Integral use of plants and their residues: the case of Cocoyam (*Xanthosoma sagittifolium*) conversion through biorefineries at small-scale

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ABSTRACT

During last decades, there has been a growing interest of decreasing the environmental impact generated by humans. This situation has been approached from different perspectives being the integral use of raw materials one of these. It was estimated that $3.7x10^9$ tonnes of agricultural residues are produced annually worldwide. The integral use of these feedstocks has been studied through the biorefinery concept. A biorefinery can be a promissory option for processing feedstocks in rural zones aiming to boost the techno-economic and social growth of these. Cocoyam (*Xanthosoma sagittifolium*) is a plant grown extensively in tropical regions. Nigeria, China and Ghana are the main producers with 1.3, 1.18 and 0.9 million tonnes/year, respectively. In Colombia, there are not technified crops of it and it is used where it grows mainly as animal feed. This plant consists of leaves, stem and a tuber but the use is generally limited to the leaves, discarding the other parts. These discarded parts have great potential (lignocellulose and starch). This work proposes different processing schemes using the parts of the plant to obtain value added products, and their techno-economic and environmental assessment. The simulation was performed with Aspen Plus and the economic package was used for the economic assessment. For the environmental assessment, Waste Algorithm Reduction of the U.S. EPA was implemented. The obtained results showed that the integral use of plants under a biorefinery scheme allows obtaining better techno-economic and environmental performance and that small-scale biorefineries can be a promissory option for boosting rural zones.

Keywords: Agroindustrial Residues, Biorefineries, Cocoyam, Small-scale, Starchy Feedstocks

1. INTRODUCTION

During the last decades, there has been a growing interest of decreasing the environmental impact that human race has generated. This situation has been approached from different perspectives: producing renewable fuels, decreasing the emission of greenhouse gases, creating alternative routes for producing chemicals normally obtained from oil, and designing processes that use renewable raw materials with the less possible production of residues, among others. Agricultural production chains were one of the main sources of residues, considering that there is a great availability of residual biomass, which is made up of by-products generated during the growing, harvesting and processing stages [1]. These residues are characterized by high rates of production that are being discarded without any technical direction, turning them into a source of environmental contamination. With this new approach, all residues started being considered as possible feedstocks to be used within the processes, decreasing the production of residues.

It was estimated that almost $3.7x10^9$ tonnes of agricultural residues are produced annually worldwide in agricultural industries [2] and Colombia has an average waste production associated to crops between 10,000-140,000 tonnes per year, which demonstrates the potential of these wastes as a raw material. Raw materials existing in the national territory are a potential source for the production of many products with high added value. Some of these residues are rice husk, bagasse from sugar cane, coffee cut stems, and mesocarp palm shells of different tropical fruits, etc. [3]. The integral use of these feedstocks has been studied through the concept of biorefineries, which are the equivalent of oil refineries but with a renewable raw material, through which multiple products are obtained from a single raw material [4]–[7]. The most used method for designing biorefineries is the knowledge-based approach, which considers factors as the composition of the raw material, available technologies, stage affecting the most the process and heat and mass integrations within the process, among others. Some biorefineries have been proposed for sugarcane [8], berries [9], castorbean [10], olive [11], and oil palm [12], among others. A biorefinery can be a promissory option for processing feedstocks in rural zones, given that they can be located on places far from urban centers and boost the economic, social and technical growth of these zones [7], [13].

Cocoyam (Xanthosoma sagittifolium (L.) Schott), is a plant original from Central America and grown extensively in tropical regions [14]. Nigeria, China and Ghana are the main producers with more than 1.3, 1.18 and 0.9 million tonnes/year, respectively [15], [16]. In Colombia, there are not technified crops of this plant and it is used where it grows mainly as animal feed (approx. 200 tonnes/year) and a small share is used for human consumption/agribusiness (20 tonnes/year) [17]. This plant consists of leaves, stem and a tuber but the use is generally limited to the leaves, while the other parts are discarded. This generates environmental and inefficiency problems. These discarded parts have great potential. The stem is mainly composed by lignocellulose and the tuber has a considerable percentage of starch. The average starch content in the cocoyam is 25% w/w [14], which can be considered as a high value compared with other starchy crops as potatoes (15%) [18] and cassava (18%) [19].

This work proposes some processing schemes using the different parts of the plant for the production of value added products, and the respective technical, economic and environmental assessment. Three scenarios were proposed: (i) base case, considering only the use of leaves as animal feed and discarding the rest of the plant; (ii) use of leaves for animal feed, stem for ethanol production and remaining solids for the animal feed and discarding the tuber; (iii) use of stem for ethanol production, tuber for the production of starch and the remaining solids together with the leaves for the animal feed. The simulation was performed with the process simulation software Aspen Plus (Aspen Technology, Inc., EE.UU.) and the economic package of the software was used for the economic assessment. For the environmental assessment, Waste Algorithm Reduction (WAR) software of the U.S. Environmental Protection Agency was implemented [20]–[22]. The obtained results showed that as the used share of the plant increases, the economic performance of the process improves and the environmental impact decreases. Two main results were obtained: first, that the integral use of plants and their residues under a biorefinery scheme allows obtaining better technical, economic and environmental performance; second, that small-scale biorefineries can be a promissory option for boosting rural zones.

2. METHODS

This work consisted in two stages: experimental and simulation. The experimental stage consisted in the obtainment of the raw material and its respective characterization in terms of the content of lignocellulosics and starch. This information is used in the second stage as the start point of the simulation.

2.1. Raw material characterization

The raw material was obtained in the municipality of Chinchiná, Caldas, Colombia at 4°58' North 75°39' West at 1381 meters above sea level. The three parts of the plant were separated (leaves, stem and tuber) and chopped separately. Then, they were dried in a convective dryer at 45 °C during 48 h until achieving a constant weight. Then, the dry material was milled using a mill blade (Thomas Model 4 Wiley® Mill) until an approximate particle diameter of 0.4 mm (Mesh 40). Fig. *1* shows the cocoyam plant and its parts.

(a) *(b)* *(c)*

Fig. 1 Cocoyam plant. (a) Plant (b) Part of the stem (left) and tuber (right) (c) Underground tuber. Taken from the authors own file

The physicochemical characterization was performed with three replicates. The compounds determined for each part of the raw material were cellulose, hemicellulose, lignin, extractives, ash and starch. Hollocellulose

(cellulose + hemicellulose) and lignin content were determined by the chlorination method and sulfuric acid method, respectively, according to the ASTM D1104 [23]. Cellulose was determined then from holocellulose and hemicellulose as the difference between holocellulose and cellulose. Extractives were determined with a water-ethanol mixture according to the methodology reported by the National Renewable Energy Laboratories (NREL) NREL/TP-510-42619 [24] and ash content was determined by the total ignition of the samples according to the NREL/TP-510-42622 [25].

2.2. Description of the scenarios

For the evaluation of the integral use of a given plant and its residues, in this specific case, cocoyam, three scenarios were proposed. Each of these scenarios propose a processing scheme using the different parts of the plant for the production of value added products considering the current use of the plant and the composition of it. The products are an additive for animal feed, ethanol (and gypsum as by-product) and starch for human consumption. Considering that currently there are no extensive or technified crops of cocoyam and that this process is aimed for small scales and rural zones, the raw material feed was 200 kg per hour. In this case, the consideration of small-scale is done with respect to the processing scale. Table 1 describes the three scenarios, the technologies used, the discarded parts of the plant and the obtained products. Three scenarios were proposed: (i) base case, considering only the use of leaves as animal feed and discarding the rest of the plant; (ii) use of leaves for animal feed, stem for ethanol production and remaining solids for the animal feed and discarding the tuber; (iii) use of stem for ethanol production, tuber for the production of starch and the remaining solids together with the leaves for the animal feed. These three scenarios were used to compare the influence of the use of the current residues generated by the plant crop in the techno-economic and environmental performance of the proposed processes. Fig. **2** shows the block diagram for the three scenarios.

Table 1 Scenarios description for the integral use of cocoyam and its residues

Scenario	**Products**		**Used parts**	**Discarded parts**	**Technologies**	**Distribution**
	Main	**Secondary**				
Sc. 1	Animal feed	-	Leaves	Stem Tuber	*Solids drying*: convective drying *Milling*: blade mill (0.6 mm particle diameter)	Additive: 100% of the leaves
Sc. 2	Animal feed Ethanol	Gypsum	Leaves Stem	Tuber	*Solids drying*: convective drying *Milling*: blade mill (0.6 mm particle diameter) *Hemicellulose hydrolysis*: sulfuric acid 2% v/v *Cellulose hydrolysis*: enzymatic hydrolysis *Ethanol production*: continuous stirred bioreactor (CSTBR) with *Zymomonas mobilis*	Additive: 100% of the leaves and remaining solids from sugars production. Sugars: 100% of stem. Ethanol: 100% of xylose and glucose from sugars production
Sc. 3	Animal feed Ethanol Starch	Gypsum	Leaves Stem Tuber	-	*Solids drying*: convective drying *Milling*: blade mill (0.6 mm particle diameter) *Hemicellulose hydrolysis*: sulfuric acid 2% v/v *Cellulose hydrolysis*: enzymatic hydrolysis *Ethanol production*: continuous stirred bioreactor (CSTBR) with *Zymomonas mobilis* *Starch extraction*: Wet milling *Starch purification:* Vacuum	Additive: 100% of the leaves and remaining solids from sugars production and starch production. Ethanol: 100% of xylose and glucose from sugars production. Starch: 100% of tuber

					filtration	

2.3. Process description

The three scenarios comprise four main sections to convert the cocoyam into the desired products. Each of these sections will be described briefly, as follows.

2.3.1. Additive production

This section aims to obtain a product to feed farm animals given its content of fiber and protein (34 and 16,6 %wt, respectively) [17], [26]. In this work, the current use of the leaves will be maintained, but it is necessary to process it for preservation purposes. The solids entering the section (whether the leaves or solid fractions from other sections) are first dried until decreasing the moisture content below 8%wt. Then, the solids are milled until a particle size of approximately 0,6 mm and pelletized.

2.3.2. Sugars extraction

The extraction of the sugars comprises three stages. The first stage consists in reducing the particle size of the feedstock, in order to increase the surface area and the accessibility of the components of the lignocellulosic matrix. After this, biomass is submitted to a dilute acid hydrolysis with 2% v/v sulfuric acid at 100 °C, according to the kinetic expression reported by Jin et al. [27]. Two fractions are obtained from this stage. The liquid fraction consists mainly in a pentose-rich stream that undergoes a detoxification stage with calcium hydroxide to eliminate the sulfuric acid. This stream is filtered and gypsum is obtained as by-product. The pentose-rich stream goes to the fermentation stage for ethanol production. The solid fraction (cellulose and lignin) undergoes an enzymatic hydrolysis at 35 °C based on the kinetic expression reported by Morales et al. [28]. The stream is filtered and the solid fraction, mainly composed by lignin, goes to the additive production section and the hexose-rich liquor is mixed with the pentose-rich stream. The sugars-rich stream is submitted to a detoxification process [29], in which the furfural and the hydroxymethylfurfural are eliminated given that they are inhibitors for the fermentation stage.

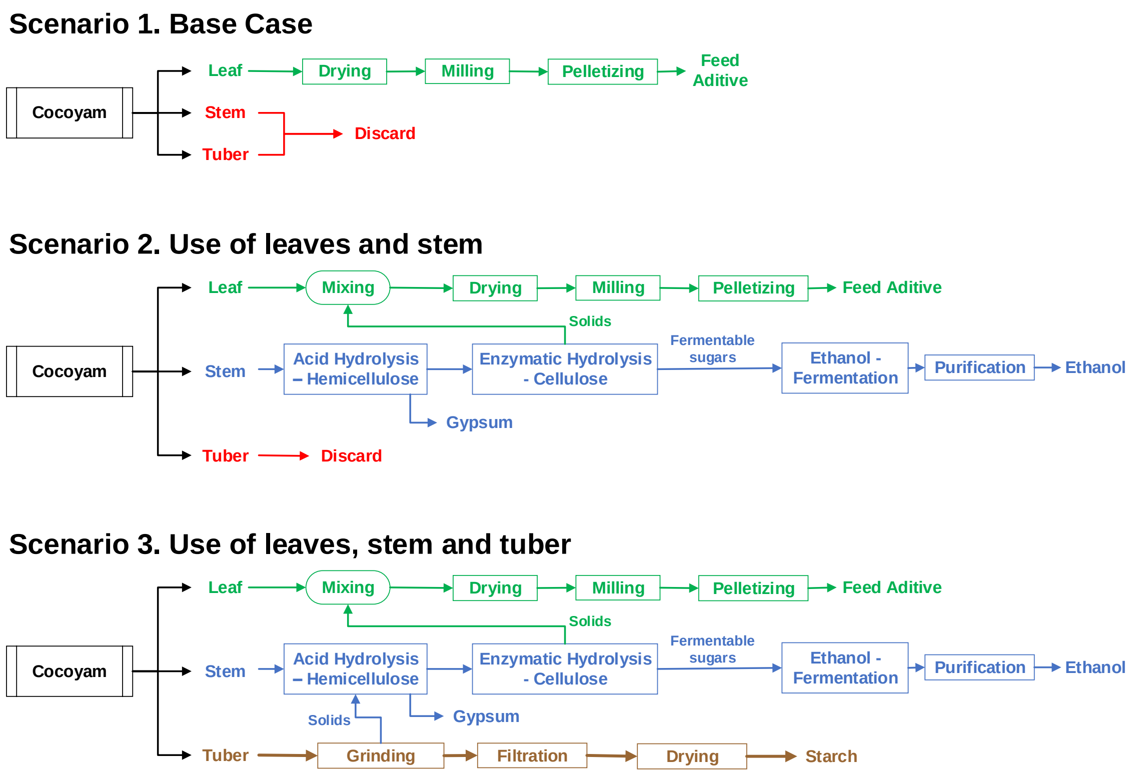


Fig. 2 Block diagram corresponding to the proposed scenarios

2.3.3. Ethanol production

The fermenting microorganism considered for ethanol production was *Zymomonas mobilis*. The sugar-rich stream is sterilized in an autoclave at 121 °C to neutralize the biological activity. Then the fermentation is carried out at 30 °C based on the kinetic model reported by Leksawasdi et al. [30] for a glucose/xylose mixture as substrate. According to different authors, when *Z. mobilis* is used for fermentations with both sugars as substrates, a yield of 0.41 grams of ethanol per gram of substrate (xylose and glucose) can be obtained [30], [31]. After the fermentation, the biomass is separated from the broth with a drum filter and the liquid stream containing a concentration between 7-12%wt of alcohol enters the purification stage. The purification consists in a distillation column in which ethanol is concentrated up to 50-55% wt, the subsequent rectification in which ethanol reaches the azeotropic composition (96%wt) and a final dehydration with molecular sieves. The final concentration of ethanol is 99.6%wt.

2.3.4. Starch production

This section aims to obtain a product for human consumption, creating a process that produces feed, food and biofuels. The process consists in extracting, purifying and preserving the starch of the tuber. The production process bases on the wet milling scheme for the production of starch from other starchy raw materials as cassava and potatoes [26], [32], [33]. The first stage consists in rating and grinding the tuber in order to break the cell walls and liberate the starch. Then, the mixture is filtered and the solid pulp is directed to the animal feed section. The liquid fraction containing the starch is vacuum filtered while adding water to simultaneously wash and separate the starch. Finally, the starch is dried/dehydrated until a final moisture below 10%wt.

2.4. Simulation procedure

For the simulation, the main simulation tool used was the commercial software Aspen Plus (Aspen Technology, Inc., EE.UU.). With the simulation, it is possible to determine the requirements of raw materials, utilities and energy needs of the process. The software offers several thermodynamic models and equations of state to describe the behavior of vapor and liquid phases and the selection of the models to be used must fit the behavior of the molecules in the process. In this case, considering that this process does not include electrolytes and operates below 10 bars, the Non-Random Two Liquids (NRTL) model was chosen. The properties used to simulate the components of biomass were taken from the NREL/MP-425-20685 "*Development of an ASPEN PLUS Physical Property Database for Biofuels Components*" [34].

2.5. Economic assessment

The software used for the economic assessment was Aspen Process Economic Analyzer (Aspen Technology, Inc., EE.UU.). This software calculates the costs of raw materials, equipment, operational costs and utilities based on the mass and energy balances obtained in the simulation. The analysis is performed in US dollars at economic typical conditions of Colombia (annual interest raw of 17%, income tax of 25%) for a ten year period, using the straight line depreciation method. Table 2 presents the raw materials and utilities costs used in the economic assessment.

Table 2 Cost of raw material, reactants, products and utilities used in the economic assessment

Item	Unit	Price	Ref.
Cocoyam[a]	USD/kg	0,88	[35]
Sulfuric acid	USD/kg	0,085	[36]
Calcium hydroxide	USD/kg	0,12	[37]
Ethanol	USD/kg	0,86	[36]
Starch	USD/kg	1,42	[38]
Animal feed	USD/kg	1,00	[39]
Gypsum	USD/kg	0,3	[39]
Water[b]	USD/m^3	0,74	-
Electricity[b]	USD/kWh	0,14	-
Fuel[c]	USD/MW	24,58	-
Operator Labor[d]	USD/h	2,56	-
Supervisor Labor[d]	USD/h	5,12	-

[a] Costs calculated in previous research
[b] Prices taken from the public enterprises that manage such services
[c] Estimated cost of gas for a period of 2015-2035 [40]
[d] Prices taken from the Ministry of Work

The economic indicator used to determine the performance of the scenarios was the gross income margin of the process (Equation 1). This indicator compares the total gross income obtained with each of the products and by-products of the process and compares it with the total cost calculated for the process with the software.

$$Gross\ Income\ Margin\ (\%) = \left(\frac{P_s - PUP}{P_s}\right) * 100 \qquad \text{Equation 1}$$

P_s: Product sales price
PUP: Unitary cost of the product

2.6. Environmental assessment

The Waste Algorithm Reduction (WAR) of the United States Environmental Protection Agency was used to perform the environmental assessment of each scenario [20]–[22]. It proposes three main impact categories: human toxicity, environmental toxicity and global warming. These main categories are subdivided into eight indexes, which are calculated depending on each of the components of the inlet and outlet streams of the process. Finally, the eight indexes are correlated in the Potential Environmental Impact (PEI). These indexes are human toxicity per ingestion (HTPI), human toxicity per dermal exposition or inhaling (HTPE), terrestrial toxicity potential (TTP), aquatic toxicity potential (ATP), global warming potential (GWP), ozone depletion potential (ODP), photochemical oxidation potential (PCOP) and acidification potential (AP). The software calculates both the outlet impact (only considering the outlet streams) and the generated impact (the difference between the impact of outlet and inlet streams), for which a negative value indicates that the environmental impact of the given index has been decreased.

3. RESULTS

3.1. Raw material characterization

Table 3 shows the chemical composition of the three parts of the cocoyam plant obtained experimentally. The values are expressed in dry basis. On a dry basis, the part with the highest share of the plant is the tuber, accounting for 60%wt of the plant while leaves only account for 10%wt. For the leaf and the stem, the most representative compounds are cellulose, hemicellulose and lignin. For the tuber, cellulose and starch are the most representative compounds. This is an excellent result considering the proposed uses for the parts of the plant. For animal feed, the fiber and protein content are very important, represented in this case in the lignocellulose and other authors reported similar values of fiber and protein, 34 and 16,6 %wt, respectively [26]. Regarding the tuber, the starch composition is considerable compared with the contents of other starchy crops as potatoes (15%) [18] and cassava (18%) [19] and the remaining solids will allow obtaining hexoses and pentoses together with the steam.

Table 3 Chemical composition obtained for the parts of cocoyam (dry basis %wt)

Component	**Weight percentage (%wt)**		
	Leaf	**Stem**	**Tuber**
Share of the Plant (dry basis - %wt)	10	30	60
Cellulose	29,96 ± 2,90	31,34 ± 2,06	24,52 ± 1,31
Hemicellulose	16,68 ± 2,07	15,44 ± 1,53	8,90 ± 0,82
Lignin	7,44 ± 0,26	10,76 ± 0,75	6,26 ± 0,58
Extractives	38,38 ± 0,79	37,17 ± 0,62	33,24 ± 0,80
Ash	7,53 ± 0,23	5,28 ± 0,18	3,45 ± 0,01
Starch	0,00 ± 0,00	0,00 ± 0,00	23,64 ± 2,25
TOTAL	100	100	100

These results in the characterization confirm the potential of this entire plant, not only because of its protein content for animal feed, but to be entirely used under a biorefinery concept in which different products are obtained taking advantage of the composition of the three parts of the plant and integrating the different sections of the process to decrease the production of residues and increasing as much as possible the use of the raw material.

3.2. Technical assessment

After performing the respective simulation for each of the scenarios, it was possible to calculate the production yields for the product(s) and the total yield of the raw material. The total yield of raw material is calculated as the total mass of obtained products compared to the feedstock flow. Table 4 shows the respective information for the three proposed scenarios.

Table 4 Obtained yields for the proposed scenarios using cocoyam as feedstock

Sc.	Description	Product(s)	Obtained Yield [kg Product/kg Cocoyam]	Total Yield of Raw Material [Total kg Product/kg Cocoyam]
1	Base Case	Animal feed	0,062	0,062
2	Leaves + Stem	Animal feed Gypsum Ethanol	0,118 0,191 0,071	0,381
3	Entire Plant	Animal feed Gypsum Ethanol Starch	0,210 0,372 0,159 0,121	0,862

As expected, with the increase of the use of plant parts, different products appear and the products obtained in the previous scenario increases its production yield. This happens because the proposed scenarios not only consider the addition of new standalone processing lines, but to integrate the use of each part as a biorefinery. Therefore, outlet streams of a given section with potential use in another section is then fed to the respective other section (e.g. remaining solids of sugar production from the stem can be used in the animal feed section). In addition, according to the sequencing in the design of the scenarios, in Scenario 3 the solid residual fraction from the starch production section is first fed to the sugar production section in order to increase the available substrate for ethanol production and the total remaining solids from these sections go to the animal feed. With this scheme, in each scenario not only improves the individual production yield for each product, but the additional obtained value added products and the total yield of the raw material. The total yields of raw material increases with each scenario showing that the amount of products obtained per kilogram of feedstock is increasing. However, it is important to mention that the usage of raw material is 10%wt, 40%wt and 100%wt for Scenario 1, 2 and 3, respectively, achieving to use the total amount of feedstock and hence decreasing the solid waste associated to it.

3.3. Economic assessment

After performing the respective economic assessment, it was found that the most representative feature contributing to the cost is the raw materials, followed by the operational costs. This costs were calculated for a working period of 8000 hours per year. The total cost for Scenarios 1, 2 and 3 is 0,56, 0,88 and 1,2 million dollars, respectively. Generally for industrial processes, especially at small-scale, raw materials account for more than 50% of the production cost [41]. Fig. **3** shows the distribution of costs for the three scenarios. As the production processes include more stages to obtain other products the operational costs and required utilities increase, decreasing the share of the raw material, but this last is still the most significant share. The inclusion of sugar obtainment and ethanol production sections imply the use of more utilities as well as operational costs associated to distillation and hydrolysis. This explains that the biggest difference can be observed between scenario 1 and 2, while scenario 3 incorporates few equipment and hence the difference is not that notorious.

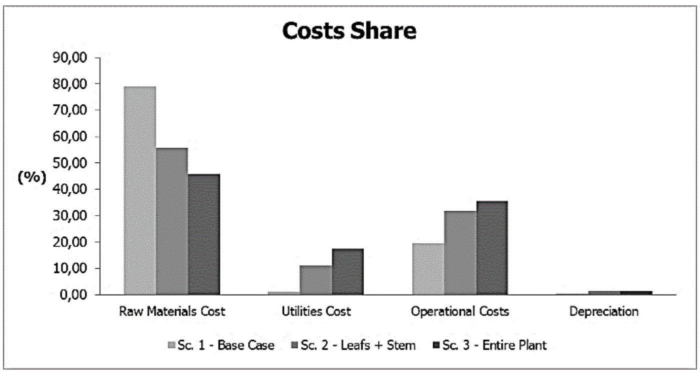


Fig. 3 Distribution of costs for the proposed scenarios using cocoyam as feedstock

Regarding the gross income margin, Table 5 shows the calculated total gross income for the three scenarios. It is clear to observe that as more parts of the plant are used, the economic performance of the process improves. This is directly associated to taking advantage of the different platforms present in cocoyam to obtain different value added products and to the integral use of the plant. Scenarios 1 and 2 present negative value for the gross income margin, which means that with the current proposed schemes the costs are considerably higher than the incomes. On the other hand, the third scenario presented a positive income margin, which shows not only that the proposed process shows a good economic performance, but that the integral use of the cocoyam under a biorefinery concept allows that the obtained by-products improve the economic performance and therefore creating a feasible process.

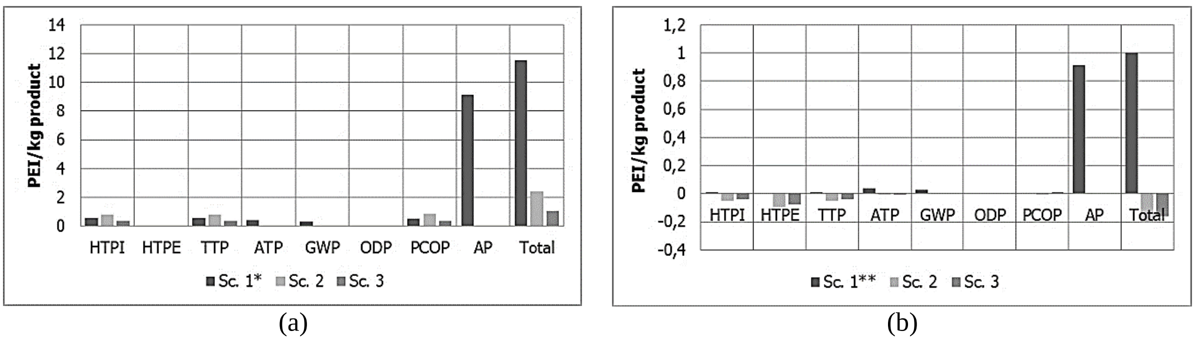
Table 5 Calculated gross income margin for the proposed scenarios

Item	Sc. 1	Sc. 2	Sc. 3
Gross Income per Product [USD/period]			
Animal Feed	98.640,00	188.480,00	335.736,00
Gypsum	-	91.896,00	594.996,00
Ethanol	-	98.177,60	219.195,42
Starch	-	-	385.832,00
Total Gross Income [USD/period]	98.640,00	378.553,60	1'535.759,42
Gross Income Margin (%)	-102,15	-33,67	21,96

Another element worth to mention is that Scenario 3 proposes a biorefinery that not only uses a plant to obtain a biofuels, but to obtain both animal feed and a compound for human consumption. This way, this biorefinery not only addresses to the production of a renewable energy source, but also to ensuring food security. In addition, the sugars platform that can be obtained from cocoyam allows the biorefinery to have certain versatility in terms of the products that can be obtained. However, the inclusion of other value added products requires further research.

3.4. Environmental assessment

Fig. **4** shows the results for the calculation of the Potential Environmental Impact both leaving the system (a) and generated by the system (b) for the proposed scenarios. Fig. **4**a shows the factors that impacts the most the PEI. For Scenario 1, all the indexes excepting for Human Toxicity per Exposition (HTPE) and Oxygen Depletion Potential (ODP) show considerable impact. Human toxicity and environment toxicity factors can be associated to the extractives, which are phenolic compounds that may be liberated to the environment if the feedstock is disposed. Global warming factors are directly associated to the decomposition of biomass. For Scenarios 2 and 3, the indexes showing more impact are the Human Toxicity per Ingestion (HTPI), Terrestrial Toxicity Potential (TTP) and Photochemical Oxidation Potential (PCOP). HTPI and TTP indexes can be associated to the compounds liberated when the stem and tuber are discarded, especially the extractives that might be released to the environment. However, the indexes decrease from Scenario 2 to 3, because of the use of the entire plant. The PCOP index can be explained by the remaining ethanol that goes out from the process in the wastes streams because volatile organic compounds, as ethanol, can form smog in the presence of NO_X gases and UV light [42].



(a) (b)

Fig. 4 Potential Environmental Impact (PEI) calculated for the proposed scenarios. (a) PEI leaving (outlet) the system (b) PEI generated (outlet – inlet) by the system.

* For scale purposes, values for the Scenario 1 had to be multiplied by a factor of 10^{-1}

** For scale purposes, values for the Scenario 1 had to be multiplied by a factor of 10^{-2}

Regarding Fig. **4**b, this information shows the results of comparing the environmental impact of the outlet streams with that of the inlet streams. It is clear to observe that Scenario 1 is the only case in which the outlet streams generate an environmental impact instead of diminishing it. Scenarios 2 and 3 show that the proposed processes decrease the environmental impact when the solid residues are used. The difference between the total PEI for Scenario 1 compared to that of Scenarios 2 and 3 is at least 100 times bigger. This information corroborates that the biorefinery scheme proposed for the integral use of the plant allows decreasing the environmental impact associated to the solid wastes.

4. CONCLUSIONS

This work demonstrated that it is technically possible, economically feasible and environmental friendly to use cocoyam to produce animal feed, ethanol and starch for human consumption. Other important conclusion is that the integral use of plants and their residues under a biorefinery scheme allows achieving better economic performance and decreasing considerably the environmental impact. In addition, considering that this is a small-scale biorefinery that showed a good performance in technical, economic and environmental terms, a small-scale biorefinery can be a promissory option for boosting rural zones. These results promote further research in the field of biorefineries and especially considering that it is possible to obtain products related to feed, food and biofuels, aiming not only to the production of renewable energy sources but to ensure food security.

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