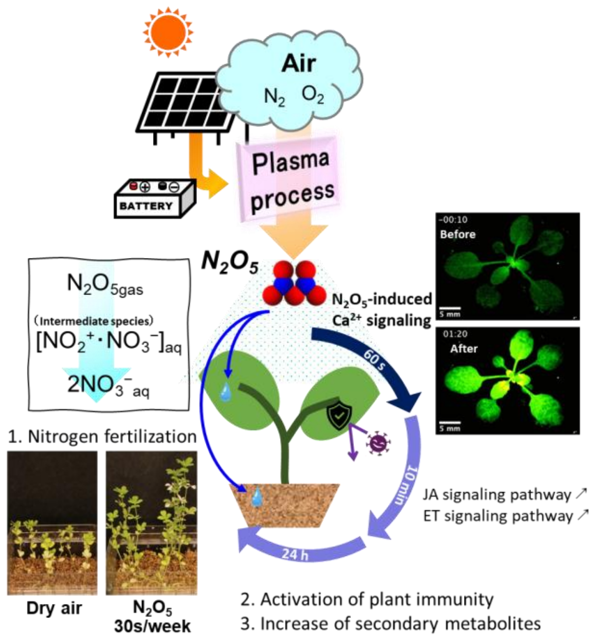

Fig. 1 Effects of plasma-generated N_2O_5 gas on plants.

very high (N_2O_5 gas: approximately 100% VS NO/NO_2 gas: approximately 3%). Therefore, N_2O_5 has the potential to lead to new applications that are difficult to achieve with conventional reactive nitrogen species, such as NO and NO_2.

References

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