**Endophytic Aureobasidium pullulans BSS6 assisted developments in phytoremediation potentials of *Cucumis sativus* under Cd and Pb stress**

**Amjad Ali1, 2#, Saqib Bilal3#, Abdul Latif Khan\*1, Fazal Mabood1, Ahmed Al-Harrasi\*1, In-Jung Lee\*3**

1UoN Chair of Oman’s Medicinal Plants & Marine Natural Products, University of Nizwa, Nizwa, Oman

2Department of Biotechnology Quaid-i-Azam University Islamabad Pakistan

3 School of Applied Biosciences, Kyungpook National University, Daegu, South Korea

Email addresses:

Amjad Ali (amjadparachinar@gmail.com), Saqib Bilal (saqib043@yahoo.com), Abdul Latif Khan (latifepm78@yahoo.co.uk), Fazal Mabood (mehboob@unizwa.edu.om), Ahmed Al-Harrasi (aharrasi@unizwa.edu.om)

#Equal contributors

\*Contributed equally to this work

**\*Corresponding authors**

Prof. In-Jung Lee

E-Mail: ijlee@knu.ac.kr

Tel: +82-53-950-5708(Office)

Fax: +82-53-958-6880

ijlee@knu.ac.kr

**Abdul Latif Khan**

latifepm78@yahoo.co.uk

**Ahmed Al-Harrasi**

aharrasi@unizwa.edu.om

**Supply Table 1:**

Three-way ANOVA Two-way ANOVA table of the ICP-MS analysis for metals uptake by plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 9.277 | <0.0001 | \*\*\*\* | 10838 |
| (Control/BSS6 vs BSS6/Metal) | 64.43 | <0.0001 | \*\*\*\* | 75264 |
| (Control/Metal vs BSS6/BSS6+Metal) | 5.442 | <0.0001 | \*\*\*\* | 6357 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 9.277 | <0.0001 | \*\*\*\* | 10838 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 2.753 | <0.0001 | \*\*\*\* | 3216 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 5.442 | <0.0001 | \*\*\*\* | 6357 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 2.753 | <0.0001 | \*\*\*\* | 3216 |

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

Three-way ANOVA Two-way ANOVA table of the ICP-MS analysis for metals availability in soil, carried out for fungal infected and non-infected soil under Pb and Cd stress at two different time points

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 4.325 | <0.0001 | \*\*\*\* | 385726 |
| (Control/BSS6 vs BSS6/Metal) | 71.04 | <0.0001 | \*\*\*\* | 6335154 |
| (Control/Metal vs BSS6/BSS6+Metal) | 8.350 | <0.0001 | \*\*\*\* | 744692 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 4.325 | <0.0001 | \*\*\*\* | 385726 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 1.788 | <0.0001 | \*\*\*\* | 159414 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 8.350 | <0.0001 | \*\*\*\* | 744692 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 1.788 | <0.0001 | \*\*\*\* | 159414 |

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

Three-way ANOVA Two-way ANOVA table for chlorophyll a in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 1.260 | 0.0169 | \* | 34.70 |
| (Control/BSS6 vs BSS6/Metal) | 30.62 | <0.0001 | \*\*\*\* | 843.2 |
| (Control/Metal vs BSS6/BSS6+Metal) | 44.08 | <0.0001 | \*\*\*\* | 1214 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 16.28 | <0.0001 | \*\*\*\* | 448.4 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 0.08510 | 0.4981 | ns | 2.344 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 4.461 | 0.0001 | \*\*\* | 122.9 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 0.3825 | 0.1611 | ns | 10.53 |

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 82.78 | <0.0001 | \*\*\*\* | 140739 |
| (Control/BSS6 vs BSS6/Metal) | 0.03294 | 0.1000 | ns | 56.00 |
| (Control/Metal vs BSS6/BSS6+Metal) | 3.919 | <0.0001 | \*\*\*\* | 6663 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 11.60 | <0.0001 | \*\*\*\* | 19731 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 1.017 | <0.0001 | \*\*\*\* | 1729 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 0.2189 | 0.0004 | \*\*\* | 372.1 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 0.2565 | 0.0002 | \*\*\* | 436.1 |

Three-way ANOVA Two-way ANOVA table for chlorophyll b in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 26.56 | <0.0001 | \*\*\*\* | 6231 |
| (Control/BSS6 vs BSS6/Metal) | 9.209 | <0.0001 | \*\*\*\* | 2160 |
| (Control/Metal vs BSS6/BSS6+Metal) | 11.15 | <0.0001 | \*\*\*\* | 2615 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 47.79 | <0.0001 | \*\*\*\* | 11210 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 0.2188 | 0.2048 | ns | 51.33 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 1.468 | 0.0035 | \*\* | 344.3 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 1.606 | 0.0025 | \*\* | 376.8 |

Three-way ANOVA Two-way ANOVA table for carotenoids in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 47.14 | <0.0001 | \*\*\*\* | 25.22 |
| (Control/BSS6 vs BSS6/Metal) | 14.83 | 0.0001 | \*\*\* | 7.935 |
| (Control/Metal vs BSS6/BSS6+Metal) | 16.15 | <0.0001 | \*\*\*\* | 8.640 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 1.374 | 0.1413 | ns | 0.7350 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 9.085 | 0.0011 | \*\* | 4.860 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 1.795 | 0.0960 | ns | 0.9600 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 0.4486 | 0.3896 | ns | 0.2400 |

Three-way ANOVA Two-way ANOVA table for catalase in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 13.36 | <0.0001 | \*\*\*\* | 5.704 |
| (Control/BSS6 vs BSS6/Metal) | 44.27 | <0.0001 | \*\*\*\* | 18.90 |
| (Control/Metal vs BSS6/BSS6+Metal) | 4.646 | 0.0047 | \*\* | 1.984 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 17.78 | <0.0001 | \*\*\*\* | 7.594 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 1.484 | 0.0825 | ns | 0.6338 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 9.564 | 0.0002 | \*\*\* | 4.084 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 1.976 | 0.0483 | \* | 0.8438 |

Three-way ANOVA Two-way ANOVA table for Lipid peroxidation in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 11.36 | 0.0075 | \*\* | 0.4214 |
| (Control/BSS6 vs BSS6/Metal) | 16.05 | 0.0022 | \*\* | 0.5954 |
| (Control/Metal vs BSS6/BSS6+Metal) | 48.92 | <0.0001 | \*\*\*\* | 1.815 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 2.948 | 0.1385 | ns | 0.1094 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 0.1456 | 0.7335 | ns | 0.005400 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 1.035 | 0.3692 | ns | 0.03840 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 0.1456 | 0.7335 | ns | 0.005400 |

Three-way ANOVA Two-way ANOVA table for glutathione in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

Three-way ANOVA Two-way ANOVA table for POD in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points Glucosidases

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 54.98 | <0.0001 | \*\*\*\* | 2774 |
| (Control/BSS6 vs BSS6/Metal) | 25.88 | <0.0001 | \*\*\*\* | 1305 |
| (Control/Metal vs BSS6/BSS6+Metal) | 9.741 | <0.0001 | \*\*\*\* | 491.4 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 4.282 | <0.0001 | \*\*\*\* | 216.0 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 1.903 | 0.0003 | \*\*\* | 96.00 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 1.763 | 0.0004 | \*\*\* | 88.94 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 0.02973 | 0.5714 | ns | 1.500 |

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.

Three-way ANOVA Two-way ANOVA table for Glucosidases in plants, carried out for fungal infected and non-infected plants under Pb and Cd stress at two different time points

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Source of Variation** | **% of total variation** | **P value** | **P value summary** | **MS** |
| Duration of stress | 54.98 | <0.0001 | \*\*\*\* | 2774 |
| (Control/BSS6 vs BSS6/Metal) | 25.88 | <0.0001 | \*\*\*\* | 1305 |
| (Control/Metal vs BSS6/BSS6+Metal) | 9.741 | <0.0001 | \*\*\*\* | 491.4 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) | 4.282 | <0.0001 | \*\*\*\* | 216.0 |
| Duration of stress x (Control/Metal vs BSS6/BSS6+Metal) | 1.903 | 0.0003 | \*\*\* | 96.00 |
| (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/BSS6+Metal) | 1.763 | 0.0004 | \*\*\* | 88.94 |
| Duration of stress x (Control/BSS6 vs BSS6/Metal) x (Control/Metal vs BSS6/B | 0.02973 | 0.5714 | ns | 1.500 |

Three-way ANOVA was followed by a Bonferroni post hoc test with a p < 0.05 for metals stress level, BSS6-inoculated and non-inoculated plants, and their interaction.