

SUPPLEMENTARY MATERIAL

Alternatives for the valorization of avocado waste generated in the different links of the value chain based on a life cycle analysis approach

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1. Valorization schemes for creole avocados

Four low-scale biorefineries were proposed in the region of Caldas, Colombia. All schemes consider the transformation of raw material from different links of the value chain into different products and by-products. First, avocado oil was produced by implementing the cold pressing method following the process described by Permal et al. [1]. Second, animal feed was obtained by drying and granulating the spent avocado pulp as described by Serna-Loaiza et al. [2]. Biogas was produced through co-digestion of seeds and peels in an anaerobic digester and was simulated considering the experimental yields obtained and reported by Rashama et al. [3]. Finally, the bioactive compounds were simulated using the methodology reported by Restrepo-Serna, et al. [4]. The simulation schemes are described below. The rejected avocado used in the simulation schemes to produce guacamole and animal feed is the avocado that does not meet market specifications at the organoleptic perspective and can be used. However, avocados or crops that are affected by pests and diseases are eliminated by biocides and remain in the field as fertilizer for the next harvest. Considering this scenario, the crop rejection flow is 6,340 tons/year, of which only 2,000 tons/year will be used, allowing a wide margin of loss for avocados that may represent a danger for human consumption.

i) Small-B1

The first biorefinery involved the agricultural stage of the avocado value chain. Rejection avocado that does not meet the organoleptic properties required by the market for consumption was considered as raw material. This scenario corresponds to the production of guacamole from avocado pulp and the production of biogas and fertilizers from spent seeds and peels as shown in **Figure S1**.

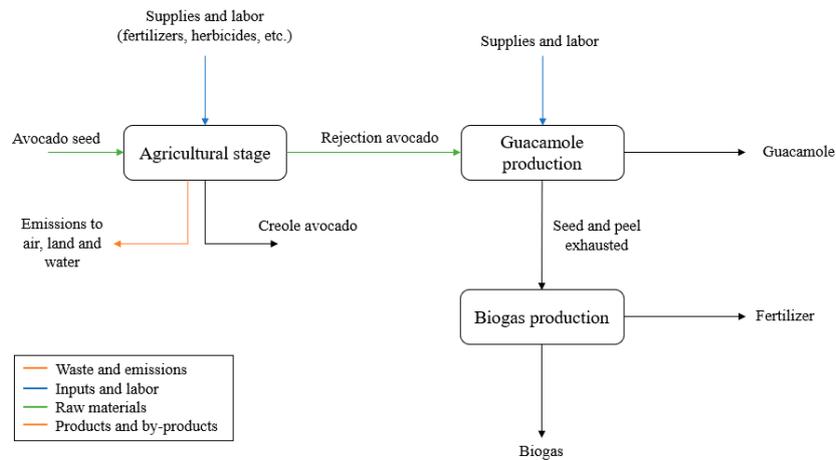


Figure S1. General scheme of guacamole, fertilizer, and biogas production (Small-B1).

ii) Small-B2

The second biorefinery involved the agricultural stage of the avocado value chain. The same feedstock as Small-B1 was considered. This scenario corresponds to the production of animal feed from avocado pulp and the production of biogas and fertilizer from the spent seeds and peels as shown in **Figure S2**.

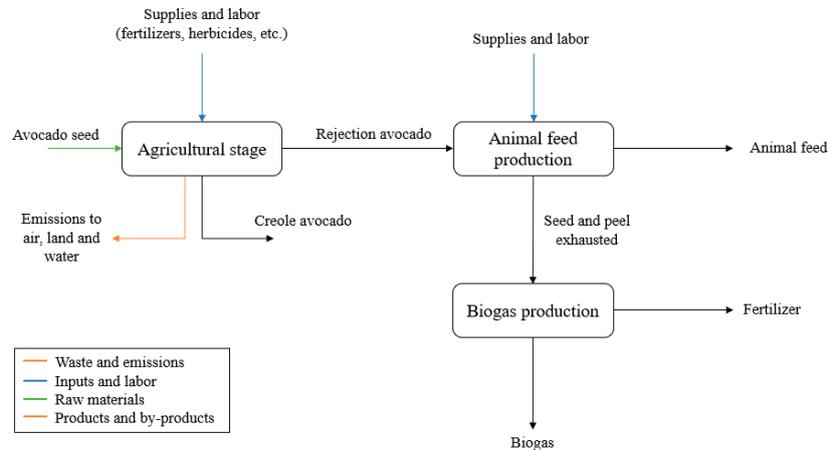


Figure S2. General scheme of animal feed, fertilizer, and biogas production (Small-B2).

iii) Small-B3

The third biorefinery involved the industrial processing stage of the avocado value chain. Rejecting avocado and residual fractions (seed and peel) from the guacamole industry were considered as raw material. This scenario involved the conditioning of the raw material followed by the production of oil from the avocado pulp and the extraction of bioactive compounds from the exhausted seeds and peels. Subsequently, biogas and fertilizer were produced from the peels and seeds resulting from the extraction process of bioactive compounds as shown in **Figure S3**.

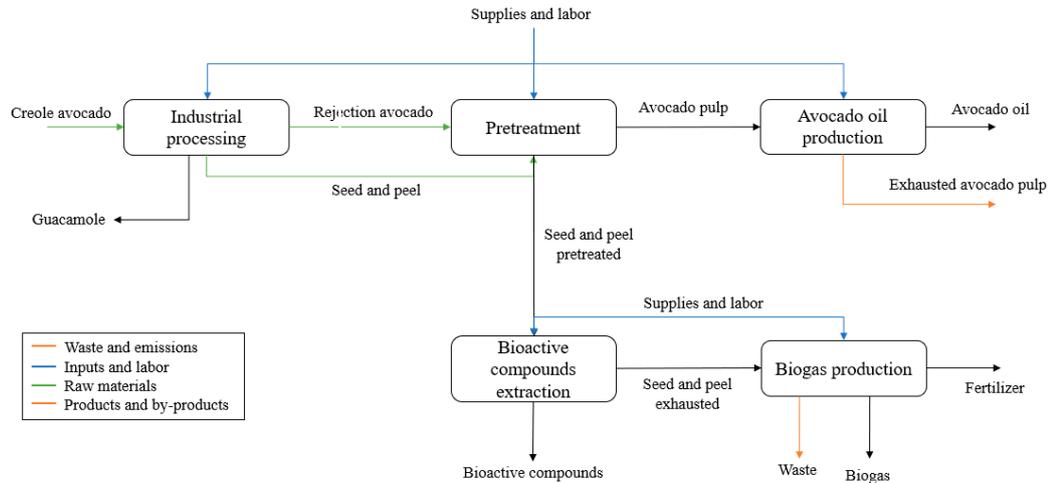


Figure S3. General scheme of guacamole, oil, bioactive compounds, fertilizer, and biogas production (Small-B3).

iv) Small-B4

The fourth small scale biorefinery involved the industrial processing stage of the avocado value chain. The same raw material as in Small-B3 was considered. For seeds and peels, the same products as in Small-B3 were obtained, and for avocado pulp, the production of animal feed was considered, as shown in **Figure S4**.

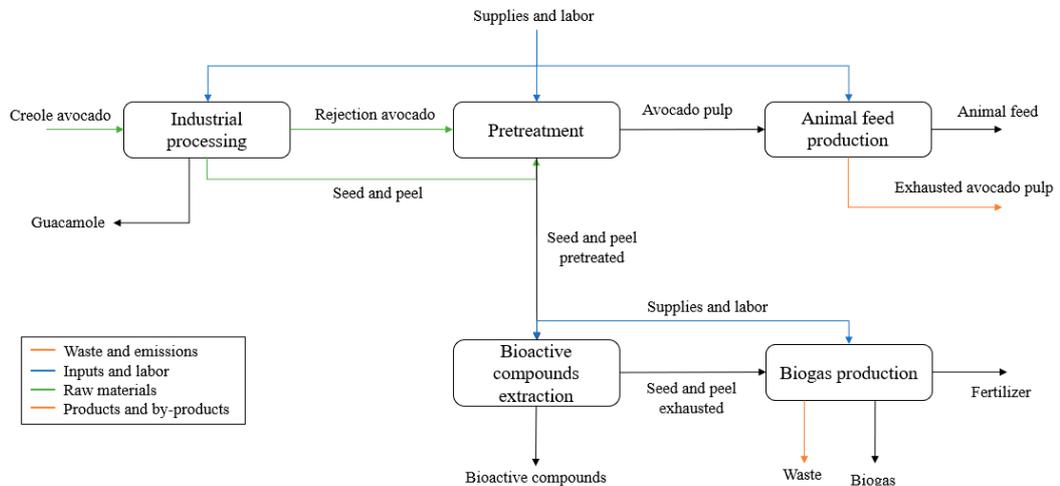


Figure S4. General scheme of guacamole, animal feed, bioactive compounds, fertilizer, and biogas production (Small-B4).

2. Economic parameters for economic assessment

Table S1 specifies the economic parameters used for the evaluation of low scale biorefinery based on the utilization of the residual fractions of creole avocado in Caldas.

Table S1. Raw materials, utilities, and parameter economics

Component	Value	Units	Economic parameters		
Creole avocado	0.670	USD/kg	Operating time	2800	Hours/year
Water	0.326	USD/m ³	Shifts	1	Shifts/day
Electricity	0.055	USD/kWh	Working time	8	Hours/day
High P. Steam (105 bar)	8.15	USD/ton	Project lifetime	10	Years
Middle P. Steam (30 bar)	8.07	USD/ton	Depreciation method	Linear	
Low P. Steam (3 bar)	7.89	USD/ton	Salvage value	15	%

3. Life cycle assessment

Table 2S specifies the inputs and outputs (Life cycle inventory LCI) of each of the actors in the first three links of the value chain. The suppliers' link considers the materials needed to build the nursery and transport agrochemicals. The small producers' link considers the crop establishment, the vegetative and productive stage, and the transportation of the avocado to the marketer. Finally, the commercialization stage considers the transportation of the raw material.

Table S2. Inventory of the creole avocado VC in the department of Caldas for the first three links.

Link	Actor	Subsystem	Activity	Inputs			Considerations	Input reduction	Type of work
				Description	Value	Unit			
Supplier	Nursery	Nursery	Nursery construction	Sunshade greenhouse	10	kg per m ²	All the materials and supplies necessary for the construction of the nursery were considered.	Due to the need for more product information and planted areas of creole avocado in the department of Caldas, only information reported for the year 2021 is considered. In this sense, considering that the Creole avocado presented a productivity participation of 9%, a reduction of the total inputs for the first two links of the VC of 91% was carried out.	Manual
				Wood	1	Wooden support every m around the nursery			
			Seed cleaning	Water	3	Liters per-15 seeds	The seeds are cleaned with hot water.		Manual
			Seed disinfection	Vitavax	10	grams per kilogram of seeds	Before germination, the seed is disinfected.		Manual
			Germinator construction	Wood	44	kg of wood for a germinator area of 1.3x1.3	All the materials and inputs necessary for constructing the germinator were considered.		Manual
			Substrate for germinator	Sand	25	Sandbags for 1 m ³ of germination area	70% of the germinator volume is filled with sand; the remaining 30% is filled with poultry manure.		Manual
				Chicken manure	7.5	Bags of poultry manure for 1 m ³ of germinator			
			Transplanting to bags	Plastic bag	1	Plastic bag per germinated seed	Seedlings are grown in plastic bags for 5 months.		Manual
			Substrate for bags	Sand	10	% of bag volume			
				Rice peel	15	% of bag volume			
				Soil	50	% of bag volume			
				Compost	25	of bag volume			
	Substrate disinfection	Betam sodium	11	grams in 160 L of water	Irrigation is done every 5 days for 5 months.	Manual			
Bag irrigation	Water	0.5	Liters per bag						
Fertilization	Bayfolan	300	ml per 100 liters of water	Fertilization is performed every 30 days for 5 months.			Manual		
	Input suppliers	Input suppliers	Transportation	Transport of inputs to the producer	50	km	An average distance is considered for the purchase of inputs.		Truck
Production			Weed control	Machete	1	Machete	Weeding is done manually.		Manual

Small producers	Crop establishment	Layout	Trefoil - 3.5 meters	142	tree/ha	The crop layout was a triangular arrangement with 9 m per tree.	Manual	
		Boring	N.A.	N.A.	N.A.		Manual	
		Fertilization and addition of agrochemicals	Cal	500	g/hole	Only one application of fertilizers and agrochemicals is considered for this stage. Fertilization is performed every 30 days for 5 months.	Manual	
			DAP	100	g/hole			
		Planting	N.A.	N.A.	N.A.	An average distance is considered for the purchase of inputs.	Manual	
		Cultivation - Vegetative and productive stage	Fertilization	15-30-15	30	g/tree	Fertilizer application is carried out every 3 months during the first year.	Manual
				15-30-15	200	g/tree	Fertilizer application is carried out every 2 months during the second year.	Manual
			Pruning	Manual scissors	N.A.	N.A.	Growth pruning and maintenance pruning are carried out. These are carried out twice a year by hand.	Manual
		Productivity	Avocado	Avocado	2615	kg/ha year	From the 4th year of planting	Manual
		Avocado transportation to the marketer	Transporter	Average distance	40	km	The distances were taken from a general average considering the location of the producers and marketers; in addition, round-trip transportation was considered (EURO 1).	Truck
Marketing	Collection centers	Transporter	Transporter	Distance	80	km	The distances were taken from a review of maps considering the location of the traders and transformers; in addition, round-trip transportation was considered (EURO 3).	Truck

Finally, **Table S3** presents the composition of the agrochemicals used in the first two links of the creole avocado VC. The crop emissions from the use of these agrochemicals were determined. This work considered the direct and indirect N₂O emissions to air, NH₃ and CO₂ emissions to air, NO₃⁻ and PO₄³⁻ emissions to water, P emissions to soil, and the amount of P emitted by water erosion in soils. The emissions were calculated based on different equation and expressions reported elsewhere [5], [6], [7], [8], [9].

Table S3. Composition of agrochemicals used in the first two links of the creole avocado VC

Agrochemical	Agrochemical type	Ingredients/ Characterization	Chemical formula	Composition (%w/w)
Vitavax	Fungicide	Carboxin	C ₁₂ H ₁₃ NO ₂ S	20
		Captan	C ₉ H ₈ Cl ₃ NO ₂ S	20
		Silica gel	SiO ₂	11
		Magnesium carbonate	MgCO ₃	5
		Ethylene glycol	C ₂ H ₆ O ₂	5
		Titanium dioxide	TiO ₂	1
		Inerts	N.A.	38
		Total	N.A.	100
Metam sodium	Fungicide	Mancozeb	C ₈ H ₁₂ MnN ₄ S ₈ Zn	64
		Metalaxyl	C ₁₅ H ₂₁ NO ₄	4
		Inerts	N.A.	32
		Total	N.A.	100
Bayfolan	Foliar fertilizer	Nitrogen	N-Total	0.114
		Phosphorus	P ₂ O ₅	0.08
		Potassium	K ₂ O	0.06
Gallinaza	Organic fertilizer	Total Nitrogen	N-Total	34.7
		Phosphorus	P ₂ O ₅	30.8
		Potassium	K ₂ O	20.9
		CaICVum	CaO	6.1
		Magnesium	MgO	7.5
		Total	N.A.	100
Agricultural lime	pH Regulator	CaICVum carbonate	CaCO ₃	90
		Magnesium carbonate	MgCO ₃	5
		Inerts	N.A.	5
		Total	N.A.	100
DAP	Edaphic Fertilizer	Total Nitrogen	N-Total	18
		Phosphorus	P ₂ O ₅	46
		Inerts	N.A.	36
		Total	N.A.	100
15-30-15	Edaphic Fertilizer	Nitrogen - Total	N-Total	13
		Phosphorus	P ₂ O ₅	26
		Potassium soluble in water	K ₂ O	13
		Inerts	N.A.	48
		Total	N.A.	100

4. References

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