STABILIZING FOOD WASTE
ANAEROBIC DIGESTION

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What is Food Waste?

“Mass of food lost or wasted in the part of food supply chains leading to edible products for human consumption”

1/3 of the food produced worldwide

Main contributor of OFMSW

FAO (2012), Gustavsson et al. (2011), Melikoglu et al. (2013), UN (2011)
What is Food Waste?

- “Mass of food lost or wasted in the part of food supply chains leading to edible products for human consumption”
- 1/3 of the food produced worldwide
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What is Food Waste?

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• 1/3 of the food produced worldwide

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EU directive (2008/98/CE)
Valorization through soil return mandatory

Composting

Anaerobic digestion (AD)

FAO (2012), Gustavsson et al. (2011), Melikoglu et al. (2013), UN (2011)
Several studies with FW as substrate for methane and/or hydrogen production

Biochemical methane potentials (BMPs): 300-600 ml CH$_4$·g VS$^{-1}$

<table>
<thead>
<tr>
<th>Country</th>
<th>TS (% w/w)</th>
<th>VS (% TS)</th>
<th>Carbohydrates (%)</th>
<th>Protein (%)</th>
<th>Lipids (%)</th>
<th>C/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>UK</td>
<td>23.7</td>
<td>91.4</td>
<td>41.4</td>
<td>15.1</td>
<td>23.5</td>
<td>13.9</td>
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<tr>
<td>Italy</td>
<td>27.5</td>
<td>86.6</td>
<td>~56.4</td>
<td>16.1</td>
<td>17.5</td>
<td>18.3</td>
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<tr>
<td>France</td>
<td>21.0</td>
<td>90.3</td>
<td>61.8</td>
<td>19.8</td>
<td>12.1</td>
<td>16.1</td>
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FW characteristics and AD

Common FW characteristics

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- Several studies with FW as substrate for methane and/or hydrogen production
- Biochemical methane potentials (BMPs): 300-600 ml CH₄·g VS⁻¹
Challenges in FW AD

Fast degradation
Main challenge in **batch** reactors: initial accumulation of VFAs and **acidification**

- Organic matter
- VFAs
- Inhibition methanogenic **archaea**
- VFA accumulation
- pH drop

High protein content
Main challenge in **long-term** operation: accumulation of NH₃ and **inhibition**

- Organic nitrogen
- NH₃
Stabilizing FW AD

Mono-digestion

- Unstable operation ("inhibited steady state")
- Failure even at low OLRs

- Addition of water as industrial solution: environmental and economical constraints

- Supplementation of trace elements (TEs)

Banks et al. (2012), Capson-Tojo et al. (2016), Nagao et al. (2012), Qiang et al. (2012)
Required for the synthesis of enzymes

Improved methane production rates and VFA degradation kinetics

Higher OLRs achieved

**TEs in Commercial FW used**

<table>
<thead>
<tr>
<th>Compound</th>
<th>Concentration (mg·kg TS⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe</td>
<td>1,114</td>
</tr>
<tr>
<td>Co</td>
<td>non-detected</td>
</tr>
<tr>
<td>Cu</td>
<td>11.2</td>
</tr>
<tr>
<td>Mn</td>
<td>27.6</td>
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<tr>
<td>Mo</td>
<td>1.26</td>
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<tr>
<td>Zn</td>
<td>38.4</td>
</tr>
<tr>
<td>Ni</td>
<td>1.19</td>
</tr>
<tr>
<td>Se</td>
<td>?</td>
</tr>
</tbody>
</table>

Lack of TEs?

Objectives: comparison stabilization options

Avoid initial VFA peak: compare 3 strategies for stabilizing FW AD

Working at low temperatures (30 °C)

NH₃ + H⁺ ↔ NH₄⁺

Co-digestion with paper waste (PW)
- C/N, inhibitors dilution, buffering capacity, slower biodegradation

VS.

Addition of trace elements (TEs)
- Enzyme synthesis

VS.

Consecutive batch reactor at increasing substrate loads
- Process applicable at industrial scale
- Simulation a plug-flow reactor with digestate recirculation
Material and Methods

Research strategy

- Four mixed pilot reactors
- Working volumes 7.5-20 l
- Mesophilic operation (37 °C)
- Commercial FW from GN

fast food
restaurant
supermarket fruit & vegetable
supermarket
fruit & vegetable
distributor
Material and Methods

Research strategy
- Four mixed pilot reactors
- Working volumes 7.5-20 l
- Mesophilic operation (37 °C)
- Commercial FW from GN

Specific conditions
- Control: fed with FW
- T30: temperature of 30 °C
- Co-PW: fed with FW and PW (3:1 w/w)
- Sup-TEs: doped with TE

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<tr>
<th>Compound</th>
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<tr>
<td>Fe</td>
<td>100</td>
</tr>
<tr>
<td>Co</td>
<td>1.0</td>
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<tr>
<td>Cu</td>
<td>0.1</td>
</tr>
<tr>
<td>Mn</td>
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</tr>
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<td>Mo</td>
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</tr>
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Material and Methods

**Research strategy**
- Four mixed pilot reactors
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**Specific conditions**
- **Control**: fed with FW
- **T30**: temperature of 30 °C
- **Co-PW**: fed with FW and PW (3:1 w/w)
- **Sup-TEs**: doped with TEs

**Feeding strategy**
- **1st load**: 0.087 kg FW·kg\textsubscript{inoculum}\textsuperscript{-1} (S/X 0.25 g VS·g VS\textsuperscript{-1})
- **2nd load**: 0.173 kg FW·kg\textsubscript{inoculum}\textsuperscript{-1}
- **3rd load**: 0.260 kg FW·kg\textsubscript{inoculum}\textsuperscript{-1}
- Twice each load
- Reactors fed if **biogas plateau** or **500 ml CH\textsubscript{4}·g VS\textsuperscript{-1}** reached
Control

Continuous accumulation of propionic acid

Gradual decrease of methane production rate & longer lag phase

Methane Yield

Propionate

TAN (NH₃ + NH₄⁺)
Control VS. T30

Continuous accumulation of propionic acid
Gradual decrease of methane production rate & longer lag phase

T30: slower kinetics and longer lag phase
Built-up of propionic acid
### Control VS. Co-PW

<table>
<thead>
<tr>
<th></th>
<th>Time (d)</th>
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<tr>
<td>Control</td>
<td>0.087</td>
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<td>0.173</td>
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#### Co-PW

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- **Continuous accumulation of propionic acid**
- **Gradual decrease of methane production rate & longer lag phase**
- **Co-PW: lower yields**
- **Higher accumulation of propionic acid (over 20 g·l⁻¹)**

\[(\text{NH}_3 + \text{NH}_4^+)\]
## Methane Yield

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<tr>
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<tr>
<td>Methane yield</td>
<td>0.087</td>
<td>0.173</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>0.173</td>
<td>0.173</td>
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<tr>
<td>TAN</td>
<td>0.173</td>
<td>0.260</td>
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- **Continuous accumulation of propionic acid**
- **Gradual decrease of methane production rate & longer lag phase**
- **Sup-TEs**: faster kinetics but still propionic acid
- **Inhibition at 0.260 kg FW·kg<sub>inoculum</sub>⁻¹**

\[(\text{NH}_3 + \text{NH}_4^+)\]

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**INRA**

**SUEZ**
Conclusions

- **Propionic acid** accumulation => key issue for FW AD
- Acidification at high loads
- Low temperature and co-digestion with PW: discarded
- **TEs** addition: improved kinetics and higher substrate loads (but still propionic acid accumulation)

**Operational implications**

- Batch mode might not be the best option
- **Methane production** cannot be used as sole criteria for reactor feeding

**Research challenges**

- Favor consumption of: propionic acid and/or HAc and/or H₂
Thank you for your kind attention
1st batch: GAC and TEs

- Similar methane yields and COD conversions
- Lag phases in methane production + GAC
- Shorter lags
- Stability up!
- Improvement due to favored HAc consumption
- Propionic acid consumption not improved...