Utilization of Soybean Hulls in Paper Production

Ana Arévalos and Jorge Rodas
Laboratorio de Control de Procesos, Departamento de Ingeniería Industrial
Facultad de Ingeniería – Universidad Nacional de Asunción. San Lorenzo, Paraguay
aarevalos@fiuna.edu.py

Eduardo Redondo
Laboratorio de Optimización, Departamento de Ingeniería Industrial
Facultad de Ingeniería – Universidad Nacional de Asunción. San Lorenzo, Paraguay
eredondo@ing.una.py

Andrea Insfran-Rivarola
Laboratorio de Producción y Métodos, Departamento de Ingeniería Industrial
Facultad de Ingeniería – Universidad Nacional de Asunción. San Lorenzo, Paraguay
andrea.insfran@ing.una.py

Regina León
Departamento de Ingeniería Industrial
Facultad de Ingeniería – Universidad Nacional de Asunción. San Lorenzo, Paraguay
rleon@ing.una.py

Abstract

In Paraguay, the opportunity to use soybean hulls in paper production stands out thanks to its cellulose content (around 40%). Therefore, the most economically convenient process has been identified in this work providing an estimated cost per tonne of paper pulp obtained from soybean hulls, in order to be installed in paper industries seeking to expand their product portfolio. The methodology adopted was based on a bibliographic review that allowed the theoretical analysis of soybean hulls characteristics as a raw material in paper production and the analysis of cellulose extraction processes from agro-industrial waste. Using only 6% of the total soybean hulls produced in the country in one year (203,566 t), a profit of US$ 1.6 million will be obtained at a sales price of US$ 775/t, making its economic value higher when it's used in paper production than in exportation or animal feeding.

Keywords
Soybean hulls, agro-waste, paper pulp, cellulose, paper production.

1. Introduction
Soybean hulls holds a high cellulose content (40%) (Camiscia et al., 2018), and its utilization as a raw material could be of interest to the paper industry. With large-scale production of paper made from soybean hulls, there would be a reduction in the quantity of imported paper reels and fiber pulp, whose values range between 600 and 900 US$/t (Dirección Nacional de Aduanas [ADUANAS] 2019, Banco Central del Paraguay [BCP] 2019, Veritrade 2020). Additionally, the identification of the most economically viable process is expected to facilitate its application in cellulose pulp industries seeking to broaden their product variety.

During 2019/2020 harvest, Paraguay ranked fifth among the world's leading Soybean producers with 9.9 million tonnes and, ranked fourth as an exporter of Soybean with 5.9 million tonnes (CAPECO 2020, CAPPRO 2020). 89% of Soybean seeds used for planting in Paraguay come from Brazil (MAG 2019).

For each tonne of soybean crushed, about 20.4% of oil, 69.9% of soybean meal and 5.8% of soybean hulls are obtained. In 2019, 38% of the total soybean production in Paraguay was industrialized (3,373,357 tonnes) and of the total produced, 96% of soybean meal, 94% of soybean oil and 37% of soybean hulls were exported (CAPPRO 2019, 2020).

1.1. Mechanical and Chemical paper pulp

Mechanical and chemical methods are applied to obtain pulp that is then converted into paper (Teschke, 2008). The process of obtaining cellulose pulp, known as pulping, consists of separating the cellulosic fibers from the lignin that holds them together (Peña et al. 2002).

Mechanical pulping is obtained by shredding trees fibers. The resulting pulp is less resistant than chemical pulping (Teschke et al. 2008).

In the chemical method, the fibers are immersed in a solution and subjected to a cooking process at high temperatures and pressures inside a digester. According to the type of reagent used, through the chemical pulp production, acid hydrolysis (Sulfite method) and/or alkaline/basic hydrolysis (Kraft method and Soda method) are produced (Peña et al. 2002 and González 2009). The chemical solution during cooking is called "white liquor" and, because it contains dissolved lignin and has a dark color is subsequently transformed into "black liquor" (Peña et al. 2002).

1.2. Paper Industry in Paraguay

In Paraguay there is no industrial production of cellulosic pulp. The existing paper companies mainly use recovered paper and cardboard waste as raw material to obtain cardboard. In addition, paper reels are imported from abroad, which are converted into numerous products such as printing paper, notebooks, office supplies or packaging (Melero et al. 2016, BCP 2019).

1.3. Agro-waste Paper Production Context

Aremu et al. (2015) obtained cellulose pulp from pineapple leaves by applying the chemical method with Soda, as in the work done by Peña et al. (2002), where the viability of producing paper pulp from banana waste was analyzed.

Carvajal et al. (2016) applied four chemical methods of lignin extraction from rice husks and sugarcane bagasse, noting that Soda method was the most economical and the least harmful to the environment.

2. Literature Review

2.1. Soybean Hulls Analysis

Soybean hulls occupy 2 to 8% of soybean seed and have 30 to 50% cellulose (Merci et al. 2019). This residue stands out among others for its low amount of lignin, making it possible to obtain pure cellulose through more economical chemical conditions and less harmful to the environment (Camiscia et al. 2018). The chemical composition of soybean hulls is compared with other lignocellulosic materials in Table 1 (Cassales et al. 2011; Carvajal et al. 2016; González et al. 2016; Merci et al. 2019).

Table 1. Chemical composition of vegetal materials.

Material	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Rice husk	39,7	15,2	28,4
Sugarcane bagasse	38,9	26,2	23,9
Soybean hulls	**31,2**	**2,3**	**1,5**
Wood	38 - 49	20 - 40	16 - 30
Banana bagasse	55,6	14	11,58

The percentages in the chemical composition shown were extracted from Merci et al. (2019) and correspond to soybean hulls imported from Brazil. In addition, soybean hulls contain pectins (4-8%), proteins (11-15%) and other components in smaller amounts (Liu et al. 2017).

Thanks to its low percentage of moisture (12.5%) ("Cáscaras Raatz" 2020), soybean hulls give the advantage of delaying deterioration and facilitating storage (González et al. 2016). Within national trade, soybean hulls have a selling price of US$130/t (892,400 Gs/t) approximately (Cargill 2020), considering US dollar at a value of 6,864 Gs (as of July 2020).

2.1.1. Main uses

For the most part, the region's agro-industries use soybean hulls in the production of animal feed (CAPPRO 2019). CAIASA uses the soybean hulls pellets that it produces as fuel for steam boilers (Osava 2016). With a 35.1% sharing of soybean processing, CAIASA allocates a total of 68,751 tonnes of hulls for this purpose.

In 2019, 71,534 tonnes of soybean hulls were exported at an average cost of US$97/t in the region (ADUANAS 2019, CAPPRO 2020).

Of the total soybean hulls produced in 2019 (195,873 tonnes) (CAPPRO 2019), the percentages corresponding to the exported quantity and its use as fuel in CAIASA are shown in Table 2 (CAPPRO, 2020). By applying Simple Moving Average (SMA) formula (1) to the years from 2017 to 2019, a more precise percentage of the use of the hulls as animal feed is obtained.

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} Data_i (1)$$

Table 2. Availability of soybean hulls in 2020.

		Current Situation (Year 2020)					
				Usage			
Year	Produced	Exported	%	Fuel	%	Animal Feed	%
2019	195.873	71.534	37	68.751	35	55.588	28
2018	212.985	106.440	50	74.758	35	31.787	15
2017	201.839	103.469	51	70.845	35	27.524	14
		Proposed Situation					
	Production	Paper	%	Animal Feed			%
	203.566	164.888	81	38.678			19

It is proposed to use 19% of the hulls produced for animal feed to national and/or foreign market and 81% to paper production. As a result, an annual value of approximately 164,888 tonnes of hulls available in the next few years is estimated and this value is used for the subsequent calculations in this work.

2.1.2. Market of Soybean-Hull paper

Potential customers for soybean hull paper are printing and paper distribution industries, which are distinguished by the quality of their printing and writing papers. Those industries import paper reams and reels for manufacturing at prices ranging from US$630/t to US$850/t (ADUANAS 2019, BCP 2019, Veritrade 2020).

As there are no industries that produce virgin fiber pulp in Paraguay, a local company will be used as an analysis, expecting it will be replicable at industrial plants in the same field. The company is Grupo Yaguareté S.A., whose business unit called Cartones Yaguareté S.A. is responsible for the packaging production, 70% of which is made of recycled paper and 30% of high-quality Kraft (virgin fiber) for the Paraguayan industry (Cartones Yaguareté S.A. [CYSA] 2017).

With the implementation of a paper production line from soybean hulls, this company could offer a differentiated product that would allow the printing industries to increase the variety of their products and reduce the number of imported tonnes of paper and virgin fiber, which in 2019 reached a total of 28,108 tonnes valued at US$4,539,000 (BCP 2019).

2.2. Cellulose Extraction Processes

The authors mentioned below agree on the low cost and low environmental impact caused by the use of Soda (NaOH) as a reagent in cellulose extraction.

In the cellulose pulp washing stages involving solvents (hexane and ethanol), the data presented by Seefeldt (2012) are used: for each raw material tonne processed, a consumption of 11.4 liters of solvent is estimated, considering that these are recovered and recirculated to the system. To calculate washing water use, the maximum capacity of the equipment where this process will be carried out (6 t/h) is taken into account (item 3.1.2.). Thus, for each tonne of cellulose produced, 5 m3 of water will be necessary, 50% of which will be recovered by evaporators.

2.2.1. Process 1: Camiscia et al. (2018)

The procedure performed by Camiscia et al. (2018) (Figure 1) allowed a yield of 41 ± 6% of the initial hulls weight in cellulose.

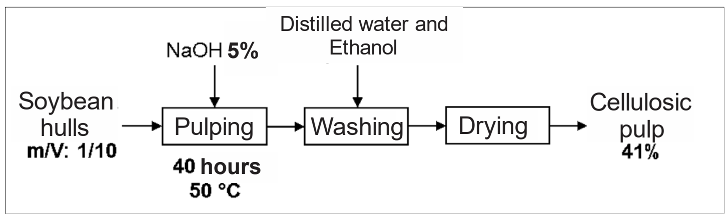


Figure 1. Process 1 Diagram

2.2.2. Process 2: Carvajal et al. (2016)

Rice husk lignin (28% lignin) was extracted by Soda-chemical method (Figure 2) (Carvajal et al. 2016).

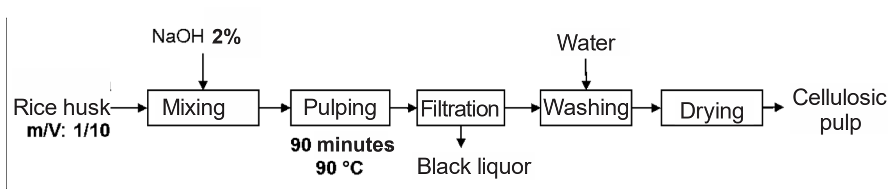


Figure 2. Process 2 Diagram

The yields on which the work of Carvajal et al. (2016) was based were extracted from Nikzard et al. (2013), who also applied the alkaline hydrolysis method to rice husk, with differences in the chemical composition of the analyzed husk, in the cooking time and at a pressure of 103.4 kPa. This experiment allowed obtaining 54.31% cellulose with 69% delignification for the rice husk containing 19% lignin. It is also mentioned that lignin removal improves cellulosic conversion so that it is quite likely to obtain a variable yield between 40 and 50% in the process of Carvajal et al. (2016) adapted to soybean hulls, since it contains very little amount of lignin (1.5%). Considering the above, a 45% expected yield is adopted.

2.2.3. Process 3: Seefeldt (2012)

Seefeldt (2012) performed a pretreatment to soybean hulls using hexane, ethanol and water, removing unwanted substances. Figure 3 represents the cellulose extraction process applied by Seefeldt (2012).

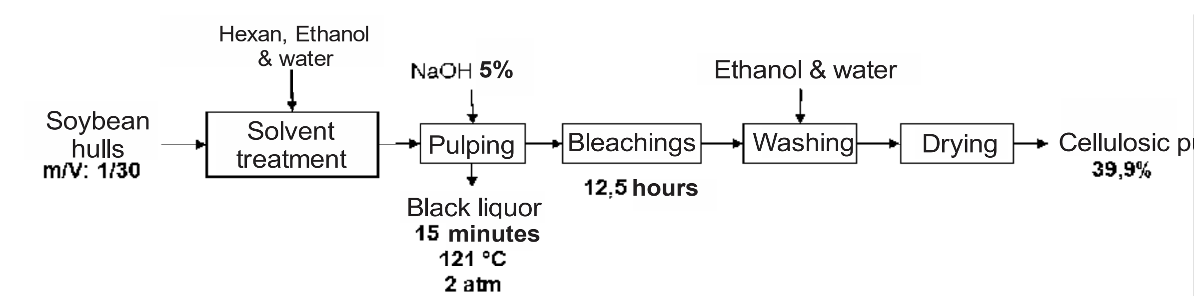


Figure 3. Process 3 Diagram.

Seefeldt (2012) proposes to take the process to industrial scale, with equipment according to the following production stages: a solid-liquid extractor is used for pretreatment, alkaline pulping is carried out in a batch reactor with forced circulation. Subsequently, the pulp is bleached inside reactors with mechanical agitation and finally, the pulp is washed with ethanol and water, and then passed to an industrial dryer.

The approximate value of the total yield of this process is 31.9%. On the other hand, Seefeldt (2012) points out that this process allows obtaining cellulose of very high quality for use in medicine. Excluding the bleaching stages, a total yield of 39.9% would be obtained, and without the pretreatment it is estimated that the total yield would be close to 45%, values similar to those presented in Camiscia et al. (2018) and Carvajal et al. (2016).

3. Evaluation of Soybean Hulls in Paper Production

The implementation of the selected process will be evaluated as the most economically convenient. First, the consumption of raw materials and inputs of the processes mentioned (Table 3) in the previous chapter is analyzed in order to obtain a base cost that will be complemented with those associated with the recovery of the black liquor, logistics and electric power. Table 3 was adapted from Seefeldt (2012); Camiscia et al. (2018); Carvajal et al. (2016) using data from Veritrade; Cargill; Empresa de Servicios Sanitarios del Paraguay S.A. [ESSAP]; Dirección Nacional de Contrataciones Públicas [DNCP]; Fluoder (2020). The volume of NaOH and water solution is considered to be equal to the sum of the mass of NaOH in liters and the volume of water (in liters). It also includes the volume of recovered liquor (85%).

Table 3. Raw material and input costs according to analyzed processes

Input	Gs/unit	Process 1	Process 2	Process 3
Soybean Hulls	893	2.439 kg **(68%)**	2.222 kg **(85%)**	2.505 kg **(53%)**
NaOH	5.060	174 kg **(27%)**	65 kg **(14%)**	306 kg **(37%)**
Water	7	4.234 L	4.015 L	7.897 L
Hexane	4.230	-	-	28 L
Ethanol	4.530	25 L	-	56 L
Total (Gs)		3.214.744	2.343.055	4.211.756
US$/t		**468**	**341**	**614**

It is observed that the costs related to soybean hulls and NaOH account for most of the total input costs. From the comparison of costs related only to input consumption, it is presumed that the process presented by Carvajal et al. (2016) is the most economically convenient. However, to support this assumption, the most significant differences between the processes presented will be shown below.

3.1. Selection of the Most Convenient Process

Processes involving greater use of NaOH reagent are Processes 1 and 3, due to the values selected for the raw material/solution and reagent concentration parameters. It is quite likely that the estimated costs for these processes are due to the medical use that will be given to the cellulose obtained, for which it will be necessary to perform the extraction under a higher reagent concentration. In addition, to increase the quality of the final product in these processes, unwanted extracts were eliminated with solvents before or after the pulping stage. Washing the cellulose with solvents after pulping or cooking would require the installation of additional washing and filtering equipment (worth about US$100,000) to avoid mixing solvents with water. Also, the recovery of solvents would mean the designation of an extra set time for their evaporation besides the time destinated to black liquor.

Process 1 (Camiscia et al. 2018) suggests that the cooking process of cellulosic fibers with the sodium hydroxide solution has a duration of approximately 40 hours.

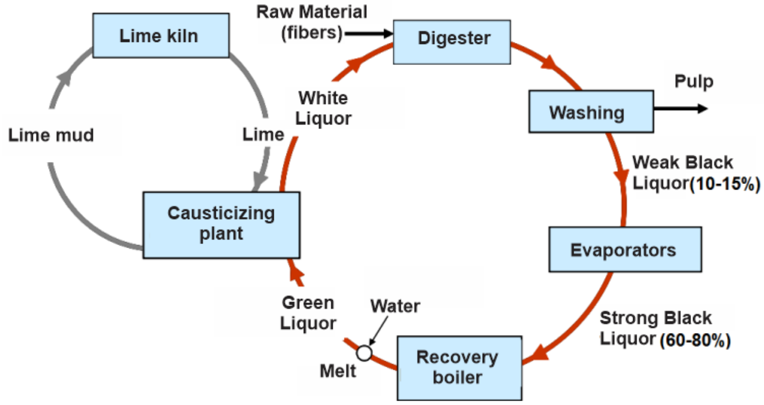
On the other hand, Process 3 (Seefeldt 2012) involves solid-liquid extraction equipment that uses solvents to remove extractives from the hulls, decreasing the pulp yield. The mentioned equipment has an acquisition value that ranges between US$25,000 and US$30,000 in the market, depending on its technical specifications.

Process 2 (Carvajal et al. 2016) stands out for using less reagent, less raw material and for not using solvents (ethanol and hexane), avoiding the acquisition of additional equipment. Finally, this is expected to produce cellulosic pulp suitable for printing and writing, so the analysis of Processes 1 and 3 is not considered relevant.

3.1.1. Black liquor Recovery

The efficiency provided by this process is approximately 97% (Tran et al. 2008). Thus, this liquor recovery process (Figure 4) (Tran et al. 2008) is adapted to the soda method of cellulose extraction from soybean hulls.

Figure 4. Black liquor recovery process.



The black liquor separated from the pulp contains 15% of solids (De Moura et al. 2018) and is concentrated in the evaporators up to more than 60% (Fleck 2009; Becerra 2016). With an estimated analysis, the percentage of solids in the weak black liquor from filtering and washing would be close to 6%. The quantities produced of black liquor per unit mass of cellulose obtained are estimated in Table 4 (Becerra 2016; De Moura et al. 2018; Alibaba 2020).

Table 4. Black liquor analysis per tonne of cellulose produced

Material	Quantity
Weak black liquor (6% of solids)	27,5 t
Concentrated liquor (up to 76%)	6,6 t
Melted black liquor (20% of the concentrated liquor)	1,3 t
Water for melting (17%)	0,2 m^3
Lime (5%) for melting	0,066 t
Cooling water for evaporators	15 m^3

3.1.2. Equipment according to production stages

It is proposed to implement the equipment in Table 5. Additionally, it is intended to convert cellulosic pulp into paper with a Fourdrinier machine. Data extracted from "Caldeiras: Previsões otimistas contam com varias justificativas" 2001; Ferrarini 2016; Alibaba; Made-In-China; Subsecretaría de Estado de Economía; Record Electric, 2020.

Table 5. Proposed Equipment according to production stages

Equipment	Cost (US$)	Import tariff (%)	Capacity	kW
Cellulose extraction				
Mixing tank	10.000	14	29,5 m^3	22
Digester	30.000	14	25 m^3	11
Filtering and washing tank	100.000	14	6,625 t	21
Fourdrinier	450.000	14	1,25 t	265
Conveyor belts	16.000	18	7,5 t	11
Liquor and solvent recovery				
Evaporators	100.000	14	10 m^3	21
Cooling tower.	14.000	14	60 m^3	6
Recovery boiler	520.000	14	2 t	6
Reactor	39.000	14	15 t	38
Lime kiln	80.000	14	1,3 t	19
Other equipment	30.000	14	-	30

The black liquor recovery circuit includes a cooling tower for the water required by the evaporators, in addition to other equipment including storage tanks and four hydraulic pumps of 7.5 kW each (Record Electric 2020).

3.2. Cellulose Production Costs

The calculus of production cost per mass unit of cellulosic pulp was based on the work of Mues et al. (2018), where fixed and variable costs are included in the determination of the production cost of Kraft and mechanical pulp. The installation of a cellulose extraction line from soybean hulls is considered to produce A4 size paper and estimated grammage of 75 g/m2 in the corrugating plant of Grupo Yaguareté, located in Ciudad del Este, Alto Paraná.

The annual production of the line is estimated according to the lower capacity established by the equipment mentioned above. That is: 1.25 t/h for the Fourdrinier equipment which, with two 8-hour shifts and 24 working days per month, will have a value of 480 t/month and 5,760 t/year of cellulose paper (Mues et al. 2018).

3.2.1. Electricity Costs

Electricity costs are obtained according to the calculation shown in Fleck (2009), with electricity rates included in Table 6 (adapted from Fleck 2009; Administración Nacional de Electricidad [ANDE] 2020). "Gs" is Paraguay's national currency Guaraní (Gs). The boiler generates the steam supplied to industrial plant equipment.

Table 6. Electricity cost calculus

Tariffs	Reserved Power		41.126	Gs/kW/month
	Excess Reserved Power		87.533	Gs/kW/month
	On-Peak Energy		331,93	Gs/kWh
	Off-Peak Energy		144,83	Gs/kWh
Data	Production hours/month	384		
	kWh/month	172.800		
	Peak and off-peak reserved power	450 kW		
	Peak Load Energy (4 hours)	1.800 kWh		
	Off-Peak Energy (12 hours)	5.400 kWh		
Calculus	In-Point Rate		2.089	US$/month
	Off-Peak Rate		2.735	US$/month
	Reserved Power Constant Rate		2.696	US$/month
	Total Tariff	**7.520**		**US$/month**

3.3. Logistics Costs

It is expected that the proposal for cellulose extraction from soybean hulls will be replicable in other industrial plants similar to the local company (Yaguareté S.A.) that was considered in the calculation of logistical costs. It is considered that soybean hulls will be acquired from Cargill production plant located 32.2 km away from the Yaguareté S.A. plant.

On the other hand, the data related to the loading and trip of Scania tractor/truck trailers (estimated dimensions of the loading space: 14m long, 3m high and 2m wide) are shown in Table 7 (data from Fundación Española para el Desarrollo de la Nutrición Animal [FEDNA] 2012; Panzera 2015; Petrobras; Dirección Nacional de Transporte [DINATRAN] 2020).

Table 7. Considered logistic data

Data	Value	
Maximum load/truck	84 m^3 or 40 t	
Fuel consumption/truck	0,294	L/km
Fuel cost (diesel)	0,79	US$/L
Cost/km	0,23	US$
Soybean Hull Density - NaOH - Ground lime	0,15 - 2,13 - 1	t/m^3
Max. load/soybean hull truck	13	t
Max. load/hydroxide and lime truck	40	t

The logistics costs are shown in Table 8 (using data from Petrobras 2020; J. C. Construcciones S.A. 2020), which considers the monthly production of 480 tonnes of pulp and cost of US$ 0.23/km.

Table 8. Logistics costs

Freight	t/month	t/trip	Trips	km/trip	US$/month
Soybean Hulls	1.067	12,60	85	32,2	**639**
Sodium Hydroxide	31	40	1	333	**78**
Quicklime	32	40	7	8	**59**
				Total	**776**

3.4. Total Cost

The calculations (Table 9) do not include costs related to real estate depreciation and effluent treatment, since this proposal will mean the expansion of an already established plant. Table adapted from Fleck (2009); Mues et al. (2018) using data from Made-In-China (2020); Alibaba (2020).

Table 9. Costs distribution

Detail				**Fixed**	**Variable**
Raw Material and inputs	**tRM/t**	**US$/t**	**t/month**	**US$/month**	
Soybean hulls	2,222	130	1.066,6		138.653
NaOH	0,065	737	31		23.125
Lime	0,066	194	32		6.135
Logistic					776
10-year Depreciation	**Adq. + Import. (US$)**		**Mant. (5%/year)**		
Mixing tank	11.400		42	137	
Digester	34.200		125	410	
Filtering and washing tank	114.000		417	1.367	
Fourdrinier	513.000		1.875	6.150	
Conveyor belts	18.880		67	224	
Evaporators	114.000		417	1.367	
Cooling tower	15.960		58	191	
Recovery boiler	592.800		2.167	7.107	
Causticizing Reactor	44.460		163	533	
Lime kiln	91.200		333	1.093	
Other equipment	34.200		125	410	
Water	**m^3/t**	**US$/$m^3$**	**m^3/month**		
Pulping and washing	4		1.928		1.967
Evaporators cooling	15	1,02	7.200	3	7.343
Melted liquor	0,2		108		110
Electricity				2.696	4.824
Salary	**Salary (US$)**		**US$/month**		
80 Operators	321		25.641	25.641	
2 Production managers	510		1.020	1.020	
2 Administration managers	510		1.020	1.020	
				49.369	182.931
			Total	**232.300 US$/month**	
			Unitary	**484 US$/t**	

Figure 5 shows the incidence of costs on the value per tonne of pulp produced according to Process 2. The cost of water used during pulp extraction was considered as a service cost.

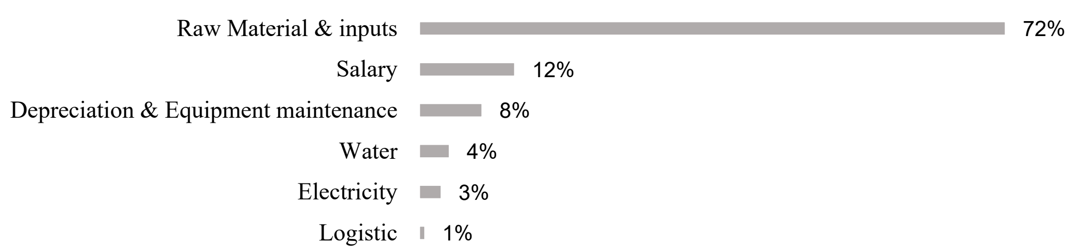


Figure 5. Percentage share according to costs.

Logistics costs are insignificant compared to other costs, meaning the location of the industrial plant would not have a major impact on the cost per unit of cellulose mass obtained from soybean hulls.

4. Economic analysis of the product

The monthly pulp production is related to the capacity of the machine with the lowest hourly production (1.25 t/h in the Fourdrinier). By having a capacity of 2 t/h in the paper machine, about 20,000 tonnes of soybean hulls would be utilized annually per production line, since the utilization reaches only 12,800 tonnes of hulls (8% of the estimated total available and 6% of the total produced in a year).

This implementation is estimated to represent the production shown in Table 10, along with wood and water savings that this would imply. About 1.76 tonnes of wood and 40 m3 of water are necessary to produce one tonne of tree cellulose pulp (Oliveira 2017, "Kopapel, company that makes paper with banana peels" 2018), considering the use of 28 m3 of water per tonne of soybean hull cellulose.

Table 10. Estimated cellulose to obtain

Available Soybean hulls: 164.888 tonnes			
Utilization	**Cellulose (t)**	**Savings**	
		Wood (t)	**Water (m^3)**
8% per line	5.760	10.138	69.120
30%	20.755	36.529	249.060
40%	27.674	48.706	332.088

Compared to the import cost of chemical pulp obtained from wood using the soda method (US$ 630), the estimated calculation of the process studied shows a positive difference (23%) that will probably be slightly reduced with the inclusion of the cost associated with effluent treatment. Since it is a non-wood raw material, the added value of soybean hulls is mainly reflected in the environmental advantages generated by its use.

It is likely that the percentage of black liquor recovery varies according to the selected industrial equipment. With a liquor recovery of 85 to 97% in Process 2 (Carvajal et al. 2016), the costs associated with raw material and input consumption are reduced by 45 to 52%, and the total cost varies between 442 and 484 US$/t for a yield of 45%.

With lower supplies acquisition costs, total unit cost per tonne could become competitive against pulp extracted from wood and non-wood sources. At a commercial level, estimated sales price between 650 and 750 US$/t for soybean hull cellulosic pulp would possibly allow to achieve profit between 3 and US$6 million (with 40% of hulls used).

5. Results

Analyzing the actual total produced soybean hulls per year (203,566 t), the Figure 6 shows profit according to the percentage of utilization in the main uses of soybean hulls. For paper calculations, a sales price equal to 600 and 750 US$/t produced at a cost of 484 US$/t was considered, applying Process 2 (Carvajal et al. 2016) with a yield of 45%.

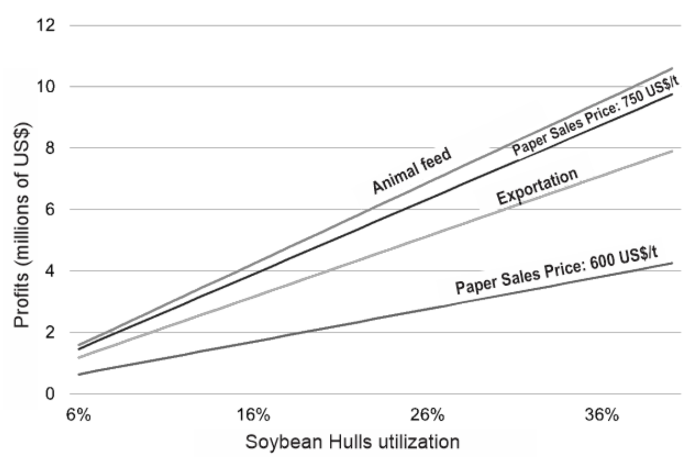


Figure 6. Profit vs. soybean hull utilization according to main uses.

With a sales price equal to US$700/t of cellulose, the value of soybean hulls used in paper production will be similar to that exported internationally (US$97/t), while with a sales price equal to US$770/t, it will have a value close to that used for animal feed in Paraguay (US$130/t).

Regarding the opportunity to produce printing or writing paper from soybean hulls and offer it to the market, for each tonne of cellulose pulp, 425 paper reams with a total of 212,500 A4-sized sheets (21 x 29.7 cm) would be obtained. The cost of A4 sheets of soybean hulls paper would be close to 15.6 Gs/sheet and, it is expected that at a sales price similar to unbleached sugarcane bagasse paper (43 Gs/sheet), its profit value would be close to 175% (JW Enterprises S.A. 2020; Bringco 2020).

Assuming only 6% of usage of the total amount of soybean hulls produced in a year, calculated using the Simple Moving Average Formula, the percentages corresponding to each use of soybean hulls are shown in Table 11.

Table 11. Distribution of Soybean hulls utilization

Produced	Exported	%	Paper	%	Fuel	%	Animal	%
203.566	81.426	40	12.214	6	71.248	35	38.678	19

6. Conclusion

The literature review allowed to identify methods for Soybean hulls utilization. Process studied by Carvajal et al. (2016) stands out as the most convenient in economic and efficiency terms. In combination with a reagent recovery system of 85%, more than 40% of yield is expected at a cost of 484 US$/t of cellulose extracted from soybean hulls.

The utilization of soybean hulls in paper production could reduce the costs associated with importing cellulose pulp for paper production, which currently amount to US$4 million per year locally.

A pulp production's line setup at a cost of US$ 484/t, using only 6% of the total amount of hulls produced in Paraguay in a year (203,566 t), would generate US$ 1.6 million of profit at a sale price equal to US$ 775 and having a higher economic value than the hulls exported or used as animal feed.

It is expected that the valorization of this residue will generate a positive socioeconomic impact in Paraguay. With the 40% of available hulls utilization, about 48,000 tonnes of wood and more than 330,000 m3 of water would be saved.

For future work, there is a need to characterize Paraguayan soybean hulls to determine the real amount of cellulose that can be extracted from them, along with the costs and benefits that their extraction implies.

References

ADUANAS, Dirección Nacional de Aduanas. Consulta de Datos Abiertos: Cascarilla, 2019.

Alibaba, High Capacity 20-ton Printing Paper Making Machine for Bamboo Pulp; Industrial Liquor Evaporation Triple-effect Vacuum Plate type Evaporator; Lime calcination furnace lime rotary kiln lime production plant; Stainless steel high pressure chemical reactor prices with magnetic stirrer agitated tank mixing tank, 2020.

ANDE, Administración Nacional de Electricidad. Pliego de tarifas N° 21, 2020.

Aremu, M. O., Rafiu, M. A., & Adedeji, K. K., Pulp and paper production from Nigerian pineapple leaves and corn straw as substitute to wood source, *International Research Journal of Engineering and Technology*, vol. 2, no. 4, pp. 1180-1188, 2015.

BCP, Banco Central del Paraguay, Boletín de Comercio Exterior - Trimestral; Informe de Comercio Exterior - Mensual, Diciembre – Cuadros, December, 2019.

Becerra, A. Evaluación de la Sustentabilidad del Aprovechamiento del Bagazo de Caña de Azúcar en el Valle del Cauca–Colombia a partir del Análisis de Ciclo Vida (Master's Thesis). Universidad Distrital Francisco José de Caldas, Colombia, 2016.

Bringco, Papelería - Resmas de papel. Available: https://www.bringco.com.py/resma-report-premium-a4-br/art_688/, 2020.

"Caldeiras: Previsões otimistas contam com varias justificativas", Química e Derivados. Available: https://www.quimica.com.br/caldeiras-previsoes-otimistas-contam-com-varias-justificativas/2/, 2001.
CAPECO, Cámara Paraguaya de Exportadores y Comercializadores de Cereales y Oleaginosas, Situación de la cosecha, producción de soja de la campaña 2018-2019 y sus implicancias, 2019.
___Áreas de Siembra, Producción y Rendimiento; Destino Final; Ranking Mundial, 2020.
CAPPRO, Cámara Paraguaya de Procesadores de Oleaginosas y Cereales, Proyección de la Agroindustria en Paraguay, 2018.
___Situación de la molienda de oleaginosas. Informe trimestral - Tercer trimestre 2019; Situación de la molienda de oleaginosas. Informativo Mensual - Diciembre 2019, December 2019.
___Histórico de Producción de Derivados de Soja de CAPPRO; La cámara. Empresas Asociadas. Capacidad Instalada e Inversiones, Molienda de Soja y Otros Granos. USDA - Estimaciones soja, 2020.
Camiscia, P., Giordano, E. D., Brassesco, M. E., Fuciños, P., Pastrana, L., Cerqueira, M. F., Picó, G.and Valetti, N. W. Comparison of soybean hull pre-treatments to obtain cellulose and chemical derivatives: Physical chemistry characterization. *Carbohydrate polymers*, vol. 198, pp. 601-610, 2018.
Cargill, Localidades. Available: https://www.cargill.com.py/es/localidades, 2020.
CYSA, Cartones Yaguarete S.A., Reporte de Sustentabilidad 2017, 2017.
Carvajal, J. C., Gómez, Á., and Cardona, C. A. Comparison of lignin extraction processes: Economic and environmental assessment. *Bioresource technology*, vol. 214, pp. 468-476, 2016.
"Cáscaras Raatz", Pellets de cáscara de soja, 2020
Cassales, A., de Souza-Cruz, P. B., Rech, R., and Ayub, M. Z. Optimization of soybean hull acid hydrolysis and its characterization as a potential substrate for bioprocessing. *Biomass and bioenergy*, vol. 35, no. 11, pp. 4675-4683, 2011.
DINATRAN, Dirección Nacional de Transporte. Normativa sobre Pesos y Dimensiones Vehiculares, vigente desde 1997, 2020.
DNCP, Dirección Nacional de Contrataciones Públicas. Adquisición de alcohol absoluto de INPASA, 2020.
ESSAP, Empresa de Servicios Sanitarios del Paraguay S.A., Tarifario de servicio, 2020.
ETSAP, Energy Technology Systems Analysis Programme, International Energy Agency, Pulp and Paper Industry, *Technology Brief*, 2015.
FEDNA, Fundación Española para el Desarrollo de la Nutrición Animal. Cascarilla de soja, 2012.
Ferrarini, R. S. (2016). Comparação de Abordagens Termoeconômicas: Aplicação a um Sistema de Cogeração do Setor de Papel Celulose (Master's Thesis). Universidade Federal do Espírito Santo, Brasil, 2015.
Fleck, J. Estudio de factibilidad económica del uso del bagazo de caña de azúcar para la obtención de papel de impresión y escritura en el Paraguay (Master's Thesis). Universidad Nacional de Misiones, Argentina, 2009.
Fluoder. Available: https://www.facebook.com/Fluoder/, 2020.
González, A. Hidrólisis, 2009.
González, K. D., Daza R., Caballero, P. A., and Martínez, C. Valuación de las propiedades físicas y químicas de residuos sólidos orgánicos a emplearse en la elaboración de papel. *Revista Luna Azul*, no. 43, pp. 499-517, 2016.
J. C. Construcciones S.A., 2020.
JW Enterprises S.A., Papelería, 2020.
"Kopapel, empresa que hace papel con cáscaras de plátano" (January 26, 2018). Available: https://elempresario.mx/emprendedores/kopapel-empresa-que-hace-papel-cascaras-platano, 2018.
La Casa de las Varillas. Materiales de construcción, 2020.
Liu, H. M., and Li, H. Y. Application and conversion of soybean hulls. In *Soybean-The Basis of Yield, Biomass and Productivity,* pp. 111-132. IntechOpen, 2017.
Made-In-China. CTI Certified FRP Closed Circuit Cross Flow Cooling Tower (JNC-70T); Chemical Mixing Tank Pulp Agitation Tank; Spherical Digester for Paper Making Production Line; Vacuum Drum Washer, Pulp Washing Equipment; Waste Paper Virgin Pulp Convey Equipment Chain Conveyor, 2020.
MAG, Ministerio de Agricultura y Ganadería, Soja, Síntesis Estadísticas, 2019.
Melero, J. M., and Steinmetz, A. Análisis de Mercado en Paraguay - Sobre la capacidad de cumplir con criterios de sustentabilidad para el sector del papel y madera, y el sector químico de limpieza, 2016.
Merci, A., Marim, R. G., Urbano, A., and Mali, S.. Films based on cassava starch reinforced with soybean hulls or microcrystalline cellulose from soybean hulls. *Food Packaging and Shelf Life*, vol. 20, no. 100321, 2019.
Moura de, J., Souza de, T., Zorthea G., Aparicio T., and Moreno F. Análise da Eficiência Energética em Segmentos Industriais Selecionados. Segmento Celulose e Papel, 2018.
Mues, F., Rolón, J. N., and Rodriguez, M. E.. Determinación de Costos para la Producción de Celulosa mediante Método Kraft y Mecánico. *Revista* Tecnología y Ciencia, no. 32, pp. 307-318, 2018.

Nikzard, M., Movagharnejad, G., Najafpour, D., and Talebnia, F. Comparative studies on the effect of pretreatment of rice husk on enzymatic digestibility and bioethanol production. *Int. J. Eng.,* vol. 26, no. 5, pp. 455–464, 2013.
Oliveira, L. How much paper can you get from a tree? (February 27, 2017). Available: https://www.linkedin.com/pulse/how-much-paper-can-you-get-from-tree-luciano-r-oliveira/, 2017.
Osava, M. La soja alimenta la industrialización en Paraguay. (March 23, 2016). Available: http://www.ipsnoticias.net/2016/03/la-soja-alimenta-la-industrializacion-en-paraguay/, 2016.
Panzera, D. Scania se destacó en la categoría «Consumo de Combustible» en el Desafío de Camiones Europeos. (January 15, 2015). Available: https://www.16valvulas.com.ar/scania-se-destaco-en-la-categoria-consumo-de-combustible-en-el-desafio-de-camiones-europeos/#:~:text=Obtuvo%20un%20promedio%20de%20consumo,de%20su%20competidor%20m%C3%A1s%20cercano, 2015.
Paradiso, A. Al rescate de la cascarilla de soja: un valioso residuo agrícola. Available: https://www.rosario-conicet.gov.ar/index.php/ver-noticias/item/991-al-rescate-de-la-cascarilla-de-soja-un-valioso-residuo-agricola, June 22, 2018.
Peña, J. A., & González, R. O. Estudio de prefactibilidad para la producción de pulpa para papel aprovechando los desechos del cultivo del plátano en la región del viejo caldas (Doctoral Thesis). Universidad Nacional de Colombia, Colombia, 2002.
Petrobras, Combustibles - Lista de precios. 2020.
Record Electric, Bombas de Aplicaciones Industriales, 2020.
Sanz, A. T. *Tecnología de la celulosa. La industria papelera*, 2014.
Seefeldt, A. T.. Obtenção de nanocompósitos de poli (ácido lático) e nanocristais de celulose de casca de soja (Bachelor's Thesis). Universidad Federal do Rio Grande Do Sul, Brasil, 2012.
Subsecretaría de Estado de Economía. Arancel a la importación - Arancel Nacional Vigente, 2020.
Teschke, K., Demers, P., Keefe, A., Astrakianakis, G., Anderson, J., and Heederik, D. *Industria del papel y de la pasta de papel.* Guía de Riesgos profesionales y controles de la Enciclopedia de Salud y Seguridad en el trabajo, 2008.
Tran, H. and Vakkilainnen, E. The kraft chemical recovery process. *Tappi Kraft Pulping Short Course*, pp. 1-8., 2008
Veritrade. Available: https://www.veritradecorp.com/es/consultas. Accessed on July 13, 2020.

Biographies

Ana Arevalos is a graduated from Industrial Engineering at Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay. She is currently completing her Master's degree in Industrial Engineering from Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay in collaboration with the Pontificia Universidad Católica de Valparaíso, Chile. She carried out this research work at the Laboratorio de Control de Procesos del Departamento de Ingeniería Industrial de la Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay.

Jorge Rodas was a Researcher at the Laboratorio de Control de Procesos del Departamento de Ingeniería Industrial de la Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay.

Eduardo Redondo is a Researcher at the Laboratorio de Optimización del Departamento de Ingeniería Industrial de la Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay.

Andrea Insfran-Rivarola is the Lean Production and Six Sigma's Professor and Researcher at the Laboratorio de Producción y Métodos del Departamento de Ingeniería Industrial de la Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay.

Regina León is a Researcher at the Departamento de Ingeniería Industrial de la Facultad de Ingeniería de la Universidad Nacional de Asunción, Paraguay.