Squeezing more than just orange juice: Citrus peel valorisation

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Harvesting → Food Manufacturing → Consumer

UFSCW

Waste to Energy, Anaerobic Digestion, Composting, Animal Feed and bedding, mulch, tilling

Current practices

SYSTEMS CHANGE APPROACH TO UFSCW

Understanding, development and application of key enabling technologies and new processes

Logistics and LCA

Waste Flow Modelling Tool

Extraction and isolation of high value functional compounds and materials

Application as Novel functional food ingredients

Opportunities for Novel non-food applications

By-products

Whole systems understanding of unavoidable food supply chain waste for re-nutrition EP/P008771/1
Upgrading unavoidable food supply chain wastes

“it’s a no brainer”

“please respect the intelligence of the entire supply chain”

Business, social and environmental case for upgrading
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33.2 million T/y

50%

16.6 million T/y

citrus peel waste

CELLULOSE NANOMATERIALS

NANO-OBJECTS

NANO-STRUCTURED

CNC/NCC
W = 3-10 nm
L/W = 5-50

CNF/NFC
W = 5-30 nm
L/W >50

MCC/CMC
W = 10-15 μm
L/W <2

CMF
W = 10-100 nm
L = 0.5-10 μm
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Essential oil (oranges)

- CPOO
- D-limonene

$4/kg

2018/19
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Choose your feedstock carefully!

International Trade Centre – Conventional Prices (Jan 2015).
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Global Pectin sales and Growth (2011-2016E)

High methoxyl (HM) pectin
Global Pectin Price ($/MT) 2011-2016E

Average Price
$18/kg
2018/9
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…..and there’s (nano)cellulosic residues

**PASSIVE**

- Secondary wall
- Primary wall
- Cellulose
- Hemicellulose
- Lignin

**ACTIVE**

- Microfibrils
- Fibril
- Amorphous regions
- Elementary fibril

**Defibrillation**

**CNF**:
- L<2um
- D<100nm

**CNC**:
- L<0.5um
- D=3-70nm
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MFC and NFC Market size (tons)

Average Price
$6/kg
2018/9
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- 50% waste
- 16.6 million T/y citrus peel waste

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**Integrated microwave waste biorefinery**

- Scalable
- Flexible
- Allows continuous processing
- Allows the use of wet feedstock – no drying step is necessary
- No necessary pre-treatment
- No acid used

**Easier/more efficient extraction of marketable chemicals generated by a single industry in-situ**

- Orange peel residue 1 → Soxhlet ethanol extraction → Flavonoids 6.13%
- Orange peel residue 2 → MW treatment 100-130 °C → Pectin 5.95%
- Wet WOP → MW assisted steam distillation 800-1200 W → D-limonene 1.09%
- Nanostructured celluloses
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**Essential oil (%) - dry basis**

<table>
<thead>
<tr>
<th>Fruit Type</th>
<th>Essential Oil (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oranges (v. Navel Navelate)</td>
<td>1.8</td>
</tr>
<tr>
<td>Oranges (v. Midknight)</td>
<td>1.4</td>
</tr>
<tr>
<td>Oranges (v. Valencia Late)</td>
<td>2.3</td>
</tr>
<tr>
<td>Lemons (v. Verna)</td>
<td>1.7</td>
</tr>
<tr>
<td>Limes (v. Persian)</td>
<td>2.2</td>
</tr>
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<td>Satsumas (v. Nihowase)</td>
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![Graph showing the yield of Pectin from different sources: South Africa, Spain Non-Waxed, Spain Waxed, Limes, and Lemons. The graph indicates the percentage of wet WOP yield for each category.](image-url)
Systems Change Thinking
Upgrading unavoidable food supply Chain Wastes: Citrus wastes
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HOW? Modified pyrolysis MW rig (Just for pectin – acid-free)

20 L scale MW rig (6 kW) able to withstand slurries, work in a semi-continuous up to 95°C and with a flow rate up to 200 L min\(^{-1}\)

Macerated orange peel & water mixture pumped through the rig
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- Process scale-up for limonene and pectin

Patented 30 L scale pressurised microwave rig
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ACID-FREE PROCESS!

Orange Peel Waste (OPW)

- Acid Depectination
- Microwave-Assisted Depectination

Orange Peel Residue (OPR)

Mesoporous Nanocellulose (MNC)

5% 10% 50%
Hy-MASS: Hydrothermal Microwave Assisted Selective Scissoring

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Hydrogels

Before stirring

HG-1  HG-2  HG-3  HG-4  HG-5  HG-6

120°C

HG-1  HG-2  HG-3  HG-4  HG-5  HG-6

220°C

After stirring (30 min.)

HG-1  HG-2  HG-3  HG-4  HG-5  HG-6

After 2 months

Gel formation kinetics

fast

After stirring (30 min.)

slow
SEM of Hydrogels

HG-1 120°C

HG-2 140°C

HG-3 160°C

HG-4 180°C

HG-5 200°C

HG-6 220°C
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Thank you and Acknowledgements

EPSRC Whole systems understanding of unavoidable food supply chain wastes for re-nutrition EP/P008771/1