Up-Regulation of Photosynthetic Activity in *Arabidopsis* Plants Exposed to a High-Dose γ-Radiation

Jin-Hong Kim, Byung Yeoup Chung*, Jae-Sung Kim, Seung Gon Wi, Myung-Hwa Baek, Ju Woon Lee
†*Advanced Radiation Technology Institute – Jeongeup (ARTIJ), Jeongeup 580-185, Korea, bychung@kaeri.re.kr*
†*New name for 'Division of Radiation Application Research, Korea Atomic Energy Research Institute (KAERI)'*

1. Introduction

Ionizing radiation with several grays can induce growth stimulation in plants. This phenomenon has been called 'radiation hormesis'. In contrast to this concept, it has been long believed that ionizing radiation causes cell death or genetic aberration in both plants and animals. A number of deleterious effects of ionizing radiation have been documented for the last half century. Nevertheless, we still have insufficient data to define the physiological effects of ionizing radiation. As an evidence against the general belief about ionizing radiation, we here report up-regulation of photosynthetic activity in *Arabidopsis* plants exposed to a high-dose γ-radiation.

2. Materials and Methods

2.1 Plant Material and γ-Irradiation

Four-week-old plants of *Arabidopsis thaliana* ecotype Columbia were irradiated with a high-dose γ-radiation (200 Gy) for 4 h, which was generated by a γ-irradiator [^{60}Co, ca. 150 TBq of capacity; Atomic Energy Canada Limited] at the Korea Atomic Energy Research Institute. Plants were grown in a growth chamber with illumination from fluorescence lamps. The growth chamber was maintained at 22/18°C (D/N) with a 14 h photoperiod.

2.2 Evaluation of Morphological Changes of Irradiated Plants during Post-irradiation Period

Lengths of inflorescence bolts (stems) were measured to quantitatively compare the morphological changes of control and irradiated plants during the post-irradiation period.

2.3 Chlorophyll Fluorescence Analysis

Chlorophyll (Chl) fluorescence was measured using a Chl fluorometer (IMAGING-PAM, Walz, Germany) as described in the operation manual. Readings were taken after the samples were dark-adapted for 15 min at room temperature. Finally, the parameters, Fo, Fm, Fv/Fm [1], qP [2,3], NPQ [2], and ETR [4], were obtained.

3. Results and Discussion

3.1 Effect of a High-Dose γ-Radiation on the Development of Arabidopsis Plants

Figure 1. *Arabidopsis* plants (left) and rosette leaves (right). Control, not treated; 200 Gy, irradiated with γ-radiation of 200 Gy.

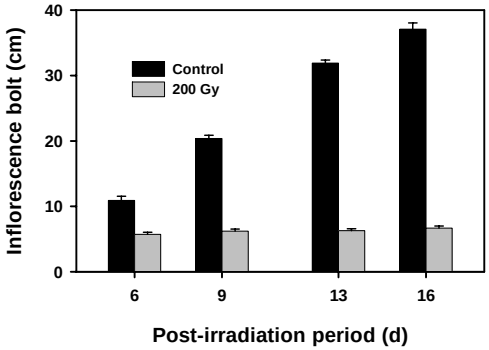

Figure 2. Development of *Arabidopsis* inflorescence bolts during the post-irradiation period.

As shown in Figures 1 and 2, a high-dose γ-radiation (200 Gy) altered dramatically the morphology of developing *Arabidopsis* plants. The irradiated plants had curled leaves and non-growing inflorescence bolts. These results imply the deleterious effects of ionizing radiation. However, their leaves were darker green than the control ones, and their non-growing bolts also flowered.

3.2 Altered Photosynthetic Activity in the Irradiated Arabidopsis Leaves

The values of Fv/Fm, the maximum photochemical efficiency of photosystem II (PSII), were not significantly changed in the irradiated *Arabidopsis* leaves during the post-irradiation period (Figure 3). In contrast, the control leaves had a noticeable reduction in the Fv/Fm at 3 and

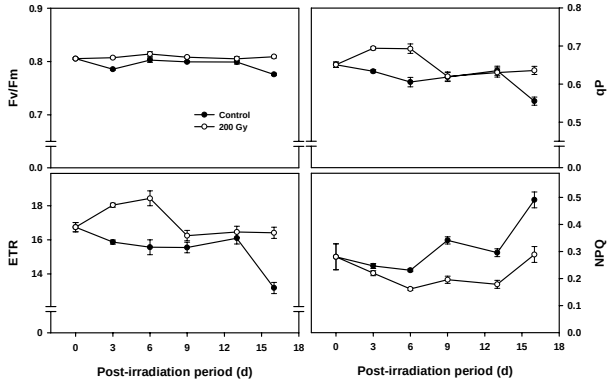

Figure 3. Chl fluorescence analysis of *Arabidopsis* rosette leaves during the post-irradiation period. Fv/Fm, the maximum photochemical efficiency of photosystem II; ETR, the apparent rate of photosynthetic electron transport; qP and NPQ, the parameters for photochemical and non-photochemical quenching, respectively. Error bars represent the S.E. (n≥3).

16 d after the γ-irradiation (DAI). Interestingly, the qP and ETR values were markedly higher in the irradiated leaves at 3, 6, and 16 DAI than in the controls. The high photosynthetic activities in the irradiated leaves at 3 and 6 DAI suggest transient up-regulation of photosynthesis. In contrast, those high activities in the irradiated leaves at 16 DAI are attributable to their delayed senescence compared with the (normal) natural senescence. The consistently low NPQ values in the irradiated leaves support this possibility.

4. Conclusion

The observations confirmed the deleterious effects of a high-dose γ-radiation on the development of *Arabidopsis* plants. However, the γ-radiation also up-regulated the photosynthesis transiently, and furthermore it delayed the natural senescence in leaves. In conclusion, these results suggest the existence of both positive and negative effects of ionizing radiation in plants.

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