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REVIEW

# Improvement and Use of Effluents for the Benefit of Coffee

## Mejoramiento y uso de los efluentes para el beneficio del café

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**ABSTRACT:** The coffee sector carries out the processing of coffee by the wet method, where polluting liquid waste is generated due to its acidity (acid pH), sedimentary solids (SS) and chemical oxygen demand (COD) values. Therefore, the objective of this work is to review the technologies to improve the coffee processing and those to use its effluents with ecological approach in El Nicho Pulper, in Cienfuegos Province, Cuba. Firstly, the technologies for coffee benefit process are described. Secondly, the peculiarities to implement new technologies are emphasized and, finally, the possibility of their implementation in Cuba is analyzed.

***Keywords***: Wastewater, Water Contamination, Wet Benefit, Treatment, Honey Water.

**RESUMEN:** El sector cafetero, realiza el procesamiento del café por vía húmeda, en donde se generan residuos líquidos contaminantes por sus valores de acidez (pH ácido), sólidos sedimentables (SS) y Demanda Química de oxígeno (DQO). Por lo cual, el objetivo de esta revisión se realiza para el mejoramiento y uso de los efluentes del beneficio del café con un enfoque ecológico en la despulpadora El Nicho de la provincia de Cienfuegos. En el trabajo, primeramente, se describirá las tecnologías del proceso de beneficio del café. Luego, se enfatiza en las peculiaridades para implementar las nuevas tecnologías y, en la tercera parte se analiza la posibilidad de su implementación en Cuba.

***Palabras clave***: Aguas residuales, contaminación del agua, beneficio húmedo, tratamiento, agua miel.

## INTRODUCTION

During the coffee harvest, the wet processing is one of the processes in which the transformation of the red fruit (cherry coffee) into clean grain (gold coffee) occurs. There are two methods to benefit coffee: dry and wet. The wet benefit is used in almost all the producing countries of Central America according to Rojas *et al.* (2017), it consists on the separation of the pulp or skin and mucilage of the coffee grain, using a mechanical pulping and high volumes of water according to González (2020), process that generates a large amount of liquid waste that is acid and has a high contaminant load.

According to Rodriguez *et al.* (2015), the relationship that exists between the different types of coffee benefit with respect to the efficient use and saving of water is known. Currently, in Colombia there are three types of benefit for the fruit, which are described as follows:

1. Conventional benefit of coffee. It is a traditional process in which water is used in all its stages (pulping, washing and transport), consuming 40 L of water for each kg of dry parchment coffee (cps) and in which the by-products obtained are not managed and are released with their high contaminant organic load.
2. Ecological benefit of coffee. It allows obtaining coffee with physical and cup quality, eliminating unnecessary processes, using demucilaginators, mechanical washers or fermentation tanks. It allows washing and classifying the coffee, with specific water consumption between 0.7 - 1 L·kg$^{-1}$ cps.
3. Ecological benefit of coffee without dumping. It allows a rational use of water and by-products such as pulp, mucilage and wastewater are treated, so that dumping is not generated in the process. It involves a mechanical washing system with a minimum amount of water (less than 0.5 L·kg$^{-1}$ cps), under the conditions established in Resolution 1207 of 2014 (República de Colombia. Ministerio de Ambiente y Desarrollo Sostenible, 2014).

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Cuba is not exempt from this practices, on the contrary, it is frequent in its coffee growing areas, due to the availability of water sources in the region. Its resulting waste, which is not well managed, the pulp and the mucilage, are composed of various proteins and sugars in the form of pectin, which are fermented by the action of the enzymes from bacteria located in the coffee fruit and the volumes of wastewater (Bello & Castillo, 1994). During fermentation, yeasts and bacteria partially oxidize sugars, generating energy and various compounds. In addition, they change the color, smell, density, acidity, pH, soluble solids, modify the temperature and chemical and microbial composition of the substrate (Puerta, 2012; 2013).

In Latin America, several tests carried out to treat these effluents have shown the chemical-physical characteristics of the wastewater, and its organic contamination with a good degree of biodegradability under anaerobic and toxic conditions, and present in dissolved form. They have pointed the biological methods as the most appropriate for their treatment (Bailly *et al.*, 1992; Bello & Castillo, 1994).

Although in smaller volume, solid residuals are also generated, consisting mainly of coffee pulp. As alternatives to the treatment and use of coffee pulp, its use in the production of biofertilizer, in livestock feeding or as fuel has been proposed, but few are applied in practice. In Cuba, according to data reported by the National Office of Statistics and Information ONEI (2017), in its edition referring to the Environmental Panorama, the available biomass corresponding to coffee residuals is not consumed. These residues are usually stored near the benefit centers generating bad odors, aquifer contamination and eutrophication of rivers and lagoons where they are discharged. Sarabia *et al.* (2017) state that anaerobic digestion is a technology with which the reduction of the contaminant load of the residual and the recovery of energy is achieved. In recent years, research have been reported on solid coffee residues as source of sugars, for the production of activated carbon and compost, as an adsorbent material for heavy metals and in the production of biodiesel (Pujol *et al.*, 2013).

Considering the diversity of studies carried out, it is necessary to create awareness in this sense, since these technologies, according to their development, report important advantages and/or gains from the energy, economic and environmental points of view. In the same way, they are sufficiently studied with concrete results for their introduction. However, this is not the Cuban case, where the non-use of its residuals and the irrational use of water constitute serious environmental problems. Hence, the importance of this study.

## DEVELOPMENT OF THE TOPIC

This work was elaborated taking bibliographic references from the years between 1990 to 2020. The fundamental sources cited are of Colombian origin, although works carried out in Brazil, Mexico, Guatemala and Cuba are also mentioned. The quotes that appear are fundamentally related to Colombia and Cuba. Criteria related to the reduction of water in the wet benefit process (PBH) and the efficient use of the residues of this process have been published. Therefore, it constitutes a bibliographic compilation of the most used techniques and procedures internationally.

It should be remembered that the wet processing process (PBH) is a process that cannot be omitted since it defines the quality of the coffee (aroma, flavor, body and acidity) and is also the first step in the agro-industrial chain. However, this importance is opposed to the environmental costs due to the affectation of ecosystems and the high consumption of water, for this reason, some technical guides denote it as a complex set of operations. Therefore, it is necessary to have specialized knowledge for the minimum requirements of those operations to avoid affecting the quality of surface water and the coffee grain. Studies carried out describe and compare the main water quality parameters from washing and pulping. It is important to emphasize that such parameters present variability due to the different volumes of water used in the process (Bailly *et al.*, 1992). Table 1 shows the most used technologies in recent years and their specific water consumption.

**TABLE 1.** Most used technologies in recent years and their specific water consumption

| Technology | Esp. Water Consumption (L/kg of cps) |
|---|---|
| Mechanical wash with Ecomill | 0.3-0.5 |
| Mechanical demucilaginated Becolsub | 0.7-1.0 |
| Other washers | 2.2-2.7 |
| Other demucilaginators | 1.5-3.3 |
| Fermentation tank | 4.0-5.0 |
| Semi-submerged channel | 6.5-8.0 |
| Submersible pump | 6.5-9.0 |
| Concrete channel | 20.0-25.0 |

Colombia is currently implementing new strategies by developing practices for saving and efficient use of water, in order to reduce or avoid potential contamination of natural resources due to the inadequate disposal of coffee by-products. With their application, a conventional mill can be transformed into an ecological mill and an ecological mill can be transformed into an ecological mill without dumping.

**Use of dry hopper or wet hopper with water consumption of less than 2 L·kg$^{-1}$ cps, for the reception and classification of the fruit**

Among the devices for hydraulic classification of the fruit that allow low water consumption are the hydraulic hopper and auger separator, the wet hopper with recirculation and the siphon tank with recirculation. To prevent contamination, wastewater from hydraulic classification must be taken to a treatment system for its use back on the crop.

**Rationalization in the consumption of water in the demucilaging, washing and classification stages of the coffee and in the cleaning of the processing plant**

The rational use of water in the natural or mechanical demucilagination and washing of coffee has made it possible to reduce the volume and increase the concentration of organic contamination in the liquid waste produced, which has made its biological treatment more economical according to Rodríguez *et al.* (2015). When the mucilage is removed by mechanical demucilation (using Becolsub technology), a simple flow control system, developed at Cenicafé, allows for a flow close to 0.8 L·kg$^{-1}$ cps. In Colombia, about 20,000 pieces of equipment are currently used, which allow 291 000 000 kg of dry parchment coffee to be obtained each year, with a saving of 11,4 000 000 m$^3$ of water (Rojas *et al.*, 2017; Rodriguez *et al.*, 2015).

When the removal of mucilage is carried out by natural fermentation, the efficient and rational use of water during coffee washing allows for an 80% reduction in water consumption. To carry out this control, the practice of rinsing the coffee inside the fermentation tanks was developed: Tina Tank technology. That coffee must rest for approximately 20 hours, so that there is a uniform fermentation. The time varies depending on the amount and the ambient temperature. The higher the temperature, the shorter the fermentation time, and the higher the amount of coffee, the longer the time. To find out its optimum point, a rod is introduced in the ferment piles to the bottom and if the parchment coffee grains no longer adhere to the rod, it is already possible to wash it and continue with the process. Another way is using a fermaestro (a tool that is placed inside the coffee in fermentation).

**Adoption of pulping and transportation of pulp without water**

Adopting the pulping of the fruits without water and their transport by gravity to the pits, is the most important environmental action in the wet processing of coffee, since water at this stage generates the greatest negative environmental impact on ecosystems, due to the great amount of organic compounds of low biodegradability, which are solubilized in the water when it comes into contact with the pulp, which is responsible for three quarters of the potential contamination that can occur in coffee mills. Its implementation cost is low.

**Construction of covered pits**

The pulp storage and processing can be done by building a covered pit, since the pulp and mucilage are 100% of the waste generated during the wet processing of coffee. The mere construction of a covered pit for pulp decomposition prevents 74% of water pollution, if the pulp is transported by gravity or mechanically, without the use of water. The pits for the pulp must be solid and durable constructions (made of adobe and cement), roofed and of sufficient size to store and process the pulp during the coffee harvest (Bailly *et al.*, 1992; Bello & Castillo, 1994).

This pit is divided into compartments, 2 to 6 m wide, depending on the production, to facilitate the storage and handling of the pulp. The length of the pit can vary between 3 to 25 m, depending on the amount of pulp to be processed. The divisions are made with bamboo stems which are supported by adobe or concrete boxes, built at the ends. The height of the walls of the pit should not be more than 2 m. The floor of the pit must be made of cement, and it is advisable to cover it with a stoneware tablet to give it a longer useful life, with a 2% unevenness towards the outside, which allows channeling the leachates from the decomposition of the pulp, to take them to a treatment system or store them to be sprayed again to the pulp. In all cases, the floor of the pit must be isolated from the ground, to avoid the infiltration of the leachate generated (Bailly *et al.*, 1992; Bello & Castillo, 1994).

**Transformation of the pulp into organic fertilizer through composting or vermicomposting, indoors**

Vermicomposting of coffee pulp is considered the simplest practice for the efficient use of this by-product, since it speeds up its transformation process, reduces labor and improves the yields of the organic fertilizer obtained.

Vermicultures can be built using different management systems such as bamboo beds, mats, bricks and plastic boxes, in which it was found that, the pulp generated by a farm that produces 1,000 cps per year (approximately 25 tons of fresh pulp), can be managed in an effective area of 25 $m^2$ of vermiculture, with a pure worm density of 5 kg.$m^2$. In other words, around a ton of coffee pulp can be handled per square meter of vermiculture per year.

More recent research carried out at Cenicafe has allowed the use of the red worm (*Eisenia foetida* Savigny) to facilitate the handling of coffee pulp during its transformation, with very good results in terms of reduction in process time, increase in earthworm biomass and the quality of the vermicompost obtained (Dávila & Ramírez, 1996); which, is an excellent soil conditioner due to its physical-chemical characteristics and a good organic fertilizer due to its great microbiological richness (Blandón *et al.*, 1998).

If worms are not available, the transformation of the pulp can be carried out by means of periodic turnings indoors, to prevent rainwater from leaching the components of the pulp and causing negative impacts on the ecosystem. Its use for the cultivation of edible mushrooms of the Pleurotus genus was also investigated, obtaining encouraging results because for each ton of fresh coffee pulp, on a wet basis, 82.10 kg of fresh mushrooms, 9.76 kg of red worm and 135.30 kg of wet vermicompost per crop cycle, can be obtained in a time of approximately three months (Rodríguez & Zuluaga, 1994).

**Use of mucilage in animal feed or its incorporation into the pulp. Addition on the pulp, of the residual water from the first two rinses, when the coffee is washed in the tank**

The main component of coffee mucilage is moisture (91.77%), followed by total sugars (6.43%), pectin (0.81%) and nitrogen (0.12%). Due to its content of reducing sugars in this fraction of the fruit and the ease of its interaction with microorganisms, it can be used for the production of honey and ethyl alcohol, and due to its anaerobic fermentation, methane gas can be produced, giving it great industrial importance and high economic interest (Rojas *et al.,* 2017; Rodriguez *et al.,* 2015).

Considering the low volumes of water used in mechanical demucilagination and mechanical washing of coffee, the application of fresh or fermented mucilage on the pulp constitutes a good management practice, given the large amount of solids that pulp can retain, when it receives highly concentrated residues. The leachates generated during mixing (fresh mucilage, fermented mucilage, wastewater from the first two rinses) with the pulp must be collected and reintegrated into the pulp in the process of decomposition (so as not to generate discharges) or taken to a treatment system (Rojas *et al.,* 2017; Rodriguez *et al.,* 2015).

In the same way, the use of coffee mucilage in pig feeding has been evaluated, using the by-product as a supplement to the concentrate according to the weight of the animal and the proportion of the diet.

Similarly, the wastewater from the first two rinses in the tank can be retained, in good proportion, by the pulp. Regarding the residual discharges derived from the PBH, the National Water Law (LAN) establishes that there must be a prior treatment to the time of its discharge in receiving bodies. As background to this issue, the standard NOM-027-ECOL-1993, specifically established the maximum permissible limits of pollutants in residual discharges from the HBP. However, this norm was abrogated when the norm NOM-001-SEMARNAT-199617 officially entered into force in January 1997 (República de Colombia. Ministerio de Ambiente y Desarrollo Sostenible, 2015; República de Colombia. Ministerio de Ambiente y Desarrollo Sostenible, 2014).

**Modular anaerobic treatment systems and artificial wetlands to treat all or part of the wastewater generated (honey water and leachate from the mucilage-pulp mixture)**

The technical-economic feasibility for the implementation of wastewater treatment systems for coffee processing depends largely on the simplicity and reliability of the system, as well as on the volume and organic load of the waste to be treated. Consequently, not using water to transport pulp and the rationalization of water consumption in the washing operation, allow reducing pollution and the volume of water that needs to be treated.

The wastewater produced during the wet benefit process of the coffee fruit is biodegradable, but it has physicochemical characteristics that are particularly aggressive towards the environment: low pH, high acidity and high concentrations of organic matter, which correspond to polluting powers between 60 and 240 times higher than domestic wastewater.

Modular Systems for Anaerobic-SMTA Treatments were designed to treat honey water from grain washing. They allow the treatment of fermented mucilage, which corresponds to 26% of the total contamination generated by the by-products. It is present in the washing wastewater, with a contribution of 24,000 mg·L-1 of Chemical Oxygen Demand (COD) per kilogram of cherry coffee, and a concentration between 25,000 and 30,000 mg·$L^{-1}$, when amounts of water between 4 and 5 L·$kg^{-1}$ cps are used in the wash. These well-operated treatment systems allow the generation of discharges that comply with the regulatory provisions for specific discharges to surface water bodies (República de Colombia. Ministerio de Ambiente y Desarrollo Sostenible., 2015). In order to protect the water resources in the coffee zone, the implementation of artificial wetlands, using aquatic plants such as the water buchon, water cabbage, water ear and duckweed, located after the SMTA allows obtaining cleaner effluents, which contribute to the preservation of water resources, while the harvested biomass can be used for the production of organic fertilizers.

### Environmental advantages of eliminating water in the pulping and transport stages of the pulp

The conventional benefit is characterized by the use of water in the stages of pulping and transport of the pulp to the decomposition pits, unlike the ecological benefit in which the pulping and the transport of the pulp to the decomposition pits are carried out without water. Decomposition is done by gravity, with air or by mechanical transport (worm screw).

In the characterizations carried out on the wastewater from the coffee washing, which is treated in the Modular Anaerobic Treatment Systems, installed in Cenicafé "La Granja" and in the "Estación Experimental Naranjal", values of oils and fats of the order 10.0 and 7.6 ppm and 6.1 and 4.8 ppm are reached. These values, naturally, before entering treatment, are lower than the maximum permissible values for punctual discharges from the coffee sector, coming from the ecological benefit, given that the norm requires a maximum value of 30 ppm (República de Colombia. Ministerio de Ambiente y Desarrollo Sostenible., 2015).

Those are some aspects of the way in which Colombia deals with this problem, but when analyzing Cuba, its wet processing process is based on obtaining washed coffee. There are possibilities of exploiting its raw material through new methods and obtaining coffee with more pronounced organoleptic characteristics. Another aspect is the research related to the use of coffee pulp, among which composting (normal or with worms) stands out.

### How to improve the process and use of the residues of processing coffee with an ecological approach in Cuba?

The wet processing facilities in Cuba generally have reception hopper, siphon, screw auger, demucilaginator, washing machine and recirculation water tank. However, to date, few studies have been reported regarding increasing the quality of coffee in the cup by reducing water consumption, improving the wet processing process and, in turn, the use of its residues in different ways. In the productive practice in the El Nicho Pulper, Cienfuegos Province, little use is appreciated in the rationalization of water and in the use of its residuals, either as organic fertilizer, fertilizer or substrate for biodigesters, etc. Faced with this situation, the following **problem** can be defined: How to improve the process and use of the residues of processing coffee with an ecological approach in Cuba? This review shows that this purpose is achievable with the use of viable methods from the technical-economic and environmental points of view that govern the regulations of our country.

As it can be seen in this work, the development of each of these variables is based on research and practices carried out by the Cenicafé Research Institute, in Colombia, a reference center for this work due to its experience and results obtained. However, for the implementation in Cuba of the most advantageous techniques for coffee processing, training, equipment and the will of the decision-makers, researchers and productive organizations involved, are necessary.

## CONCLUSIONS

In El Nicho Pulper, in Cienfuegos Province, has been confirmed that only 9.5% of the weight of the fresh fruit is used in the coffee industry, while 90.5% remains as waste, noting that 58.6% comes from of the wet processing process.

In the Cuban case, the ecological benefit is used for *Arabica coffee*, but still water consumption has not been significantly reduced (in the demucilagination, washing and classification stages of the coffee and in the cleaning of the benefit plant), causing notable discharges.

Coffee residuals are not used in the different existing modalities such as transformation of the pulp into organic fertilizer, the use of mucilage in animal feed or its incorporation into the pulp, addition of the residual waters of the first two rinses when the coffee is washed, on the pulp. Finally, it is clarified that these technologies are perfectly feasible to put into practice under the current conditions in Cuba.

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