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Identification of abundance, chemical composition, and microbiological profiles of Cigarette Butts discarded in the sand of four tourist beaches in Cartagena, Colombia

Claudia Díaz-Mendoza[1], Bernardo Bolaño Matos [2], Sara Sánchez Hernández [2], Glicerio León Méndez [3], Olga Mile Pérez Palencia [4], Jorgelina Pasqualino[1], Rosa Acevedo-Barrios[5]

[1]Grupo de Investigación en Sistemas Ambientales e Hidráulicos (GISAH), Escuela de Ingeniería Arquitectura & Diseño, Universidad Tecnológica de Bolívar, Cartagena, Colombia. cdiaz@utb.edu.co; jpasqualino@utb.edu.co
[2] Environmental Engineering. Fundación Universitaria Tecnológico Comfenalco Cartagena
[3] Pharmaceutical Chemist, Msc Chemistry, PhD in Engineering, Fundación Universitaria Tecnológico Comfenalco Cartagena
[4] Bacteriologist, Universidad de Cartagena (University of Cartagena), Omperezbacte@hotmail.com
[5]Departamento de Ciencias Básicas, Universidad Tecnológica de Bolívar racevedo@utb.edu.co

Abstract*– Cigarette butts are among the most prevalent solid waste materials found on urban streets. Composed of key components such as filters, tobacco remnants, and wrapping paper, millions of these CBs are discarded onto sidewalks, eventually entering stormwater systems and reaching surface water bodies, with the ultimate destination often being the ocean. Coastal ecosystems serve as repositories for cigarette butt waste, posing significant environmental challenges due to the presence of toxic compounds and the complex degradation process. This directly impacts the sanitary and ecological quality of beach environments. The study aimed to evaluate the potential environmental impact of CBs disposal on beaches through the physical, chemical, and microbiological analysis of cigarette butts and their degraded fibers, which result from decomposition. Findings revealed the presence of microorganisms, including Escherichia coli and Clostridium species, highlighting a potential risk to human health.

***Keywords*-- cigarette butts, environment, impacts, beaches, fibers.**

I. INTRODUCTION

The most abundant solid waste found on urban beaches with anthropogenic activities is cigarette butts (CBs) [1]. The high global consumption of cigarettes is well-documented, with many being discarded in urban streets, beaches, parks, and other locations, making them a prevalent type of waste.

The plastic component of cigarette filters can persist in the environment for extended periods without decomposing, even after weathering, leading to the formation of small plastic debris particles with potential toxicity. These particles can release chemicals into the soil and water as they degrade [2]. The decomposition of cellulose filters varies depending on the environment in which they are disposed of. Research by [3] compared the degradation of conventional cellulose filters with plastic filters under various environmental conditions. The study demonstrates that cellulose filters decompose more rapidly than plastic filters due to the metabolic activity of microbial enzymes, but their degradation is influenced by environmental factors such as humidity and nutrient availability [3].

According to [4] CBs undergo a decomposition process characterized by an initial stage lasting a few weeks to approximately 30 days, during which the butts lose about 15% to 20% of their mass. This loss is independent of the type and presence of soil or incubation conditions. Over the following two years, the decomposition of CBs progresses very slowly, with reported mass losses of around 10% between one month and two years. Between three and five years after the process begins, decomposition rates vary depending on the treatment or environment. In the absence of soil, the mass loss is around 50%; in pasture soils, it is approximately 80%; and in dune sand, it ranges between 70% [4].

There is significant interest in the issues associated with the disposal of CBs, considering that the volume of this waste has increased, with the global weight of CBs estimated to reach 1.2 million tons annually [5]. According to the International Coastal Cleanup report, which is based on data from coastal cleanups conducted in over 100 countries, cigarette butts were identified as the most common type of waste found on beaches. Ghana (3,561,310 units of CBs) tops the list as the largest contributor, followed by Canada (167,811 units of CBs) and Chile (73,405 units of CBs) [5]. In the International Coastal Cleanup 2024, global reports indicated the collection of 385,285 CBs in the United States, 715,875 CBs in Thailand, and 118,609 CBs in Germany [6].

Studies highlight the importance of raising awareness about the environmental impact and risks associated with CBs in marine ecosystems, as well as the urgency of implementing effective public management strategies to address this type of waste [7]. The study also emphasizes the risks posed by the increasing presence of CBs, which can negatively impact marine organisms and classify them as emerging pollutants. These pollutants primarily originate from endocrine disruptors (EDs), pesticides, pharmaceuticals, hormones, toxins, industrial synthetic dyes, and the hazardous contaminants they contain. Although most of these pollutants lack defined regulatory guidelines, they can have detrimental effects on humans and aquatic organisms even at low concentrations [8].

Consequently, the study underscores the need to prioritize the removal of cigarette butts from beaches, not only for aesthetic purposes but also to mitigate a potential source of contamination in the marine environment.

CBs are the waste generated from cigarette filters because of smoking activity. They are composed of paper and cellulose acetate, a type of plastic with low biodegradability that absorbs the chemicals present in cigarette smoke [9]. It is important to note that global cellulose acetate production, primarily used for cigarette filter manufacturing, is approximately 640,000 tons. Assuming that 60% of these filters are discarded into various aquatic environments, including coastal areas, around 0.3 million tons of potential microplastics are being directly and consistently introduced from this source [10].

The disposal of CBs is associated with the presence of metals such as Cd, Fe, As, Ni, Cu, Zn, and Mn, which can enter the marine environment and coastal areas annually [11]. In the study by [12] it is mentioned that smoked cigarette filters contain heavy metals such as Pb, Cd, Hg, and As, in addition to many chemicals, including 70 known carcinogens. These toxic substances can bioaccumulate and pass-through trophic chains, for example, from fish to humans.

Another point of interest for the study is the presence of microorganisms associated with cigarette butts discarded directly as waste on beaches or transported by various mechanisms such as wind or marine currents. Some of these microorganisms, including bacteria and fungi, may negatively impact sanitary quality by directly affecting the health of beach users or associated biota. Fecal coliforms, also known as thermotolerant coliforms due to their ability to withstand temperatures up to 45°C, are a reduced group of quality indicator microorganisms of fecal origin. These include microorganisms such as *E. coli*, as well as *Citrobacter freundii* and *Klebsiella pneumoniae*. They are considered hygiene indicators, as their presence signals fecal contamination from human or animal sources [13].

II. MATERIALS AND METHODS

A. *Georeferencing samples of cigarette butts on selected beaches*

The beaches are within the jurisdiction of the Cartagena district and have connotations of tourist beaches due to the high influx of tourists (Table 1). The sampling was conducted between May and June 2019.

TABLE 1. COORDINATES OF THE STUDY BEACHES

COORDINATES	STUDY BEACHES
10°23’59”N 75°33’39”W	Bocagrande
10°22’34”N 75°34’25”W	Tierra Bomba
10°28’37”N 75°29’46”W	La Boquilla
10°13’03”N 75°36’47”W	Playa Blanca

The Bocagrande beach (Figure 1) is part of the Historical and Northern Caribbean Locality and belongs to community unit No. 1, located to the northwest with coordinates 10°23’59”N 75°33’39”W of the urban area of the district with an area of 745.63 hectares and a perimeter of 52,250. Population growth has had significant impacts, especially in environmental terms. Knowledge of the origin and routes of entry into marine ecosystems is essential to address the problem of marine debris.

One kilometre and a half from the city of Cartagena de Indias is the island of Tierra Bomba (Figure 2) with coordinates 10°22’34”N 75°34’25”W, which has approximately 2,000 hectares, inhabited by a total of 9,000 people. The island has four townships that are part of this territory (Tierra Bomba, Punta Arenas, Bocachica and Caño del Oro or del Loro).

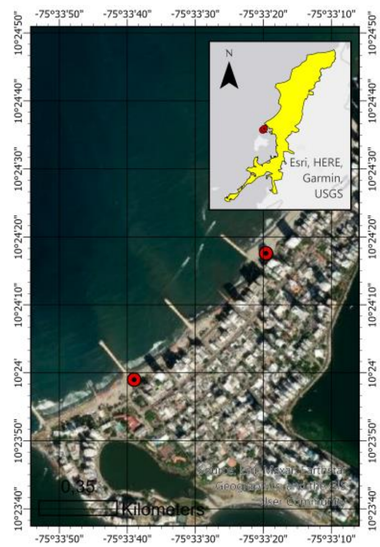

Figure 1. Bocagrande Beach

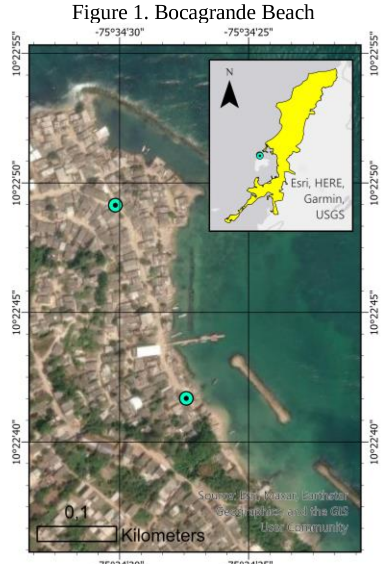

Figure 2. Tierra Bomba Beach

Boquilla beach (Figure 3) is a village that belongs to the District of Cartagena de Indias, located two kilometres north of this city with coordinates 10°28'37"N 75°29'46"W along the Vía al Mar highway. The processes of modernization, urbanization and economic development of Cartagena have turned this sector into a great tourist attraction for its beaches and a large line of luxury hotels for tourism, which has generated great pressure on the beach ecosystem.

Playa Blanca beach (Figure 4), which is located on the island of Barú on the Colombian Caribbean Coast, with coordinates 10°13'03"N 75°36'47"W, is the closest insular part to the continental territory of the Cartagena District.

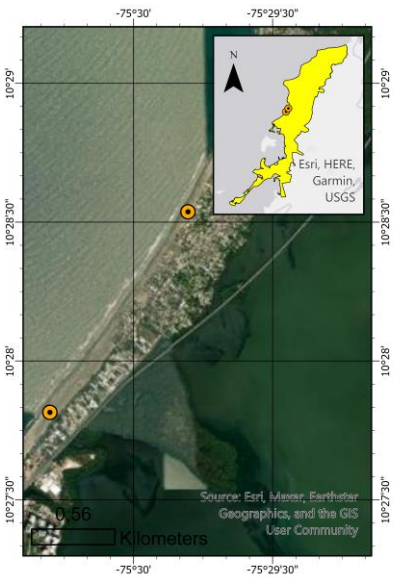

Figure 3. Boquilla Beach

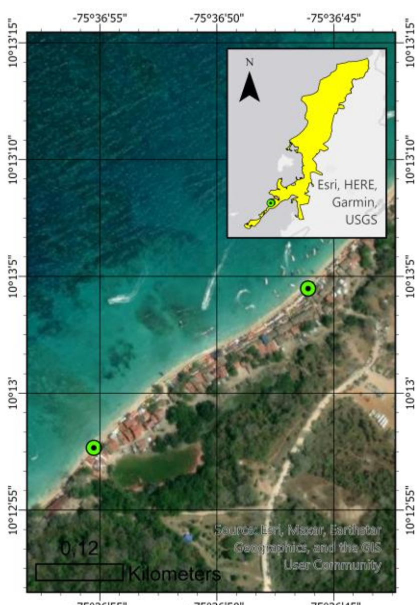

Figure 4. Barú Beach

B. Identification of collected material

The methodology used in this study included a review of secondary information with the aim of validating collection techniques through citizen science methodologies. Additionally, the protocols related to sample chain of custody and laboratory testing procedures were verified. Four tourist beaches were selected as study sites, based on their typology and relevance to the research objectives.

Two types of materials disposed in the sand of the beach have been considered, the first being the CBs as the main result of the consumption of the product, that is, the material discarded by the consumer, transported by wind or water, but without decomposition. The second material in the characterization is CBFs, which are the butts in an advanced state of decomposition; in this state, the butt has lost the paper that covers it and the trace of nicotine, leaving only the filter material.

The CB and CBF samples used for the characterizations were sourced from four independent cleanup campaigns, each conducted at one of the selected beaches by volunteer groups. These activities followed a methodology similar to that of the Ocean Conservancy's International Coastal Cleanup, which mobilizes individuals to participate in the removal of litter from coastal environments [14]. Over a two-hour period, volunteers collected CBs along linear transects of approximately 200 meters, parallel to the coastline. The samples were manually collected by the volunteer groups using gloves to ensure safety and prevent contamination. Samples intended for counting and brand identification were placed in collection bags, while those intended for microbiological analysis were stored in sterile Ziploc bags. At the end of each campaign, all collected samples were transported to the laboratory for quantification of the number of CBs and their corresponding brands, as well as for conducting microbiological tests.

To determine the presence or absence of microorganisms in the CBs collected from the beaches, triplicate samples were taken using the TSB Broth (Soybean Casein Digest Broth, liquid medium for bacterial enrichment). Three bottles with a capacity of 200 ml each were prepared, containing a total of 600 ml of water, equally divided among them. Each bottle was supplemented with 20 grams of TSB broth and inoculated with 22.5 grams of cigarette butts. The bottles were then incubated at 37 °C for 8 hours.

For bacterial identification, the following culture media were used: AGAR SPS (8 grams of material, Merck), CROMOCULT (6.6 grams of material, Merck) and PLATE COUNT (4.5 grams of material, Merck). In three Erlenmeyer flasks, the different culture media were dissolved in 200 ml of water, then placed on a heating and stirring plate to fully dissolve the medium. Subsequently, the media were sterilized at 121°C for 15 minutes to destroy vegetative forms and spores. The sterilized media were stored in Petri dishes, and a control sample was left for error verification.

Following the 8-hour incubation period in TSB broth, 100 µL of each sample were extracted using a micropipette and subsequently inoculated onto the respective culture media. In the case of AGAR SPS, the protocol differed: the TSB broth was first inoculated into the medium, after which an additional layer of AGAR SPS was poured to complete the setup. The inoculated plates were incubated until the following day.

A Gram stain was performed to classify the bacteria into two major groups: Gram-positive and Gram-negative.

For the analysis of lignin-cellulose by Fourier transform infrared spectroscopy on the IRAffinity-1 FTIR SHIMADZU equipment, Series: A213749, tablets of approximately 1 cm in diameter were prepared by homogeneously mixing dry potassium bromide (KBr) powder with dry starch in a ratio of 1:50 (0.15 g and 0.003 g) and moulding the mixture in a hydraulic press. The FTIR spectra were obtained by collecting an average of 64 sweeps between 400 and 4000 cm^{-1} [15]. Differential Scanning Calorimetry (DSC) analysis was performed to characterize the thermal behavior of cellulose acetate present in CBs. Approximately 5–10 mg of each sample was placed in a sealed aluminum pan and subjected to a controlled heating program from 25 °C to 700 °C at a rate of 10 °C/min. The analysis allowed the identification of thermal transitions such as the glass transition temperature (Tg) and decomposition events associated with the cellulose acetate matrix.

III. Results

A. *Quantification of CBs and CBFs material*

The characterization was performed according to the number of units collected from CBs, obtaining the total number of butts and CBFs found per selected beach (Bocagrande, Playa Blanca, Boquilla, Tierra Bomba), as indicated in Figure 5.

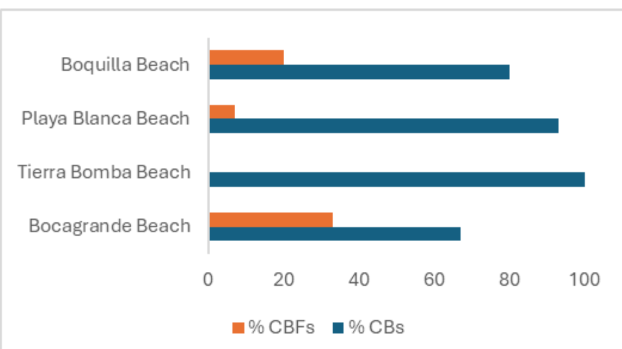

Figure 5. Percentages of CBs and CBFs collected per beach

The graph shown the total distribution of the debris in each beach and its corresponding percentage. In total, 13,134 units were collected between CBs and CBFs. A total of 71% were CBs and the remaining 29% corresponded to the CBFs (butts in advanced decomposition state). Bocagrande Beach exhibited the highest presence of CBs, with a total count of 11,293 items, comprising 67% CBs and 33% CBFs. It is important to note that this beach has a greater influx of tourists, not only nationals but also foreigners.

During the cleaning campaign carried out in Bocagrande, 2,970.1 g were collected, distributed among CBs and associated fibers. Collections were made along the beach in groups of 10 people for approximately 2 hours; the collection was carried out in the dry season.

The collection of CBs was conducted at Tierra Bomba beach, over a period of 2 hours, with groups of 5 participants. The total sample comprised CBs weighing 83.6 g. In Boquilla beach 145.4 g of material consisting of CBFs and CBs were collected. Finally, on Barú beach 255.1 g of CBs were collected. The distribution of weights also corresponds in greater proportion to the beach of Bocagrande, as indicated in Figure 6.

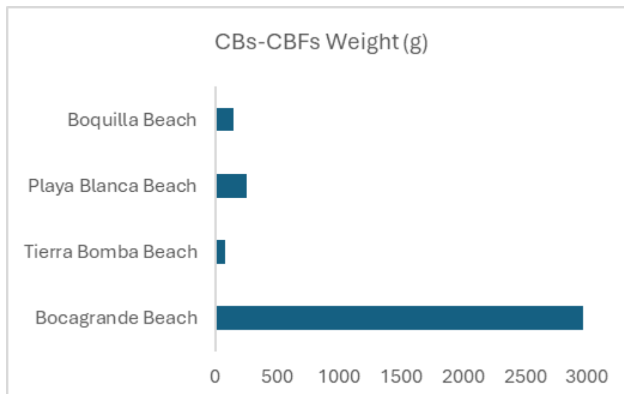

Figure 6. Total weight of waste collected per beach

To draw conclusions regarding the trend of CBs disposal by beachgoers and to formulate potential recommendations for cigarette producers and distributors regarding their responsibility for the waste generated, the analysis included the identification of the different cigarette brands linked to the butts retrieved from the beach.

It was possible to identify a great variety of cigarette brands arranged as butts; in total, 24 brands of cigarette butts were identified, where the tendency to find more waste from some brands in all the beaches was recorded. Figure 7 shows the values resulting from the characterization by brands of all the samples collected and discriminated by each beach. As seen, these are the brands with the highest values found in the characterization, which can give us an idea of which of these products are most consumed by beach users (Chesterfield, Luchies, Malboro and Rothmans). Nevertheless, the graph shown, in a general, the large number of brands and waste that can be collected in only 2 hours and only throughout 200 metres.

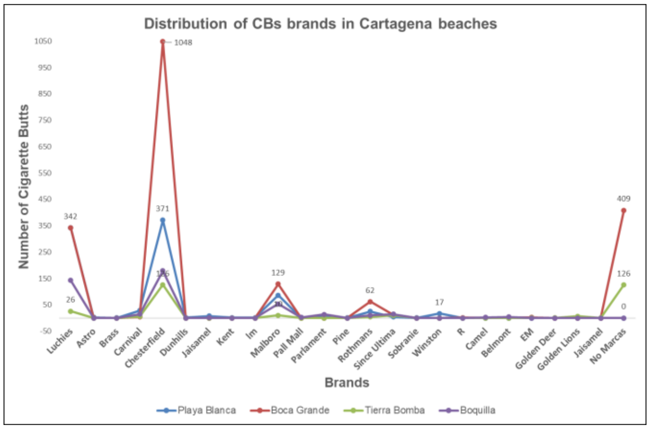

Figure 7. Characterization of CBs by brands

B. *Chemical characterization of CBs*

Differential scanning calorimetry analysis for a commercial cellulose sample (Figure 8) shows an endothermic peak at 84.91 °C associated with water evaporation. Similarly, the DSC analysis performed on the experimentally obtained cellulose (Figure 9) shows a peak associated with moisture loss but displaced to 120.3 °C. In addition, an endothermic peak is observed at 330.5 °C and 357.4 °C for commercial cellulose and experimental cellulose values, respectively, associated with the fusion of crystalline phases of the cellulose polymer.

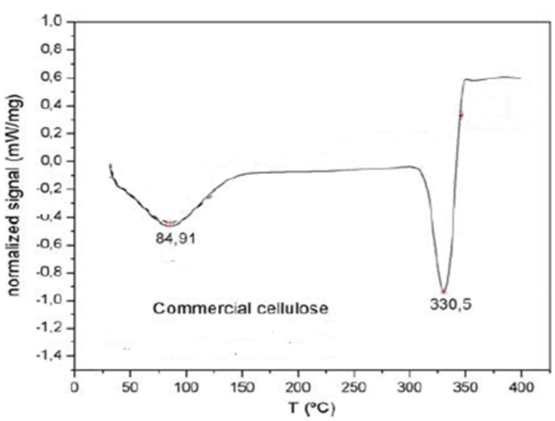

Figure 8. DSC for a commercial cellulose

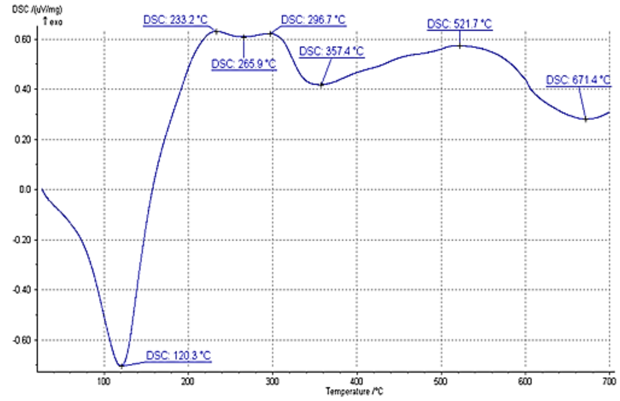

Figure 9. DSC for sample cellulose

For the analysis of lignin-cellulose by Fourier transform infrared spectroscopy, the FTIR spectra were obtained by collecting an average of 64 sweeps between 400 and 4000 cm^{-1} [15]. The results obtained from the test are shown in Table 2, where the average values obtained from the identified components are shown.

TABLE 2. RESULTS OF THE FTIR ANALYSIS FOR THE DETERMINATION OF LIGNIN-CELLULOSE

Component	Average value	SD
Acid Detergent Fibre	52.9	0.05
Neutral Detergent Fibre	74.15	0.1
Crude Fat	0.45	0.33
Lignin	90.5	0.25
Cellulose	43.85	0.5
Hemicellulose	21.25	0.33
Carbon	23.67	0.5
Hydrogen	3.68	0.05
Nitrogen	0.29	0.33
Oxygen	21.9	0.5

C. *Microbiological characterization*

According to the preparation of the culture media, incubation and Gram staining it was possible to identify some microorganisms that are present in the CBs. In Chromocult agar culture medium, the presence of the bacterium *Escherichia coli* (Figure 10) was observed, which is shaped like bacilli and is a Gram-negative bacterium. *E. coli* is a common bacterium in the intestinal tract of animals, including humans.

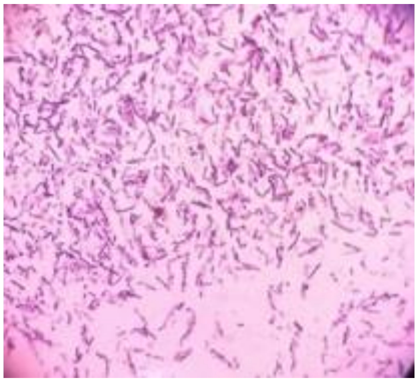

Figure 10. *E. coli* bacteria Bacilli Gram negative structure

Clostridium bacteria growth was obtained with SPS Agar, bacteria which is commonly found among a wide range of potentially pathogenic microorganisms among smokers and people exposed to tobacco smoke in environments. Bacteria such as *Acinetobacter, Clostridium* or *Pseudomonas aeruginosa*, found in cigarettes, could cause infectious and chronic diseases of the respiratory system [16].

Gram-negative bacillus bacteria such as *Pseudomona aeruginosa* were also identified. The high number of possible nonenteric pathogens, *Staphylococcus aureus* and *Pseudomonas aeruginosa*, in beach sand has been related to factors that affect their survival and distribution, as well as those of a possible fecal indicator, *Clostridium perfringens*. Studies [17] indicate that there is a greater survival and proliferation of *Staphylococcus aureus* and *Pseudomonas aeruginosa* in beach sand than in seawater, which was related to the size of intermediate sand particles (850 µm - 2 mm) constituting the main micro niche. For the case study of this project, the growth of *Pseudomonas aeruginosa* in the CBs and CBFs debris was validated, determining that greater abundance was found in the CBFs.

IV. Discussion

At Bocagrande Beach, a total of 7,618 CBs were collected along a 200 m transect, reflecting a pattern like that described in a study conducted on urban beaches in Northeast Brazil, where cigarette butts accounted for 38.36% of the total waste collected, amounting to 10,880 items during a peak tourist season month [18]. This highlights a significant tendency for cigarette butt disposal in beaches with high tourist activity.

Another reference study is research conducted on Moroccan Mediterranean beaches, which identified 7,395 cigarette butts, accounting for 14.62% of the total litter collected over several years. The study highlights significant differences in cigarette butt abundance based on beach typology, seasonality, sediment type, and the number of beach users [19]. In Alicante, Spain, cigarette butts increased from 4,607 in spring to 12,843 in summer, highlighting seasonal variations in littering [20].

The environmental impact of CBs is significant due to the toxic substances they release, necessitating improved waste management and increased public awareness to mitigate their effects. Specific global data on the most common CB brands are limited; however, regional studies indicate a diverse range of discarded brands. In the present study, 25 CB brands were identified across all beaches. Similarly, another study in Brazil identified 22 cigarette brands in coastal areas, highlighting the variety of brands present in different environments [21].

The study [22] performed on recovered cellulose acetate (CA) reveals variations in the decomposition temperature range between 338 and 438 °C, with peak decomposition rates observed at 352 °C and 357 °C for the original CA and recovered CA, respectively. This process results in an approximate 60% weight loss for both polymers, followed by an additional 13-15% loss due to the thermal breakdown of residual CBs components. These findings are consistent with the present study, where an endothermic peak is noted at 330.5 °C and 357.4 °C for commercial cellulose and experimental cellulose, respectively.

Cigarette butts are primarily composed of cellulose acetate with a 2.45 degree of substitution, a material that degrades slowly and may require up to 18 months to decompose under typical littering conditions [23]. The cellulose acetate contained in cigarette butts degrades slowly under environmental conditions, remaining trapped within the sand matrix on the beaches where it is discarded.

In the conducted study, *Clostridium* and *Pseudomonas aeruginosa* bacteria were identified in CBs and CBFs. According to the literature, bacterial species associated with marine aquatic systems include *Amycolatopsis sp.*, *Alcanivorax sp.*, *Azotobacter sp.*, *Bacillus sp.*, *Brevibacillus sp.*, *Cycloclasticus sp.*, *Streptomyces sp.*, *Clostridium sp.*, *Hyphomonas sp.*, *Methanosarcina barkei*, *Pseudomonas aeruginosa*, and *Schlegelella sp.* Most of these bacteria have demonstrated the ability to produce extracellular hydrolytic enzymes such as chitinase, keratinase, lipase, protease, and xylanase, contributing to the biodegradation of microplastics [24]. The results obtained highlight the colonization of cellulose acetate from CBs and CBFs in this coastal environment.

It is important to highlight the risk posed by beachgoers' contact with waste such as CBs and CBFs, which can become potential niches for *Pseudomonas aeruginosa*, an opportunistic pathogen in humans responsible for causing severe acute and chronic infections, particularly in individuals with compromised immune systems [25].

V. Conclusions

Bocagrande Beach recorded the highest values of cigarette CBs and CBFs, in contrast to Tierra Bomba Beach, which showed the lowest presence of CBs. Notably, Tierra Bomba is an island beach.

For the chemical analysis, the percentage of lignin-cellulose in the CBs was measured, and the calorimeter changes of the cellulose in the butts were evaluated using commercial cellulose as a reference. These analyses show the chemical changes that the waste undergoes, based on the climatic conditions to which it is subjected in the environment. In the same way, chemical components present in the CBs were identified by infrared spectrophotometry. In this last test, the amount of lignin, cellulose, hemicellulose, and ash among other components was finished, and it should be noted that no contaminants were found that are significantly dangerous for health and ecosystems.

In the microbiological analysis, bacteria pathogenic to human health and affecting the sanitary quality of the ecosystem were identified. The bacteria identified are *Escherichia coli*, *Clostridium spp.* and *Bacillus*, such as *Pseodomonas*. These pathogenic microorganisms can cause chronic respiratory and intestinal diseases and have their origin in the filtering material of the butts; the debris, when exposed to ambient temperature, sea water and other environmental conditions, constitutes the favourable medium for the growth of the colonies. The comparison of bacterial growth behavior among CBs discarded on beach sand, unsmoked CBs, and CBs discarded in other environments such as parks or streets represents a knowledge gap that requires further in-depth research.

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