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LETTER TO THE EDITOR

Cadmium and high light stress interactions highlight limits of PSII in *Arabidopsis thaliana*

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Recently, Giordano *et al.* (2025) published an important article about the combinatory effect of cadmium (Cd) toxicity and high light stress on the photosynthetic performance in *Arabidopsis thaliana*. From this study, it was found that when *A. thaliana* is exposed to a higher concentration of Cd, three factors negatively impact the photosynthetic machinery of *A. thaliana*. There is compelling evidence that Cd contributes to the light stress experienced by *A. thaliana*, exacerbating it and thereby contributing to the three factors mentioned: impaired electron transport, elevated nonphotochemical quenching (NPQ), and a lowered F_V/F_M ratio. These factors demonstrate how a combination of converging physiological signals (*i.e.*, functional, protective, and efficiency-related) influences the photochemical machinery of *A. thaliana* in response to Cd exposure.

The implications of these findings apply to other plant species, not just *A. thaliana*, because Cd is a widespread environmental contaminant. Bharagava and Saxena (2020) state that agricultural and industrial activities produce Cd; however, when Cd accumulates in soils, crop productivity is affected in the long term (Alloway 2013). Cd, as reported in several other studies (Schiller and Dau 2000, Sigfridsson *et al.* 2004, Pagliano *et al.* 2006), interferes with the oxygen-evolving complex (Pagliano *et al.* 2013). This induces reactive oxygen species (ROS) (Cho and Seo 2005), causing photoinhibition and oxidative damage (Faller *et al.* 2005), while, in the process, impairment of PSII protein turnover occurs (Geiken *et al.* 1998).

Giordano *et al.* (2025) provide novel insight that practically shows photoinhibitory quenching overpowering energy-dependent quenching, highlighting the limitations imposed by Cd and high light on PSII (Fig. 1S, *supplement*). Therefore, the interaction of Cd and light stress induces structural damage, instead of just regulating energy dissipation, and this confirms earlier evidence that excess light accelerates Cd-induced PSII damage (Cai *et al.* 2023, Zhou *et al.* 2024). In addition, the presence of L- and K-bands in OJIP transients in Cd-exposed plants, a feature reported in barley (Kalaji *et al.* 2011) and pea (Jiang *et al.* 2006) plants as well, indicates that Cd causes a direct limitation of the oxygen-evolving complex activity, as well as interference with the antenna PSII connectivity. This shows that K- and L-band emergence is not a general chlorophyll fluorescence marker of stress limited to *A. thaliana*, as it is also seen in legumes (van Heerden *et al.* 2003, 2004) and cereals (Strasser *et al.* 2004, Antunović Dunić *et al.* 2023).

The use of Kautsky kinetics, OJIP (origin, 1st electron intermediate peak, 2nd electron intermediate peak) analysis, and other fluorescence methods is crucial for dissecting the various alterations that occur in the photosystem due to stress (Roháček 2002, Strasser *et al.* 2004). Most importantly, however, Cd-induced stress causes a decline in performance index (PI_{ABS}), thereby supporting the use of the utilized methods as a sensitive biomarker for PSII impairment (Dobrikova *et al.* 2021, Chen *et al.* 2022). This decline in performance index has also been observed in several other plants, including spinach, barley (Vassilev *et al.* 2003), rice (Lee *et al.* 2025), and pea (Hattab *et al.* 2009). The importance of reporting performance index decline in *A. thaliana* rests on the fact that there is less comprehensive data on PI_{ABS} responses to multiple stresses in this model organism. Furthermore, to dissect which genes and pathways are responsible for PSII activity in response to Cd, PI_{ABS} declination enables mechanistic studies on specific genes, especially since *Arabidopsis* contains a diverse array of molecular genetic tools, such as mutants, transcriptomics, and CRISPR lines (Pegler *et al.* 2021). By using *A. thaliana* in this study, the authors have created a baseline by which stress responses can be assessed in other *Arabidopsis* species under regulated conditions (Giordano *et al.* 2025). Moreover, the reported study allows for the expansion of our understanding of how PSII in *A. thaliana* responds to combined stressors, not just one, and this is essential as *Arabidopsis* has been well-studied under drought, light, and nutrient stresses (Fischer *et al.* 2017), but not under the simultaneous exposure to high light and cadmium.

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The broader significance of these results lies in facilitating and enhancing our understanding of multi-stress interactions. Ben Ammar *et al*. (2008) and Hakmaoui *et al*. (2007) state that Cd toxicity, on its own, causes disruption of chloroplast infrastructure and reduction in biomass. However, the addition of high light stress causes photoinhibition to amplify, resulting in slower recovery and greater energy dissipation (Jin *et al*. 2014, Hikosaka 2021). Thus, the synergistic effect highlights the imperativeness of considering multiple stress factors in agricultural and ecological contexts (El Rasafi *et al*. 2022, Didaran *et al*. 2024).

Future study strategies should explore how the effect of the interaction between Cd and high light can be mitigated. These protective strategies used must include antioxidant production enhancement (Bi *et al*. 2009, Namdjoyan *et al.* 2011), plant growth-promoting bacteria (He *et al*. 2020, Wu *et al*. 2020), and xanthophyll cycle activity monitoring (Pogson *et al*. 1998, Li *et al*. 2000). These wider approaches hold promise for the development of crop varieties and management practices that can tolerate contaminated environments that contain multiple co-occurring stressors.

In conclusion, Giordano *et al*. (2025) enrich our mechanistic understanding of how heavy metals, such as Cd, and high light interact with each other to damage and/or impair photosynthetic processes. The linkage between Cd toxicity and the exacerbated photoinhibition in *A. thaliana* shows the vulnerability and adaptive limits of PSII under compound stress conditions.

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