Plasma Irradiation May Promote Phytoremediation

Takao FUKUYAMA[1)]*, Yuma KUHARA[1)], Rio SUGATA[1)], Shinji YOSHIMURA[2)]

[1)] *Faculty of Education, Nagasaki University, 1-14 Bunkyo-machi, Nagasaki 852-8521, Japan*
[2)] *National Institute for Fusion Science, National Institutes of Natural Sciences, Toki 509-5292, Japan*

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Atmospheric pressure plasma jet irradiation on plant leaves causes stomatal opening and promotes transpiration, which consequently enhances the plant's water uptake. This phenomenon has potential applications in promoting phytoremediation, where plants are used to take up and purify aqueous solutions containing harmful substances.

Keywords: atmospheric pressure plasma jet, phytoremediation, plants, transpiration, water uptake

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Research on atmospheric-pressure plasma jets has been widely pursued, ranging from fundamental physics to practical applications. Specifically, progress has been made in characterizing chemical reaction mechanisms and evaluating the physiological impacts of plasma irradiation. Significant knowledge has also been accumulated through the exploration of chemical processes induced by plasma-material interactions. Moreover, the effects of non-thermal plasma jets on living organisms have been rigorously investigated in an effort to uncover their fundamental biological mechanisms.

While the temperature changes on sample surfaces during plasma jet irradiation are not yet fully elucidated, they offer a significant area for research. We have focused on the thermal response of plant leaves and identified that plasma irradiation can induce localized cooling below room temperature. This effect is likely driven by accelerated transpiration. This study reports that He plasma jets generated at atmospheric pressure can facilitate both transpiration and water uptake in plants. Based on these findings, we propose the potential application of plasma-induced transpiration in the field of phytoremediation [1, 2].

This report is organized as follows. First, we describe the experimental setup for applying an atmospheric-pressure He plasma jet to plants and measuring the process. Next, we discuss the changes in temperature and plant cells induced by the plasma irradiation. Subsequently, the variations in water uptake caused by the irradiation are examined. Finally, the report is summarized.

This study is conducted using the experimental setup shown in Fig. 1. An atmospheric-pressure helium plasma jet is generated by applying a high-voltage, low-frequency AC potential to the electrodes. In the experiment, stainless-steel electrodes are wrapped around a glass tube with an inner diameter of approximately 10 mm. Helium gas is introduced at a flow rate of 113.4 ± 11.1 mL s^{-1}, and atmospheric-pressure glow discharge plasma is generated using a power supply (276 W, approx. 10.11 kHz, LHV-10AC, Logy Electric). The target plant leaves are positioned several centimeters away from the nozzle of the glass tube and irradiated with the plasma jet.

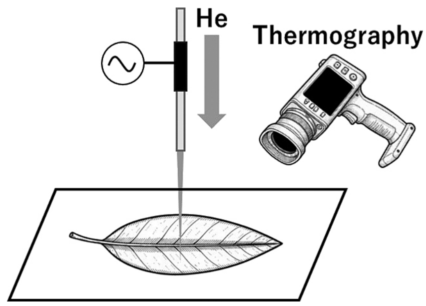

Fig. 1. Experimental setup for the plasma jet irradiation of plant samples.

The following two plant species are subjected to plasma irradiation for several tens of seconds:

- *Commelina communis* (Commelinaceae, Commelina)
- *Lantana camara* (Verbenaceae, Lantana)

Figure 2 shows the thermographic observation of *Commelina communis* leaves following plasma irradiation. The ambient temperature is 26.0°C. As indicated in Fig. 2, the temperature decreases below room temperature, revealing that the irradiated area is cooler than the surrounding tissue. Figure 3 presents the temperature variation of the irradiated area on *Commelina communis* after the completion of plasma jet irradiation. As shown in Fig. 3, the temperature decreases over time, eventually falling to approximately 7°C below room temperature.

Subsequently, leaf cells are observed via optical microscopy to evaluate the opening and closing state of stomata [3] induced by plasma jet irradiation. Figure 4 illustrates the condition of stomata in the same observed region of

**Corresponding author's e-mail: fukuyama-takao@nagasaki-u.ac.jp*

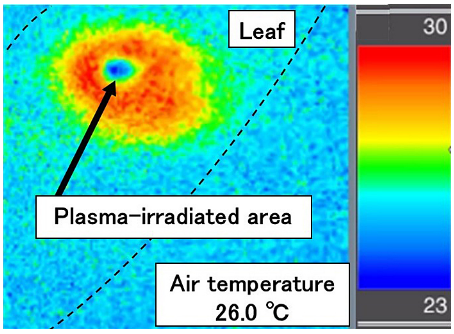

Fig. 2. Thermal profiles of *Commelina communis* leaves post-plasma jet treatment. Dashed curve outlines the leaf.

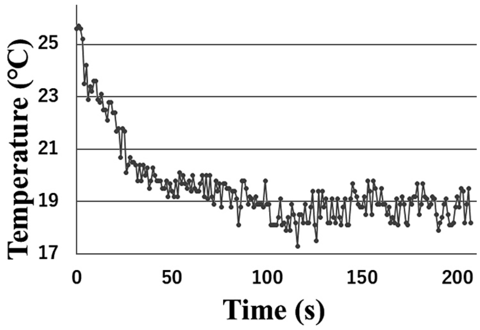

Fig. 3. Temporal change in temperature at the irradiated site on *Commelina communis* after plasma jet irradiation.

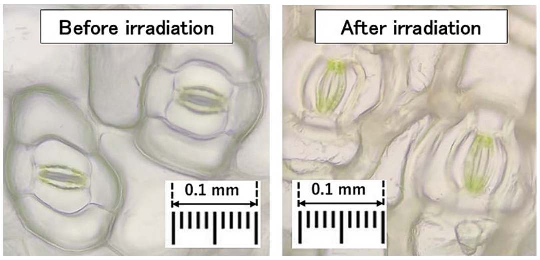

Fig. 4. Leaf cells of *Commelina communis* before and after plasma jet irradiation.

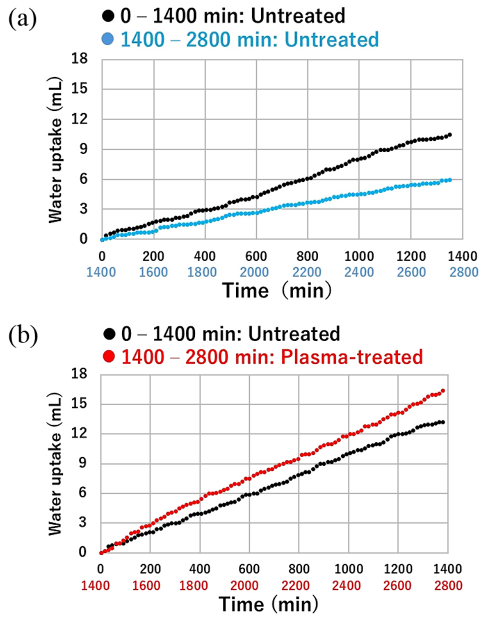

Fig. 5. Water uptake of *Lantana camara* measured over 2,800 minutes using the same individual plant. (a) Non-irradiated: continuous measurement throughout 0–2,800 min. (b) Plasma-irradiated: measured without irradiation during 0–1,400 min, then briefly plasma-irradiated and measured during 1,400–2,800 min.

Commelina communis before and after irradiation. As shown in the figure, it is revealed that the stomata open and the chloroplasts become localized toward the cell periphery. The stomatal opening and the subsequent decrease in leaf surface temperature to below ambient levels are attributed to the latent heat of vaporization resulting from enhanced transpiration through the stomata.

Therefore, as shown in Fig. 5, cut stems of *Lantana camara* are used as experimental plants to investigate differences in water uptake following plasma jet irradiation. Although phytoremediation typically involves root uptake, this study uses cut stems instead. Since water transport occurs through the xylem from roots to leaves, the mechanism is considered analogous.

As shown in Fig. 5(a), the water uptake of the non-irradiated plants during 1,400–2,800 min was lower than that during 0–1,400 min, indicating that the water uptake capacity declined over time due to plant deterioration. In contrast, Fig. 5(b) demonstrates that the water uptake during 1,400–2,800 min did not decrease relative to the initial period; rather, it increased, suggesting that plasma irradiation promoted water uptake in the plants. The above results suggest the following mechanism: irradiation of plant leaves with plasma jets induces stomatal opening, which consequently enhances transpiration and water uptake. This finding indicates the potential to augment phytoremediation—a method that utilizes plants to remove contaminants such as heavy metals and radionuclides from soil and water through uptake—by applying plasma jet irradiation. To realize this application, future studies must demonstrate three key elements: (1) generation of air plasma under atmospheric pressure conditions, (2) validation using plant species known to be effective for phytoremediation, and (3) experimental confirmation of enhanced uptake when plants are supplied with water containing heavy metals or other target contaminants.

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