Analysis of biorefinery platforms based on technical characteristics of the raw materials: a comparison between orange and plantain peels waste

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Introduction

Fermentable sugars can be an interesting platform to be obtained from lignocellulosic matrix, due to the content of cellulose and hemicellulose, which after certain processes, can produce C5 and C6 sugars. Under the concept of biorefinery, this process has high potential and great interest due to the sustainable use of by-products. However, challenges have been identified when establishing an analysis methodology to identify the best raw material for this type of processes, based on technical and economic aspects. For example, composition, prices in the market, availability of the raw material, and technologies for transformation can define the feasibility of any biorefinery.

Methodology

In this work, two raw materials (orange peel waste (OPW) and plantain peel (PP)) of great interest for fermentable sugars production were studied, in the context of the region of Montes de María in Colombia. The conceptual design and optimization methodology were used for this purpose, after rigorous raw materials characterization. The material and energy balances were obtained using the Aspen Plus V.9.0 software for the conceptual design. Besides, the investment costs of each process unit were obtained by the Aspen Economic Analyzer V.9.0 software. Balances and costs were the input to the mathematical development of optimization. A superstructure was established for this purpose. GAMS software was used. Figure 1 and Figure 2 show the structures considered.

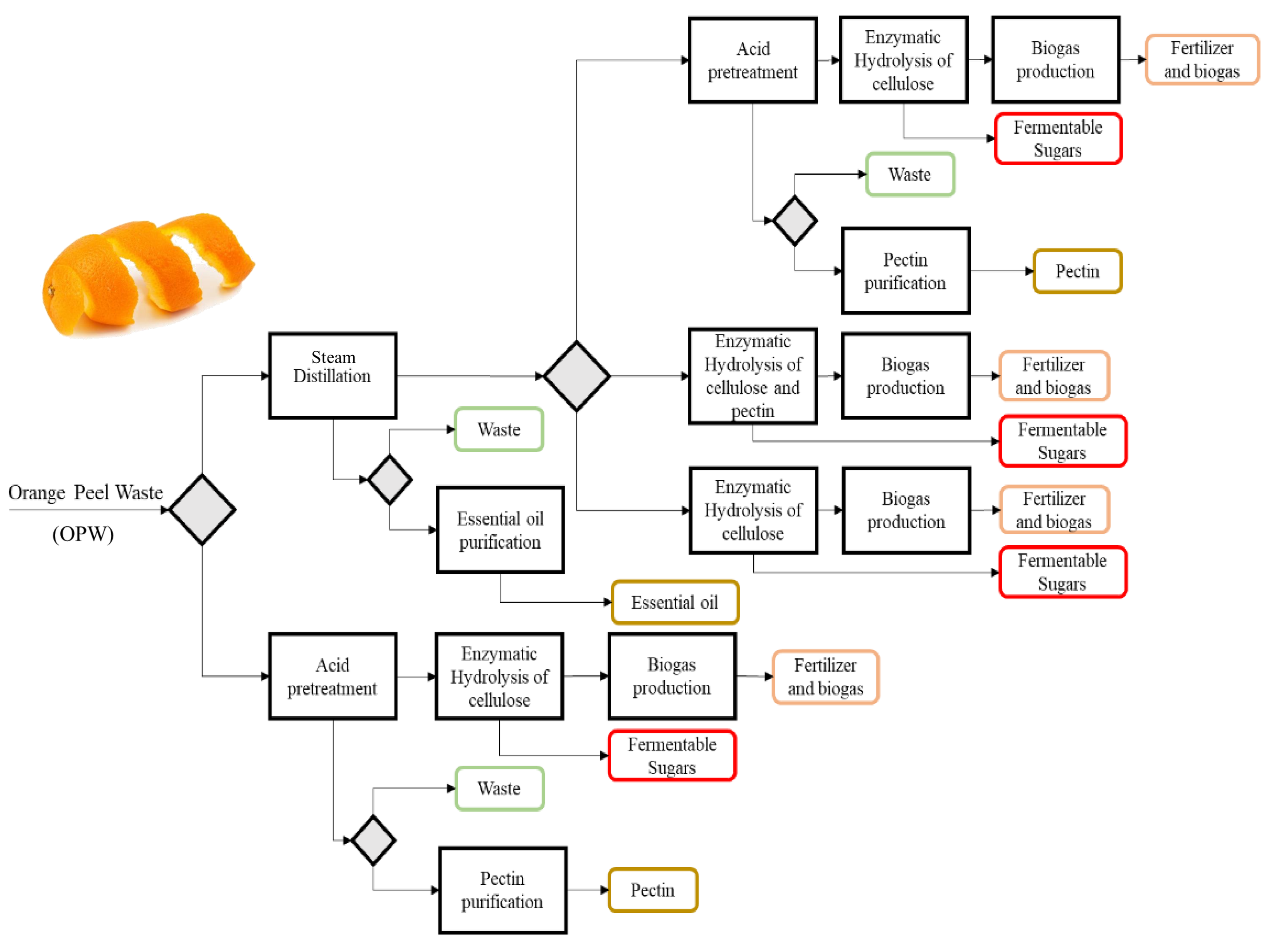

Figure 1. Super-structure for OPW Biorefinery

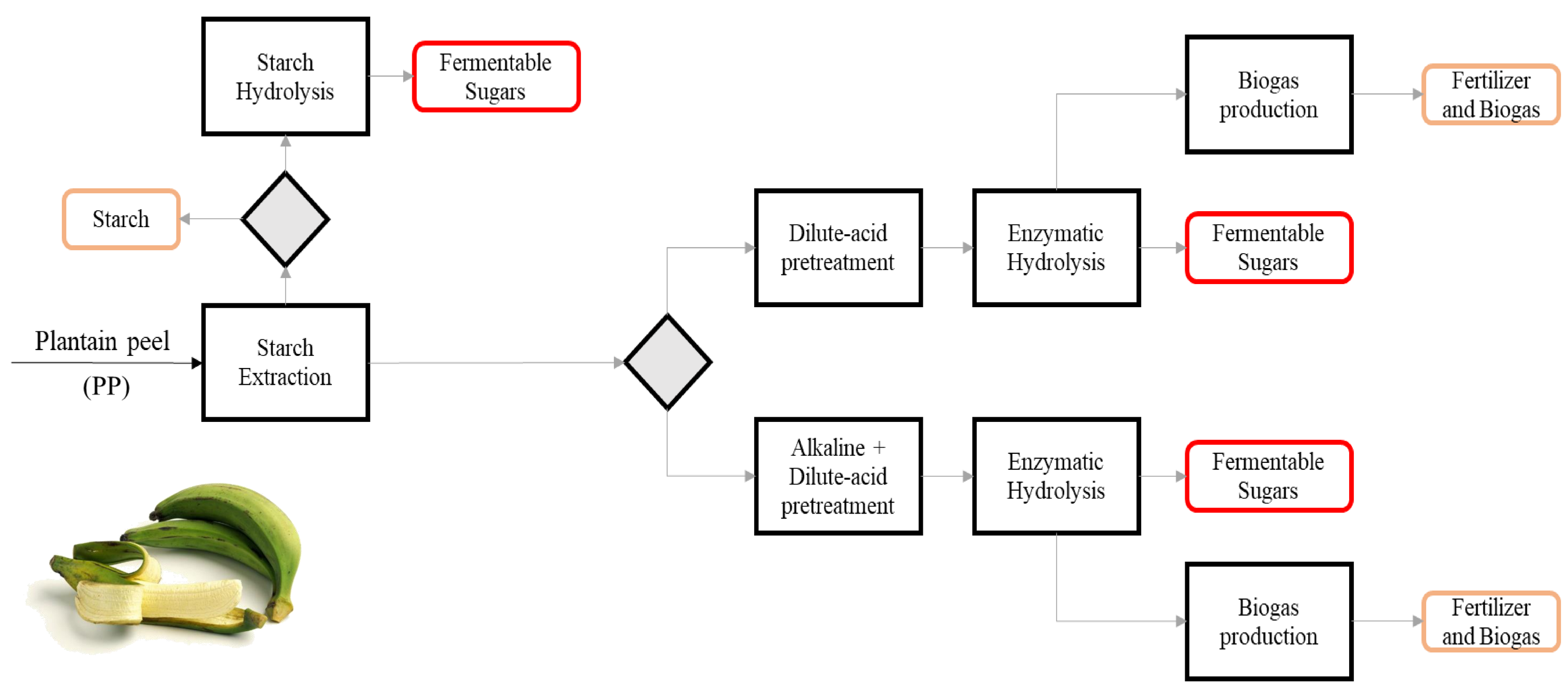

Figure 2. Super-structure for PP Biorefinery

$$Z = S^{Prod} - C^{RM} - C^{Reac} - C^{Util} - C^{Invs}$$

Equation shows the objective function to be developed in terms of the product sales (S^{Prod}), raw material cost (C^{RM}), reagent cost (C^{Reac}), utility cost (C^{Util}), and investment cost (C^{Invs}). Finally, the optimized schemes were compared in economic terms (context of Colombia). Furthermore, the optimal schemes were analyzed on the same low-scale considering the production in depressed zones of Colombia (140 kg/h).

Results & Discussion

Figure 3 and Figure 4 show the optimized flowsheet diagrams for OPW-based biorefinery and PP-based biorefinery, respectively of the restricted small scale of the Montes de María region. As can be seen, the OPW biorefinery begins with the distillation stage. The resulting stream is taken to the enzymatic hydrolysis process of the cellulose and pectin contained in the stream to result in fermentable sugars. The residues obtained are taken to anaerobic digestion to obtain fertilizer and biogas. In the plantain peel biorefinery case, the residue undergoes the starch extraction process, which will be one of the by-products of the process. The stream is rich in lignocellulosic material undergoes a pretreatment process with dilute acid and then an enzymatic hydrolysis step in which fermentable sugars are obtained. The carbohydrate-rich residues from these stages are finally taken to anaerobic digestion to obtain biogas. As a summary of the technical analysis, the results for each optimized biorefinery's mass and energy indicators are shown in Table 1.

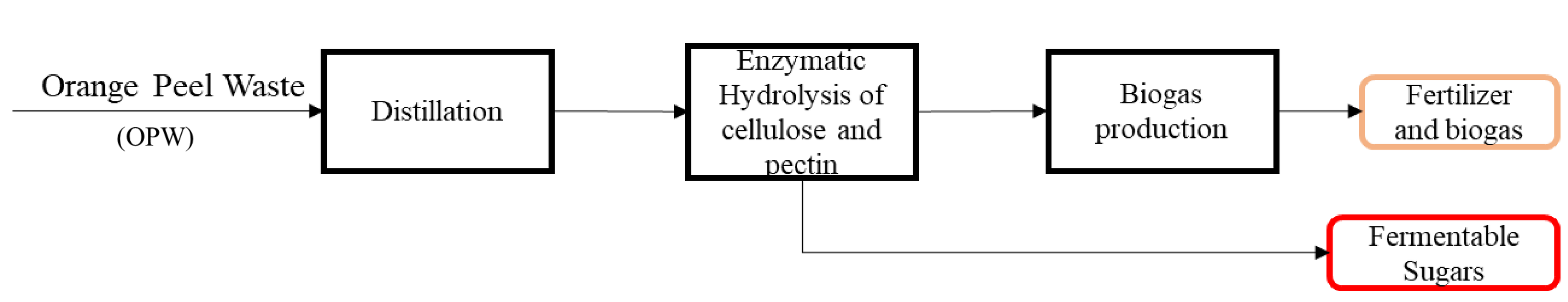

Figure 3. Scheme of the optimal OPW biorefinery

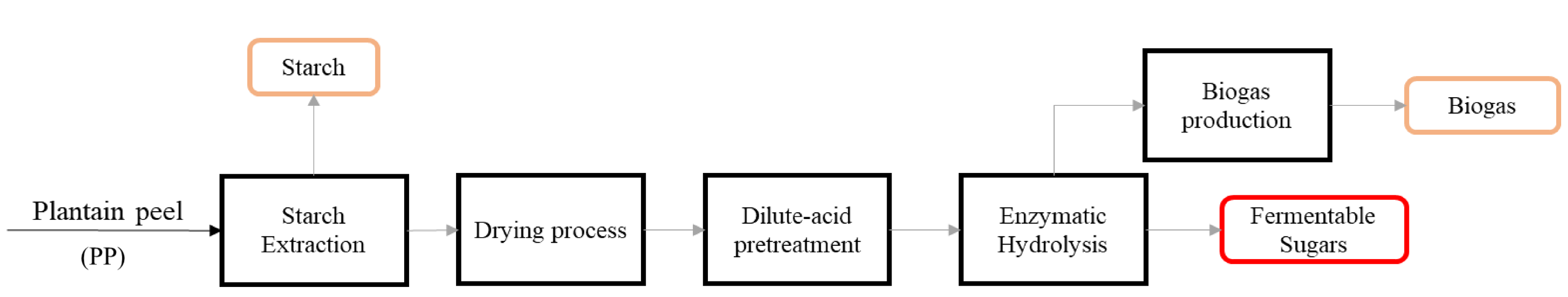

Figure 4. Scheme of the optimal PP biorefinery

Table 1. Technical indicators obtained from the optimized biorefineries schemes

Indicators	Optimized OPW biorefinery (140 kg/h)	Optimized Plantain peel biorefinery (140 kg/h)
	Mass Indicator	
Fermentable sugars yield	3.86 kg/kg OPW	0.14 kg/kg Plantain peel
Biogas yield	0.03 kg/kg OPW	0.03 kg/kg Plantain peel
Fertilizer yield	0.32 kg/kg OPW	-
Starch yield	-	0.02 kg/kg Plantain peel
Reaction mass efficiency	11.24 %	5.92 %
Annual Productivity	0.053 %	0.002 %
	Energy Indicators	
Specific energy consumption	3.21 MJ/kg OPW	0.52 MJ/kg Plantain peel
Overall energy efficiency	5.14 %	1.59 %
Self-generation index	13.58 %	9.98 %

The economic results of the optimized biorefineries showed a non-favorable behavior for the NPV. For both cases, 20 years of the project were analyzed, showing that the NPV for that year is -13.52 and -18.92 mUSD for OPW and PP-optimized biorefineries. The costs that most influenced the determination of the cost of production in both cases were raw materials, reagents, and utilities (about 65 % for the OPW biorefinery and approximately 78 % for the plantain peel biorefinery). As expected, the capital costs for the OPW-optimized biorefinery were higher than those obtained for the PP biorefinery. Comparing the different processing stages (distillation for the OPW biorefineries and starch extraction for the PP biorefinery), it is notable that the equipment and requirements for utilities and energy supplies are very different, causing the distillation process to be more expensive. However the increase of the scale can change these results approaching a feasible alternative.

Conclusions

The optimization methodology applied to the design of biorefineries was developed in this work. It could be shown that the optimized biorefinery schemes showed high productions of fermentable sugars, which are platform products widely used in biotechnological processes since they allow obtaining various value-added products. The best raw material with the best performance in the analysis was OPW, with a production yield of fermentable sugars (3.86 kg/kg) higher than the obtained from plantain peel biorefinery (0.14 kg/kg). The scale analysis of the integration of other regions to the project should be analyzed in the future.

Acknowledgments

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