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Meio Ambiente

Análise da gestão ambiental de indústrias de amido de mandioca: oportunidades para uma produção mais limpa

Analysis of the environmental management of cassava starch industries: opportunities for a cleaner production

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ABSTRACT: Cassava processing to obtain starch generates large amounts of solid waste and effluents that can become environmental liabilities. The aim of this study was to profile the cassava industries in Paraná, Brazil, regarding the use of natural resources and waste generated, as well as the environmental management strategies adopted, to identify opportunities that result in Cleaner Production (CP). A questionnaire was applied in 18 industries, and the bagasse generated in seven of them had its physical-chemical composition determined. The amount of bagasse generated ranged from 200 to 1000 kg ton^{-1} of processed roots, that was generally intended for animal feed; but it has potential for other applications due to its starch content (57.7 g 100 g^{-1}) and dietary fibers (35.3 g 100 g^{-1}). There was significant water consumption (1.50 to 19.20 m^3 ton^{-1} of roots) resulting in high effluent generation (1.25 to 11.52 m^3 ton^{-1} of roots), which entails costs for treatment. All the industries have biodigesters, a covered lagoon system, one of the main CP mechanisms, as it enables firewood replacement that generates greenhouse gas emissions and waste from boilers; and there is production of energy and biofertilizers. Of the industries, ~30% stood out in terms of efficiency in water consumption, generation of solid and liquid waste, with cost reduction in effluent treatment. The transfer of technologies between industries is important to promote the sustainability of the production chain, with the adoption of CP.

Keywords: Bagasse; Biodigester; Effluents; Natural resources.

RESUMO: O processamento de mandioca para obtenção de amido gera grandes quantidades de resíduos sólidos e efluentes que podem se tornar passivos ambientais. O objetivo deste estudo foi traçar perfis das indústrias de mandioca do Paraná, Brasil, quanto ao uso dos recursos naturais e resíduos gerados, bem como as estratégias de gestão ambiental adotadas, para identificar oportunidades que resultem em Produção Mais Limpa (PML). Foi aplicado questionário em 18 indústrias, e o bagaço gerado em sete delas foi determinada a composição físico-química. A quantidade de bagaço gerado variou de 200 a 1000 kg ton^{-1} de raízes processadas, o qual é geralmente destinado à alimentação animal, mas tem potencial para outras aplicações devido ao teor de amido (57,7 g 100 g^{-1}) e fibras alimentares (35,3 g 100g^{-1}). Houve consumo de água significativo (1,50 a 19,20 m^3 ton^{-1} de raízes) resultando em alta geração de efluentes (1,25 a 11,52 m^3 ton g^{-1} de raízes), o que acarreta custos para tratamento. As indústrias possuem biodigestores, sistema de lagoas cobertas, um dos principais mecanismos da PML, pois possibilita a substituição de lenha que gera gases causadores do efeito estufa e resíduos nas caldeiras; e permite a produção de energia e biofertilizantes. Das indústrias, ~30% se destacaram em termos de eficiência no consumo de água, geração de resíduos sólidos e líquidos, com redução de custos com tratamento de efluentes. A transferência de tecnologias entre as indústrias é importante para promover a sustentabilidade da cadeia produtiva, com a adoção de PML.

Palavras-chave: Bagaço; Biodigestor; Efluentes; Recursos Naturais.

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INTRODUCTION

Brazil is one of the world's largest producers of cassava (*Manihot esculenta* Crantz) with an estimated production of 18 million tons (FAO, 2020). In the country, a part of the roots is intended for starch extraction (Rojas *et al*., 2019). In 2018, Brazilian production of cassava starch, also known as *fécula* or *polvilho*, reached 536 thousand tons, destined basically for the domestic market. Most of the cassava processing industries are located in the state of Paraná/Brazil (59%), with production capacity above 60% of the national one (SEAB 2016).

The extraction of cassava starch in industries occurs by a set of processes that involve the steps of weighing and unloading the roots, peeling and washing, crushing, sifting (separation of fibers), soaking, concentration by decantation or centrifugation and dehydration. These processes require intense consumption of thermal, electrical and water energy (Padi; Chimphango, 2020a). It is estimated that 10 to 60 m^3 of water are consumed for each ton of starch produced, and 70% of the consumption occurs in the washing and soaking steps for fiber separation (Ghimire *et al*., 2015; Chavalparit; Ongwandee, 2009).

The cassava industries generate significant amounts of solid waste, with bagasse being the main residue, obtained in the crushing and sieving of the roots (Zhang *et al*., 2016). For every ton of processed cassava root, 928 kg of bagasse is generated (on wet basis), which still contains 45 to 78% of the starch and a high amount of fiber, so, it can be a raw material for several products (Teixeira *et al*., 2012). However, the high moisture content of the cassava bagasse, 75 - 88%, makes it difficult to transport and store, imposing immediate disposal or its use as animal feed (Cereda, 2005; Martinez *et al*., 2018).

The liquid residue of starch extraction, known as *manipueira*, is composed of water, fibers, starch, minerals and cyanogenic compounds (Zhang *et al*., 2016; Sánchez *et al*., 2017). The amount generated varies between industries, even with the use of similar technologies (Tran *et al*., 2015). In the South Region of Brazil, where most of the country's automated industries are concentrated, this effluent is subjected to treatment in ponds; most of them are covered for biogas uptake (Sánchez *et al*., 2017).

Although the industry of cassava starch extraction can cause negative environmental impacts, strategies can be adopted to meeting proper conducts, as the installation of biodigesters (Hansupalak *et al*., 2016). The biogas produced in the biodigester can cover 100% of the thermal energy needed to dry the starch and still meet part of the electricity demand of the industry (Yin *et al*., 2019).

Other strategies can be used to implement clean technologies, such as water recycling, use of cassava bagasse in other processes, such as ethanol production and reuse of treated wastewater in fertigation (Tran *et al*., 2015, Pingmuanglek *et al*., 2017). In Brazil, the treatment system in covered anaerobic ponds eliminates the cyanide problem and reduces oxygen demand to acceptable levels, sufficient for its discharge into waterbodies. In addition, industries can have partnerships with cattle farming and use wastewater for pasture irrigation and bagasse for animal feeding (Sánchez *et al*., 2017). However, there is a lack of studies on Brazilian industries that correlate the process variables with strategies adopted for Cleaner Production (CP).

In view of the importance of the cassava processing industries for Brazil, especially for the state of Paraná, this study aims to investigate the profiles of these companies regarding the use of the main natural resources and the wastes generated, as well as to investigate the strategies adopted for environmental management.

2. MATERIAL AND METHODS

2.1 SURVEY OF CASSAVA STARCH INDUSTRIAL UNITS

Brazil had 71 cassava starch extraction industries, being 42 locatedin the state of Paraná (SEAB, 2016). To know which industrial units were in operation in the period of this research, data from ABAM - Brazilian Association of Starch Producers and SIMP – Paraná Cassava Industries Union were used to create a database. As inclusion criteria, companies should be registered in at least one of the entities, produce cassava starch as the main product and be in operation between the years 2017 and 2019. Thus, 33 industries were obtainedas target population, distributed in the Northwest and West regions of the state of Paraná/Brazil.

2.2 DATA COLLECTION

Primary sources of information were used to carry out this research. Datawas collected through a questionnaire sent by e-mail to managers or owners of the 33 starch industries surveyed. The questionnaire was prepared based on a literature review, focusing on the characterization of the resources and inputs used, environmental aspects, costs in the treatment and destination of waste and cleaner production technologies used by the sector (Tran *et al*., 2015; Hansupalak *et al*., 2016; Pingmuanglek *et al*.,2017). This questionnaire was subjected to preliminary tests through personal interviews with owners and managers who hold knowledge about the environmental sector of four industries, and it was approved by the Human Research Ethics Committee at the State University of Maringá (protocol 38766514.7.0000.0104).

After the test, the final questionnaire was structured in a series of questions distributed in seven categories (profile of agroindustry's, production, water, effluent, solid waste, implementation of Cleaner Production Technology, environmental management). In total, 21 documents were received, of which 18 were considered complete and valid, constituting the sample of the survey (54.5% of the target population). Data were tabulated and analyzed in Excel spreadsheets. These 18 industries have more than 10 years of activity in the market, and they are characterized as small (11.11%) and medium-sized (88.89%) companies (SEBRAE 2003).

PHYSICOCHEMICAL CHARACTERIZATION OF CASSAVA BAGASSE

Cassava bagasse was characterized by samples collected in 7 of the 18 industries investigated. The content of proteins, ashes, moisture, starch, and dietary fiber was determined based on AOAC methods 920.87, 923.03, 925.09, 996.11, 991.43, respectively (AOAC, 2005). These analyses were performed in triplicate and the means were compared by the Tukey test with a 95% confidenceinterval, using the *Statistica* 7.0 software.

PRINCIPAL COMPONENT ANALYSIS (PCA)

PCA was applied using the variables: consumption of raw material (ton cassava/day), water consumption (m^3/processed roots), starch production (ton/day), effluent (m^3/ton of roots), cost of effluent treatment ($) and solid waste (kg/ton of roots), the latter being the accounting between the total peels added to the total bagasse. These variables were quantitatively relevant for the evaluation of a sustainable production process.

Only one industry (Nº. 4) was not analyzed by this methodology, due to the absence of filling in one of the variables analyzed. The data obtained from 17 industries was analyzed using the Past 4.03 software.

3. RESULTS AND DISCUSSION

3.1 NATURAL RESOURCES USED IN THE CASSAVA PROCESSING

Figure 1 shows the inputs and outputs in cassava processing of the 18 investigated industries. The variation in the values can be related to different factors, such as characteristics of the raw material and the technology used in the cassava processing. Figure 2 shows the daily amount of processed cassava (raw material), starch production and water consumption in the 18 manufacturers evaluated.

Regarding the variability of the results found in Figure 2A, it is important to highlight differences in relation to the extraction technologies adopted in each unit. Due to the difficulty of accessing financial investments, many companies still use obsolete processes and equipment that cause low efficiency in the starch extraction. Another factor to consider refers to the species and source of the raw material (Chavalparit; Ongwandee, 2009).

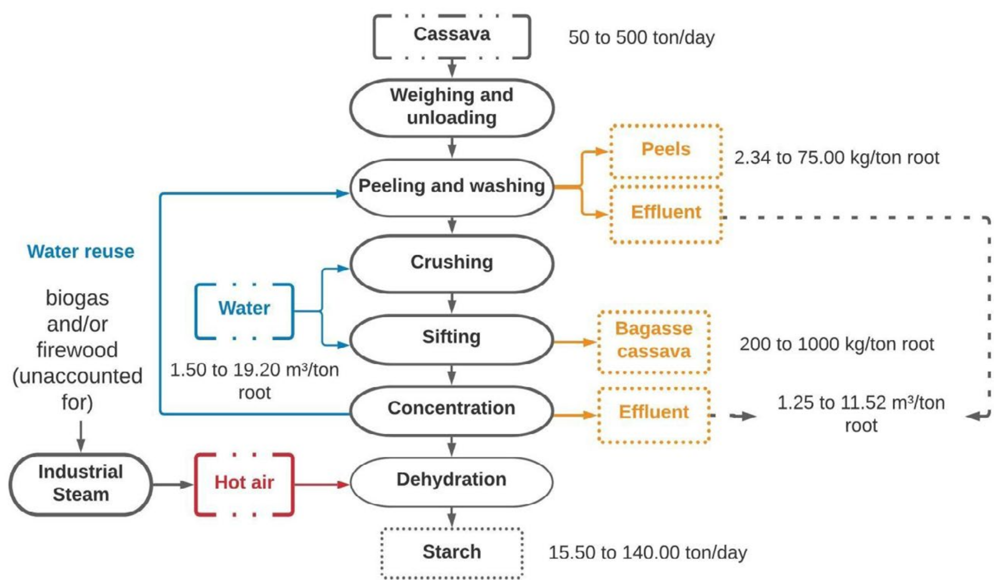

Figure 1. Starch production from cassava roots

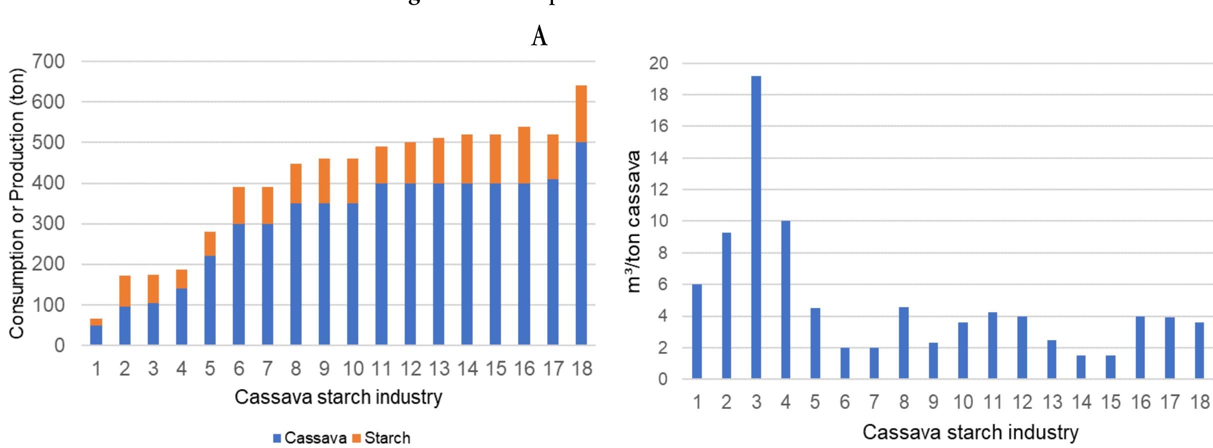

Figure 2. Consumption of cassava and starch production (A) and water consumption (B) in the cassava starch industries

Most of the industries investigated use from 300 to 400-ton day^{-1} of cassava for the production of 90 to 140-ton day^{-1} of starch, with yield ranging from 22.5 to 31.6%. According to the data collected, the starch was also processed in other types of products, such as sour starch, *tapioca* flour, *biju*, *sagu*, tissue gum, gelatinized starch, dextrin and liquid vegetable glue.

Water consumption ranges from 1.5 to 19.2 m^3 ton^{-1} cassava (Figure 2 B). The source of water used by most industries is from underground wells (77.8%),surface and groundwater (16.7%) and only surface water (5.6%). Tran *et al.* (2015) also found significant differences in water use by industries in Vietnam, Colombia and Thailand.

It should be noted that although this study did not survey the amount of water consumed at each stage of the industrial process, Pingmuanglek *et al*. (2017) identified that starch extraction (or separation of fibers) is responsible for more than 60% of water use in the supply chain. Water consumption can be influenced by the scraping efficiency and the destination given to the final product (food use or not) (Tran et al., 2015).

In addition, water consumption can be reduced with reuse in the early stages of the process (Sánchez *et al.*, 2017). This practice was reported by 55.6% of the starch industries participating in this study, which use part of the water from the starch extraction for the prewashing of the cassava roots (removing the coarser dirt). Due to the high generation of wastewater in the starch extraction step, most of it is directed to the treatment ponds, and only a small portion is recycled.

Most industries (61.1%) reported not having a water flow meter, and the amount consumed is quantified through estimates. For the effective management of water, avoiding losses, it is necessary to accurately measure itsconsumption, preferably at each processing step. Facts like this show that the abundance of this natural resource creates certain carelessness from some industries.

The industrial plants use thermal and electrical energy. Hot air used in the starch drying process corresponds to 10 to 20% of the energy consumed by the industries in this study. It was reported by 88.9% of industries that the production of hot air is carried out by boilers, from the burning of woodchips and biogas. One of the industries use only biogas produced in the biodigester as energy source in all industrial structure, besides releasing the amount not used to the company responsible for the supply of electricity for the Paraná state. This industry has already received for two consecutive years the seal of the Social Service of Industry (SESI), for the recognition of actions related to the achievement of the Sustainable Development Goals (SDGs). There is other industry that intends to use only biogas as a source of electricity; however, they are still looking for technologies that are feasible for the best use of biogas. The other industries use the electricity provided by the state company (COPEL) as the only source of energy for the engines used, as well as lighting and ventilation system.

2.3 SOLID WASTES OF THE CASSAVA PROCESSING

The main solid residues generated in the extraction of cassava starch arepeels and bagasse, and the average production of these residues is shown in Figure 3.

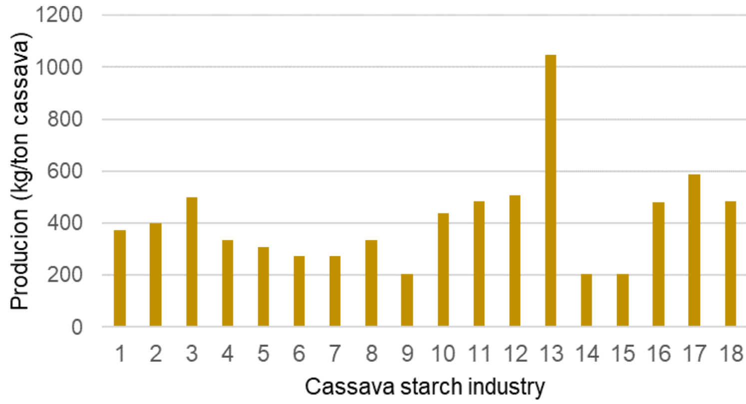

Figure 3. Average production of cassava peels and bagasse by the cassava starch industries

The amounts of wastes produced varied greatly in the investigated industries, ranging from 2 to 75 kg ton^{-1} of cassava for peels and from 200 to 1,000 kg ton^{-1} of cassava for bagasse. Due to the incorporation of water into the waste during starch extraction, up to 100% of solid waste can be achieved. One industry reported that for every 1,000 kg of cassava roots, 500 kg corresponds to solid waste, being 10% peels and 90% bagasse. The diversity of results found is related to the production capacity of each industrial plant, as well as thetype of technology adopted in the processing (Tran *et al*., 2015). The monthly production of solid wastes generated by the 18 cassava industries ranged from 205 to 1,047 kg of waste per ton of roots.

Animal feed was cited as the main destination of solid waste from cassava processing; 94.4% of the industries use the peels and bagasse for cattle feeding and 5.6% use the pells for fertilization. Another 5.6% realize a drying process to produce flour from the cassava bagasse, which is destinated to animal feed industries. In relation to the wastes disposal, 77.8% of the industries answered to have profits with the peels and 88.9% with the bagasse, ranging U$ 1.91 (R$10.00) to U$ 3.82 (R$20.00) a ton of waste. The selling values of these wastes shows its low commercial value, which can be changed with the application of technologies to improve its utilization.

It is important to point out that 11.1% of the industries reported to have costs with the disposal of both residues, 5.6% of the industries donated the waste and other 5.6% use the peel in the industrial unit. Thus, cassava bagasse, the main solid by-product of starch industries, can be considered an excellent material to be exploited for more noble purposes than those found in this research, enabling greater financial returns for industries. There were studies that investigated the bagasse application in lactic acid production (Chen *et al*. 2020), cyclodextrin production (Rojas *et al*., 2019), film production for food packaging (Travalini *et al*., 2019), conversion of the residue into biogas (Padi; Chimphango, 2020b), bioethanol production (Padi; Chimphango, 2021; Rewlay-Ngoen *et al*., 2020) and biodiesel removal of waterbodies (Keller *et al*. 2020).

Finally, the starch agroindustries were asked about the adoption of a waste management system (encompassing all waste produced) and only one unit attested not to have it. In Brazil, food industries are supervised by the state environmental institutes of each state. In Paraná, the activity is supervised by the IAT – Water and Land Institute, which provides parameters for the disposal of effluent, gas emissions from boilers and the correct disposal of solid waste.

In the case of bagasse and cassava peels, there is no specific regulation. However, according to the Solid Waste National Politic, instituted by Law 12.305 of 2010, the waste cannot be released in the environment, and neither be burned in the open or in containers/facilities not licensed for this purpose (Brasil, 2010). In addition, the IAT also requests that companies that allocate waste to animal feed follow the instructions of an Agricultural Defense Agency, such as the Paraná Agricultural Defense Agency. The starch industries investigated in this study, that generates ashes from the boilers, incorporated them in soil for agricultural use, as determined by the same regulatory agency.

3.3 PHYSICOCHEMICAL CHARACTERIZATION OF CASSAVA BAGASSE

Cassava bagasse is the main solid waste generated by starch industries and it has high moisture content, which is related to the addition of large amounts of water during the starch extraction step. In this study the moisture of the cassava bagasse was 87.59±0.29 g $100g^{-1}$, and the chemical compositionin dry basis is shown in Table 1.

Starch and dietary fibers are the main components of the cassava bagasse, whose contents are related to the process/technology adopted during the extraction of the main product (Rojas *et al.*, 2019). Regarding to the starch content, the industries 3, 6, 8 and 18 showed higher levels (60.5 to 67.0 g $100g^{-1}$) compared to the others (47.3 to 50.3 g 100 g^{-1}) ($p<0.05$). Similarly, Martinez *et al.* (2018) reported levels of 59.9 to 68.3% of starch when assessingindustrial plant residues in the states of Paraná and Mato Grosso do Sul/Brazil. Rojas *et al.* (2019) evaluated residues from starch industries located in the stateof São Paulo/ Brazil and found values similar to that of this study (47.1 and 50.5 g 100 g^{-1} of starch). Starch is the main component of cassava and can reach up to 80% of the dry weight of the root. Although the industries seek to extract it to the maximum, extraction efficiency is low (approx. 25% of the starch on a wet basis), which causes significant loss to the residue (Zhu, 2015).

Table 1. Physicochemical composition of bagasse from the cassava industries

Industry	Starch (g 100 g^{-1})*	DF** (g 100 g^{-1})*	Proteins (g 100 g^{-1})*	Ashes (g 100 g^{-1})*
3	67.0^{a} ± 2.6	24.6^{d} ± 0.6	$2.1^{b,c}$ ± 0.0	1.3^{d} ± 0.0
5	49.8^{b} ± 3.8	39.6^{a} ± 0.9	1.2^{d} ± 0.0	2.6^{a} ± 0.1
6	63.9^{a} ± 5.5	$35.5^{b,c}$ ± 1.2	2.2^{b} ± 0.1	$2.5^{a,b}$ ± 0.0
8	61.5^{a} ± 0.4	39.8^{a} ± 1.0	2.9^{a} ± 0.2	2.2^{c} ± 0.2
12	47.3^{b} ± 1.4	$38.1^{a,b}$ ± 0.6	1.5^{d} ± 0.1	2.7^{a} ± 0.1
16	50.3^{b} ± 4.2	$35.7^{b,c}$ ± 1.6	1.9^{c} ± 0.0	$2.3^{b,c}$ ± 0.1
18	60.5^{a} ± 0.9	33.7^{c} ± 0.7	2.4^{b} ± 0.0	1.8^{d} ± 0.1

*Values on dry basis. ** DF – dietary fibers. Means followed by the same letter (in each column) did not differ statistically ($p<0.05$) by theTukey test.

The second main component of bagasse, dietary fibers, showed a variation from 24.6 to 39.8 g 100 g^{-1} values lower than those found by Rojas *et al.* (2019). As for the other components, proteins, and ashes, these ranged from 1.2 to 2.9 g 100 g^{-1} and 1.3 to 2.7 g 100 g^{-1}, respectively. The highest protein content was found in Industry 8, while for ash industries 5 and 12 had the highest values ($p<0.05$). Other studies have shown values of 0.6 to 2.1 g 100 g^{-1} for proteins and 1.4 to 1.5 g 100 g^{-1} for ashes (Souza *et al.*, 2018; Rojas *et al.*, 2019). These variations in chemical composition are common among lignocellulosic materials and they can be attributed to differences in species, plant age, and growing conditions such as soil, geographic location, and climate (Andrade-Mahecha *et al.*, 2015). Factors such as grinding and granulometry of the material influence the extraction of lignocellulosic material.

3.4 WASTEWATER

Wastewater from starch industries is known as *manipueira* and has a high pollutant load and toxic potential (Cremonez *et al*., 2021). There is a wide variation in the amount of effluent generated, with a higher prevalence (61.1%) of 3.1 to 6 m^3 ton^{-1} root (industries 1, 5, 8-13, 16-18). Otherwise, the industries 2, 6, 7, 14, 15 (27.8% of the total) generated 1 to 3 m^3 of wastewater ton^{-1} root. Other studies reported values closeto the maximum found in this work, with effluent production of 12 m^3 ton^{-1} (COLIN *et al.,* 2007; Kamaraj *et al*., 2006). This value was similar to the one observed for industry 3 (11 m^3 of wastewater ton^{-1} root). The industry 4 answered 'unquantified' for the question about the wastewater generated in the cassava processing.

The type of processed cassava, bitter or sweet, has different amounts of cyanide (cyanogenic acid) and can influence the toxicity of the *manipueira* as well as the volatilization in the process (Sanchez *et al*., 2017). The toxicity of *manipueira* is due to the presence of easily hydrolysable cyanogenic glycosides forming hydrocyanic acid (HCN) (Oghenejoboh, 2015). The cyanide is toxic to humans and animals, being able to reach a concentration of 1000 mg per kg of roots (Cremonez *et al*., 2021). In addition to cyanide, wastewater still has a highorganic load of Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Oghenejoboh *et al*., 2021).

The legal aspect that starch industries of the state of Paraná/Brazil must respect in relation to the conditions of dumping of liquid effluents is resolution of the State Council for the Environment 070/09. This document establishes the parameters for the release of liquid effluent into receiving bodies for waters without effluent segregation (*manipueira* + root wash water) of 100 mg L^{-1} for BOD, 250 mg for COD mg L^{-1}, 0.2 mg L^{-1} of cyanide, as well as other parameters related to acute toxicity levels (Paraná, 2009). Therefore, the *manipueira* must undergo treatment beforebeing released, which is carried out in all the industries that participated in this study. The wastewater generated undergoes to the preliminary treatment (grating), followed by the biological treatment in anaerobic and facultative ponds, being the first a biodigester. The costs for effluent treatment are shown in Figure 4.

There is a wide range of costs involved in the effluent treatment which is related to the size and maintenance of ponds, purchase of compounds used in the treatment of effluent and labor, with the highest prevalence (50%) in the range of U$ 289.32 (R$ 1,500) and U$ 385.77 (R$ 2,000.00). There is a growing concern around the world in the development of strategies that enable the reduction in operating costs of effluent treatment techniques (GEEM, KIM, 2014). In addition, the improvement of effluent treatment system can be aninteresting factor to increase biogas production.

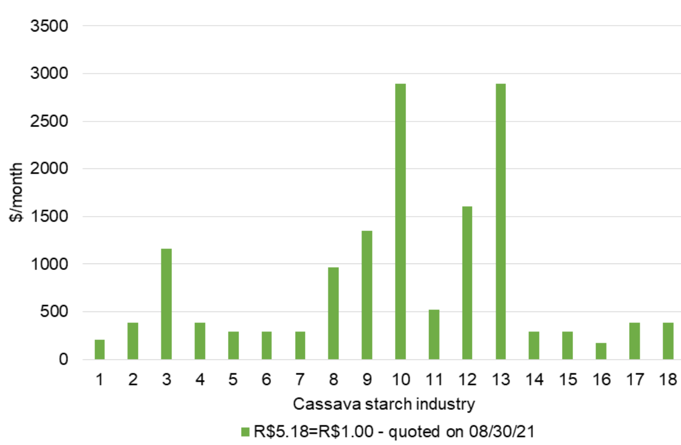

Figure 4. Effluent treatment costs in the cassava industries investigated.

3.5 ENVIRONMENTAL MANAGEMENT

Most industries (55.6%) admitted adopting at least one of the International Organization for Standardization (ISO) standards; ISO 14001 was identified in only one of them (5.6%). ISO 9001, which certifies Quality Management Systems, was the most cited among the participants, with 33.3% representativeness, followed by ISO 22,000, which deals with Food Safety Management (16.7% of industries) and ISO/IEC 17025:05 which deals with laboratory accreditation and is applicable to calibration and testing laboratories (5.6% of industries).

Only 22.22% of companies reported to use tools that assist in the company's Environmental Management, such as the 5S indicator and Environmental Certification, and 55.56% reported to conduct training on environmental issues to employees.

When questioned about a possible problem with the community due to the installation and operation of the industry, only one of them (5.6%) reported asetback in its first year of installation, in which residents complained of bad smell and the company sought to correct the problem through the appropriate effluent treatment.

Regarding the difficulties in complying with the legal determinations required by the environmental legislation, 33.3% of the starch industries reported they had already had an obstacle, mainly regarding effluent treatment. Environmental legislation and the bureaucratic process were identified as one of the biggest challenges for companies related to the environment. Other difficulties related to water reuse; employee awareness, effluent treatment and waste disposal were expressively reported.

3.6 IDENTIFICATION OF ACTIONS FOR CLEANER PRODUCTION (CP)

None of the industries investigated in this study have knowledge about the Cleaner Production program, however, most of them (77.8%) reported having an interest in knowing it. All the industries produce biogas by covering the first pond of the effluent treatment system with a high-density polyethylene blanket, creating a single chamber biodigester. This technique is already usedin biogas plants around the world (Sánchez *et al*. 2017; Hansupalak *et al*. 2016).

Biodigesters provide several economic and environmental benefits for industries. All the industries of this research approved their cost-benefit, reporting a payback time of 1 to 2 years (44.4%), less than one year (38.9%) and 4 to 5 years (16.7%). The rapid return of the economic investment is given by the savings obtained with the purchase of woodchips, with values ranging from U$ 1928.83 (R$ 10,000) to U$ 9644.13 (R$ 50,000) monthly. The reduction in wood consumption ranged from 50 to 100%, since there are companies that no longer use woodchips.

Other benefits of biodigesters reported by the industries were reduction in the generation of waste from the burning of firewood from boilers, reduction of the organic load of the effluent and the possibility of using the wastewater in the irrigation of the surrounding pastures of the industry. This practice known asfertigation was reported by 83.3% of industries. It is important to highlight that one of the great environmental benefits with the installation of the biodigester is the reduction of atmospheric emission, since it prevents the release of gases. The generated biogas can be used to generate the energy used in the industries equipment, as reported by one of the participants.

In addition to the biodigester, other devices/actions were identified, such as the use of the vibrating screen in the process of discharging the raw material, reported by 55.56% of industries. This device allows waste and sediment that comes from the field not to be inserted into the production process, resulting in lower water consumption in the washing and organic load of the effluent; in addition, it improves the quality of the extracted starch.

The use of an industrial press was reported by one (5.56%) of the industries, and of a roaster by another unit (5.56%), to reduce the volume of cassava bagasse. However, these processes require energy consumption, and they can cause emission of pollutants. Despite the cost associated with drying and milling used in the processing of bagasse flour, this could be compensated by the higher added value of the product, lower cost with transportation and longer shelf life, due to the removal of water. Studies carried out in Brazil have shown that cassava bagasse could be considered an alternative ingredient for the food industry (Fiorda *et al*. 2013, 2015).

The drying process could still be studied, allowing the recovery of water in another stage of production, through a condensation process. However, it is important to highlight the use of cyclones since moist air may contain dust or starch particles.

The installation of hydrocyclones, responsible for the purification and clarification of starch, before drying, was pointed out by three industries as responsible for reducing water consumption. The use of a gas scrubber minimized the level of contaminants released into the atmosphere and it also helps to increase the production yield. Finally, the use of reinforced packages and the conduction of employees training were pointed out by Industry 9 as a way for waste reduction.

The devices and actions identified above demonstrate that the reduction of waste generation and atmospheric emissions resulted in economic gains, according to reports from the industries. This shows that CP, in addition to bringing benefits in the environmental area, can also be an important ally in reducing production costs.

As for the other actions/devices that result in reduced waste generation, 16.7% of the companies reported they do not adopt preventive maintenance on the engines of the equipment. This maintenance is extremely important, because in addition to reducing costs with corrective actions and production stoppage, it contributes to the reduction of risks of work accidents, energy consumption and, depending on the equipment, reduces the waste generation (Souza *et al.* 2018). It was found that 11.1% do not acquire or regulate their equipment periodically to reduce energy consumption, and 5.6% have alighting system that provides savings. Some professionals have reported replacing incandescent and steam lamps with LED lamps (Light Emitting Diode). One of the industries stated that the lights work with a solar energy presence sensor. Although the practices adopted contribute to the reduction of energy consumption, it is important to highlight that the process of extraction and separation of starch are the largest consumers of energy in the supply chain, corresponding to about 70% of the total use (Pingmuanglek *et al*. 2017).

Regarding an important device for controlling atmospheric emissions, boiler filters, 50% of industries reported they do not have them. Despite this, all industries in this study provide semi-annual reports about the emissions to environment, in accordance with the limits established by the current standards.

3.7 PRINCIPAL COMPONENT ANALYSIS

In the Principal Component Analysis (PCA), the variables were arranged in two main components that explained 45.5% and 31.4% of the total variation, totaling 76.83% of explanation, a satisfactory result for the representativeness of the applied analysis (Figure 5).

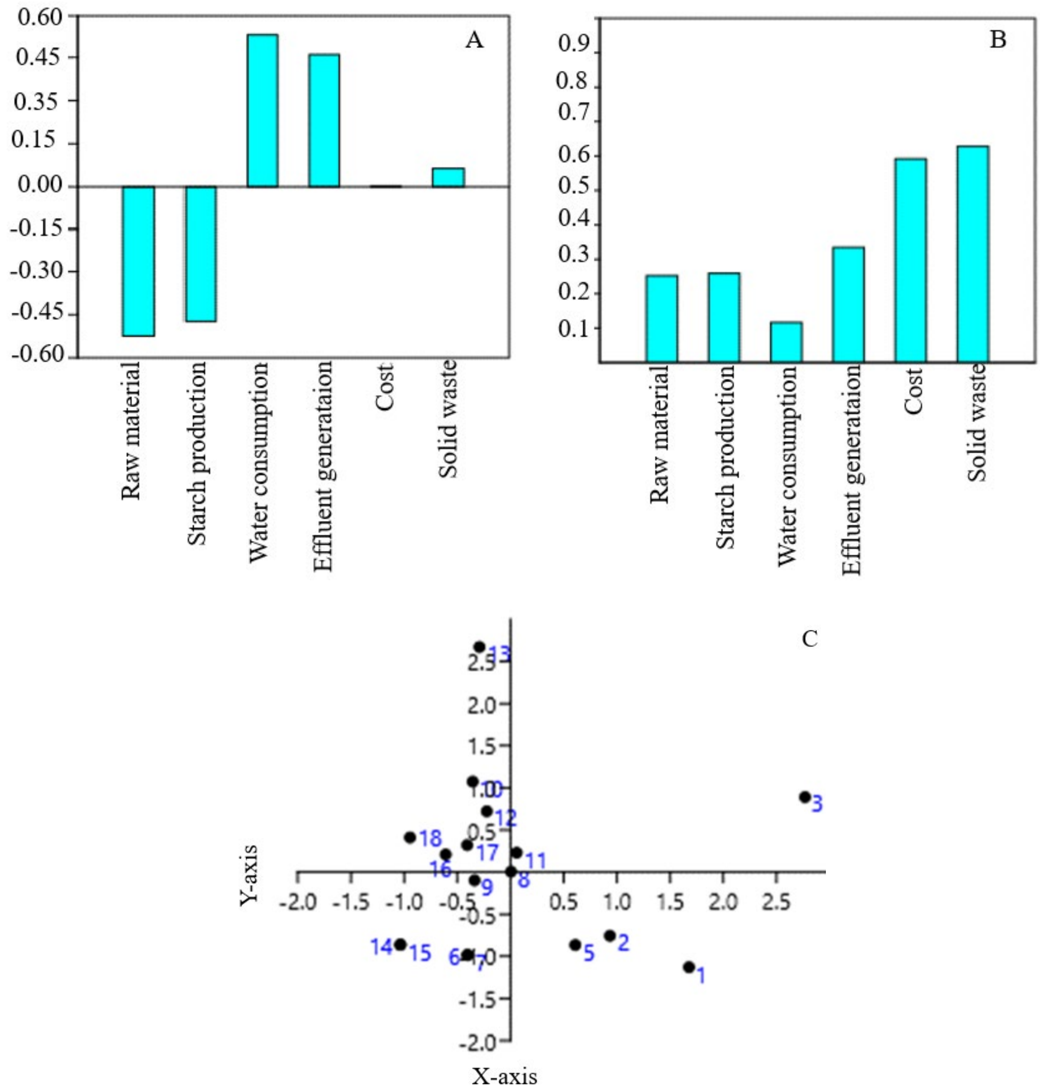

Figure 5. Principal component analysis: correlations obtained for axis x (A) and y (B), and, classification chart of cassava industries (C)

Figure 5 provides the visualization in bars referring to the analysis of the predicted loads for each axis. Figure 5A shows the representativeness of the variables water consumption (0.53) and effluent generation (0.46) for of axis x, and Figure 5B highlights the representativeness of the variables cost with effluent treatment (0.59) and solid waste (0.63) in the axis y.

It should be noted that the water consumption and effluent generated are directly proportional (axis x), as well as the variables costs and solid waste (axis y). Waste generation can be influenced by several factors, such as the use of older technologies and the purpose of the final product. The costs of effluent treatment may be linked, in addition to the use of older technologies, to the under sizing of treatment ponds or optimization of biogas generation.

Thus, considering the representativeness of the two axes, 17 of the participating companies could be related regarding the variables analyzed, for evaluation as to the situational characterization of Cleaner Production (Figure 5C). The industry 1, for example, was positioned in the positive quadrant for x-axis and negative for y-axis. Thus, this company has high water consumption and effluent generation, while waste generation and effluent treatment costs arelow. This is the only industry that roasts and sells bagasse as raw material to produce animal feed, with high added value. Industries 2 and 5 have a similar behavior (especially related to water consumption and effluent generation), and although they also show positive values for x-axis, these are lower than those observed to industry 1.

The industry 3, in turn, stands out for the highest value in x-axis and positive value in y-axis, meaning that it has the highest water consumption and effluent generation, as well as a positive trend for waste and effluent costs generated. It is noteworthy that the industry reported that it has much old equipment and an oversize of its effluent treatment system, which may justify the results identified. The company does not have a water flow meter or a control in its generation.

The industry 11, despite having the same trend as the industry 3 (located in the positive quadrant of the two axes), has lower values, close to zero. This industry is the only one to have ISO 14001, in addition to ISO 9001 and 17025. At the center of the axes the industry 8 is located, which has more modern technology. Most of the industries (10, 12, 13, 16, 17 and 18) have lower water consumption and effluent generation, but higher waste production and treatment costs, being company 13 the major highlight in this production.

Finally, the industries that obtained the highest prominence regarding the cleaner production, within the parameters analyzed, were 6, 7, 9, 14 and 15 (29.41% of the total evaluated). Industry 9 is the only one that generates energyfor the supply of the entire production system from biogas. According to the industry, one of the biggest difficulties in relation to waste management is to keep low costs and ensure high biogas generation. The company has hydro cyclones, named as responsible for reducing water consumption.

In view of the above, it is verified that the industry 3 was the one that produced with the highest water consumption and effluent generation, industry 13 with the highest waste generation and costs in effluent treatment, industry 14with lower water consumption and effluent generation and industry 1 with lower waste production and costs. After analysis and treatment of the data obtained, feedback was given to the industries, with suggestions for improvements in the Environmental Management Program.

4 FINAL CONSIDERATIONS

The results demonstrate variability of resource consumption and waste generation among the 18 participating industries. Cassava bagasse is the main solid waste generated (200 to 1,000 kg per ton of processed cassava) and it has high content of starch (47.3 to 63.9 g 100 g^{-1}) and dietary fibers (24.6 to 39.8 g 100g^{-1}). All industries have biodigesters for the liquid effluent treatment, being this action a cleaner production practice. Water consumption ranged from 1.5 to 19.2 m^3 ton^{-1} of cassava. Although part of the resource is reused by the industries, there is still generation of significant amounts of effluents (1.2 to 11.5m^3 per ton of cassava). Finally, PCA analysis showed that 29.41% of the industries have the highest efficiency in the use of natural resources and lower waste generation, which shows that actions related to cleaner production and technology transfer should be encouraged to achieve sustainability of thecassava processing.

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