Food residue biorefineries: Design strategy based on multifeedstocks analysis

C.A. Carlos Ariel, O.S. Mariana, S.T. Juan-Camilo

Instituto de Biotecnología y Agroindustria, Departamento de Ingeniería Química, Universidad Nacional de Colombia, Manizales, Caldas, Zip Code: 170003, Colombia.
Presenting author email: ccardonaal@unal.edu.co

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Commercial and residential solid or semi-solid waste generated at the municipal level is denominated as municipal solid waste (MSW) [1]. This type of waste excludes agro-industrial or industrial waste (AgW) generated in processing stages (i.e., liquid, solid and gaseous waste). The composition of MSW differs according to socio-economic and cultural context. However, it is estimated that a person generates 0.3 - 0.74 kg of MSW per day [2]. In 2018, 292.4 million tons of MSW were reported in the world [3]. This value is expected to increase to 3.4 billion tons by 2050 [4]. Different international organizations such as the Food and Agriculture Organization of the United Nations (FAO) and the World Bank have managed to determine the global composition of MSW to seek alternatives for reduction or disposal. Food and Green Waste correspond to 44% of MSW that generally ends up in the open dump. In fact, only 67% of this MSW was managed in an environmentally safe way in 2018 [5]. According to the FAO, Food is something that provides nutrients (i.e., macronutrients such as carbohydrates, fats and proteins and micronutrients such as minerals and vitamins). Therefore, Food Residues (FR) is all waste of food that had or has any nutritional properties. Considering the above, examples of FR are organic waste generated in food production (kitchen waste), organic waste discarded in a supermarket (peel, seeds, fruits and vegetables that do not meet quality standards, bones, blood, meat. in poor condition, expired processed foods, among others) and organic food losses or AgW generated in food processes. On the other hand, Green Waste (GW) corresponds to the waste produced in gardens, including grass clippings, twigs, weeds, leaves and flowers. Some definitions focus on quantitative loss and waste throughout the food supply chain. From the above, FR can be classified into two global groups Food Waste (FW) and Food Losses (FL) or AgW. According to FAO, "*The Food Losses (FL) is the decrease in the quantity or quality of food resulting from decisions and actions of food suppliers in the supply chain, excluding retailers, food service providers, and consumers*". All food that is discarded or incinerated from harvest (slaughter, recovery) to transformation or marketing. On the other hand, "*Food Waste (FW) is the decrease in the quantity or quality of food resulting from decisions and actions of retailers, food services and consumers*". Among the alternatives to reduce FLW is to make the food supply chain technical from the post-harvest stage [6]. However, in low-income countries, this alternative is difficult to do despite the fact that reducing food losses manages to reduce production costs. An alternative is the integral use of RF generated at any stage of the food supply chain to produce energy vectors or added-value products.

The definition of the transformation routes, fractions, and types of products obtained from FL and FW allows it to elucidate the importance of complete chemical characterization when proposing multicomponent processes. The multicomponent processes are called biorefineries. Reducing FLW is a goal stipulated in the Sustainable Development Goals (SDGs) that allows linking other mints such as food security, nutrition, and environmental sustainability. This is reflected in one of the goals enshrined in SDG 12 (responsible consumption and production) *"reduce per capita global FLW at the retail and consumer level by half and reduce the loss of food throughout production and the supply chain including post-harvest loss by 2030"* [7]. Food Waste or Food Residue biorefineries are considered key concepts to make the existing food value chains in the world more sustainable. Most of the residues of these value chains are well identified and characterized. However, the challenge is practically resumed in two aspects. The first issue corresponds to the residue supply chain standardization and optimization involving one residue as a feedstock or different feedstocks (other food wastes) in the same Biorefinery. The second issue is the technological configuration of the Biorefinery based on food waste. In this case, different stages should be considered:

1. Food residue characterization and deductive analysis of the best range of products to be obtained independently on the scale (to establish the minimum scale required to get economic feasibility).
2. Integration analysis of possible food waste-derived feedstocks to fix the required minimum scale of the Biorefinery (in case of scarcity of one feedstock).
3. Final food waste Biorefinery Design with end feedstocks requirements and technological lines configuration.

The problem of integrating different feedstocks in Food Waste or Food Residue Biorefineries is a very important task to viabilities most of the small-scale projects based on the residues from the food supply chains. It is explained by the fact that a high number of food industries and supply systems are small scale systems and the biorefineries usually require medium or high scale feedstocks supply to get the desired feasibility. Here, it is proposed a new strategy for defining the best technological configuration using concepts of composition of the feedstocks, platforms and products for Food Waste or Food Residue Biorefineries. Then, the present work makes emphasis in solving the challenge of the technological configuration of Food waste or Food Residue Biorefineries. The strategy is well described and demonstrated in two different examples use of wood residues and fruit residues. The strategy to define the best technology configuration was based on three steps. The first step was to define the bioprocesses with the highest economic feasibility (lower capital cost and operational costs) and the lowest environmental impact (lower amount of equivalent carbon dioxide emitted per kilogram of the product obtained). In this sense, a portfolio of bioprocesses was evaluated that involved the production of energy vectors such as biogas, ethanol, butanol, and energy by combustion and gasification and added-value products such as succinic acid, levunilic acid, citric acid, and sorbitol. The bioprocesses were simulated in the Aspen Plus V.9.0 software. Capital costs and operational costs were obtained in Aspen Economic Analyzer V.9.0 software. Finally, the environmental impact was obtained in the SimaPro software. Different biorefinery scenarios were proposed from the range of bioprocesses selected for the two case studies. In the second step, the effect of the integration of raw materials on the performance of the biorefineries was analyzed. For this, aspects such as transportation (logistics) and supply (quantity) of raw materials are considered. Finally, the third step was to evaluate the sustainability of the biorefineries obtained in steps one and two to find the best technological configuration. As a final result, the calculated indicators demonstrated how the use of the proposed strategy makes it easier to achieve or improve the sustainability of Food Waste Biorefineries. The potential of a raw material to be used in any transformation process is determined by the chemical characterization [8]. The design of bioprocesses or biorefineries depends on the economic, technical, social, and environmental context of the place that is going to be considered [9]. This design is linked to the purpose of the biorefinery [10]. However, chemical characterization information should be considered necessary to define the process flow [11].

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