

Article

Evaluation of Heavy Metal Content in Plastic Bags Used as Improvised Food Cooking Covers: A Case Study from the Mozambican Community

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Abstract: The widespread use of plastic bags as improvised food cooking covers in Mozambican communities has raised public health concerns, increasing interest in studying these plastic bags, which contain heavy metals additives used to improve their physical and chemical properties. This study aims to evaluate the levels of heavy metals commonly used in plastic bags used as improvised food cooking covers, focused on Mozambican communities that have this habit. Using spectroscopic techniques, Fourier Transform Infrared Spectroscopy (FTIR) and Atomic Absorption Spectroscopy (AAS), we analyzed plastic bag samples to identify polymer types, chemical composition, and heavy metal concentrations. FTIR analysis confirmed low- and high-density polyethylene (LDPE and HDPE) as the primary materials, with spectra peaks between 2800 and 3000 cm⁻¹, indicating stretching vibrations characteristic of LDPE and HDPE. The density measurements varied between 0.04 and 0.08 g/cm³ with very low uncertainty values (0.27% and 0.098%). The heavy metal analysis revealed concentrations higher than those stipulated in international standards. The results in terms of the percentage of LDPE samples in relation to the HDPE samples are as follows: Cd: 69.71% (LDPE < HDPE); Cu: 220.44% (LDPE > HDPE); Pb: 24% (LDPE < HDPE); and Zn: 51.53% (LDPE < HDPE). These findings highlight the potential public health risks associated with the use of plastic bags in cooking and underscore the need for regulatory intervention.

Keywords: public health; FTIR; AAS; LDPE; HDPE; plastic bag density

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1. Introduction

The use of plastic bags as improvised pan covers is common in Mozambican communities. While practical and economical, the health risks due to potential contamination with harmful substances, including heavy metals [1], are a growing concern. The scarcity of literature on the contamination of food intended for human consumption by heavy metals leaching from plastic bags [2,3] further justifies the need for the research we developed and present in this work.

Plastic bags, both non-degradable and degradable, significantly impact environmental pollution and public health. Bioplastics, made from renewable sources or designed to biodegrade, offer a sustainable alternative [3–5]. Common plastics include polypropylene (PP), polyvinyl acetate (PVA), polystyrene (PS), polyvinyl chloride (PVC), polyamide (PA), linear low-density polyethylene (LLDPE), low-density polyethylene (LDPE), and high-density polyethylene (HDPE) [5–7]. Among these, LDPE and HDPE, widely used thermoplastics, serve diverse purposes like supermarket bags, industrial packaging, medicinal serum bags, and food packaging due to their densities and structural properties [1,3,8]. However, global plastic production is increasing, with 80% ending up in landfills or oceans, while only 9% is recycled [3,8,9].

This widespread use of disposable plastic bags, especially in food packaging, raises concerns about the potential health risks posed by heavy metal additives [10,11]. Heavy metals, substances with high atomic weights, often harm human and environmental health, particularly when they come into contact with food or water [12–15]. The properties of heavy metals make them effective additives [16], which are incorporated into plastic bags to enhance specific properties like the heat resistance and durability. Heavy metals such as lead, cadmium, copper, and zinc are common additives used to stabilize or color plastics [3,16–18].

Plastic bags contain additives that enhance their properties, but these additives do not form permanent bonds, making it easier for them to migrate during heat treatment [19–21]. This is due to the diffusion between materials, which occurs with random molecular movements. In addition, various factors, such as the temperature, food acidity, cooking time, and the type of plastic, influence the migration of heavy metals [21–23].

For these reasons, the migration of plastic components into food is regulated by different factors. International standards are set by regulations for plastic materials in this context [23,24]. The European directive 2002/72/EC, for example, limits the transfer of plastic components to a maximum of 10 mg/dm². In addition, heavy metals such as Pb, Cd, Cr, and Hg must remain below the limit of 100 mg/kg [25]. The European Commission sets specific limits for arsenic in salt, while in the Netherlands, the limits for Cr, Pb, Cd, and Hg are set at 100 mg/kg by mass [25,26].

In resource-limited settings, plastic bag additives like cadmium, lead, and zinc can leach into food under high temperatures [20,27–29]. The inclusion of heavy metals in plastics remains a contentious topic, with growing regulatory oversight aimed at reducing their use due to the associated hazards. European directive 2002/72/EC and other international standards have established strict limits on the acceptable levels of heavy metals in consumer plastics [24,25]. These measures aim to balance the practical benefits of these additives with the need to safeguard public health and the environment [17]. Despite this progress, studies continue to reveal concerning levels of heavy metals in consumer plastics, including children's toys and food containers, underscoring the need for stricter enforcement [30–33].

In Mozambique, plastic bags are often used as cooking covers for food preparation, favored for their affordability, flexibility, and availability. Additionally, their ability to act as thermal insulators makes them an appealing and practical option for cooking [20,34]. The use of plastic bags for cooking is widespread among Mozambican communities, especially in rural areas, where access to modern cooking tools is limited. This method is often seen as a convenient and efficient way to prepare food, ensuring a consistent and quick cooking process despite the lack of advanced kitchen equipment. These practices are deeply rooted, making it hard for Mozambicans to recognize the health and environmental risks.

It is well known that exposing plastics to high temperatures can reduce their durability and cause them to degrade rapidly [21]. In turn, fragments of plastic bags can

become lodged in the cracks of food, allowing heavy metals to migrate into the food. Mozambican plastic production policies are still inefficient in terms of their application. In addition, the majority of plastics in Mozambique are imported and/or produced with less oversight from regulatory bodies, and studies focus on the pollution of rivers and oceans [35].

This study focuses on evaluating the presence of Pb, Cu, Cd, and Zn in plastic bags used in food preparation within Mozambican communities due to their toxicological significance. Lead (Pb) is linked to nerve damage, cognitive issues, and infertility. Cadmium (Cd) is found in cancerous breast tissues. Zinc (Zn) exposure causes copper deficiency, anemia, and immune weakening. Excess copper (Cu) exposure leads to anemia, diarrhea, and infertility [3,36,37].

In light of these findings, this study aims to evaluate the content of heavy metals in plastic bags used as part of food cooking containers in Mozambican communities and contribute to the promotion of monitoring the presence of heavy metals in plastic bags in Mozambique.

2. Materials and Methods

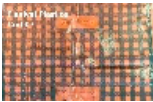
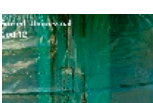
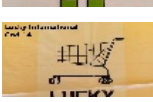
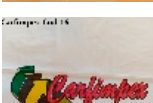
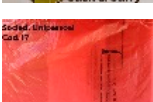
2.1. Materials

Sample Overview

Samples of different plastics obtained in different locations in Mozambique were analyzed, representing the types of plastics used in communities and sources from supermarkets, wholesale markets, grocery stores, hardware stores, and clothing shops. The materials were presented in their original distribution form, totaling seventeen flexible, lightweight, transparent, and waterproof plastic bags with different characteristics regarding the color, size, mass, and thickness. This versatility is due to the use of additives combined with polymers [1]. The most common plastics, with the characteristics described above and used in supermarkets, industrial bags, and medicinal serum bags, are derived from polyethylene, such as high-density polyethylene (HDPE) and low-density polyethylene (LDPE), which are obtained through the polymerization of ethylene, a polymer with a simple chemical structure [1,2]. Table 1 provides the materials analyzed along with some of their detailed characteristics.

Table 1. Materials and some of their characteristics.

Cod e	Photography	Origin	Color	Characteristics
1		Supermarket No. 1	Orange, Red	Recycled material 30%; Thickness 30 µm
2		Intermoda	White, Black	60 µm; LDPE
3		Fashion Moda	Black, Brown	LDPE
4		Pep	Yellow, Blue, and White	Recycled material 30%; Thickness 30 µm; HDPE; 38 L

5		SPAR VIP Manica Shopping	Green, White, and Red	100% Pure material; Thickness 30 µm; HDPE; 24 L
6		Shoprite	Yellow, Red	Recycled material 30%; Thickness 30 µm; HDPE; 24 L
7		Common Flexible Plastic	Red, Black	Recycled material 40%; Thickness 30 µm
8		Common Flexible Plastic	Blue	Recycled material 40%; Thickness 30 µm
9		Fang Zhene	Black	Recycled material 40%; Thickness 30 µm
10		Common Plastic	Golden 60%	
11		Recheio_Cash & Carry	Blue, White, and Red	100% Pure material; Thickness 30 µm; HDPE; 24 L
12		Hope Plastic_Unipersonal Society	Blue, Black	
13		Beira Hardware	Green, White	30 µm, 60% Pure matter
14		Lucky International	Yellow, Black	
15		Jasmine Garden Supermarket	Golden 40%, Black	HDPE
16		Carfimpex_Cash & Carry	White, Black, Red, Green, and Yellow	100% Pure material; thickness 30 µm; HDPE; 24 L
17		Hope Plastic_Unipersonal Society	Red, Black	

2.2. Sample Preparation for Density Determination

The density of the samples was evaluated by weighing a piece of film and measuring its thickness, using Equation (1):

$$\rho = \frac{m}{A \cdot e} \quad (1)$$

To evaluate the density, squares measuring 5.0 cm × 5.0 cm were cut and weighed on an analytical balance, and the thickness was evaluated using a micrometer. Each measurement was repeated 5 times.

2.3. Plastic Bags' Characterization Based on Fourier Transform Infrared Spectroscopy

Fourier Transform Infrared Spectroscopy (FTIR) provides insights into the structural and chemical composition of samples, enabling the identification of functional groups, type of polymers, and even trace elements such as heavy metals [3]. In this study, FTIR was used to determine the primary chemical compositions of the plastic bag samples.

Sample Preparation for FTIR Analysis

The plastic bags were cut into small pieces measuring 5.0 cm by 5.0 cm, in order to analyze them by FTIR. A total of 17 samples, including both LDPE and HDPE were characterized. Spectra data were collected using a PerkinElmer Spectrum IR FTIR spectrophotometer (manufactured by PerkinElmer, Inc: Waltham, MA, USA), operating over a wavelength range of 4000 to 500 cm^{-1} , and processed with Spectrum IR software (version 10.5.4). Figure 1 illustrates the detailed procedure followed for the FTIR characterization of the plastic bag samples.

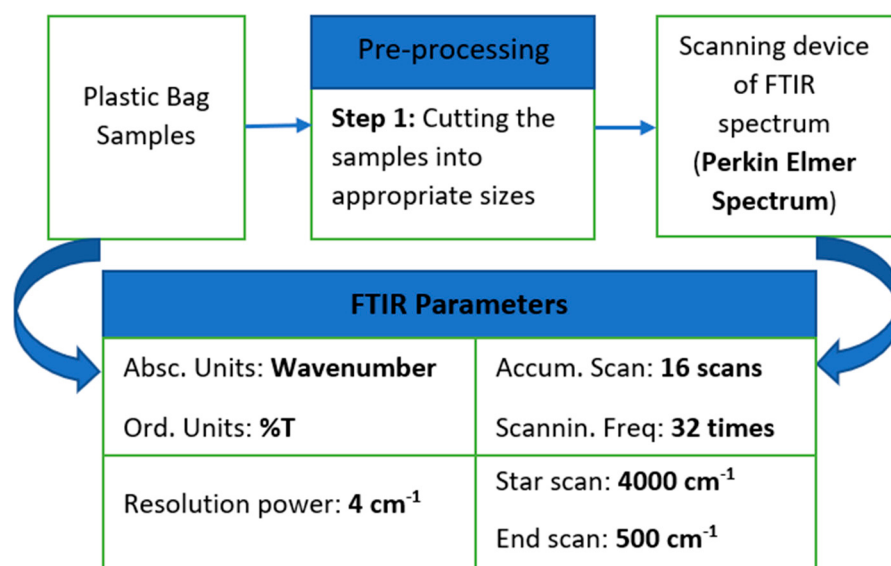


Figure 1. FTIR analysis procedure.

2.4. Plastic Bags' Characterization Based on Atomic Absorption Spectroscopy

In this study, the concentrations of heavy metals present in liquid samples were quantified by Atomic Absorption Spectrometry (AAS). This technique allows for the determination of elements in a sample by measuring the radiation absorbed by the chemical element of interest [9]. AAS is widely recognized for its high sensitivity and specificity, with very low detection limits for heavy metals [8]. The principle of this technique is based on the absorption of light at specific wavelength, by the atoms of the elements of interest in the gas phase. Thus, the intensity of the absorbed radiation is proportional to the concentration of the element in the sample, allowing for its precise quantification [33].

The calibration curves were constructed using 5 standard solutions for each element, and the resulting equations and R^2 values are as follows: $A = 0.0010828 + 0.0175285 \left[\text{Pb} \left(\frac{\text{mg}}{\text{L}} \right) \right]$; $R^2 = 0.999046$; $A = 0.0013385 + 0.0288037 \left[\text{Cd} \left(\frac{\text{mg}}{\text{L}} \right) \right]$; $R^2 = 0.996499$; $A = 0.0039032 + 0.0574645 \left[\text{Cu} \left(\frac{\text{mg}}{\text{L}} \right) \right]$; $R^2 = 0.992967$. These calibration parameters demonstrate the high linearity of the calibration curves, ensuring reliable quantification of the analytes. The quantification limits for the analyzed metals were Pb 0.03, Cd 0.004, Cu 0.025, and Zn 0.05 mg/L. Some samples were analyzed in duplicate to assess

the overall precision of the method, including replication of both the sampling and digestion processes. The highest relative standard deviation observed was 20%, indicating that the method is precise. The results revealed different levels of each metal across different sample types.

2.4.1. Sample Preparation for AAS Analysis

Sample preparation was carried out by digesting 0.10 g of a sample previously cut into 2×2 mm pieces in 20 mL of aqua regia (3:1 concentrated nitric acid to concentrated hydrochloric acid) in a heated vessel at 85 °C for 3 h. Before analysis, a 1 mL aliquot of the digested sample was diluted to 10 mL with deionized water. A detailed scheme of the digestion procedure is shown in Figure 2.

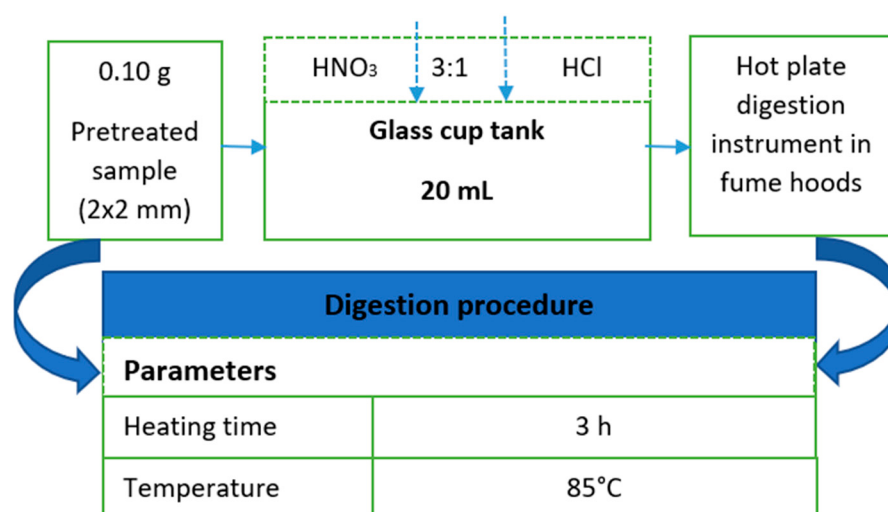


Figure 2. AAS digestion procedure.

2.4.2. Reagents

The AAS technique requires rigorous methodological procedures for sample characterization with reagents of analytical-grade purity [36], given that this technique has very low detection limits. The Table 2, presents the used reagents and their properties.

Table 2. Reagents and some of their properties.

Reagents	Chemical Formula	Purity (%)	Brand
Nitric Acid	HNO ₃	≥65	PronaLAB®
Hydrochloridric Acid	HCl	≥37.0	VWR® Chemicals

2.4.3. Conversion of Instrument Data into mg/kg Concentration

The instrument data were initially obtained in mg/L and required conversion to mg/kg using Equation (2).

$$\text{Element (mg. kg}^{-1}\text{)} = \frac{\text{mg. L}^{-1} \text{ of the solution. V. FD}}{\text{Sample weight in grams}} \quad (2)$$

where V is the volume of the solution, and FD is the dilution factor [37].

3. Results

3.1. Determination of the Density

The results of the density determination are shown in Table 3. The average mass, the average thickness, the indicated thickness of the bag, and the density value with the associated uncertainty are presented.

Table 3. Sample density values determined through mass and thickness, measured considering an area of 25.0 cm².

Samples	Average Mass (g)	Average Thickness (mm)	Thickness of the Bag (μm)	Density (g/cm ³)
Cod.01	0.02359	0.1236	30	0.0763 ± 0.0002
Cod.02	0.0388	0.2614	60	0.0593 ± 0.0004
Cod.03	0.03109	0.1864	---	0.0667 ± 0.0003
Cod.04	0.03615	0.1902	30	0.0760 ± 0.0004
Cod.05	0.01636	0.0824	30	0.0794 ± 0.0002
Cod.06	0.01900	0.1092	30	0.0695 ± 0.0002
Cod.07	0.03079	0.1778	30	0.0692 ± 0.0003
Cod.08	0.01899	0.1196	30	0.0635 ± 0.0002
Cod.09	0.01864	0.1480	30	0.0503 ± 0.0002
Cod.10	0.00968	0.0950	---	0.04075 ± 0.00001
Cod.11	0.01748	0.1228	30	0.0569 ± 0.0002
Cod.12	0.01694	0.1378	---	0.0491 ± 0.0002
Cod.13	0.02502	0.1414	30	0.0707 ± 0.0002
Cod.14	0.02082	0.1432	---	0.0581 ± 0.0002
Cod.15	0.01416	0.1010	---	0.0560 ± 0.0001
Cod.16	0.01558	0.1072	30	0.0581 ± 0.0001
Cod.17	0.01196	0.1068	---	0.0447 ± 0.0001

It can be seen that the experimentally measured thickness values are significantly higher than those indicated on the bag, by 3 to 4 times. This variation can be attributed to the mechanical difference between the materials, as the main component, that is, HDPE has greater rigidity and heat resistance, while LDPE is more flexible and can be more permeable. These differences in mechanical properties significantly influence the density values observed. In addition, it can be seen that the discrepancies between them influence the concentrations of heavy metals present in the plastic bags. However, the density measurement was crucial for investigating the hypothesis regarding the correlation between the density and the concentration of heavy metals. This hypothesis is supported by the total heavy metal content values obtained in this study, which provide a basis for further verification. Additionally, the density variations may also arise from additives used during manufacturing, which change the material's composition and structure [38–40].

The results demonstrate that the samples exhibit a relatively low density, as expected, highlighting the peculiar characteristics of HDPE and LDPE. For example, previous studies present density values for HDPE between 0.941 and 0.965 g/cm³ and for LDPE between 0.910 and 0.940 g/cm³ [38]. The variation in density values was between 0.04 and 0.08 g/cm³ and was characterized by a very low uncertainty (0.025% and 0.25%, respectively). The observed densities were significantly lower and distinct compared to other studies [39]. This result can be explained by the addition of different additives, such as metals, and by the composition of the molecular structures of the samples in studies, which may present more dense or less compacted networks.

3.2. Characterization of the Plastic Bags by FTIR

Figures 3 and 4 show the FTIR spectra for the LDPE and HDPE samples. All seventeen samples were analyzed, with nine identified as LDPE (Cod.01, Cod.07, Cod.09,

Cod.02, Cod.03, Cod.08, Cod.10, Cod.12, Cod.17, and Cod.07R) and eight as HDPE (Cod.04, Cod.05, Cod.13, Cod.14, Cod.15, Cod.16, Cod.06, and Cod.11).

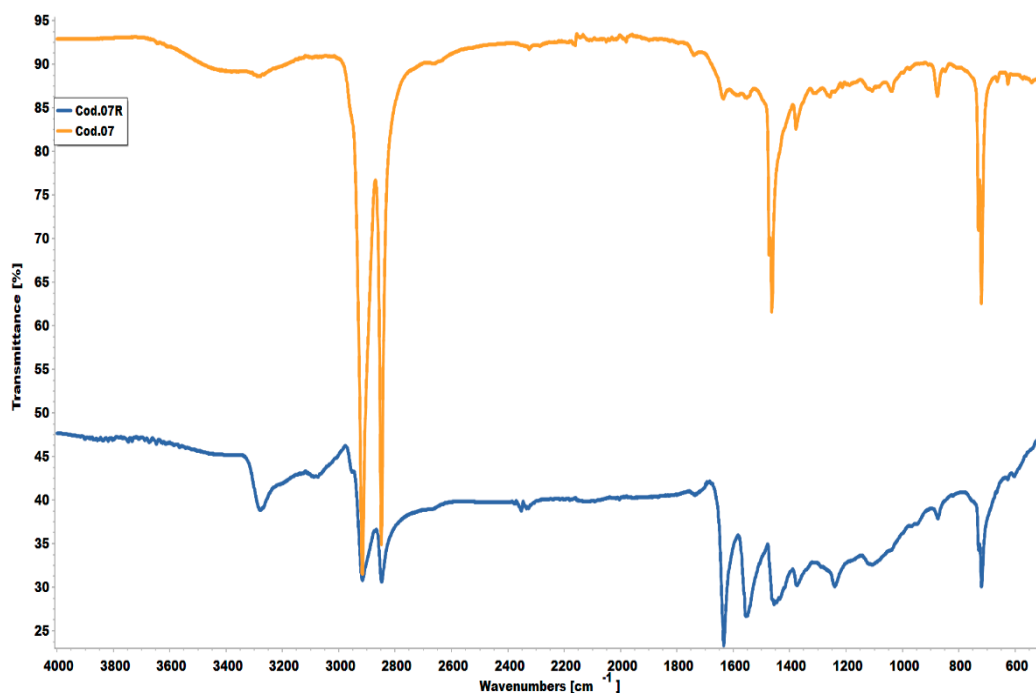


Figure 3. FTIR spectra of Cod.07 and Cod.07R representing nylon obtained by Perkin Elmer Spectrum IR.

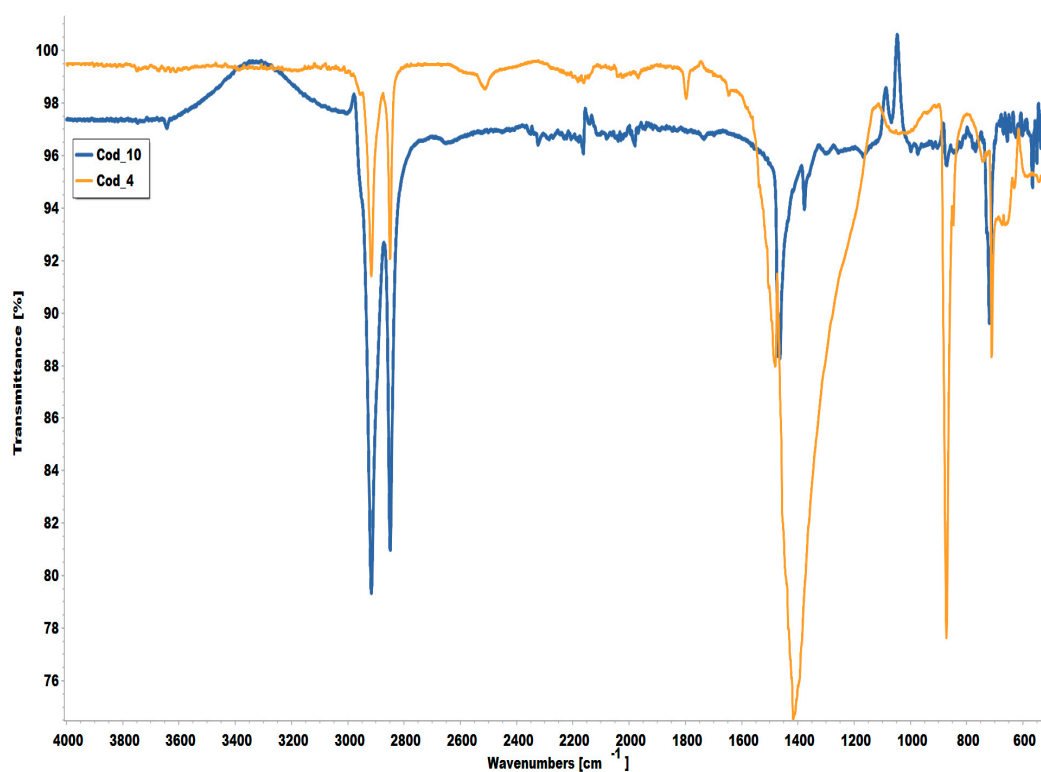


Figure 4. FTIR spectra of LDPE and HDPE for samples Cod.10 and Cod.04, respectively, obtained by Perkin Elmer Spectrum IR.

In the spectral region between 2800 and 3000 cm^{-1} , characteristic stretching vibrations for polyethylene are observed. Specifically, the HDPE exhibits peaks at 2916.50 and

2848.50 cm^{-1} , while the LDPE shows peaks at 2926.65 and 2858.39 cm^{-1} . These variations in peak positions reflect differences in the crystalline structure and chain branching of the two materials, which are key to differentiating them. The higher branching in LDPE disrupts the crystalline regions more significantly, leading to slight shifts in the spectral peaks.

The peaks at 1462.64 cm^{-1} in the LDPE and 1462.07 cm^{-1} in the HDPE correspond to C–H bending vibrations, indicating a shared structural feature. Additionally, the peaks at 875.88 cm^{-1} in the LDPE and 875.89 cm^{-1} in the HDPE are attributed to the C=CH bending vibrations of alkenes, demonstrating functional composition similarities. The peak at 718.86 cm^{-1} , common to both LDPE and HDPE, further supports these shared characteristics.

Despite these similarities, clear differences can be discerned in the number and arrangement of peaks within the mid-infrared region, particularly between 500 and 1600 cm^{-1} . The LDPE spectra display four peaks in this range, whereas the HDPE spectra reveal five distinct peaks. This additional peak in the HDPE reflects its higher degree of crystallinity and reduced chain branching compared to the LDPE. The difference in peak intensity and sharpness further highlights the greater structural order in the HDPE [20,38,41].

Furthermore, variations in the obtained spectra compared to those reported in previous studies [41] can be attributed to the differences in instrumentation, transformation processes, and sample preparation methods. These factors influence the interferogram and spectral output, potentially leading to minor deviations in peak positions and intensities. Such variations underscore the need to consider experimental conditions when interpreting spectroscopic data [3,41].

By focusing on these structural distinctions, particularly the differences in branching and crystallinity as revealed through spectral analysis, LDPE and HDPE can be effectively differentiated despite their compositional similarities.

The spectra presented in Figure 3 correspond to sample Cod.07 and its replica Cod.07R, which are identified by areas of different colors, namely yellow and blue, respectively. The difference in transmittance shows that the sample is, in part, composed of other molecular structures, which results in a lower transmittance. Through the equipment's software, it was possible to identify the presence of nylon in the Cod.07R sample, which may have been added to the plastics to increase the tensile and impact resistance of the base material, making them more durable and capable of withstanding greater loads without deformation and even improving the thermal resistance [40]. These factors contribute to the observed variations in the plastic fingerprint area despite both samples originating from the same plastic.

The spectra in Figure 4 represent the differences and similarities between the LDPE and HDPE samples. It shows the behavior of the spectra for the samples characterized by FTIR for LDPE and HDPE, respectively.

Regarding the functional groups and structural characteristics, the analyzed samples exhibit spectra characteristic of the methyl group (CH_2) in both the LDPE and HDPE. Both spectra display closely positioned peaks, indicative of C–H bending vibrations at 1462.64 cm^{-1} and C=CH bending vibrations at 875 cm^{-1} , typical of alkenes. Similar results were reported [3,41], where the observed spectra bands suggested molecular structures with prominent bending and oscillation vibration. The differences in C–H stretching peaks between LDPE and HDPE highlight their distinct structural characteristics. HDPE, with a more crystalline and linear chain structure, shows slightly shifted stretching peaks compared to LDPE, which has a more branched and less crystalline configuration [20,38].

The HDPE peaks in Figure 4 show a noticeable displacement, likely due to its crystalline structure, which leads to reduced vibration forces in the initial spectra and a consequent shift in position of the peaks. Previous studies also noted this phenomenon,

suggesting that variations in the vibration force constant play a critical role in determining for the peak position [42].

3.3. Quantification of Heavy Metals in the Plastic Bags by AAS

The concentrations of the commonly occurring metals in plastic bags, including cadmium, copper, lead, and zinc, were quantified using Atomic Absorption Spectroscopy (AAS). These measurements were conducted at the LCR–Waste Characterization Laboratory of CVR, located at the Campus of Azurém, University of Minho, Portugal, an internationally accredited laboratory in accordance with the NP EN ISO/IEC 17025 standard [43].

The presence of these metals in plastic bags highlights the need for regulatory evaluation, especially given the potential health risks associated with high concentration of toxic metals like lead and cadmium. The measured concentration exceeded the permissible limits established for plastic supermarket bags, as indicated by the Chinese regulatory sector, Chinese Standard.net [3,44].

The results of the 17 samples made of high-density polyethylene (HDPE) and low-density polyethylene (LDPE) are presented in Figures 5 and 6.

For the nine LDPE samples (Cod.01, Cod.02, Cod.03, Cod.07, Cod.08, Cod.09, Cod.10, Cod.12, and Cod.17), the Cd concentrations in samples Cod.01 and Cod.07 were identical, as were the Pb(II) concentrations across all samples. However, the concentrations of Cu(II) and Zn(II) are different, with Zn(II) consistently present in higher concentrations in all samples. Notably, Cod.03 exhibited the highest Cu(II) content among the LDPE samples, even when compared to the HDPE samples.

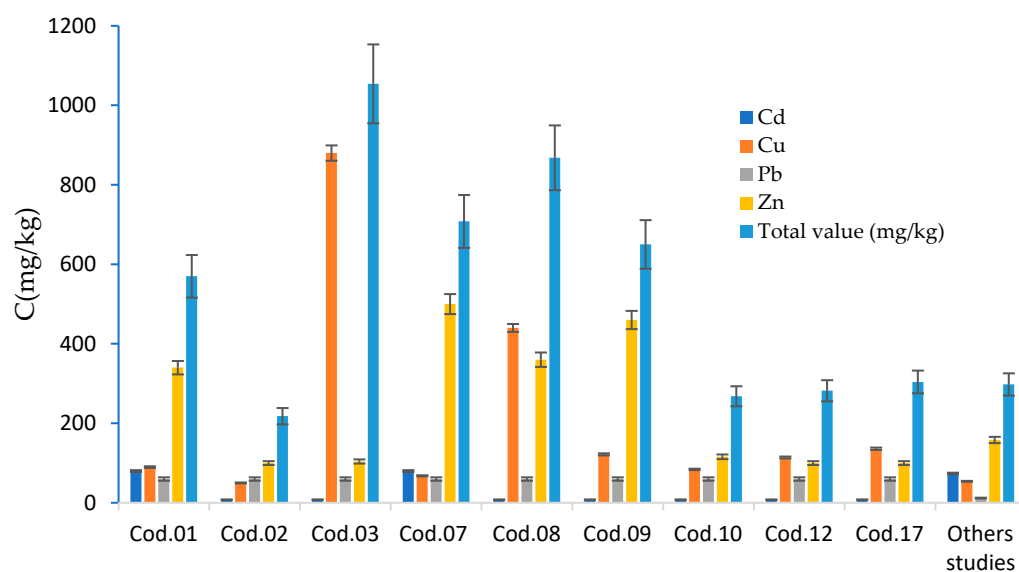


Figure 5. Results obtained by AAS for the LDPE samples.

The samples Cod.04, Cod.05, Cod.06, Cod.11, Cod.13, Cod.14, Cod.15, and Cod.16, classified as high-density polyethylene (HDPE), presented the concentrations shown in Figure 6. The Zn(II) concentrations were found to be higher in all the HDPE samples; however, in sample Cod.06, the Zn(II) levels were lower in comparison to Pb(II). The Cd(II) levels were consistently similar across most samples, except for samples Cod.04, Cod.06, and Cod.11, where a significant increase was observed relative to the other samples, including those made of LDPE. For Cu(II), the HDPE samples generally had lower levels compared to the LDPE. Notably, sample Cod.03 was identified as having the highest Cu(II) concentration among all the tested samples.

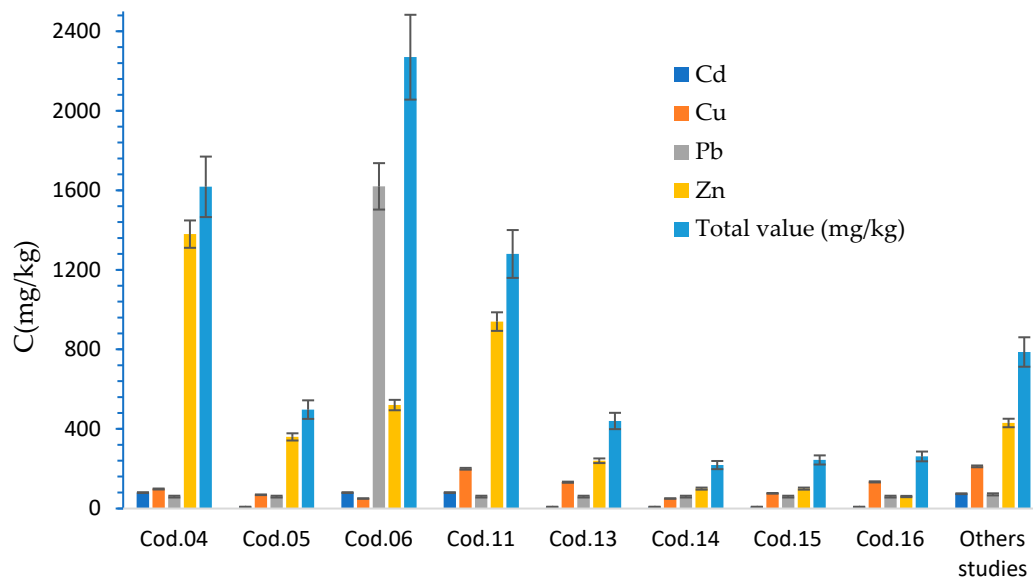


Figure 6. Results obtained by AAS for HDPE samples.

These results demonstrate a significant deviation from the established standards [3,31].

Recent studies conducted by Jiang et al., 2023, highlight concerning findings regarding the presence of heavy metals in plastic bags, with concentrations exceeding average levels. These concentrations, expressed in units of mg/kg, are as follows: Zn (120.42 ± 85.15) > Pb (96.43 ± 6.57) > Cu (45.21 ± 56.55) > Cr (6.03 ± 6.82) > Ni (2.13 ± 2.14) > As (0.19 ± 0.15) > Hg (0.17 ± 0.71) > Cd (0.14 ± 0.20). It is important to note that the concentrations of heavy metals varied based on the type of sample (HDPE vs. LDPE), as these polymers possess distinct molecular structures and other characteristics, such as roughness, color, and odor [3,45]. Through the findings presented in Figures 5 and 6, it is possible to observe that the samples with higher total heavy metals content values tend to exhibit higher densities. This supports the hypothesis that density correlates positively with the concentration of heavy metals, for example, the LDPE analysis: Cod.01-570 mg/kg (0.0763 g/cm^3) and the HDPE analysis: Cod.06-2270 mg/kg (0.0695 g/cm^3).

These findings are consistent with other studies carried out on plastic bags [16]. Notably, less toxic heavy metals, such as Zn(II) and Cu(II) were detected at remarkably high levels, reaching 365.9 and 184.2 mg/kg, respectively. In contrast, highly toxic heavy metals such as Cd and Hg were found in concentrations that exceeded the regulatory limits, exceeding 0.5 mg/kg. The final bars of Figures 5 and 6 summarize the total content of these metals, as legislation specifies a maximum allowable value for this parameter. The sample with the highest metal content was Cod.06 for LDPE, while Cod.03 had the highest levels for HDPE. Both values significantly exceeded the limits established in the relevant regulation [46].

European legislation stipulates that the total maximum values allowed levels of lead, cadmium, chromium, and mercury in plastic bags intended for food contact must not exceed 100 mg/kg [46,47]. However, these values from this study reveal that the concentration of Cd(II) and Pb(II) alone reach 1700 mg/kg, indicating that the heavy metal content far exceeds the internationally recognized safety thresholds.

As discussed in the Introduction, the use of plastic bags for food cooking poses health risks and represents an unsustainable practice for Mozambican communities. The results presented in Figures 5 and 6 underscore the urgent need for change, advocating for the adoption of safer food preparation methods and more sustainable practices regarding plastic bag usage in the region. This research further concludes that introducing news

perspectives and implementing sustainable alternatives to plastic bags in Mozambique can promote healthier eating habits and contribute to a safer environment.

4. Limitations of the Study and Suggestions for Safe Practices for Food Cooking

To the best of our knowledge, this is the first study on the evaluation of heavy metals from plastic bags used as improvised food cooking covers in Mozambique, despite many local studies reporting plastic waste that ends up polluting rivers and oceans [39]. However, the study has certain limitations. This study involved identifying the polymeric materials and quantifying heavy metal in the plastic bags but did not include the heavy metal content that can migrate from plastic bags to food. Again, only 17 samples were tested for heavy metal concentrations in the plastic bags, which may not provide a comprehensive representation of the concentration of heavy metals status of all plastic bags used in Mozambique. Moreover, this study only analyzed four heavy metals using aqua regia as the principal component of the digestion, usually recommended by EC 94/62/EC of 20 December 1994 [24].

The findings indicate the potential risks associated with the use of plastic bags for cooking food, highlighting the urgent need for stringent regulations and continuous monitoring of these materials to safeguard public health. We encourage the use of reusable, sustainable (e.g., banana leaves and coconut fibers), and certified food-safe containers to eliminate exposure to heavy metals.

5. Conclusions

The main objective of this work was to evaluate the heavy metal content in plastic bags used as improvised food cooking covers within the Mozambican community. From a scientific point of view, this research contributes to the promotion of sustainable development and the implementation of practices that are both environmentally friendly and protective of public health. In terms of awareness-raising, the study contributes by encouraging approaches that increase the understanding of the risks associated with the inappropriate use of plastics, urging families to consider safer alternatives, such as reusable and sustainable containers. To achieve this, common heavy metals found in plastics, such as cadmium, copper, lead, and zinc were quantified in order to determine their concentrations in plastic bags used as improvised food cooking covers in local communities of Mozambique.

Seventeen samples of plastic bags were analyzed using Fourier Transform Infrared Spectroscopy (FTIR) allowing for the classification of the plastics into two categories: high-density polyethylene (HDPE) and low-density polyethylene (LDPE). Few bags had labeling indicating their composition; however, the FTIR spectra confirmed the material type for those with existing labels. Of the samples analyzed, eight were identified as HDPE and nine as LDPE.

Regarding the assessment of the heavy metal content, all plastic samples were analyzed by Atomic Absorption Spectroscopy (AAS). The results indicated high levels of Cu(II) and Zn(II) across all samples. Notably, sample Cod.06 exhibited the highest Pb(II) concentration, measuring 1620 mg/kg. Furthermore, samples Cod.03, Cod.04, and Cod.06, presented concentrations of Cu(II), Zn(II), and Pb(II) that significantly exceeded the thresholds set by international standards (ISO, Germany, and Switzerland), as well as those reported by [3].

The comparative analysis of the LDPE and HDPE samples revealed the following percentages: Cd: 69.71% (LDPE < HDPE); Cu: 220.44% (LDPE > HDPE); Pb: 24% (LDPE < HDPE); and Zn: 51.53% (LDPE < HDPE). This indicates that the LDPE samples contained

significantly higher concentration of Cu compared to the HDPE, while the HDPE samples exhibited higher levels of Cd, Pb, and Zn.

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