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Use of by-products generated in the processing of coffee berries: A review

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ABSTRACT

Coffee production plays an essential role in the Brazilian economy, and a large production centre is located in Minas Gerais. In recent years, there has been an increase in coffee cultivation, consequently generating coffee wastewater (CW) and solid waste (Exocarp, outer mesocarp, parchment, and dregs) during the processing stage. Thus, the present review study seeks to characterize these by-products from the coffee production chain and present their possible applications in agribusiness and other sectors towards a circular economy, mainly related to reuse as fertilizer or energy and biomaterial recovery. An extensive literature review was collected in major scientific databases using keywords related to the valorization and application of coffee industry waste. CW treatment is complex given the high concentrations of organic matter, phenols, and nutrients, especially potassium. Still, its use as a liquid fertilizer is highly recommended as it can increase crop yield. In this regard, CW should be applied to soil according to nutritional criteria, with potassium as the reference chemical element. The wastewater production and its potential for soil contamination can be reduced by applying biological, physical, or chemical treatment along with recirculation routes during the washing/peeling/pulping of coffee berries. Moreover, the solid waste from coffee production can be used for energy generation, wastewater treatment (as an organic filter material or biochar), and as organic fertilizer (*in natura* or composted).

Key words: Coffee wastewater; fertigation; nutrients; recirculation; agro-industrial solid waste.

1 INTRODUCTION

Agriculture is of great importance to the Brazilian economy, representing up to 29% of the country's gross domestic product (GDP) in 2021 when considering the production, processing, and distribution of agricultural products (United States Department of Agriculture - USDA, 2022). Among the primary agricultural activities, coffee production is the third largest export sector in the country, accounting for approximately US$719.88 million (7.29% of national agribusiness exports) (Brazilian Confederation of Agriculture and Livestock, 2021).

Minas Gerais state has prominent coffee activity, being responsible for 21.9 million bags of Arabica coffee and 283.4 thousand bags of Conilon coffee (out of national production totals of 31.4 million and 16.29 million bags, respectively) (Companhia Nacional de Abastecimento - CONAB, 2021), with fundamental contributions from the south of the state in terms of both quantity and quality.

According to the National Supply Company (*Companhia Nacional de Abastecimento* – CONAB), the production of coffee bags in 2022 was estimated to be 16.8% higher, with an increase of 18.9% in the south of Minas Gerais (CONAB, 2022). However, as production increases, there is also an increase in the generation of by-products from agricultural activity and product processing (beverage production); i.e., the larger the output, the more waste will be generated.

Coffee processing occurs in two different ways, wet or dry. Brazil processes about 90% of the produced Arabica coffee beans via the dry path; the remaining is processed via the wet path instead, which generates, besides high-quality beverages, a larger amount of solid waste and wastewater (International Coffee Organization - ICO, 2022). In the wet process, the berries are washed, separated (into floater, green, and cherry portions, usually by mechanical density-based approaches), peeled, demucilated, and pulped, thus generating coffee wastewater (CW). This process also generates solid waste, including Exocarps, outer mesocarp, and parchment. In addition, the beverage production consists of roasting, grounding, and then straining the coffee beans with boiled water, which results in coffee dregs (Pereira et al., 2019; Ijanu; Kamaruddin; Norashiddin, 2020; Wu et al., 2022).

According to Matos (2010) and Campos et al. (2021), 3 to 5 L of CW is produced for each litre of processed berries; and three tons of solid waste is generated for each ton of processed grains. Due to its physical, chemical, and biological properties, the storage and disposal of this waste material can cause adverse environmental impacts, e.g., soil acidification and salinization, leaching and groundwater contamination, eutrophication of water bodies, and greenhouse gas emissions (Ijanu; Kamaruddin; Norashiddin, 2020; Campos et al., 2021).

On the other hand, CW and other coffee industry residues are rich in organic matter and nutrients, which indicates a potential for agricultural use as well as energy and biomaterial recovery (Campos et al., 2021; Hoseini et al., 2021). Given this scenario, the present study aimed to review the possible applications of some by-products from coffee production and processing and present their applications towards a circular economy, which corresponds to opportunities to reduce environmental liabilities typical of highly productive coffee countries, such as Brazil.

2 METHODOLOGY

For preparing this extensive literature review, the following keywords were used to search for scientific articles in databases such as Web of Science, Scopus, ScienceDirect, SpringerLink, Scielo, and *Portal de Periódicos da CAPES* (Brazil): coffee processing, coffee waste, coffee wastewater, husk, biochar, fertigation, reuse, Exocarp, coffee pulp, coffee skin, silverskin, parchment, coffee dregs, coffee spent, coffee by-products, coffee waste valorization, and equivalent terms in Portuguese. Moreover, data on coffee production was based on collection from agents such as the United States Department of Agriculture (USDA), National Supply Company from Brazil (CONAB), Brazilian Confederation of Agriculture and Livestock (CNA), and International Coffee Organization (ICO).

3 COFFEE WASTEWATER (CW)

3.1 Characteristics and impacts of improper disposal

In the process of berry washing (separation), fragments of leaves and branches are separated and combined with the solid components of the berry that are removed in later stages. During peeling and demucilation, part of the pulp (mucilage) is removed by water, reducing the risk of fermentation (Ijanu; Kamaruddin; Norashiddin, 2020; Campos et al., 2021; Das, 2021). In this process (wet method), 4 tons of water is required to produce 1 ton of processed grains, generating 1 L of wastewater for every 10 to 15 L of berries during washing (separation) and 10 L for every 1 L of berries in the peeling and demucilation process (Matos; Lo Monaco; Silva, 2001). Thus, it appears that there is a high demand for water and that the water quality tends drop during berry processing, generating a high volume of CW with high pollution potential.

Given this scenario, Matos et al. (2007a) evaluated the possibility of reducing water consumption by introducing CW reuse in conjunction with the physical and chemical processes of solids removal and pH correction. By adding 3.0 g L^{-1} lime to recirculated wastewater used for peeling, the amount of water wasted was reduced without damaging the quality of the beverage (Matos et al., 2007a). Lime enhances the removal of solids in sedimentation tanks, which are used for CW treatment before recirculation (Balladares et al., 2018; Prasad et al., 2019).

Matos et al. (2007b) evaluated other types of coagulants and determined the most appropriate pH ranges for reducing the concentration of suspended solids (SS) and the electrical conductivity (EC) of the recirculated CW, observing that moringa seed extract provided the best results at the natural pH of the wastewater (pH = 4.27). When using aluminium sulfate and ferric chloride, it was necessary to correct the pH to 7.27 (Matos et al., 2007b). By performing recirculation, Soares et al. (2015) reduced water consumption to 0.3 L of water for each litre of processed coffee berries.

Even if the volume of wastewater produced is reduced, it is necessary to establish an appropriate final destination solution for CW to avoid negative impacts on the physical environment. The potential consequences of improper CW disposal include surface sealing (significant presence of solids), soil salinization (high EC), death of plants, and contamination of groundwater; conversely, the discharge of CW into a watercourse may result in reduced concentration of dissolved oxygen (DO) (high concentration of organic matter) and changes in water quality (Ijanu; Kamaruddin; Norashiddin, 2020; Campos et al., 2021).

Another possible consequence pointed out by some authors is the chemical dispersion of clay; however, the necessary water conditions associated with a high risk of such soil physical disruption require a high sodium adsorption ratio (SAR) and low EC, which do not occur with CW (Matos; Matos, 2017). Table 1 shows the physical, chemical and biochemical characteristics of CW and sanitary sewage, illustrating the potential of CW to cause adverse environmental impacts if it is improperly disposed of.

The characteristics of CW changes according to the type of processed berry (Arabica or Conilon), the stages of wet processing, the amount of water used and the number of recirculation cycles (Prezotti et al., 2012). Moreli et al. (2010) observed that the levels of K, N and Ca increased in CW with recirculation of the water used in wet processing, with accumulation rates of 1.810, 1.030 and 0.183 mg L^{-1} per minute of recirculation, respectively. When the number of recirculation cycles increases, the concentrations of nutrients and organic matter in the CW increase due to the increases in the amounts of mucilage and berry fragments in the water used during processing (Moreli et al., 2010). Prezotti et al. (2012) surveyed the characteristics of CW from forty properties in Espírito Santo, which illustrated great variability, as shown in Table 2. The same authors also gathered information from these farms, separating the wastewater according to the stage in which it was generated (Prezotti et al., 2012) (Table 3).

Table 3 shows lower nutrient concentrations in water samples collected from the washing step and higher concentrations in samples collected from the peeling and demucilation steps. The explanation, according to Prezotti et al. (2012), lies in the characteristics of each phase. During washing, the grain Exocarps are not disrupted; therefore, the contribution of ions in the water is due to impurities, such as dust and soil, that were adhered to the surface of the grains (Prezotti et al., 2012).

Table 1: Comparison of the characteristics of sanitary sewage and coffee wastewater (CW).

	Unit	Sanitary sewage	CW
TS	mg L^{-1}	700 – 1,350	10,600 – 22,000
BOD_5	mg L^{-1}	200 – 500	5,800 – 9,700
COD	mg L^{-1}	400 – 800	8,000
O & F	mg L^{-1}	55 – 170	–
N-total	mg L^{-1}	35 – 70	400 – 600
P-total	mg L^{-1}	5 – 25	10 – 100
K	mg L^{-1}	< 1 – 6	1,200
Na	mg L^{-1}	24 – 47	< 10
pH	–	6.7 – 7.5	4.0 – 7.0
EC	dS m^{-1}	0.5 – 3.6	1.0 – 4.9

TS – total solids; BOD5 – biochemical oxygen demand obtained on the fifth day of incubation of the sample at 20 °C (standard BOD); COD – chemical oxygen demand; O & F – oils and fats; N-total – total nitrogen; P-total – total phosphorus; K – potassium; Na – sodium; pH – potential of hydrogen; EC – electrical conductivity. Source: Jordão and Pessôa (2005), Matos Magalhães and Sarmento (2010) and von Sperling (2014).

Rigueira et al. (2010) also characterized the wastewater generated in the processing of coffee berries, considering each stage separately. The results reinforced the conclusions of Prezotti et al. (2012). The wash water had an EC of 0.60 dS m^{-1}, and the concentrations of total P, total N and total K were 1889, 75, 15 and 77 mg L^{-1}, respectively (Rigueira et al., 2010). During peeling, pulping and demucilation, the water content was 1.09 dS m^{-1}, and the concentrations of total P, total N and total K were 6384, 168, 23 and 157 mg L^{-1}, respectively (Rigueira et al., 2010).

3.2 Treatment

CW is richer in nutrients and has a higher organic load than sewage; therefore, its treatment presents technical challenges (Ijanu; Kamaruddin; Norashiddin, 2020). Thus, several studies have explored methods of adjusting CW quality for release into a watercourse, such as the use of hybrid anaerobic reactors (two types of support media) (Silva et al., 2010), anaerobic filters (Fia et al., 2011), surface runoff treatment ramps (Matos et al., 2005), constructed wetlands (Fia et al., 2010a; Rossmann et al., 2012; 2013) and cascade aeration systems (Eustáquio Júnior et al., 2014).

However, due to the presence of phenolic compounds that are resistant to biodegradation, aerobic biological systems may not be very effective for treating CW (Fia et al., 2007). Thus, aerobic reactors can be combined with anaerobic systems, which are more effective in removing phenolic compounds (Fia et al., 2010b), and/or lime can be added to precipitate these compounds (Prasad et al., 2019).

Other researchers have evaluated more complex processes, such as Fenton and photo-Fenton processes (Kondo et al., 2014), the use of folic acid (Teixeira; Matos; Rossmann, 2012) and advanced electrochemical oxidation processes (Villanueva-Rodríguez et al., 2014), which are expensive and may not be viable for installation at most farms. In addition to being characterized by difficult degradation, the high potassium concentration of CW hinders its treatment. Fia et al. (2008) evaluated subsurface horizontal flow constructed wetland systems (SSHF-CWSs) with cattail (*Typha sp.*) and alligator weed (*Alternanthera philoxeroides* Mart.) as an alternative to conventional systems, which have low K removal capacity. However, the species did not adapt well to the high concentrations of nutrients present in the wastewater and extracted fewer nutrients (Fia et al., 2008). In another study, Fia et al. (2010a) obtained more success using ryegrass (*Lolium multiflorum*) and black oat (*Avena strigosa* Schreb.) grown in SSHF-CWSs that treated CW after passing through anaerobic filters. Thus, the pre-treatment conditions and the plant species used play an important role in the success of treatment.

Table 2: CW samples collected from disposal lagoons at 40 farms in the Arabica coffee-producing region of Espírito Santo, Brazil.

Nutrient content limits	N	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B
	mg L^{-1}									
Maximum	205.0	23.0	875.0	94.0	28.0	40.0	44.0	80.0	28.0	12.0
Minimum	1.5	1.0	1.5	1.0	1.0	1.0	1.0	1.0	0.3	1.0
Average	106.0	5.0	225.0	30.0	9.0	2.0	3.0	5.0	31.0	1.0
Standard deviation	63.0	6.0	202.0	22.0	8.0	11.0	12.0	22.0	127.0	4.0
CV%	60.0	137.0	97.0	73.0	83.0	459.0	444.0	447.0	406.0	366.0

Source: Prezotti et al. (2012).

Table 3: Average nutrient levels in CW samples collected from 40 processing units at various processing stages of Arabica coffee berries.

Processing step	N	P	K	Ca	Mg	Cu	Zn	Mn	Fe	B
	mg L^{-1}									
Washing	7.5	0.3	14.0	17.6	3.0	0.03	0.01	0.04	0.66	0.00
Peeling	118.2	6.3	218.0	35.2	9.5	4.1	4.6	8.2	49.5	1.4
Demucilation	93.7	7.9	308.0	31.1	12.3	0.1	0.3	0.6	5.9	0.2
Disposal in lagoons	90.4	7.2	280.0	30.1	11.1	0.1	0.2	0.3	6.7	0.2

Source: Prezotti et al. (2012).

3.3 Fertigation and other possible uses

Due to the difficulty of CW treatment and its rich nutrient content, fertigation has gained increasing attention as an alternative for CW disposal. This technique uses wastewater as a liquid fertilizer that is applied in accordance with nutritional criteria. The dose is calculated by taking into account the concentrations of nutrients in the wastewater and the crop's need for macro- and micronutrients, defined according to the concentration of a reference chemical element in the leaf. For CW, the dose is calculated based on the potassium concentration (Matos; Matos, 2017; Campos et al., 2021).

Lo Monaco et al. (2009) observed improvements in the chemical attributes of soil with CW application, with increased concentrations of exchangeable potassium and EC, indicating a greater richness of cations and anions in the soil and, consequently, higher pH. Likewise, Garcia et al. (2008) reported increases in potassium content, pH, base saturation, effective cation exchange capacity (CEC), and sum of bases and reductions in exchangeable aluminium, aluminium saturation and potential acidity. Given these conditions, an increase in agricultural production may be made possible by providing a range of nutrients. For example, Lo Monaco et al. (2011) observed adequate leaf contents of potassium, iron and zinc upon CW application (equivalent dose of 66.4 g pit^{-1}), in addition to nitrogen, phosphorus and manganese at levels above what is considered adequate for coffee plants.

Prezotti et al. (2012) correlated the applied CW dose and maize yield by using the modified equation $P_{maize} = 29.378 + 0.847\ CW - 12.849\ CW^{0.5}$, where P_{maize} is the maize biomass (g) and CW is the dose of wastewater. This equation indicates that production per leaf increases up to a given application amount but that soil salinization and phytotoxicity of the crop occur at higher levels, thus reducing productivity (Prezotti et al., 2012). At the doses and concentrations of CW administered by Ribeiro et al. (2009), fertigation contributed to the vegetative growth of coffee plants (plant height, branch diameter and nutrient contents) and was equal to or better than (depending on the variable analysed) traditional irrigation and potassium fertilization. Thus, it is possible to save water and inputs by performing fertigation. For example, Marques et al. (2017) calculated a cost reduction of US$445.00 ha^{-1} in fertilization and US$6.00 ha^{-1} in irrigation (58% water savings) for elephant grass (*Pennisetum purpureum*) fertigation with sewage.

Other possible uses for CW have been less discussed recently, including the production of bioethanol (Blinová et al., 2017) and biogas via anaerobic treatment (Pin et al., 2020). For instance, Prado, Campos e Silva (2010) observed the production of 0.545 to 0.602 m^3 of biogas and 0.382 to 0.421 m^3 of methane for each kg of COD removed in an upflow anaerobic sludge blanket (UASB) reactor treating CW.

4 EXOCARP AND PULP

4.1 Characteristics

The coffee berry is composed of the parchment (or endocarp, outer coating of the bean), mucilage (removed in demucilation), pulp (mucilage + pulp = mesocarp), Exocarp and grain (endosperm) (Figure 1) (Durán et al., 2017; Hall; Trevisan; Vos, 2022). During peeling, the parchment and Exocarp are removed, resulting in a production of approximately 3.0 tons of waste per ton of processed berry (Matos; Magalhães; Sarmento, 2010), thus requiring an appropriate final destination.

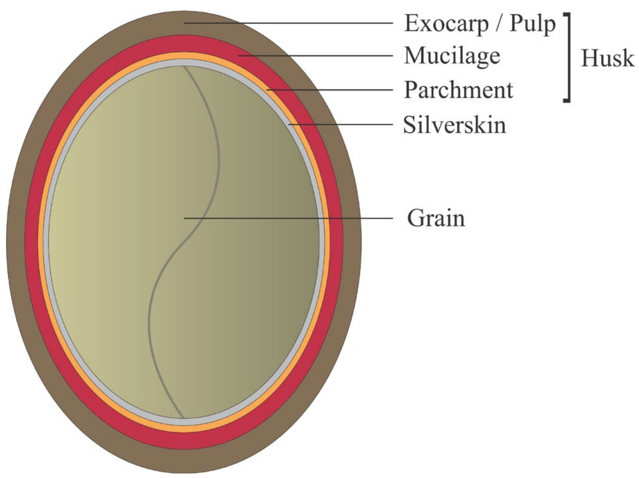

Figure 1: Scheme of the coffee berry and its parts.

Adapted from Durán et al. (2017).

According to Durán et al. (2017), the pulp represents 39-49% of the mass of the fresh berry (6-8% of the mucilage); the mucilage represents 22-31% of the dried berry; the parchment represents approximately 3.8% of the fresh berry; and the Exocarp represents 12% of the fresh berry. Tables 4 and 5 show the characteristics of the pulp and Exocarp, respectively.

Table 4: Composition of minerals in coffee berry pulp (dry matter basis).

Minerals	Content
Ca (mg kg^{-1})	554.0
P (mg kg^{-1})	116.0
Fe (mg kg^{-1})	15.0
Na (mg kg^{-1})	100.0
K (mg kg^{-1})	1,765.0
Zn (mg kg^{-1})	4.0
Cu (mg kg^{-1})	5.0
Mg (mg kg^{-1})	6.3
B (mg kg^{-1})	26.0

Source: Braham and Bressani (1978).

Table 5: Composition of minerals in coffee berry Exocarp (dry matter basis).

Minerals	Content
N – total (dag kg^{-1})	1.9
P – total (dag kg^{-1})	0.2
Ca (g kg^{-1})	3.0
Na (g kg^{-1})	40.7
K (g kg^{-1})	47.1
Zn (mg kg^{-1})	4.4
Cu (mg kg^{-1})	18.7
Mg (mg kg^{-1})	0.3

Source: Brandão et al. (2000).

4.2 Possible uses of waste

Due to the characteristics of the pulp and Exocarp, they have the potential for use as a source of K in soils. Fernandes et al. (2013) and Bosa et al. (2019) concluded that it is possible to reduce mineral fertilization with the use of coffee straw, an agroindustrial waste serving as a source of N, P, K and S. Other authors, such as Malta et al. (2008), Piccolo et al. (2013) and Sediyama et al. (2016), obtained good results using coffee Exocarp, showing an increase in soil nutrient levels and better beverage quality (coffee) than obtained with mineral fertilization. Lo Monaco et al. (2013) and Teixeira, Matos e Melo (2016), in turn, introduced coffee husk as a structuring agent (high carbon/nitrogen (C/N) ratio material) in the composting of poultry litter (low C/N ratio), thus generating waste with marketable organic compost characteristics.

Brandão et al. (2000) evaluated the use of coffee Exocarp in organic filters, which was effective in the removal of SS (> 90%) from swine wastewater (SWW). With a calorific value of 3,933.0 kcal kg^{-1}, coffee Exocarps have the potential to generate energy, for example, in the drying of beans (Vale et al., 2007).

Murthy and Naidu (2012), Castillo et al. (2021), and Bondam et al. (2022) cite other possible uses of Exocarp and pulp in animal and human feed, as pharmaceutical ingredients, as vermicompost as a substrate for the production of edible fungi, as a source of substances for food pigments, in the extraction of phenols, and in the production of ethanol and biosorbents. Munirwan et al. (2022) discuss the potential of applying coffee husk ash as a soil stabilization agent. On the other hand, Jayachandra, Venugopal and Appaiah (2011) used coffee Exocarps pre-treated with the fungus *Mycotypha* for biomethanation. The biogas produced can be used in an engine to produce electrical energy, and all the residual heat can be used to dry coffee (Pin et al., 2020; Battista et al., 2021; Mahmoud; Atabani; Badruddin, 2022).

Due to the presence of large amounts of caffeine, phenols and free tannins (polyphenols), coffee residues can be toxic, and their treatment may be challenging (Hoseini et al., 2021; Bondam et al., 2022). Composting, preliminary biodegradation, and the use of fungi (Hanc et al., 2021; Hoseini et al., 2021; Sabogal-Otálora; Palomo-Hernández; Piñeros-Castro, 2022) or hot water/thermal treatment (Campos et al., 2021; Bomfim et al., 2022) can reduce toxicity, thus increasing the amount of safety waste to be added to soil.

5 PARCHMENT AND COFFEE DREGS

5.1 Characteristics

Similar to coffee Exocarp, parchments (Figure 1) also have a high calorific value, which indicates the potential for energy generation (Srisang et al., 2022). Protásio et al. (2012) prepared coffee Exocarp and parchment briquettes by roasting and carbonization and evaluated their energy production potential, obtaining better results after performing the latter transformation process.

Moreover, in the preparation of beverage coffee, hot water is added to a filter containing the grounds resulting from the roasting of dried and peeled berries, thus generating dregs as the remaining organic solid material. The potential use of this waste from the coffee chain has been the subject of research in recent years (Gebreeyessus, 2022).

5.2 Possible uses of waste

As previously discussed, fertigation with CW has enormous potential for improving soil attributes, increasing productivity, and decreasing production costs. However, even though localized application implies a better distribution of water and nutrients, it also carries a high risk of clogging with solids (and biofilm formation). To reduce the concentration of SS, Cunha et al. (2006) evaluated the use of parchment in organic filters for CW treatment, which subsequently increased the irrigation system's operation time and improved distribution uniformity during fertigation.

Furthermore, Magalhães, Lo Monaco, and Matos (2013) obtained a reduction in oils and fats (O & F) of 82.3% in SWW after the substrate was passed through parchment-containing filters. However, the parchment needed to be compressed to reach better filtering efficiencies (Matos; Magalhães; Funakaga, 2006). According to Matos, Magalhães e Sarmento (2010), parchment-containing filters (for retaining particles from 3.0 to 8.0 mm) can work without interruption for approximately 1.5 h before the filter material needs to be replaced; the discarded material can then be composted afterward.

Regarding the use of coffee dregs as an agricultural fertilizer, Cruz and Cordovil (2015) compared the application of this waste in its raw form. The authors reported a decrease in lettuce, carrot, and spinach yield was observed with an increase in the amount of dregs added, probably due to the presence of caffeine, which may result in lower nitrogen availability to plants and even repress their growth (Cruz; Cordovil, 2015). Ribeiro et al. (2017) also observed growth inhibition when mixing *in natura* coffee dregs into industrial and domestic residues added to soil. Thus, it seems necessary to treat coffee dregs before their addition to soil.

For another perspective, Zhang and Sun (2017) used coffee waste in the composting of cattle manure and observed an improvement in the characteristics of organic compost. Castilhos et al. (2008) found that coffee dregs used as vermicompost had a higher content of humic substances than did cattle, sheep, pig and quail manure and yerba mate; humic substances are essential for improving soil structure (cementing agent) and increasing soil CEC (González-Moreno et al., 2020).

Murthy and Naidu (2012) conducted a review on the sustainability of the coffee industry, pointing out possible uses for the waste generated in berry processing and in beverage preparation. Among the options presented by the authors is the manufacture of activated charcoal or biochars from coffee dregs. For example, Namane et al. (2005), Reffas et al. (2010), Ching et al. (2011), Oliveira et al. (2021), Jóźwiak et al. (2021), Nguyen et al. (2021), and Yen et al. (2022) were successful in removing methane, heavy metals, phenols, dyes, ethylene, n-butane, phosphorus, iron, and nano-sized polystyrene plastic by applying untreated coffee dregs or after their activation with zinc chloride, phosphoric acid, nitric acid, potassium hydroxide, sulfuric acid by burning (in the absence of oxygen), and pyrolysis.

Other possible uses for coffee dregs mentioned by Murthy and Naidu (2012) include animal feed, oil production, biodiesel, bioethanol, adsorbents and antitoxic agents. Vitěz et al. (2016) also highlighted the potential for biogas production. Thus, given the presented results, there are different possibilities for using coffee processing by-products, which allows them to no longer be seen as an environmental problem but as a source of nutrients, carbon and energy.

6 CONCLUSIONS

Large amounts of by-products are generated in the processing of coffee berries and in beverage production, such as CW, Exocarps, parchments, pulps and coffee dregs, and it is necessary to present alternatives for their use/disposal;

CW treatment is complex due to the high organic load, presence of phenols and high potassium concentration. Anaerobic treatment may be more effective than aerobic treatment in reducing BOD;

Many studies show the potential for using CW in fertigation, with improved soil chemical attributes and increased crop productivity. However, the dose should be calculated according to nutritional criteria, with potassium as the chemical reference element;

The recirculation of CW reduces water consumption in the processing of coffee berries. To apply this technique, it is necessary to use chemical and physical processes for coagulation, sedimentation and pH control; and

Exocarp, pulp, parchment and coffee dregs have been found to be successful in the production of biogas, organic compounds, organic filters, and biochars, among others, as a source of nutrients, organic matter and energy.

7 AUTHORS' CONTRIBUTION

MPF Jr, MPM, and RF wrote the manuscript and performed the experiment, MPF Jr, JCS, MPM, and RF supervised literature survey and review and co-work the manuscript, and JCS and ARS co-worked the manuscript, MPM and RF conducted all statistical analyses.

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