*Supplementary information for*

# Removal of metals and inorganics from rendered fat using polyamine-modified cellulose nanocrystals

Outline

Table SI 1: Results obtained from real samples after water wash and CNC-PEI treatment. Control samples remained untreated and were analyzed in order to compare samples before and after removal.

Figure SI 1. Optimization of the extraction temperature. Sample volume 10 mL, 5 minutes water wash, 10 minutes sorbent extraction, 2 minutes 9000 rpm centrifugation.

Figure SI 2. Extraction rates as a function of time. All the analytes were fitted using a pseudo-second-order kinetics. The response of all the extracted species showed similar behaviors.

Table SI 2: Summary of removal of various contaminants from fat using other extraction materials or techniques. n/d: not discussed, *does not mention removal of ionic species (specifically targeted by the application described in this report)

**Table SI 1**: Results obtained from real samples after water wash and CNC-PEI treatment. CKN - chicken fat, T - beef tallow, WG - white grease. Control samples remained untreated and were analyzed to compare samples before and after removal.

| Sample | Source | | Na | K | Ca | Mg | Fe | P | S | Total (ppm) | Average Removal |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CKN | Control | 11.25 | 30.04 | 5.52 | 0.86 | 0.20 | 42.84 | 5.25 | 95.97 | 96.4% |
| | | CNC-PEI | 1.87 | 0.91 | 0.53 | 0.03 | 0.02 | 0.02 | 0.08 | 3.45 | |
| | | Reduction | 83.4% | 99.8% | 90.5% | 96.4% | 91.9% | 100.0% | 98.5% | | |
| 2 | CKN | Control | 92.51 | 20.65 | 29.39 | 2.56 | 1.98 | 20.10 | 1.94 | 169.12 | 91.9% |
| | | CNC-PEI | 8.13 | 1.30 | 3.03 | 0.06 | 0.04 | 0.88 | 0.24 | 13.68 | |
| | | Reduction | 91.2% | 98.9% | 89.7% | 97.5% | 98.1% | 97.6% | 87.5% | | |
| 3 | CKN | Control | 27.41 | 28.17 | 20.55 | 3.14 | 0.17 | 56.85 | 4.53 | 140.81 | 97.5% |
| | | CNC-PEI | 1.14 | 0.54 | 0.70 | 0.20 | 0.01 | 0.98 | 0.01 | 3.59 | |
| | | Reduction | 95.8% | 99.9% | 96.6% | 99.5% | 93.5% | 100.0% | 100.0% | | |
| 4 | CKN | Control | 78.33 | 28.80 | 64.96 | 4.93 | 0.35 | 73.59 | 4.93 | 255.89 | 97.7% |
| | | CNC-PEI | 1.12 | 0.06 | 4.51 | 0.07 | 0.02 | 0.08 | 0.08 | 5.94 | |
| | | Reduction | 98.6% | 99.8% | 93.1% | 98.6% | 95.3% | 99.9% | 98.4% | | |
| 5 | CKN | Control | 90.60 | 32.34 | 33.61 | 4.02 | 0.31 | 70.47 | 5.09 | 236.45 | 95.7% |
| | | CNC-PEI | 4.75 | 0.12 | 5.23 | 0.11 | 0.01 | 0.01 | 0.00 | 10.22 | |
| | | Reduction | 94.8% | 99.6% | 84.4% | 97.2% | 96.5% | 100.0% | 100.0% | | |
| 6 | CKN | Control | 89.18 | 24.61 | 9.59 | 1.17 | 0.30 | 24.58 | 3.23 | 152.67 | 92.2% |
| | | CNC-PEI | 11.59 | 0.01 | 0.10 | 0.01 | 0.02 | 0.10 | 0.08 | 11.90 | |
| | | Reduction | 87.0% | 100.0% | 99.0% | 99.3% | 94.4% | 100.0% | 97.5% | | |
| 7 | CKN | Control | 76.52 | 22.42 | 5.57 | 0.76 | 0.21 | 23.38 | 2.67 | 131.54 | 91.3% |
| | | CNC-PEI | 10.00 | 0.02 | 0.09 | 0.01 | 0.02 | 1.21 | 0.08 | 11.43 | |
| | | Reduction | 86.9% | 99.9% | 98.3% | 98.6% | 92.3% | 100.0% | 97.0% | | |
| 8 | CKN | Control | 143.74 | 59.73 | 34.12 | 4.01 | 0.29 | 115.87 | 11.56 | 369.32 | 92.7% |
| | | CNC-PEI | 24.79 | 0.04 | 0.08 | 0.01 | 0.01 | 2.13 | 0.08 | 27.14 | |
| | | Reduction | 82.8% | 99.9% | 99.8% | 99.9% | 98.1% | 100.0% | 99.3% | | |
| 9 | CKN | Control | 34.29 | 52.68 | 33.58 | 3.44 | 0.26 | 104.10 | 10.43 | 238.77 | 98.3% |
| | | CNC-PEI | 1.80 | 0.01 | 0.81 | 0.01 | 0.01 | 1.35 | 0.08 | 4.07 | |
| | | Reduction | 94.8% | 100.0% | 97.6% | 99.7% | 95.7% | 100.0% | 99.2% | | |
| 10 | CKN | Control | 63.35 | 60.61 | 34.38 | 4.07 | 0.29 | 116.51 | 11.64 | 290.87 | 95.1% |
| | | CNC-PEI | 10.43 | 1.60 | 0.06 | 0.01 | 0.01 | 1.97 | 0.09 | 14.17 | |
| | | Reduction | 83.5% | 97.4% | 99.8% | 99.8% | 96.6% | 98.3% | 99.2% | | |
| 11 | CKN | Control | 29.48 | 43.78 | 30.16 | 4.79 | 0.45 | 83.12 | 9.86 | 201.64 | 97.4% |
| | | CNC-PEI | 5.01 | 0.07 | 0.15 | 0.01 | 0.01 | 0.08 | 0.00 | 5.32 | |
| | | Reduction | 83.0% | 99.8% | 99.5% | 99.9% | 97.5% | 99.9% | 100.0% | | |
| 12 | CKN | Control | 32.37 | 44.50 | 22.58 | 3.32 | 0.27 | 83.12 | 9.70 | 195.86 | 95.4% |
| | | CNC-PEI | 4.63 | 0.82 | 0.33 | 0.91 | 0.01 | 1.35 | 1.02 | 9.07 | |
| | | Reduction | 85.7% | 98.2% | 98.5% | 72.6% | 96.3% | 98.4% | 89.5% | | |
| 13 | CKN | Control | 19.01 | 41.76 | 23.62 | 3.79 | 0.26 | 82.32 | 10.35 | 181.10 | 98.4% |
| | | CNC-PEI | 2.30 | 0.15 | 0.09 | 0.02 | 0.01 | 0.08 | 0.18 | 2.83 | |

| # | Type | | | | | | | | | Total | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Reduction | 97.5% | 99.6% | 99.6% | 99.4% | 95.7% | 99.9% | 100.0% | | |
| 14 | CKN | Control | 124.94 | 42.57 | 36.65 | 3.83 | 0.35 | 63.82 | 8.97 | 281.13 | 95.9% |
| | | CNC-PEI | 11.22 | 0.04 | 0.06 | 0.01 | 0.01 | 0.08 | 0.08 | 11.49 | |
| | | Reduction | 91.0% | 99.9% | 99.8% | 99.9% | 96.8% | 99.9% | 99.1% | | |
| 15 | CKN | Control | 35.89 | 23.20 | 13.01 | 2.05 | 0.30 | 39.40 | 5.42 | 119.27 | 94.7% |
| | | CNC-PEI | 5.79 | 0.19 | 0.09 | 0.01 | 0.02 | 0.08 | 0.11 | 6.29 | |
| | | Reduction | 83.9% | 99.2% | 99.3% | 99.6% | 94.5% | 99.8% | 100.0% | | |
| 16 | CKN | Control | 102.83 | 44.11 | 34.44 | 3.77 | 0.42 | 66.78 | 9.38 | 261.74 | 95.7% |
| | | CNC-PEI | 10.95 | 0.13 | 0.05 | 0.00 | 0.01 | 0.00 | 0.08 | 11.23 | |
| | | Reduction | 89.4% | 99.7% | 99.8% | 99.9% | 97.4% | 100.0% | 99.1% | | |
| 17 | CKN | Control | 125.11 | 50.95 | 32.34 | 5.16 | 0.42 | 77.99 | 11.16 | 303.13 | 95.5% |
| | | CNC-PEI | 11.86 | 0.51 | 0.05 | 0.00 | 0.01 | 1.20 | 0.00 | 13.63 | |
| | | Reduction | 90.5% | 99.0% | 99.8% | 99.9% | 98.7% | 98.5% | 100.0% | | |
| 18 | CKN | Control | 116.87 | 36.15 | 27.54 | 3.85 | 0.44 | 62.22 | 8.00 | 255.07 | 95.4% |
| | | CNC-PEI | 11.23 | 0.26 | 0.08 | 0.01 | 0.01 | 0.08 | 0.00 | 11.66 | |
| | | Reduction | 90.4% | 99.3% | 99.7% | 99.8% | 98.7% | 99.9% | 100.0% | | |
| 19 | CKN | Control | 101.68 | 32.23 | 19.23 | 2.41 | 0.29 | 53.57 | 6.55 | 215.97 | 95.6% |
| | | CNC-PEI | 9.13 | 0.20 | 0.06 | 0.00 | 0.01 | 0.08 | 0.08 | 9.56 | |
| | | Reduction | 91.0% | 99.4% | 99.7% | 99.8% | 96.2% | 99.9% | 98.8% | | |
| 20 | CKN | Control | 102.84 | 37.57 | 22.81 | 3.33 | 0.25 | 64.06 | 7.76 | 238.63 | 96.0% |
| | | CNC-PEI | 8.92 | 0.30 | 0.04 | 0.03 | 0.01 | 0.08 | 0.08 | 9.45 | |
| | | Reduction | 91.3% | 99.2% | 99.8% | 99.9% | 95.7% | 99.9% | 99.0% | | |
| 21 | T | Control | 79.37 | 8.71 | 14.31 | 1.89 | 0.65 | 14.97 | 1.46 | 121.34 | 92.2% |
| | | CNC-PEI | 9.00 | 0.25 | 0.09 | 0.01 | 0.01 | 0.08 | 0.08 | 9.53 | |
| | | Reduction | 88.7% | 97.1% | 99.4% | 99.5% | 98.3% | 99.5% | 94.4% | | |
| 22 | T | Control | 356.65 | 174.24 | 36.06 | 5.54 | 8.85 | 22.58 | 7.28 | 611.20 | 95.9% |
| | | CNC-PEI | 23.15 | 0.71 | 0.40 | 0.05 | 0.08 | 0.16 | 0.24 | 24.80 | |
| | | Reduction | 93.5% | 99.6% | 98.9% | 99.1% | 99.1% | 99.3% | 96.7% | | |
| 23 | T | Control | 820.94 | 18.04 | 82.98 | 5.14 | 7.07 | 44.28 | 3.07 | 981.52 | 97.5% |
| | | CNC-PEI | 23.15 | 0.71 | 0.40 | 0.05 | 0.08 | 0.16 | 0.24 | 24.80 | |
| | | Reduction | 97.2% | 96.1% | 99.5% | 99.0% | 98.9% | 99.6% | 92.1% | | |
| 24 | T | Control | 326.02 | 179.23 | 3.63 | 4.18 | 7.55 | 8.73 | 4.93 | 534.27 | 94.4% |
| | | CNC-PEI | 19.84 | 6.76 | 2.10 | 0.37 | 0.53 | 0.08 | 0.49 | 30.16 | |
| | | Reduction | 93.9% | 96.2% | 42.1% | 91.2% | 92.9% | 99.1% | 90.2% | | |
| 25 | WG | Control | 152.69 | 15.56 | 64.84 | 5.05 | 0.85 | 36.27 | 1.78 | 277.04 | 93.6% |
| | | CNC-PEI | 16.69 | 0.73 | 0.13 | 0.02 | 0.01 | 0.08 | 0.16 | 17.81 | |
| | | Reduction | 89.1% | 95.3% | 99.8% | 99.7% | 98.7% | 99.8% | 90.9% | | |
| 26 | WG | Control | 64.53 | 19.23 | 60.57 | 4.30 | 1.01 | 35.55 | 3.15 | 188.35 | 94.5% |
| | | CNC-PEI | 6.64 | 1.02 | 1.01 | 0.15 | 0.04 | 0.85 | 0.65 | 10.37 | |
| | | Reduction | 89.7% | 94.7% | 98.3% | 96.4% | 95.6% | 100.0% | 79.5% | | |
| 27 | WG | Control | 65.78 | 61.64 | 272.75 | 18.00 | 4.08 | 149.90 | 8.97 | 581.12 | 97.2% |
| | | CNC-PEI | 8.40 | 1.86 | 2.67 | 0.25 | 0.07 | 0.64 | 2.59 | 16.48 | |
| | | Reduction | 87.2% | 97.0% | 99.0% | 98.6% | 98.4% | 99.6% | 71.2% | | |
| 28 | T | Control | 65.12 | 64.81 | 180.50 | 15.21 | 8.68 | 133.09 | 9.22 | 476.62 | 95.2% |

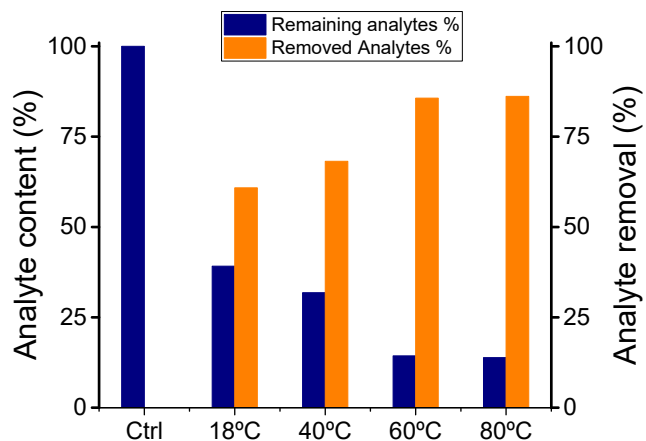| | CNC-PEI | 3.51 | 4.16 | 7.47 | 0.99 | 0.56 | 5.30 | 0.97 | 22.97 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Reduction | 94.6% | 93.6% | 95.9% | 93.5% | 93.5% | 96.0% | 89.5% | | |



Figure SI 1. Optimization of the extraction temperature. Sample volume 10 mL, 5 minutes water wash, 300 mg CNC-PEI, 10 minutes sorbent extraction, 2 minutes 9000 rpm centrifugation.
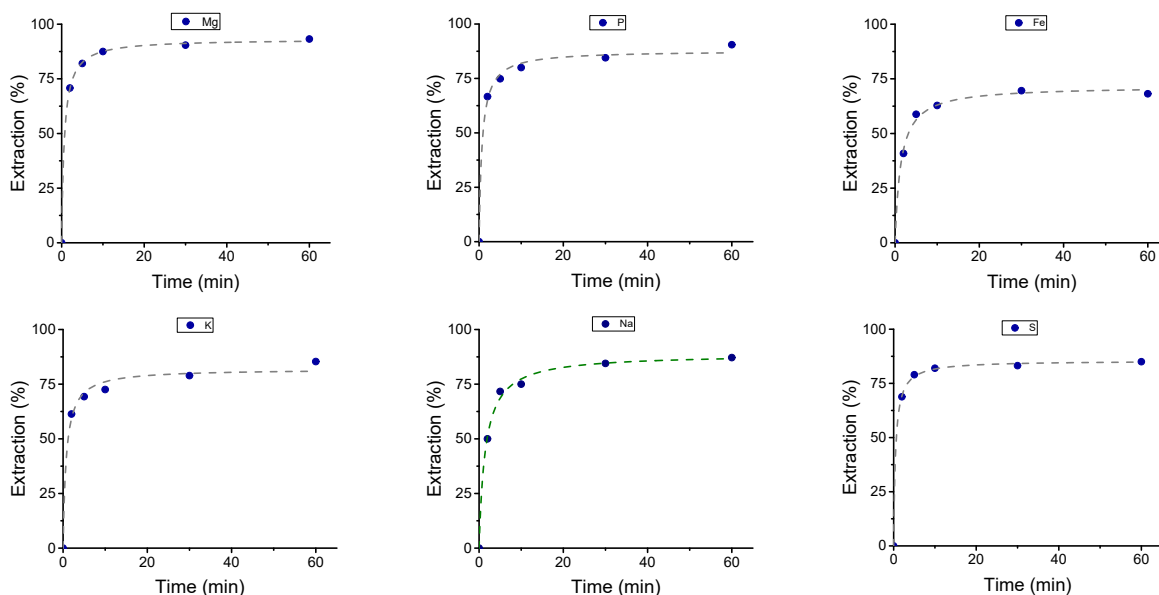


Figure SI 2. Extraction rates as a function of time. All the analytes were fitted using a pseudo-second-order kinetics. The response of all the extracted species showed similar behaviors.

**Table SI 2**: Summary of removal of various contaminants from fat using other extraction materials or techniques. n/d: not discussed, *does not mention removal of ionic species (specifically targeted by the

application described in this report)

| Source | Notes | Relevant contaminant | Efficiency | Ref. |
|---|---|---|---|---|
| Waste animal fats | Review* | Various | | [1] |
| Waste animal fats | Deep Eutectic Solvent* | Glycerol | > 95% | [2] |
| Biodiesel | Rinse w/$H_2SO_4$ or p-toluene sulfonic acid | Fatty acids | n/d | [3] |
| Rendered pork | $H_2SO_4$ wash* | Fatty acids | 83% | [4] |
| Sunflower oil | $Na_2CO_3$ / $H_2O$ wash | Ca and Na | > 95% | [5] |
| Highly-degraded base fat | Vacuum distillation | Fatty acids | < 96% | [6] |
| | | Ca, Mg, Na | > 99% | |
| | | K | 90% | |
| Crude biodiesel | Review | Ca | 50 – 90% | [7] |
| | | Na and K | n/d | |
| Biodiesel from waste animal fats | Neutralization/water wash/dry<br><br>Cationic resins | Na and K | n/d<br>(only final values reported) | [8] |
| Vegetable and motor Oils | Deep Eutectic Solvent Extraction | Ag, Al, B, Ba, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sn, Ti, V and Zn | 35 – 99% | [9] |
| Aqueous food industry waste | Soybean oil residues used as adsorbents | Cd, Zn and Pb | 30 – 90% | [10] |
| Spiked Soybean Oil | Hollow fiber membrane | Cu, Fe, Mn | 95% | [11] |
| Waste animal fats, waste cooking oil | Bentonite adsorbents<br><br>Deep Eutectic Solvents | Na, K, Ca, Mg, P, B, Fe | 80 – 93% | [12] |
| Vegetable oils and animal fats | Acid treatment/Clay | P, Na, K, Ca, Mg, Cu, ZN, Mn and Fe | >98% (from 50-800 ppm to < 1ppm) | [13] |

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