Supplementary Information (SI) for Environmental Science: Nano.

Supporting Information

S1. Supplemental Methods

S1.1 Determination of phytohormones

Fresh rice leaves (0.20 g) were immersed in 2 mL pre-chilled 80% methanol solution and extracted at 4°C in a refrigerator for 12 h. After centrifugation at 4500 rpm for 10 mins at 4°C, the supernatant was collected and filtered through a 0.22 μm nylon membrane. The phytohormone content in the leaves was determined using HPLC-DAD method (Agilent 1260, USA). A ZORBAX SB-C18 chromatographic column (4.6 mm × 150 mm, 5 μm) was employed with a mobile phase of methanol: water: acetic acid = 45:50:5. The elution was performed isocratically with an injection volume of 10 μL, a flow rate of 1 $mL \cdot min^{-1}$, and a column temperature of 30°C. Detection of endogenous hormone content changes in leaves was carried out at a wavelength of 254 nm.

S2. Results

S2.1 Effect of PBCDs on phytohormones

Under Cd-0 treatment, different concentrations of PBCDs can increase the levels of GA3, 6-BA, and IAA, with the exception of ABA (Fig. S1). Notably, the most significant increases in GA3 and IAA were observed at a spraying concentration of 250 $mg \cdot L^{-1}$, showing increments of 46.11% and 27.62%, respectively. 6-BA reached its highest increase under the PS500 treatment, with a rise of 15.36%. Typically associated with plant growth inhibition, ABA exhibited an exceptional increase of 4.25% under the PS1000 treatment. Generally, ABA showed a decreasing trend across other treatments, indicating that foliar application of PBCDs did not induce significant stress responses.

Under Cd-5 stress, different endogenous hormones play critical roles in rice plants, the foliar application of various concentrations of PBCDs led to an upregulation of GA3, 6-BA, IAA, and ABA compared to the control group. GA3 levels increased by 18.69% to 74.31% in many treatments (Fig. S1A), except for the PS50 treatment, where no significant was observed compared to the control. 6-BA, which plays a crucial role in regulating plant growth and development, increased in rice leaves under Cd stress with appropriate concentrations of PBCDs. Compared to PS0, the concentration of 6-BA significantly increased by 1.82% ~ 9.36% under the PS50, PS100, and PS500 treatments. Conversely, the PS1000 and PS250 treatments exhibited decreases of 6.04% and 1.66%, possibly due to variations in leaves Cd content. The trend of IAA changes largely mirrored that of gibberellin. After different PBCDs treatments, IAA levels increased by 49.24% ~128.98% (Fig. S1C). ABA, plays a crucial role in the response to Cd stress, it was found that ABA decreased by 4.59% ~ 8.23% under the PS50, PS250, and PS1000 treatments, while the PS100 and PS500 treatments led to increases of 7.83% and 1.58%, respectively (Fig. S1D). Overall, our results demonstrate that PBCDs can modulate defense-related phytohormone to mitigate Cd toxicity.

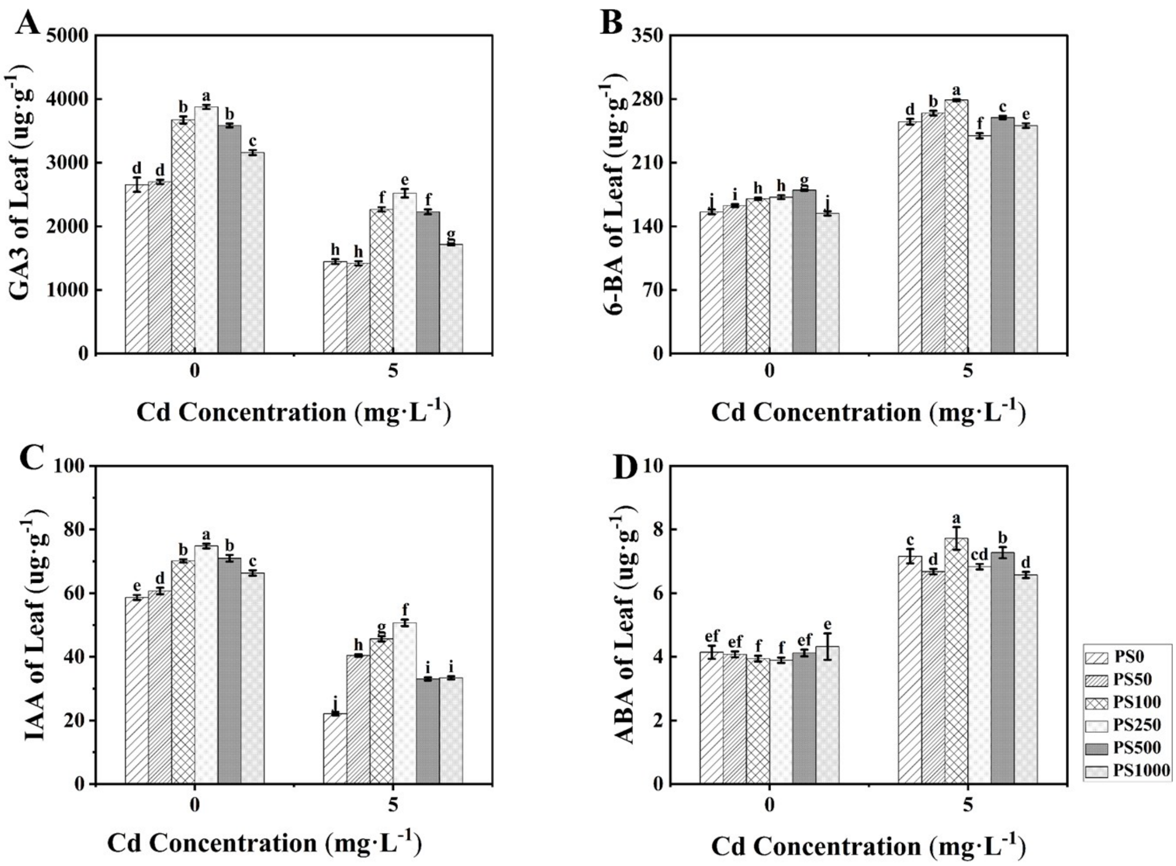

Fig. S1. Effects of PBCDs on phytohormones in rice leaves. A) GA3, B) 6-BA, C) IAA, D) ABA. Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.

Table S1 The influence of PBCDs on the length of shoots and roots in rice under Cd-0 treatment (cm)

PBCDs Concentration (mg·L^{-1})	0	50	100	250	500	1000
Shoot length	65.59 ± 1.15a	64.68 ± 2.17a	65.49 ± 2.13a	64.32 ± 0.46a	63.26 ± 0.42ab	59.98 ± 0.76b
Root length	25.40 ± 0.10ab	26.84 ± 1.29a	22.72 ± 1.27b	23.09 ± 0.76ab	23.61 ± 1.73ab	24.20 ± 1.82ab

Note: Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.

Table S2 The influence of PBCDs on the length of shoots and roots in rice under Cd-5 treatment (cm)

PBCDs Concentration ($mg\cdot L^{-1}$)	0	50	100	250	500	1000
Shoot length	43.30 ± 1.55a	45.10 ± 0.80a	45.38 ± 1.00a	45.55 ± 1.80a	44.87 ± 1.33a	45.09 ± 1.01a
Root length	16.61 ± 1.06c	19.03 ± 0.62abc	21.67 ± 2.49ab	21.79 ± 1.43ab	22.28 ± 1.21a	18.41 ± 1.38bc

Note: Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.

Table S3 The influence of PBCDs on organic acid content in rice roots under Cd-0 treatment ($\mu g\cdot g^{-1}$)

PBCDs Concentration ($mg\cdot L^{-1}$)	0	50	100	250	500	1000
OA	943.77 ± 142.61a	752.11 ± 76.19ab	468.56 ± 229.45b	102.33 ± 81.10c	552.92 ± 53.20b	523.15 ± 65.85b
TA	4423.28 ± 319.55a	4370.78 ± 566.90a	4055.50 ± 545.71a	3603.90 ± 352.63a	2452.33 ± 288.68b	844.35 ± 237.96c
CA	1539.04 ± 206.31a	1374.88 ± 35.51a	1322.72 ± 316.15a	1321.20 ± 61.98a	326.36 ± 102.98b	1487.78 ± 105.49
FA	189.70 ± 29.58b	210.96 ± 6.96b	193.68 ± 7.43b	253.13 ± 15.49a	129.33 ± 6.83c	190.56 ± 12.52b
SA	549.32 ± 76.31b	690.60 ± 57.94a	497.53 ± 59.08b	704.55 ± 41.81a	324.12 ± 7.13c	487.18 ± 66.86b
AA	383.62 ± 37.86bc	568.52 ± 31.15b	585.19 ± 62.40b	513.63 ± 63.00b	848.06 ± 119.29a	279.13 ± 139.12c
PA	1061.69 ± 54.84b	1179.69 ± 159.29b	683.13 ± 97.40c	1578.28 ± 196.11a	397.92 ± 75.08c	691.65 ± 132.01c

Note: OA (Oxalic Acid), TA (Tartaric Acid), CA (Citric Acid), FA (Fumaric Acid), SA (Succinic Acid), AA (Acetic Acid), PA (Propionic Acid). Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.

Table S4 The influence of PBCDs on organic acid content in rice roots under Cd-5 treatment ($\mu g\cdot g^{-1}$)

PBCDs Concentration ($mg\cdot L^{-1}$)	0	50	100	250	500	1000
OA	1387.76 ± 118.99bc	1664.12 ± 153.14ab	1806.87 ± 130.37a	1290.89 ± 132.75c	1484.54 ± 244.98abc	1493.28 ± 65.57abc
TA	6623.04 ± 966.46a	6732.77 ± 1110.49a	7718.29 ± 934.98a	6565.71 ± 1408.01a	8379.65 ± 1257.67a	6403.73 ± 1151.78a
CA	1377.33 ± 107.67c	2141.38 ± 392.48b	1547.82 ± 120.81c	2690.03 ± 68.70a	2534.95 ± 248.67ab	1592.83 ± 131.84c
FA	115.92 ± 24.70c	263.88 ± 61.94a	235.51 ± 43.17ab	174.02 ± 13.05bc	207.12 ± 35.46ab	167.16 ± 14.85bc
SA	321.45 ± 29.97b	292.14 ± 96.80c	264.74 ± 60.29c	341.06 ± 22.13bc	469.97 ± 38.78a	442.54 ± 32.89ab
AA	439.16 ± 45.86c	926.64 ± 97.15ab	1159.63 ± 3657.79a	579.19 ± 128.52bc	621.37 ± 80.62bc	498.04 ± 66.08c
PA	612.89 ± 109.67bc	934.43 ± 149.72a	741.81 ± 65.36ab	355.46 ± 28.43d	953.35 ± 45.81a	466.56 ± 121.86cd

Note: OA (Oxalic Acid), TA (Tartaric Acid), CA (Citric Acid), FA (Fumaric Acid), SA (Succinic Acid), AA (Acetic Acid), PA (Propionic Acid). Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.

Table S5 The influence of PBCDs on phenolic acid content in rice roots under Cd-0 treatment ($\mu g \cdot g^{-1}$)

PBCDs Concentration ($mg \cdot L^{-1}$)	0	50	100	250	500	1000
GA	14.10 ± 0.68a	14.83 ± 0.23a	18.88 ± 4.56a	13.54 ± 0.96a	12.47 ± 4.62a	11.46 ± 1.24a
NCGA	3.84 ± 1.23ab	3.05 ± 2.06ab	3.13 ± 1.21ab	6.23 ± 1.29a	3.29 ± 0.37ab	2.71 ± 0.98b
p-HBA	1.82 ± 0.38a	1.56 ± 0.32a	1.33 ± 0.69a	1.37 ± 0.55a	2.37 ± 0.42a	2.82 ± 1.04a
VA	8.17 ± 0.59a	9.09 ± 0.08a	7.77 ± 0.60a	5.85 ± 0.97b	4.58 ± 0.93b	4.68 ± 1.17b
SYA	24.54 ± 3.33b	30.74 ± 3.38a	26.38 ± 1.86ab	18.08 ± 2.24c	17.78 ± 1.30c	17.34 ± 2.33c
p-CA	8.10 ± 0.71a	4.76 ± 0.64b	4.77 ± 0.92b	3.20 ± 0.55c	2.30 ± 0.11c	1.79 ± 0.30c
FA	93.55 ± 13.36ab	112.92 ± 8.40a	75.07 ± 11.17b	106.01 ± 8.09a	36.67 ± 7.68c	78.35 ± 6.49b
BA	176.8 ± 38.1abc	289.27 ± 38.05a	170.91 ± 59.3bc	263.06 ± 75.0ab	119.71 ± 34.84c	118.79 ± 27.02c
CinA	4.16 ± 0.19a	4.33 ± 4.21a	4.07 ± 0.17a	4.33 ± 0.16a	4.15 ± 0.09a	4.03 ± 0.16a

Note: GA (Gallic acid), NCGA (Neochlorogenic Acid), p-HBA (p-Hydroxybenzoic acid), SYA (syringic acid), p-CA (p-Coumaric acid), FA (Ferulic acid), BA (Benzoic acid), CinA (Cinnamic acid). Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.

Table S6 The influence of PBCDs on phenolic acid content in rice roots under Cd-5 treatment ($\mu g \cdot g^{-1}$)

PBCDs Concentration ($mg \cdot L^{-1}$)	0	50	100	250	500	1000
GA	11.92 ± 1.40c	12.49 ± 0.44bc	14.87 ± 2.00ab	12.55 ± 0.79bc	15.43 ± 0.86a	10.13 ± 0.76c
NCGA	11.36 ± 1.52c	17.78 ± 0.13ab	19.33 ± 1.57a	15.08 ± 1.42bc	20.17 ± 1.18a	15.31 ± 2.22bc
p-HBA	1.91 ± 0.39b	2.35 ± 0.45ab	2.57 ± 0.17ab	2.04 ± 0.52b	2.00 ± 0.21b	3.36 ± 0.97a
VA	8.48 ± 0.78c	9.85 ± 0.63abc	12.90 ± 1.23a	12.02 ± 2.69ab	9.66 ± 0.70bc	9.27 ± 1.33bc
SYA	26.56 ± 4.21ab	32.02 ± 2.96a	30.37 ± 4.21ab	23.06 ± 12.25ab	25.10 ± 2.45ab	17.02 ± 2.47b
p-CA	15.77 ± 0.88ab	15.16 ± 1.76ab	18.76 ± 3.09a	15.09 ± 1.74c	14.07 ± 1.74ab	10.58 ± 2.32b
FA	192.0 ± 31.51b	290.60 ± 25.46a	313.52 ± 30.36a	121.31 ± 17.83c	110.71 ± 30.87c	61.9 ± 16.22c
BA	55.51 ± 6.02a	72.55 ± 2.54a	58.46 ± 6.06a	32.09 ± 5.07b	66.13 ± 13.21a	62.76 ± 4.89a
CinA	5.67 ± 1.07a	7.43 ± 1.10a	7.75 ± 0.99a	7.41 ± 0.91a	7.12 ± 0.19a	6.49 ± 1.60a

Note: GA (Gallic acid), PCA (protocatechuic acid), p-HBA (p-Hydroxybenzoic acid), VA (Vanillic Acid), SYA (syringic acid), VAN (Vanillin), p-CA (p-Coumaric acid), FA (Ferulic acid), BA (Benzoic acid), CinA (Cinnamic acid). Bars represent standard deviation (± SD) of the means (n = 3). Treatments marked with different letters are significantly different at $P < 0.05$.