Food Residues Biorefineries: Design strategy based on multifeedstocks analysis

Carlos Ariel Cardona Alzate, Mariana Ortiz-Sanchez, Juan Camilo Solarte-Toro

1Instituto de Biotecnología y Agroindustria, Departamento de Ingeniería Química, Universidad Nacional de Colombia, Manizales, Caldas, Zip Code: 170003, Colombia.
Content

1. Introduction
2. Research objective
3. Methodology
4. Results
5. Conclusions
6. Acknowledgments
7. References
1. Introduction

No Renewable Resources

Traditional linear economy scheme - Oil-based economy.

Alternative for improving the efficiency and sustainability of different types of productive chains:

Renewable Resources

Supply Chain

- Harvest / Slaughter
- On-farm, Post-Harvest / Slaughter operations
- Transport Storage Distribution
- Processing and Packaging
- Retail
- Public and Household consumption

Biomass

- Agricultural Biomass and Residues
- Forestry biomass and Residues
- Lignocellulosic biomass and Residues
- Agroindustrial Residues
- Municipal Solid Waste

Food products

Organic solid waste

Heat and power (Bioenergy)

Pharmaceutical and natural products

Global Warming
Ozone depletion
Natural resources pollution
Acid precipitation
Oil spills
1. Introduction

![Stages of the Food Supply Chain](image)

**Figure 1.** Residues classification generated in the stages of the supply chain

- **Agronomic loss**
- **Agroindustrial loss**
- **Organic kitchen food waste**
- **Organic retail food waste**

**Standard residues**

**Non standard residues**
1. Introduction

Relation between biomass conversion, responsible consumption and production with other SDGs

Sustainability development models:
- Bioeconomy
- Circular Economy
- Linear Economy

Reducing Environmental Impacts
- SDG 1: No Poverty
- SDG 7: Affordable and clean energy
- SDG 8: Decent work and economic growth
- SDG 9: Industry, innovation and infrastructure
- SDG 10: Reduced inequalities
- SDG 11: Sustainable cities and communities
- SDG 13: Climate action
- SDG 14: Life below water
- SDG 15: Life on land

BioProducts PORTFOLIO

Food residues

Biomass conversion
2. Research objective

This work focuses on proposing a new strategy for defining the best technological configurations using concepts of composition of the feedstocks (including the multifeedstocks), platforms and products for Food Residues Biorefineries.
3. Methodology

Biorefinery design strategy for biomass valorization

Analysis of the routes for biomass processing towards sustainable development in the conceptual design step: Strategy based on the compendium of bioprocesses portfolio

Marina Ortiz-Sanchez, Carlos Ariel Cardona Alzate

Institute of Biotechnology and Agronomy, Department of Agricultural Sciences, National University of Colombia, Manizales, Colombia

LIMITING FACTORS

- The technological context of the analyzed region;
- The type of products to be obtained based on the context;
- The economic viability of the products based on the generation scale;
- What type of benefit (economic, environmental, and/or social) is targeted to be achieved in the productive chain.
3. Methodology

Bioprocesses portfolio

Figure 2. Bioprocesses addressed to upgrade each fraction of biomass
3. Methodology

Bioprocesses portfolio

Figure 3. Bioprocess and TRL relation (a) cellulose; (b); hemicellulose and lignin (c); extractives and fats (d); pectin and starch (e) all fractions raw material
3. Methodology

Cellulose fraction

<table>
<thead>
<tr>
<th>BioProcess</th>
<th>Platform</th>
<th>BioProcess</th>
<th>Yield (ton of product/Ton raw material fraction)</th>
<th>Carbon conversion efficiency (%)</th>
<th>Power requirement (kWh/Ton raw material fraction)</th>
<th>Thermal energy consumption (MWh/kg raw material fraction)</th>
<th>CapEx* (MUSD)</th>
<th>OpEx* (MUSD)</th>
<th>Production cost/Selling price ratio</th>
<th>Climate change (kg CO2 eq/Product)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalytic glucose production from CELULOSE</td>
<td>Glucose platform - Catalytic</td>
<td>BioP-Pt1</td>
<td>0.41</td>
<td>37.05</td>
<td>0.72</td>
<td>2.40 (H:80.5%, C: 19.5%)</td>
<td>a: 0.23</td>
<td>b: 0.09</td>
<td>30.5</td>
<td>0.48</td>
</tr>
<tr>
<td>Enzymatic hydrolysis from CELULOSE</td>
<td>Glucose platform - Enzymes</td>
<td>BioP-Pt2</td>
<td>0.80</td>
<td>92.60</td>
<td>1.80</td>
<td>0.73 (L:100%)</td>
<td>a: 1.42</td>
<td>b: 0.53</td>
<td>0.21</td>
<td>0.28</td>
</tr>
<tr>
<td>Fermentation - Saccharomyces cerevisiae, Distillation</td>
<td>Ethanol</td>
<td>BioP-C1</td>
<td>0.30</td>
<td>46.20</td>
<td>4.00</td>
<td>61.90 (M: 1%, L: 76%, C: 23%)</td>
<td>a: 1.82</td>
<td>b: 0.67</td>
<td>1.00</td>
<td>1.38</td>
</tr>
<tr>
<td>Fermentation - Clostridium acetobutylicum, Distillation</td>
<td>ABE</td>
<td>BioP-C2</td>
<td>0.25</td>
<td>40.51</td>
<td>1.50</td>
<td>0.07 (M: 98.2, C:1.8)</td>
<td>a: 0.26</td>
<td>b: 0.59</td>
<td>2.41</td>
<td>2.41</td>
</tr>
<tr>
<td>Fermentation - Lactobacillus casei, Distillation</td>
<td>Lactic acid</td>
<td>BioP-C3</td>
<td>0.66</td>
<td>65.75</td>
<td>3.10</td>
<td>44.30 (M: 1.3%, L: 9%, C: 89.7%)</td>
<td>a: 1.44</td>
<td>b: 0.53</td>
<td>3.11</td>
<td>3.16</td>
</tr>
<tr>
<td>Catalytic upgrading - Distillation</td>
<td>Levulinic acid</td>
<td>BioP-C4</td>
<td>0.56</td>
<td>72.75</td>
<td>8.8</td>
<td>31.00 (H: 63%, M: 24%, C: 13%)</td>
<td>a: 1.53</td>
<td>b: 0.57</td>
<td>0.20</td>
<td>2.89</td>
</tr>
<tr>
<td>Fermentation - Bacillus megaterium</td>
<td>PHB</td>
<td>BioP-C5</td>
<td>0.23</td>
<td>32.11</td>
<td>8.86</td>
<td>24.87 (L: 95%, C: 5%)</td>
<td>a: 3.69</td>
<td>b: 1.36</td>
<td>0.79</td>
<td>1.45</td>
</tr>
<tr>
<td>Fermentation - Aspergillus Terreus</td>
<td>Itaconic acid</td>
<td>BioP-C6</td>
<td>0.52</td>
<td>60.30</td>
<td>11.83</td>
<td>75.38 (L: 96%, C: 4%)</td>
<td>a: 2.19</td>
<td>b: 0.81</td>
<td>1.96</td>
<td>1.12</td>
</tr>
<tr>
<td>Catalytic upgrading - Distillation</td>
<td>Polylactic acid</td>
<td>BioP-C7</td>
<td>1.95</td>
<td>N.A.</td>
<td>17.17</td>
<td>0.1 (L:100%)</td>
<td>a: 0.16</td>
<td>b: 0.36</td>
<td>35.5</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Table 1. Mass, energy, economic and environmental indicators

Figure 4. Mass, energy, economic and environmental indicators of cellulose bioprocesses
3. Methodology

Strategy based on portfolio of BioProcesses according to Food residues valorization:

Value chain
- Identifying the stages and actors corresponding to the first three stages of the value chain

The characterization of the FR generated
- (i) Generation place; (ii) Total generation volume: generation cycle, quantity, status; (iii) Chemical composition; (iv) Current use

The possible forms of integration
- Food loss integration;
- Food waste integration:
- Food loss and Food Waste integration.

MULTIFEEDSTOCKS are just 2 or more feedstocks to be considered in terms of compositions to be summed strategically

Food residues conversion routes easier to implement

Strategy of biomass valorization
- Portfolio of bioprocess

The needs of the stages and actors
- Contextualizes the possible FR valorization routes with the needs of the value chain
3. Methodology

Example: Orange Peel Wastes (Food Loss)

The current market in Colombia

![Image showing Orange crop, industrial processing, juice and pulp, leaves, branches, flowers, and orange peel waste]

Chemical composition:
- Polyphenolic compounds
- Pectin
- Cellulose and hemicellulose
- Protein
- Fats

The bioprocesses were filtered from the Technological Readiness Level (TRL implemented) and the lowest values of operating costs (OpEx) and capital cost (CapEx).

- OPW generated in a small-scale industry with a flow of 140 kg/h was considered.
- The value chain identification includes the stages of producers (crop) and processors (agribusiness).
- Agricultural residues such as leaves, branches, and flowers are generated in the producer stage (2 and 2.8 tons per hectare per year).
- These residues are disposed of in the field.
4. Results

Application of the strategy:

**Step 1**
Define the sustainable objective according to the factors that impact the valorization of biomass

The objective of valorization was to increment the economic impact of the use of FL

**Step 2**
Select the BioProcesses according to the type of Biomass fractions using TRL

**Extractives:** Bioactive compounds by agitated solvent extraction and supercritical fluid extraction.

**Cellulose:** Glucose by catalytic process and enzymatic hydrolysis, Ethanol, ABE; Lactic acid, Levulinic acid; Polylactic acid

**Hemicellulose:** Xylose production by acid hydrolysis, Furfural, Xylitol and Pentane

**Pectin:** Pectin extraction

**Starch:** Glucose production by enzymatic hydrolysis.

**All residual fraction:** Biogas production

**Step 3**
Choose the range of BioProcesses considering the objective of the analysis

**Extractives:** Bioactive compounds by agitated solvent extraction

**All residual fraction:** Biogas production
Scenario 1

valorizing the leaves, stems, and flowers in the producer stage to obtain biogas

Scenario 2

The OPW valorization for the production of bioactive compounds and biogas

Scenario 3

The integration of the residues from the producer stage and the transformation stage to obtain polyphenolic compounds (from OPW) and biogas (from the mixture of exhausted OPW and leaves, stems, and flowers).
4. Results

The first analysis involved the evaluation and comparison of the three scenarios in terms of the economic metrics considering a fixed flow rate.

**Figure 5.** Net present value over the project lifetime for each scenario.

**Figure 6.** Costs distribution of the proposed biorefineries at a processing scale of raw material of 140 kg/h.
The second analysis was done to understand the influence of the scale in each scenario in terms of the economic metrics.

Figure 7. Economic performance of the OPW biorefineries at different scales over the project lifetime for each scenario. a) Scenario 1, b) Scenario 2, c) Scenario 3.

The application of the Food Residues valorization strategy determined the best scenario considering the stated objective. In this sense, scenario 2 has a Minimum Processing Scale for Economic Feasibility (MYSELF) with a lower raw material flow than scenarios 1 and 3 (it is necessary to increase the processing scale from 3.36 tons/day to 11.5 tons/day).
5. Conclusion

- Food Residues integration as an alternative for the generation of added-value products can improve the value chain sustainability since emissions of polluting agents are reduced.
- Indeed, the analyzed case study allowed to elucidate how the generation of added-value products such as polyphenolic compounds increases the viability of the orange value chain through the implementation of biorefinery with good economic performance.
- Finally, an analysis related to the possible scale and technologies to be introduced are a fundamental input to propose valorization alternatives. Finally, the proposed methodology can be applied to any food waste since the value chains are already previously defined and the disposal problems are current problems that require a contextualized solution.
6. Acknowledgments

"Business and innovation competencies for economic development and productive inclusion of the regions affected by the Colombian conflict“  
SIGP code 58907. Contract number: FP44842-213-2018
7. References


Food Residues Biorefineries: Design strategy based on multifeedstocks analysis

Carlos Ariel Cardona Alzate

Corresponding author email: jcsolartet@unal.edu.co

Thank you for your attention