Comparison of processing lines to transform agro-industrial avocado residues into bioproducts and bioenergy

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1. Introduction

Worldwide, Colombia is the fourth producer of avocado preceded by Mexico, Dominican Republic and Peru [1], [2]. According to the Ministry of Agriculture and Rural Development, for 2021, a planted area of 92699ha of avocado at national level was reported [2]. This planted area involves all avocado varieties that there are in the country where predominate Lorena and Hass varieties. Avocado Hass represents the 34% of the total planted area [2]. For 2021, a planted area of 31518ha for Hass avocado which corresponded to a production of 214678 ton [2]. The main contributor departments to this production were Antioquia, Caldas, Tolima, Valle del Cauca, Meta, Santander y Risaralda (with 5% of the national production) [1], [2].
The 50% of Hass avocado produced in the country is exported to Netherlands, Spain, United Kingdom, Belgium and United States, among others [1], [2]. The other 50% is used in domestic consumption and by national agro-industrial companies. In the last years, the avocado Hass production has been increasing and thus, those specialized companies in his processing have been consolidated with the obtaining of avocado sauce (*i.e.*, guacamole) and oil. The relation peel:seed:pulp for Hass avocado corresponds to 8.5:11.5:72%, respectively. Therefore, these companies are only taking advantage of 72% of fruit and the remaining percentage is discarded. It represents an inappropriate biomass use and an additional cost associated to waste disposal [3]. In this sense, the agro-industrial avocado residues are seed and peel, which represent 28% of the fruit and in flow terms corresponds to approximately 30000 ton per year. This biomass contents starch, cellulose, hemicellulose and lignin, and can be transform in food products, biofuels, bioenergy and biomaterials [4]. For this reason, this work aims to compare different processing lines for the extraction of starch, phenolic compounds, and sugars as bioproducts, as well as generate energy using biochemical and thermochemical methods as anaerobic digestion and pyrolysis, respectively. The comparison is carried out through technical, energy and economic indicators.

2. Material and methods

The avocado seed and peel were provided by an agro-industrial company dedicated to pulp use, placed at Department of Risaralda, in the central region of Colombia. For the biomass preparation, both residues were manually cut, the seed in cubes of 2cm and the peel in strips. Then, the materials were dried in an oven for 24h at 40°C. Finally, were milled and sieved until a particle size of 0.425mm. The physicochemical characterization involves chemical, proximate and elemental analysis of materials was carried out in triplicate. Initially, the chemical composition was determined using NREL standards (National Renewable Energy Laboratories) for moisture, extractives (NREL TP-510-42619) [5], ashes (NREL TP-510-42622) [6] calculation. Then, the determination of holocellulose and cellulose, and Klason's lignin were carried out according to ASTM D1104 and ASTM D1106, respectively [7]. The proximate analysis considers four measures, ash, volatile matter, moisture, and fixed carbon. The determination of ash, volatile matter and moisture was carried out through the protocol reported on the ASTM E1755 – 01 [8], ASTM E872 – 82 [9] and ASTM E871 – 82 [10], respectively. Finally, the fixed carbon was estimated as the difference between the ash and volatile matter content on dry basis. The ultimate or elemental analysis allows the quantification of C/H/O in a sample. In this work, this analysis was carried out using standard ASTM D591-92 with the EMA 502 Elemental Analyzer CHNS-O. The Calorific value was determined using an IKA C-6000 bomb calorimeter based on ASTM E711 – 87 [11]. Also, the residues were structurally characterized through diffraction X-ray and thermogravimetric analysis.

Processing lines for the extraction of starch, phenolic compounds, and sugars as bioproducts were considered. On the other hand, the bioenergy generation was assessed through anaerobic digestion (biogas and fertilizer) and pyrolysis (biocarbon, bio-oil and gases). Technical, energy and economic indicator were used to compare the processing lines. The indicators were calculated based on mass and energy balances generated using the commercial package Aspen Plus (Aspen Technology, Inc., USA) where the experimental chemical characterization of the residues was fed [12]–[14]. The capital and operating costs were calculated using the software Aspen Process Economic Analyzer v10. This analysis was estimated in US dollars for a 20-year period at Colombian economy conditions. As economic indicators were considered the production cost, CAPEX (based on fixed capital costs of equipment) and OPEX (calculated as the sum of costs of raw materials, utilities, maintenance, labor, fixed and general costs and overhead).

3. Results and discussion

Table 1 indicates the physicochemical characterization of avocado residues. When comparing the obtained results for the elemental analysis with those reported by García-Vargas et al. (2020) it is possible to infer that the values are quite close [15]. García-Vargas et al. (2020) present values of 49.83, 5.71, 42.2 and 0.97% for C/H/O/N of avocado peel, respectively [15]. Also, the authors report an elemental analysis for avocado seed of 42.05, 5.58, 50.79 and 0.66% for C/H/O/N, respectively [15]. This work presents the chemical analysis involving moisture, ash, extractives and holocellulose (cellulose + hemicellulose). In the case of avocado peel, cellulose and hemicellulose contribute 28.93 and 12.04%, respectively. Meanwhile, for the seed these individual measures were not possible due to a significative starch content that interfere in the cellulose essays. Merino et al. (2021) reported a similar content of holocellulose (58%) for the seed in comparison with that value that reports this work (51%) [16]. On contrary, the holocellulose content reported by Merino et al (2021) for peel is 75%, which is considerably higher than this work (40.97%) [16].

Table 1. Physicochemical characterization of avocado peel and seed (% dry basis).

Component	Avocado peel		Avocado seed	
	%	(±)	%	(±)
Proximate analysis				
Volatile matter	74.67	0.41	81.53	0.12
Fixed carbon	20.16	0.61	15.81	0.11
Ash	5.17	0.24	2.66	0.04
Elemental analysis				
Carbon	49.34	0.07	44.47	0.03
Hydrogen	7.04	0.06	6.20	0.02
Nitrogen	1.10	0.01	0.92	0.03
Oxygen	42.51	0.14	48.42	0.02
High heating value HHV (MJ/kg)	21435.3	206.62	16383.5	270.82
Chemical analysis				
Moisture	5.76	0.06	8.41	0.02
Ash	4.61	0.24	1.93	0.04
Holocellulose	40.97	4.28	51.00	5.79
Lignin	32.32	2.53	24.53	2.41
Extractives	16.35	1.73	14.12	1.18

4. Conclusions

According to the physicochemical composition of avocado peel and seed, these residues have a high potential to be transform in different valuable compounds through stand-alone processes or biorefinery context. Particularly, the seed is rich in starch and holocellulose. The peel, in addition to the content of phenolic compounds (extractives), it is rich in lignin and cellulose.

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