**Supplementary material:**

**Pulp and Paper Industry Side-Stream Materials as Feed for the Oleaginous Yeast species Lipomyces starkeyi and *Rhodotorula* toruloides**

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Table 4. Sugar concentrations (gKg-1, analysed by MoRe Research Örnsköldsvik AB) in the culture media (10 g freeze-dried material per liter) before and after fermentation of different side-stream lignocellulosic material with *R. toruloides* (RT) and *L. starkeyi* (LS).

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Side-stream lignocellulosic material** | **Analyzed** | **Arabinose** | **Galactose** | **Glucose** | **Xylose** | **Mannose** |
| **Steam exploded hardwood liquor (SEHW)** | before | 0.13 | 0.29 | 0.82 | 4.7 | 0.41 |
| after-RT | 0.05 | 0.2 | 0.21 | 0.57 | 0.3 |
| after-LS | 0.13 | 0.41 | 0.47 | 0.36 | 0.61 |
| **Bio sludge (BS)** | before | 0.11 | 0.33 | 1.39 | 0.19 | 0.41 |
| after-RT | 0.03 | 0.2 | 0.26 | 0.05 | 0.27 |
| after-LS | 0.06 | 0.23 | 0.64 | 0.11 | 0.27 |
| **Black liquor (BL)** | before | 0.05 | 0.08 | 0.02 | 0.05 | 0.002 |
| after-RT | 0.006 | 0.11 | 0.03 | 0.01 | 0.16 |
| after-LS | 0.05 | 0.08 | 0.02 | 0.05 | 0.01 |
| **Chemical sludge (CS)** | before | 0.005 | 0.02 | 0.02 | 0.003 | 0.009 |
| after-RT | 0.005 | 0.08 | 0.06 | 0.003 | 0.13 |
| after-LS | 0.009 | 0.05 | 0.09 | 0.009 | 0.04 |
| **Sulfite liquor (SL)** | before | 0.03 | 0.2 | 0.39 | 0.35 | 0.96 |
| after-RT | 0.001 | 0.1 | 0.18 | 0.02 | 0.3 |
| after-LS | 0.003 | 0.12 | 0.15 | 0.03 | 0.28 |
| **Lignosulfonate (LGN)** | before | 0.002 | 0.03 | 0.07 | 0.02 | 0.11 |
| after-RT | 0.003 | 0.13 | 0.06 | 0.02 | 0.33 |
| after-LS | 0.001 | 0.08 | 0.08 | 0.02 | 0.11 |

Table 5. Phenolic compounds analysis (µM, two replicates) in the culture media before and after fermentation of the lignocellulosic material with L. *starkeyi* (LS) and *R. toruloides* (RT)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Material** | **Steam exploded hardwood liquor (SEHW)** | **Bio sludge (BS)** | **Black liquor (BL)** | **Chemical sludge (CS)** | **Sulfite liquor (SL)** | **Lignosulfonate (LGN)** |
|  **Compound** | before | after-LS | after-RT | before | after-LS | after-RT | before | after-LS | after-RT | before | after-LS | after-RT | before | after-LS | after-RT | before | after-LS | after-RT |
| **Cinnemaldehyde** | 7.08 ± 0.13 | nd | nd | nd | nd | nd | 0.09 ± 0.08 | nd | nd | 0.05 ± 0.02 | 0.05 ± 0 | nd | 0.36 ± 0.01 | nd | nd | 0.20 ± 0 | nd | nd |
| **Sinapaldehyde** | 12.51 ± 0.53 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| **Syringaldehyde** | 117.24 ± 5.13 | nd | 3.59 ± 0.40 | nd | nd | nd | nd | nd | nd | 0.04 ± 0.02 | 0.04 ± 0 | nd | nd | nd | 0.07 ± 0 | nd | nd | nd |
| **Vanillin** | 39.01 ± 1.51 | 0.85 ± 0.38 | 1.21 ± 0.09 | 0.46 \* | nd | nd | 30.79 ± 20.26 | nd | 0.72 ± 0.18 | 0.92 ± 0.47 | 1.65 ± 0.11 | 0.01\* | 6.45 ± 0.38 | nd | 0.07\* | 1.35 ± 0.44 | nd | nd |
| **Vanillic acid** | 12.21 ± 0.75 | 15.91 ± 1.53 | nd | 0.34\*  | nd | nd | 23.12 ± 1.13 | 60.18 ± 0.31 | 0.70 ± 0.07 | 0.92 ± 0.42 | 2.28 ± 0.30 | 0.16\* | 5.60 ± 0.58 | 5.75 ± 0.07 | 1.54 ± 0.05 | 6.05 ± 2.53 | nd | nd |
| **Gallic acid** | 0.53 ± 0.33 | 0.15\* | 0.21\*  | nd | 0.19 ± 0.03 | 0.22 ± 0.06 | nd | 0.76 ± 0.03 | nd | 0.13 ± 0.09 | 0.26 ± 0.02 | 0.20 ± 0.19 | nd | 0.09\* | 0.10\* | 0.12 ± 0.10 | nd | 0.11\* |
| **Ferulic acid** | nd | 2.16 ± 0.45 | nd | 0.03\*  | 0.05 ± 0 | nd | 0.77 ± 0.53 | 1.81 ± 0.32 | nd | nd | 0.03 ± 0.01 | nd | nd | 0.16 ± 0 | 0.02\* | nd | nd | nd |
| **Caffeic acid** | 0.16 ± 0.04 | 0.17 ± 0.09 | 0.05\*  | nd | nd | nd | nd | < nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| **p-Coumaric acid** | nd | 0.05 ± 0.02 | nd | 0.05\*  | nd | nd | 0.13 ± 0.10 | 0.33 ± 0.04 | nd | nd | nd | 0.09 ± 0.08 | nd | nd | nd | nd | nd | nd |
| **4-Hydroxybenzoic acid** | nd | nd | nd | nd | nd | nd | 0.04 ± 0.03 | nd | nd | nd | 0.03 ± 0 | 0.03 ± 0.01 | 0.04 ± 0.02 | nd | 0.06 ± 0.01 | 0.03 ± 0 | 0.03 ± 0 | nd |
| **Sinapic acid** | nd | 0.76 ± 0.20 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd |
| **Syringic acid** | 18.68 ± 0.45 | 33.94 ± 6.02 | 25.25 ± 2.44 | nd | nd | nd | 0.04 \* | 0.15 ± 0.03 | nd | 0.05 ± 0.03 | 0.11 ± 0.02 | nd | 0.07 ± 0.01 | 0.10 ± 0.01 | nd | 0.10 ± 0.06 | nd | nd |
| **Protocatechuic acid** | 5.43 ± 0.05 | 9.95 ± 1.70 | 1.26 \* | nd | nd | nd | nd | 0.16 ± 0.02 | nd | nd | nd | nd | 0.26 ± 0.05 | 0.76 ± 0.03 | 0.05 \* | 0.16 ± 0.09 | 0.13 \* | 0.1\* |
| **Phtalic acid** | 0.21 ± 0.04 | 0.38 ± 0.10 | 0.25 ± 0.04 | 0.09\* | 0.11 \* | 0.13 ± 0 | nd | 0.31 ± 0.03 | 0.36 ± 0.08 | 0.08 \* | 0.22 ± 0.07 | 0.25 ± 0.25 | 0.04\* | 0.16 ± 0 | 0.22 ± 0.03 | 0.06\* | 0.04\* | 0.15 ± 0.07 |
| **Salicylic acid** | 0.24 ± 0.01 | 0.36 ± 0.07 | 0.05 ± 0.01 | 0.17 ± 0.21 | 0.06 ± 0.03 | nd | 0.60 ± 0.36 | 1.26 ± 0.07 | 0.06 ± 0 | 0.05 ± 0.03 | 0.15 ± 0 | 0.28 ± 0.21 | 0.38 ± 0.02 | 0.52 ± 0.01 | 0.59 ± 0 | 0.40 ± 0.15 | 0.15 ± 0.05 | nd |

Values mark with “\*” one replicate, the uncertainty value “0” means the value is less than 0.005 and nd - below detection limit

Table 6. Concentration of elements (mg/L) in the culture media before and after fermentation of different lignocellulosic material with *L. starkeyi* (LS) and *R. toruloides* (RT)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Element  | **Steam explored hardwood liquor (SEHW)** | **Bio sludge (BS)** | **Black liquor (BL)** | **Chemical sludge (CS)** | **Sulfite liquor (SL)** | **Lignosulfonate (LGN)** |
| before | after-LS | after-RT | before | after-LS\* | after-RT | before | after-LS\* | after-RT | before | after-LS | after-RT | before | after-LS | after-RT | before | after-LS | after-RT |
| U | 0.025 ± 0.012 | 0.025 ± 0.005 | 0.025 ± 0.006 | 0.036 ± 0.018 | 0.019 | 0.049 ± 0.025 | 0.005 ± 0.003 | 0.028 | 0.016 ± 0.009 | 0.059 ± 0.007 | 0.05 ± 0.01 | 0.043 ± 0.006 | 0.017 ± 0.016 | 0.033 ± 0.004 | 0.031 ± 0.001 | 0.025 ± 0.01 | 0.028 ± 0.01 | 0.031 ± 0.022 |
| Ba | 0.012 ± 0 | 0.012 ± 0 | 0.017 ± 0 | 0.064 ± 0.001 | 0.165 | 0.144 ± 0.001 | 0.083 ± 0.001 | 0.082 | 0.033 ± 0 | 0.091 ± 0 | 0.083 ± 0 | 0.031 ± 0 | 0.023 ± 0 | 0.024 ± 0 | 0.023 ± 0 | 0.012 ± 0 | 0.011 ± 0 | 0.013 ± 0 |
| Si | 0.57 ± 0.009 | 9.206 ± 0.06 | 5.078 ± 0.005 | 4.931 ± 0.034 | 15.053 | 3.077 ± 0.143 | 23.631 ± 1.309 | 24.702 | 6.71 ± 0.028 | 1.497 ± 0.006 | 1.89 ± 0.008 | 1.788 ± 0.011 | 0.418 ± 0.002 | 1.697 ± 0.037 | 2.276 ± 0.019 | 0.616 ± 0.001 | 1.507 ± 0.034 | 1.463 ± 0.023 |
| V | 0.001 ± 0 | 0.001 ± 0.001 | 0.001 ± 0 | 0.001 ± 0.001 | 0.0003 | 0.001 ± 0.002 | 0.024 ± 0 | 0.014 | 0.012 ± 0.003 | 0.003 ± 0.001 | 0.002 ± 0.001 | 0.019 ± 0 | 0.0001 ± 0.00004 | 0.0004 ± 0.0006 | 0.006 ± 0 | 0.002 ± 0.001 | 0.008 ± 0 | 0.006 ± 0.001 |
| Tl | 0.015 ± 0.001 | 0.013 ± 0 | 0.013 ± 0.001 | 0.012 ± 0.001 | 0.011 | 0.011 ± 0.005 | 0.009 ± 0.001 | 0.011 | 0.01 ± 0.004 | 0.01 ± 0 | 0.007 ± 0.003 | 0.011 ± 0 | 0.014 ± 0 | 0.01 ± 0.007 | 0.009 ± 0.003 | 0.009 ± 0.006 | 0.004 ± 0.003 | 0.008 ± 0.004 |
| Th | 0.006 ± 0.001 | 0.007 ± 0.002 | 0.007 ± 0.003 | 0.01 ± 0.002 | 0.007 | 0.006 ± 0.002 | 0.01 ± 0.001 | 0.006 | 0.008 ± 0.001 | 0.012 ± 0.004 | 0.015 ± 0.004 | 0.018 ± 0.003 | 0.009 ± 0.004 | 0.009 ± 0.001 | 0.008 ± 0 | 0.006 ± 0.002 | 0.008 ± 0.001 | 0.008 ± 0.001 |
| Ag | 0.074 ± 0.016 | 0.079 ± 0.005 | 0.067 ± 0.015 | 0.009 ± 0 | 0.006 | 0.007 ± 0.001 | 0.006 ± 0.001 | 0.004 | 0.005 ± 0 | 0.055 ± 0.008 | 0.047 ± 0.006 | 0.058 ± 0.002 | 0.068 ± 0.008 | 0.062 ± 0.004 | 0.068 ± 0.004 | 0.062 ± 0.014 | 0.071 ± 0.003 | 0.081 ± 0.01 |
| Se | 0.041 ± 0.003 | 0.032 ± 0.013 | 0.026 ± 0.01 | 0.021 ± 0.001 | 0.021 | 0.026 ± 0.013 | 0.02 ± 0.002 | 0.023 | 0.018 ± 0.001 | 0.015 ± 0.008 | 0.023 ± 0.001 | 0.023 ± 0.004 | 0.022 ± 0.001 | 0.029 ± 0.003 | 0.04 ± 0.003 | 0.039 ± 0.006 | 0.028 ± 0.01 | 0.032 ± 0.008 |
| Al | 0.115 ± 0.001 | 0.318 ± 0.009 | 0.173 ± 0.002 | 1.688 ± 0.02 | 0.125 | 0.106 ± 0.009 | 1.225 ± 0.002 | 0.945 | 0.502 ± 0.009 | 0.559 ± 0 | 0.505 ± 0.014 | 2.204 ± 0.014 | 0.384 ± 0.001 | 0.434 ± 0.001 | 0.456 ± 0.006 | 0.407 ± 0.002 | 0.337 ± 0.004 | 0.403 ± 0.005 |
| As | 0.028 ± 0.001 | 0.025 ± 0.001 | 0.02 ± 0.007 | 0.017 ± 0.002 | 0.024 | 0.015 ± 0.006 | 0.021 ± 0.001 | 0.029 | 0.015 ± 0.001 | 0.015 ± 0.001 | 0.019 ± 0.002 | 0.017 ± 0.002 | 0.027 ± 0.003 | 0.024 ± 0.006 | 0.026 ± 0.004 | 0.026 ± 0.007 | 0.026 ± 0.004 | 0.021 ± 0.003 |
| Ca | 35.331 ± 1.125 | 1.386 ± 0.013 | 19.599 ± 0.738 | 30.64 ± 0.3 | 258.908 | 217.711 ± 13.864 | 1.467 ± 0.045 | 1.785 | 2.12 ± 0.029 | 17.124 ± 0.881 | 17.677 ± 0.043 | 21.599 ± 0.063 | 14.323 ± 0.403 | 5.366 ± 0.258 | 10.385 ± 0.174 | 15.319 ± 0.562 | 12.84 ± 0.759 | 12.057 ± 0.52 |
| Cr | 0.049 ± 0.001 | 0.072 ± 0.002 | 0.033 ± 0 | 0.018 ± 0.001 | 0.009 | 0.006 ± 0.001 | 0.006 ± 0 | 0.014 | 0.013 ± 0 | 0.005 ± 0.001 | 0.005 ± 0 | 0.01 ± 0.001 | 0.053 ± 0.001 | 0.072 ± 0.001 | 0.011 ± 0 | 0.013 ± 0.001 | 0.015 ± 0.001 | 0.014 ± 0 |
| Cu | 0.078 ± 0.001 | 0.109 ± 0.001 | 0.072 ± 0.001 | 0.44 ± 0.007 | 0.099 | 0.044 ± 0.001 | 0.06 ± 0.001 | 0.057 | 0.05 ± 0.001 | 0.004 ± 0 | 0.007 ± 0 | 0.029 ± 0.001 | 0.077 ± 0.002 | 0.112 ± 0.003 | 0.027 ± 0.001 | 0.073 ± 0.002 | 0.193 ± 0.002 | 0.106 ± 0 |
| Fe | 1.414 ± 0.024 | 1.368 ± 0.043 | 0.673 ± 0.004 | 0.335 ± 0.004 | 0.419 | 0.223 ± 0.001 | 0.613 ± 0.008 | 0.408 | 0.072 ± 0.001 | 4.357 ± 0.12 | 2.249 ± 0.064 | 7.074 ± 0.118 | 0.389 ± 0.005 | 0.503 ± 0.013 | 0.08 ± 0.001 | 0.144 ± 0.001 | 0.187 ± 0.002 | 0.133 ± 0.002 |
| K | 41.458 ± 1.628 | 91.725 ± 0.118 | 47.326 ± 0.233 | 48.335 ± 0.887 | 39.704 | 110.948 ± 6.469 | 146.403 ± 3.027 | 158.449 | 218.482 ± 1.352 | 5.884 ± 0.264 | 18.195 ± 0.085 | 95.945 ± 0.352 | 12.314 ± 0.122 | 41.933 ± 2.432 | 94.992 ± 1.251 | 14.89 ± 0.472 | 103.778 ± 4.278 | 102.081 ± 3.004 |
| Mg | 11.821 ± 0.401 | 14.818 ± 0.043 | 10.246 ± 0.048 | 10.759 ± 0.23 | 21.476 | 12.858 ± 0.09 | 1.364 ± 0.014 | 3.255 | 3.378 ± 0.029 | 4.343 ± 0.026 | 4.949 ± 0.057 | 5.171 ± 0.029 | 3.109 ± 0.127 | 3.851 ± 0.187 | 1.729 ± 0.012 | 3.517 ± 0.193 | 3.379 ± 0.192 | 1.655 ± 0.03 |
| Mn | 8.361 ± 0.256 | 9.531 ± 0.051 | 5.925 ± 0.04 | 0.554 ± 0.006 | 2.755 | 1.985 ± 0.006 | 0.64 ± 0.005 | 0.746 | 0.596 ± 0.003 | 0.342 ± 0 | 0.325 ± 0.008 | 0.343 ± 0 | 1.185 ± 0.003 | 1.414 ± 0.026 | 0.833 ± 0.006 | 1.403 ± 0.004 | 0.939 ± 0.015 | 0.975 ± 0.016 |
| Ni | 0.138 ± 0.001 | 0.166 ± 0.004 | 0.079 ± 0.002 | 0.076 ± 0.003 | 0.023 | 0.018 ± 0.001 | 0.008 ± 0.001 | 0.015 | 0.01 ± 0 | 0.005 ± 0.001 | 0.007 ± 0 | 0.007 ± 0.001 | 0.05 ± 0.001 | 0.07 ± 0.002 | 0.013 ± 0 | 0.013 ± 0.001 | 0.016 ± 0.001 | 0.015 ± 0.001 |
| Pb | 0.017 ± 0.002 | 0.007 ± 0.003 | 0.004 ± 0.004 | 0.008 ± 0.001 | 0.009 | 0.009 ± 0.002 | 0.006 ± 0.001 | 0.012 | 0.009 ± 0.001 | 0.007 ± 0 | 0.005 ± 0 | 0.006 ± 0.001 | 0.006 ± 0.002 | 0.008 ± 0.003 | 0.006 ± 0.001 | 0.007 ± 0 | 0.007 ± 0.002 | 0.009 ± 0.001 |
| Zn | 0.229 ± 0.005 | 0.277 ± 0.009 | 0.246 ± 0 | 5.473 ± 0.02 | 0.125 | 0.15 ± 0.001 | 0.052 ± 0.002 | 0.102 | 0.244 ± 0.006 | 0.117 ± 0.001 | 0.102 ± 0.02 | 0.197 ± 0.001 | 0.158 ± 0.001 | 0.305 ± 0.009 | 0.091 ± 0.007 | 0.176 ± 0 | 0.306 ± 0.008 | 7.605 ± 0.084 |
| Sn | 0.008 ± 0.001 | 0.007 ± 0.002 | 0.005 ± 0.001 | 0.007 ± 0.001 | 0.01 | 0.007 ± 0.001 | 0.006 ± 0.002 | 0.001 | 0.005 ± 0.001 | 0.006 ± 0 | 0.006 ± 0.001 | 0.005 ± 0 | 0.007 ± 0.003 | 0.009 ± 0.003 | 0.008 ± 0 | 0.006 ± 0.003 | 0.004 ± 0.001 | 0.006 ± 0.003 |

Columns with \* one replicate and standard deviation of 2 replicates ”0” = >0.0005