*Supplementary material*

**Table S1.** Equations of mathematical model for metal ion biosorption efficiency *R(%)* (a) and biosorption capacity *q(mg/g)* in coded (a) and real (b) coordinates.

| Sorbent | Metal ion | Model equations (coded variables) | |
|---|---|---|---|
| | | Metal ion biosorption efficiency, *R(%)* | |
| Soybean biomass | Pb(II) | $R = 64.72 + 3.24A + 4.26B - 5.91C + 4.33D + 6.89A^2 - 1.48B^2$ | (1a) |
| | Cd(II) | $R = 72.12 + 3.51A + 4.37B - 6.67C + 3.99D - 0.34E - 6.69A^2 + 1.70CE$ | (2a) |
| | Zn(II) | $R = 56.03 + 2.19A + 3.61B - 5.84C + 3.15D - 0.62E - 5.02A^2 - 1.2B^2 + 1.35CE$ | (3a) |
| Soybean waste biomass | Pb(II) | $R = 63.22 + 4.92A + 4.76B - 5.33C + 4.27D - 5.91A^2 - 1.21B^2$ | (4a) |
| | Cd(II) | $R = 71 + 1.95A + 3.99B - 5.37C + 2.94D + 0.31E - 6.04A^2 - 2.28B^2 + 1.46C^2 + 1.28E^2 + 1.54CE$ | (5a) |
| | Zn(II) | $R = 61.16 + 4.6A + 3.49B - 5.83C + 2.76D - 6.08A^2 - 2.68B^2 - 1.95D^2$ | (6a) |
| | | Biosorption capacity, *q (mg/g)* | |
| Soybean biomass | Pb(II) | $q = 14.85 + 1.58A - 2.5B + 3.61C + 0.99D + 1.04E - 1.08A^2 - 0.99BC - 0.58BD$ | (7a) |
| | Cd(II) | $q = 10.6 + 1.03A - 2.18B + 4.10C + 0.089D + 2.14E - 1.07A^2 + 1.26D^2 + 0.88E^2 + 0.48AC - 0.67BC + 1.64CE$ | (8a) |
| | Zn(II) | $q = 8.75 + 0.054A - 1.39B + 1.56C + 0.47D + 0.047E - 0.6A^2 - 0.7B^2 - 0.66C^2 - 0.45D^2 - 0.7BC - 0.26BE - 0.35CE$ | (9a) |
| Soybean waste biomass | Pb(II) | $q = 18.39 + 1.76A - 3.33B + 4.17C + 0.38D + 1.01E - 1.69A^2 + 0.83BC - 0.74DE$ | (10a) |
| | Cd(II) | $q = 15.94 + 1.06A - 1.69B + 4.92C + 0.069D + 3.62E - 2.05A^2 - 1.94B^2 + 0.6D^2 - 0.38BC - 0.91CD + 2.54CE + 0.84DE$ | (11a) |
| | Zn(II) | $q = 10.54 + 0.86A - 1.86B + 2.01C - 0.25D + 1.24E - 1.27A^2 - 0.35B^2 - 0.47C^2 - 0.33D^2 + 0.54E^2 - 0.73BC - 0.53BE - 0.38DE$ | (12a) |
| | | **Model equations (real variables)** | |
| | | Metal ion biosorption efficiency, *R (%)* | |
| Soybean biomass | Pb(II) | $R = -41.09 + 41.435x_1 + 1.808x_2 - 0.069x_3 + 0.118x_4 - 5.15x_1^2 - 0.028x_2^2$ | (1b) |
| | Cd(II) | $R = -2.125 + 40.588\,x_1 + 0.594x_2 - 0.25x_3 - 0.109x_4 - 0.499x_5 - 5.007x_1^2 + 3.869x_3x_5$ | (2b) |
| | Zn(II) | $R = -5.948 + 30.06x_1 + 1.49x_2 - 0.237x_3 + 0.086x_4 - 0.451x_5 - 3.75x_1^2 - 0.022x_2^2 - 0.004x_3x_5$ | (3b) |
| Soybean waste biomass | Pb(II) | $R = -38.034 + 37.397x_1 + 1.65x_2 - 0.063x_3 + 0.116x_4 - 4.42x_1^2 - 0.022x_2^2$ | (4b) |
| | Cd(II) | $R = 6.73 + 35.599x_1 + 2.435x_2 - 0.385x_3 - 0.08x_4 - 1.189x_5 - 4.52x_1^2 - 0.043x_2^2 + 0.00073x_3^2 + 0.014x_5^2 + 0.0036x_3x_5$ | (5b) |
| | Zn(II) | $R = -57.05 + 38.11x_1 + 2.703x_2 - 0.141x_3 + 0.341x_4 - 4.551x_1^2 - 0.0495x_2^2 - 0.0015x_4^2$ | (6b) |
| | | Biosorption capacity, *q (mg/g)* | |
| Soybean biomass | Pb(II) | $q = -20.71 + 7.45x_1 + 0.197x_2 + 0.078x_3 + 0.075x_4 + 0.11x_5 - 0.81x_1^2 - 0.0016x_2x_3 - 0.0022x_2x_4$ | (7b) |
| | Cd(II) | $q = 12.05 + 5.83x_1 - 0.062x_2 - 0.004x_3 - 0.169x_4 - 0.761x_5 - 0.803x_1^2 - 0.001x_4^2 - 0.009x_5^2 + 0.009x_1x_3 - 0.002x_2x_3 + 0.004x_3x_5$ | (8b) |
| | Zn(II) | $q = -24.13 + 3.44x_1 + 0.755x_2 + 0.2x_3 + 0.075x_4 + 0.189x_5 - 0.452x_1^2 - 0.013x_2^2 - 0.0004x_3^2 - 0.00036x_4^2 - 0.0023x_2x_3 - 0.0038x_2x_5 - 0.001x_3x_5$ | (9b) |
| Soybean waste biomass | Pb(II) | $q = -21.07 + 11x_1 - 0.168x_2 + 0.079x_3 + 0.069x_4 + 0.303x_5 - 1.263x_1^2 - 0.00133x_2x_3 - 0.002x_4x_5$ | (10b) |
| | Cd(II) | $q = -25.35 + 12.4x_1 + 1.517x_2 + 0.022x_3 - 0.082x_4 - 0.533x_5 - 1.53x_1^2 - 0.036x_2^2 + 0.0005x_4^2 - 0.0011x_2x_3 - 0.00053x_3x_4 + 0.006x_3x_5 + 0.0024x_4x_5$ | (11b) |
| | Zn(II) | $q = -23.47 + 7.187x_1 + 0.515x_2 + 0.165x_3 + 0.068x_4 + 0.069x_5 - 0.948x_1^2 - 0.0065x_2^2 - 0.0003x_3^2 - 0.002\,x_4^2 + 0.006x_5^2 - 0.0024x_1x_3 - 0.0077x_2x_5 - 0.0011x_4x_5$ | (12b) |

**Table S2.** Results of tests for model adequacy.

| Source | Sum of Squares | Degrees of freedom | Square mean | *F* | Prob>*F* |
|---|---|---|---|---|---|
| Soybean biomass, Pb(II), *R(%)* | | | | | |
| Mean | 1.445E+005 | 1 | 1.445E + 005 | | |
| Linear | 3751.6 | 5 | 714.32 | 8.65 | < 0.0001 |
| 2Fi | 79.53 | 10 | 7.95 | 0.073 | 0.9999 |
| Quadratic | 2577.16 | 5 | 515.43 | 22.01 | < 0.0001 |
| Cubic | 413.45 | 15 | 27.56 | 1.67 | 0.2210 |
| Residual | 148.69 | 9 | 16.52 | | |
| Total | 1.513E + 0.005 | 45 | 3362.51 | | |
| Soybean waste biomass, Pb(II), *R(%)* | | | | | |
| Mean | 1.43E + 0.05 | 1 | 1.43 + 005 | | |
| Linear | 4050.30 | 5 | 810.06 | 13.26 | < 0.0001 |
| 2Fi | 90.27 | 10 | 9.03 | 0.11 | 0.9995 |
| Quadratic | 1867.72 | 5 | 373.54 | 21.14 | < 0.0001 |
| Cubic | 276.36 | 15 | 18.42 | 1.12 | 0.4449 |
| Residual | 147.71 | 9 | 16.41 | | |
| Total | 1.494E + 005 | 45 | 3320.39 | | |
| Soybean biomass, Cd(II), *R(%)* | | | | | |
| Mean | 1.941E + 005 | 1 | 1.941E + 005 | | |
| Linear | 3985.29 | 5 | 797.06 | 10.14 | < 0.0001 |
| 2Fi | 145.61 | 10 | 14.56 | 0.14 | 0.9986 |
| Quadratic | 2516.46 | 5 | 503.29 | 29.99 | < 0.0001 |
| Cubic | 381.81 | 15 | 25.45 | 10.96 | 0.0005 |
| Residual | 20.90 | 9 | 2.32 | | |
| Total | 2.012E + 005 | 45 | 4470.53 | | |
| Soybean waste biomass, Cd(II), *R(%)* | | | | | |
| Mean | 1.938E + 005 | 1 | 1.938E + 005 | | |
| Linear | 2479.76 | 5 | 495.95 | 6.11 | 0.0003 |
| 2Fi | 116.85 | 10 | 11.69 | 0.11 | 0.9996 |
| Quadratic | 2612.13 | 5 | 552.43 | 28.58 | < 0.0001 |
| Cubic | 432.74 | 15 | 28.85 | 43.93 | < 0.0001 |
| Residual | 5.91 | 9 | 0.66 | | |
| Total | 1.995+005 | 45 | 4432.65 | | |
| Soybean biomass, Zn(II), *R(%)* | | | | | |
| Mean | 1.127E + 005 | 1 | 1.127E + 005 | | |
| Linear | 2693.90 | 5 | 538.78 | 11.20 | < 0.0001 |
| 2Fi | 90.81 | 10 | 9.08 | 0.15 | 0.9985 |
| Quadratic | 1405.51 | 5 | 281.10 | 17.79 | < 0.0001 |
| Cubic | 360.13 | 15 | 24.01 | 11.34 | 0.0004 |
| Residual | 19.06 | 9 | 2.12 | | |
| Total | 1.173 + 005 | 45 | 2605.77 | | |
| Soybean waste biomass, Zn(II), *R(%)* | | | | | |
| Mean | 1.163E + 005 | 1 | 1.163E + 005 | | |
| Linear | 3244.33 | 5 | 648.87 | 10.44 | < 0.0001 |
| 2Fi | 38.69 | 10 | 3.87 | 0.047 | 1.0000 |
| Quadratic | 1969.93 | 5 | 393.99 | 22.73 | < 0.0001 |
| Cubic | 253.49 | 15 | 16.90 | 0.94 | 0.5636 |
| Residual | 162.58 | 9 | 18.06 | | |
| Total | 1.220E + 005 | 45 | 2711.14 | | |
| Soybean biomass, Pb(II), *q(mg/g)* | | | | | |
| Mean | 8575.32 | 1 | 8575.32 | | |
| Linear | 1032.18 | 5 | 206.44 | 42.14 | < 0.0001 |

| | | | | | |
|---|---|---|---|---|---|
| 2Fi | 56.53 | 10 | 5.65 | 1.18 | 0.3444 |
| Quadratic | 69.09 | 5 | 13.82 | 4.73 | 0.0038 |
| Cubic | 19.91 | 15 | 1.33 | 0.24 | 0.9929 |
| Residual | 50.15 | 9 | 5.17 | | |
| Total | 9803.18 | 45 | 217.85 | | |
| Soybean waste biomass, Pb(II), *q(mg/g)* | | | | | |
| Mean | 12653.80 | 1 | 12653.8 | | |
| Linear | 1416.79 | 5 | 283.36 | 39.65 | < 0.0001 |
| 2Fi | 43.56 | 10 | 4.36 | 0.54 | 0.8493 |
| Quadratic | 155.82 | 5 | 31.16 | 9.43 | < 0.0001 |
| Cubic | 28.4 | 15 | 1.89 | 0.33 | 0.9704 |
| Residual | 50.91 | 9 | 5.66 | | |
| Total | 14349.28 | 45 | 318.87 | | |
| Soybean biomass, Cd(II), *q(mg/g)* | | | | | |
| Mean | 6074.94 | 1 | 6074.94 | | |
| Linear | 1180.7 | 5 | 236.14 | 26.61 | < 0.0001 |
| 2Fi | 112.12 | 10 | 11.21 | 1.39 | 0.2339 |
| Quadratic | 216.86 | 5 | 43.37 | 60.84 | < 0.0001 |
| Cubic | 15.49 | 15 | 1.03 | 5.73 | 0.0060 |
| Residual | 1.62 | 9 | 0.18 | | |
| Total | 7601.72 | 45 | 168.93 | | |
| Soybean waste biomass, Cd(II), *q(mg/g)* | | | | | |
| Mean | 7230.14 | 1 | 7230.14 | | |
| Linear | 1786.39 | 5 | 357.28 | 19.45 | < 0.0001 |
| 2Fi | 267.35 | 10 | 26.73 | 1.73 | 0.1219 |
| Quadratic | 421.55 | 5 | 84.31 | 73.80 | < 0.0001 |
| Cubic | 22.17 | 15 | 1.48 | 2.54 | 0.0808 |
| Residual | 5.25 | 9 | 0.58 | | |
| Total | 9732.84 | 45 | 216.29 | | |
| Soybean biomass, Zn(II), *q(mg/g)* | | | | | |
| Mean | 1857.31 | 1 | 1857.31 | | |
| Linear | 199.40 | 5 | 39.88 | 20.16 | < 0.0001 |
| 2Fi | 23.15 | 10 | 2.31 | 1.24 | 0.3066 |
| Quadratic | 39.20 | 5 | 7.84 | 12.71 | < 0.0001 |
| Cubic | 5.83 | 15 | 0.39 | 0.39 | 0.9486 |
| Residual | 8.97 | 9 | 1.00 | | |
| Total | 2133.85 | 45 | 47.42 | | |
| Soybean waste biomass, Zn(II), *q(mg/g)* | | | | | |
| Mean | 3435.69 | 1 | 34.36 | | |
| Linear | 394.48 | 5 | 78.90 | 17.94 | < 0.0001 |
| 2Fi | 31.52 | 10 | 3.15 | 0.65 | 0.7567 |
| Quadratic | 116.80 | 5 | 23.26 | 24.21 | < 0.0001 |
| Cubic | 22.24 | 15 | 1.48 | 14.55 | 0.0002 |
| Residual | 0.92 | 9 | 0.10 | | |
| Total | 4001.66 | 45 | 88.93 | | |

**Table S3.** ANOVA for the polynomial (quadratic) model for *R*(%) in case of Pb(II) retention on soybean biomass and soybean waste biomass, respectively.

| Source | Sum of Squares | Degrees of freedom | Square mean | *F* | Prob>*F* |
|---|---|---|---|---|---|
| Soybean biomass, Pb(II), *R(%)* | | | | | |
| Model | 6066.99 | 6 | 1011.17 | 53.11 | <0.0001 |
| A | 453.62 | 1 | 453.62 | 23.83 | <0.0001 |
| B | 787.61 | 1 | 787.61 | 41.37 | <0.0001 |
| C | 1515.02 | 1 | 1515.02 | 79.58 | <0.0001 |
| D | 813.50 | 1 | 813.50 | 42.73 | <0.0001 |
| $A^2$ | 2493.88 | 1 | 2493.88 | 131.0 | <0.0001 |
| $B^2$ | 114.79 | 1 | 114.79 | 6.03 | <0.0188 |
| Residual | 723.42 | 38 | 19.04 | | |
| Lack of correlation | 722.90 | 36 | 20.08 | 76.25 | 0.0130 |
| Pure error | 0.53 | 2 | 0.26 | | |
| Corrected sum of squares (Cor. Total) | 6790.41 | 44 | | | |
| Soybean waste biomass, Pb(II), *R(%)* | | | | | |
| Model | 5888.99 | 6 | 981.17 | 68.37 | <0.0001 |
| A | 1046.40 | 1 | 1046.40 | 72.91 | <0.0001 |
| B | 982.26 | 1 | 982.26 | 68.44 | <0.0001 |
| C | 1231.92 | 1 | 1231.92 | 86.84 | <0.0001 |
| D | 789.71 | 1 | 789.71 | 55.03 | <0.0001 |
| $A^2$ | 1835.45 | 1 | 1835.45 | 127.89 | <0.0001 |
| $B^2$ | 76.48 | 1 | 76.48 | 5.33 | 0.0265 |
| Residual | 545.36 | 38 | 14.35 | | |
| Lack of correlation | 545.04 | 36 | 15.14 | 92.69 | 0.0107 |
| Pure error | 0.33 | 2 | 0.16 | | |
| Corrected sum of squares (Cor. Total) | 6432.36 | 44 | | | |

**Table S4.** ANOVA for the polynomial (quadratic) model for *q*(mg/g) in case of Pb(II) retention on soybean biomass and soybean waste biomass, respectively.

| Source | Sum of Squares | Degrees of freedom | Square mean | *F* | Prob>*F* |
|---|---|---|---|---|---|
| Soybean biomass, Pb(II), *q(mg/g)* | | | | | |
| Model | 1137.99 | 8 | 142.25 | 56.98 | <0.0001 |
| A | 108.73 | 1 | 108.73 | 43.55 | <0.0001 |
| C | 563.11 | 1 | 563.11 | 225.56 | <0.0001 |
| D | 42.65 | 1 | 42.65 | 17.08 | 0.0002 |
| C | 563.11 | 1 | 563.11 | 225.56 | <0.0001 |
| D | 42.65 | 1 | 42.65 | 17.08 | 0.0002 |
| E | 47.14 | 1 | 47.14 | 18.88 | 0.0001 |
| $A^2$ | 63.79 | 1 | 63.79 | 25.55 | <0.0001 |
| BC | 31.20 | 1 | 31.20 | 12.50 | 0.0011 |
| BD | 10.81 | 1 | 10.81 | 4.33 | 0.0446 |
| Residual | 89.97 | 36 | 2.50 | | |
| Lack of correlation | 89.61 | 34 | 2.64 | 20.27 | 0.0481 |
| Pure error | 0.26 | 2 | 0.13 | | |
| Corrected sum of squares (Cor. Total) | 1227.86 | 44 | | | |
| Soybean waste biomass, Pb(II), *q(mg/g)* | | | | | |
| Model | 1611.23 | 8 | 201.40 | 86.07 | <0.0001 |
| A | 134.68 | 1 | 134.68 | 57.56 | <0.0001 |
| B | 479.50 | 1 | 479.50 | 204.90 | <0.0001 |
| C | 752.22 | 1 | 752.22 | 321.45 | <0.0001 |
| D | 6.16 | 1 | 6.16 | 2.63 | 0.1134 |
| E | 44.23 | 1 | 44.23 | 18.9 | 0.0001 |
| $A^2$ | 154.92 | 1 | 154.92 | 66.20 | <0.0001 |
| BC | 22.11 | 1 | 22.11 | 0.45 | 0.0040 |
| DE | 17.40 | 1 | 17.40 | 7.44 | 0.0098 |
| Residual | 84.24 | 36 | 2.34 | | |
| Lack of correlation | 84.04 | 34 | 2.47 | 23.92 | 0.0409 |
| Pure error | 0.21 | 2 | 0.1 | | |
| Corrected sum of squares (Cor. Total) | 1695.48 | 44 | | | |