Organic kitchen food waste valorization applying the biorefinery concept in the Colombian context

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1. Introduction

**Municipal Solid Waste (MSW)**

The quantity and composition of MSW depend on the socio-economic and cultural context analyzed.

Overall average generation of waste per person is very high [1]. The MSW generation is increasing worldwide [2].

Some predictions calculate an increase to **3.4 billion tons by 2050** [3].

**Industrial and Agri-industrial Solid Waste (AgR)**

The generation of AgR can cover an average of **30-50% by weight of the raw material** used.

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**Citrus supply chain**

Orange crop

- **FOOD LOSSES**
  - Sheets
  - Stems
  - Flowers

- **60% national production**

Sale for immediate consumption

- **FOOD LOSS**
  - Orange peel
  - 40-50% of the fruit

Agro-industrial processing

- **40% national production**
1. Introduction

Figure 1. General steps of Supply Chain

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1. Introduction

Agricultural or Farming Production
Post-harvest, Handling, Slaughter and Storage
Process distribution and Transportation
Products for immediate consumption
Processing and Packaging
Distribution
Manufacturing and Packaging
Consumption

FOOD WASTE: organic kitchen food waste

Biological resources. Negative impacts on sustainable development: for example the use of crops for food products

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1. Introduction

Global impacts of residues generation

**Economic impact**

The economic impact is defined as the combined costs incurred to produce, deliver, and dispose of residues.

Impact estimates vary significantly by method, waste type, region, scale, and stage.

**Social impact**

The social impact is directly and indirectly, related to social welfare, human health, and employment.

**Environmental impact**

The FAO estimates that the generation of residues represents 8% of global GHG emissions [4]. This is primarily due to the residues elimination pathways. Various environmental impacts on soil and water are also presented.

The FAO estimated a total economic cost of USD 1055 billion, an environmental cost of USD 696 billion and a social cost of USD 882 billion [4].
This work was focused on determining the prefeasibility in technical and economic terms of the most promising alternatives for using food waste generated in Colombia.

Factors to consider:
- Productive chain
- Scale of raw material
- Technological context
- Type of products to obtain

Sustainability of the food supply chain

Factors to consider:
- Economic impact
- Environmental impact
- Social impact

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3. Methodology

Organic Kitchen Food Waste in Colombia

National studies of food waste generated in Colombia were based on the seven food groups proposed by the FAO

<table>
<thead>
<tr>
<th>Input</th>
<th>The share lost in food supply chain</th>
<th>Flow generated in Colombia (ton/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish</td>
<td>3</td>
<td>0.5</td>
</tr>
<tr>
<td>Meat</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Cereals</td>
<td>19</td>
<td>8</td>
</tr>
<tr>
<td>Roots and tubers</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Fruits and vegetables</td>
<td>44</td>
<td>62</td>
</tr>
<tr>
<td>Dairy</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Oilseeds and legumes</td>
<td>8</td>
<td>2</td>
</tr>
</tbody>
</table>

The most representative food of each group was selected according to national consumption statistics.

Scenario 1
Biogas and Fertilizer production by Anaerobic Digestion

Scenario 2
Ethanol production by Fermentation (Saccharomyces cerevisiae)

Scenario 3
Ethanol production and Biogas and Fertilizer production by Fermentation and Anaerobic Digestion
3. Methodology

**Organic Kitchen Food Waste brutto composition Model for Colombia**

<table>
<thead>
<tr>
<th>Input</th>
<th>The most representative product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fish and eggs</td>
<td>(80%) Eggs peel</td>
</tr>
<tr>
<td>Meat</td>
<td>(45%) Chicken bone</td>
</tr>
<tr>
<td>Cereals</td>
<td>(5%) Meat waste</td>
</tr>
<tr>
<td>Roots and tubers</td>
<td>(30%) Cassava peel</td>
</tr>
<tr>
<td>Fruits and vegetables</td>
<td>(10%) Carrot peel</td>
</tr>
<tr>
<td>Dairy</td>
<td>(16%) Onion peel</td>
</tr>
<tr>
<td>Oilseeds and legumes</td>
<td>(10%) Bean residues</td>
</tr>
<tr>
<td></td>
<td>(3%) Cabbage residues</td>
</tr>
<tr>
<td></td>
<td>(5%) Mango peel and seed</td>
</tr>
<tr>
<td></td>
<td>(1%) Pumpkin peel</td>
</tr>
<tr>
<td></td>
<td>(5%) Guava Pulp</td>
</tr>
<tr>
<td></td>
<td>(1%) Strawberry Pulp</td>
</tr>
<tr>
<td></td>
<td>(5%) Guava Pulp</td>
</tr>
<tr>
<td></td>
<td>(1%) Celery residues</td>
</tr>
<tr>
<td></td>
<td>(2%) Lulo peel and Pulp</td>
</tr>
<tr>
<td></td>
<td>(2%) Apple residues</td>
</tr>
<tr>
<td></td>
<td>(1%) Beetroot peel</td>
</tr>
<tr>
<td></td>
<td>(1%) Celery residues</td>
</tr>
<tr>
<td></td>
<td>(1%) Celery residues</td>
</tr>
<tr>
<td></td>
<td>(1%) Celery residues</td>
</tr>
</tbody>
</table>

*Table 2. Composition model of Organic Kitchen Food Waste*
3. Methodology

Experimental work

- Chemical characterization

<table>
<thead>
<tr>
<th>Compound</th>
<th>Method</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extractives</td>
<td>NREL/TP-510-42619</td>
<td>[7]</td>
</tr>
<tr>
<td>Holocellulose</td>
<td>Han, J.S., Rowell, J.S.: Chemical Composition of Fibers</td>
<td>[8]</td>
</tr>
<tr>
<td>Cellulose</td>
<td>TAPPI T203</td>
<td>[9]</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>Subtraction between the holocellulose and cellulose</td>
<td></td>
</tr>
<tr>
<td>Acid insoluble</td>
<td>TAPPI T222</td>
<td>[10]</td>
</tr>
<tr>
<td>lignin</td>
<td>Yu et al. (1996)</td>
<td>[11]</td>
</tr>
<tr>
<td>Total pectin</td>
<td>Rivas et al. (2008)</td>
<td>[12]</td>
</tr>
<tr>
<td>Fat</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>ASTM E871-82</td>
<td>[13]</td>
</tr>
<tr>
<td>Moisture</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. The methods used for chemical characterization of raw material

- Fermentable sugar production

Enzymatic hydrolysis with cellulases, glucoamylases and pectinases enzymes

Reducing sugar concentration was analyzed with DNS (3,5-Dinitrosalicylic acid) method
3. Methodology

Simulated and evaluated processes

Organic Kitchen Food Waste Valorization

Conceptual Design

- Technical and Energy
  - Yield
  - Power requirement
  - Thermal energy consumption

- Economic
  - CapEx
  - OpEx
  - Production cost/Selling Price ratio

Tools

- Aspen plus and Aspen Energy Analyzer
- Aspen Process Economic Analyzer

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4. Results

Chemical characterization of Organic Kitchen Food Waste

Table 4. The methods used for chemical characterization of raw material

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>81.9</td>
<td>75.9</td>
<td>80.3</td>
<td>N.R.</td>
<td>75.2</td>
<td>78.4</td>
</tr>
<tr>
<td>Total sugar</td>
<td>48.3</td>
<td>42.3</td>
<td>59.8</td>
<td>56.2</td>
<td>50.2</td>
<td>36.5</td>
</tr>
<tr>
<td>Starch</td>
<td>42.3</td>
<td>7.06</td>
<td>N.R.</td>
<td>N.R.</td>
<td>46.1</td>
<td>16.1</td>
</tr>
<tr>
<td>Cellulose</td>
<td>N.R.</td>
<td>N.R.</td>
<td>N.R.</td>
<td>46.3</td>
<td>N.R.</td>
<td>23.8</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>N.R.</td>
<td>10.26</td>
<td>N.R.</td>
<td>36.5</td>
<td>N.R.</td>
<td>12.6</td>
</tr>
<tr>
<td>Lignin</td>
<td>N.R.</td>
<td>N.R.</td>
<td>0.8</td>
<td>N.R.</td>
<td>N.R.</td>
<td>2.4</td>
</tr>
<tr>
<td>Fats</td>
<td>N.R.</td>
<td>3.10</td>
<td>15.7</td>
<td>15.6</td>
<td>18.1</td>
<td>3.9</td>
</tr>
<tr>
<td>Protein</td>
<td>17.8</td>
<td>3.9</td>
<td>21.8</td>
<td>N.R.</td>
<td>15.6</td>
<td>2.4</td>
</tr>
<tr>
<td>Pectin</td>
<td>N.R.</td>
<td>N.R.</td>
<td>N.R.</td>
<td>4.3</td>
<td>N.R.</td>
<td>1.1</td>
</tr>
<tr>
<td>Ash</td>
<td>N.R.</td>
<td>1.25</td>
<td>1.9</td>
<td>1.9</td>
<td>2.3</td>
<td>1.2</td>
</tr>
</tbody>
</table>

The production of fermentable sugars from the enzymatic hydrolysis of OKW was between 80 - 115 g/L. These results are similar to those reported in previous studies.
4. Results

Technical and energy analysis

Table 5. Mass and energy indicators

<table>
<thead>
<tr>
<th>Input</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product yield</td>
<td>Biogas: 1.105 m³/kg of raw material</td>
<td>Ethanol: 0.024 kg/kg of raw material</td>
<td>Ethanol: 0.024 kg/kg of raw material</td>
</tr>
<tr>
<td></td>
<td>Methane: 0.638 m³/kg of raw material</td>
<td>Concentration fermentable sugars: 100 g/L</td>
<td>Concentration fermentable sugars: 100 g/L</td>
</tr>
<tr>
<td>Power requirement</td>
<td>1.372 kWh/ton of raw material</td>
<td>3.561 kWh/ton of raw material</td>
<td>4.713 kWh/ton of raw material</td>
</tr>
<tr>
<td>Thermal energy consumption</td>
<td>Medium Pressure Steam: 0.645 MJ/kg of raw material</td>
<td>Medium Pressure Steam: 1.852 MJ/kg of raw material</td>
<td>Medium Pressure Steam: 2.842 MJ/kg of raw material</td>
</tr>
<tr>
<td></td>
<td>High Pressure Steam: 38.013 MJ/kg of raw material</td>
<td>High Pressure Steam: 38.013 MJ/kg of raw material</td>
<td>High Pressure Steam: 38.013 MJ/kg of raw material</td>
</tr>
<tr>
<td></td>
<td>Cooling water: 13.014 MJ/kg of raw material</td>
<td>Cooling water: 13.014 MJ/kg of raw material</td>
<td>Cooling water: 13.014 MJ/kg of raw material</td>
</tr>
</tbody>
</table>
4. Results

Economic analysis

Figure 2. OKFW valorization in Scenario 1 (Biogas)

Figure 3. OKFW valorization in Scenario 2 (Bioethanol).

Figure 4. OKFW valorization in Scenario 3 (Bioethanol + Biogas).

Processing scale: 36.5 t/d
5. Conclusions

- The Organic Kitchen Food Waste is a potential raw material to be upgraded applying the biorefinery concept since this raw material has the potential to provide a series of different platforms (e.g., sugars).

- The integration of ethanol production with biogas and fertilizer makes possible the valorization of Organic Kitchen Food Waste in economic terms.

- In addition, the compositional model can be applied in any other context considering the socioeconomic conditions.
6. Acknowledgments

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Thank you for your attention