Mini Review

BIOMEDICAL Journal of Scientific & Technical Research

ISSN: 2574 -1241

DOI: 10.26717/BJSTR.2023.52.008260

# Valorization of Coffee Residue Waste: Mini Review

**Ghenwa kataya[1], May Issa[2]* and Akram Hijazi[1]**

*[1]Doctoral School of Science and Technology, Research Platform for Environmental Science (PRASE), Lebanese University, P.O. Box 6573/14 Beirut, Lebanon*

*[2]Department of Environment, Faculty of Agriculture and Veterinary Sciences, Lebanese University, P.O. Box 6573/14 Beirut, Lebanon*

***Corresponding author:** May Issa, Department of Environment, Faculty of Agriculture and Veterinary Sciences, Lebanese University, P.O. Box 6573/14 Beirut, Lebanon

**ARTICLE INFO**

**Received:** August 17, 2023

**Published:** August 25, 2023

**Citation:** Ghenwa kataya, May Issa and Akram Hijazi. Valorization of Coffee Residue Waste: Mini Review. Biomed J Sci & Tech Res 52(3)-2023. BJSTR. MS.ID.008260.

**ABSTRACT**

Coffee, a widely consumed product on a global scale, is responsible for a significant amount of waste that poses detrimental effects on the environment when improperly disposed of. This waste also generates greenhouse gas emissions, thereby contributing to the overarching issue of climate change. However, an insightful analysis of the composition of coffee residues reveals its latent beneficial properties, suggesting its potential value in diverse domains. This includes both the use of the solid waste generated from coffee and the extraction of its compounds. In this concise overview, we highlight the chemical composition of coffee residue, drawing from prior research, and shed light on the possible applications that can be pursued, with a particular emphasis on its promising role in the field of biomedical applications.

**Keywords:** Coffee Residues; Food Waste; Biochar; Composition; Application; Biomedical; Valorization

## Introduction

Coffee, a tropical crop from the Rubiaceae family, originated in Africa and Asia and is made from the Coffee species of shrubs or small trees (Coffee Research Institute [1]). The essential requirements for the growth of coffee are the following: warm tropical regions between the Tropics of Cancer and Capricorn, ample rainfall, no frost, and elevations of at least 2,000 meters above sea level. The first significant harvest can take up to five years, and the trees can continue to produce crops for 15 years (Nigam Singh [2]). Today, Coffee is cultivated worldwide in more than 70 countries. Among these, Brazil, Vietnam, Colombia, Indonesia, and Ethiopia emerge as the primary coffee producers. The beans extracted from these plants play a pivotal role in enhancing the flavors of various beverages and products. Notably, the global coffee production reached a remarkable 175.35 million 60-kilogram bags during 2020-2021, indicating an increase from the previous year's output of 165 million, as reported by "Coffee World Market and Trade" (2020). The heart of coffee production lies predominantly in South America, with Brazil standing out as the largest contributor (Statista [3]). It is important to note that there are more than 124 distinct species of coffee trees. Nevertheless, the lion's share of the worldwide coffee supply can be attributed to only two major bean types: Arabica and Robusta (Pebble and Pine [4]). Arabica beans have a milder taste and contain less caffeine compared to Robusta beans, which have a more robust aroma. The Robusta tree is bushier in appearance, with larger leaves and berries that grow in clusters (Kenya Research institute [5]). It's worth mentioning that for every 1 kilogram of instant coffee produced, 2 kilograms of used coffee grounds are generated (Blinova [6]). The significant and diverse waste generated from both coffee production and consumption, such as coffee husks or residues, holds great importance Therefore, gaining insight into the composition of this waste is vital for the purpose of valorizing it. This knowledge can help mitigate its environmental repercussions and enhance its valorization. In this short review, our objective is to delve into the chemical composition of coffee residues, emphasizing their diverse range of applications across various sectors and especially the biomedical applications.

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## Chemical Composition of Coffee Residues

Exhausted coffee wastes refer to the spent coffee grounds or coffee residues that are left over after the brewing process. These coffee grounds can no longer be used to brew coffee and are considered waste material (Pujol, et al. [7]). The composition of coffee residues depends on the processing method and type of beans used. The roasting process greatly affects the chemical composition of coffee, and the presence of certain compounds, minerals, and polyphenols can be used to differentiate between Robusta and Arabica coffee varieties (Dippong, et al. [8]). Coffee residues contain a variety of components such as: cellulose, hemicellulose, lignin, ashes, minerals, fats, proteins, and a combination of dietary fibers—soluble, insoluble, and total. According to several studies conducted, it reveals that coffee residues contain 12.4% cellulose, 39.1% hemicellulose, along with specific components such as 3.6% arabinose, 19.07% mannose, and 43% GA lactose. Furthermore, the composition includes 23.9% lignin, 2.29% fat, 17.44% protein, and a notable percentage of total dietary fiber around 60.49% (Cruz and Prihadi [9,10]). Intriguingly, coffee residues go beyond just lignocellulosic elements; they have recoverable compounds like essential oils and flavonoids. However, these compounds are found in relatively lower concentrations, approximately 10 wt.%, due to prior hydrothermal extraction methods. Also, traces of inorganic micronutrients, including calcium, magnesium, and sodium, are also present, though at levels below 5.0% of the dry weight, as pointed out by (Mussatto [11]). For a comprehensive view, please refer to Table 1, which provides insight into the ultimate, proximate, and biochemical composition of coffee residue.

**Table 1:** Composition, ultimate, and proximate analysis of coffee residues (Cerino-Córdova, et al. [31]).

| Biochemical composition | |
|---|---|
| Compound | Concentration (wt%db*) |
| Lipids | 6.7–19 |
| Carbohydrates | 14.1–72.4 |
| Proteins | 4.3–17 |
| Mannose | 21.2–47 |
| Galactose | 25–30 |
| Glucose | 19–24 |
| Arabinose | 3.8–6 |
| Caffeine | 0.96–7.9 |
| Oil | 10–20 wt% |

| Ultimate analysis | |
|---|---|
| Element | Ww % db* |
| C | 52.1–53 |
| H | 6.8–7.03 |
| N | 1.71–3.47 |
| S | 0.1 |
| O | 34.7–38.1 |

| Proximate analysis | |
|---|---|
| Value | ww%db* |
| Moisture | 11.5–61 |
| Volatile | 79.5 |
| Ash | 0.68–2.2 |
| Fixed carbon | 8.2 |

Table 2 illustrates the variations in elemental analysis, atomic ratios, and acidic groups between two distinct types of coffee residues, EC1 and EC2. The observed values exhibit slight differences, with some being higher or lower when comparing the two residues types. These disparities can be attributed to the distinctions in coffee varieties or the roasting methods, as previously mentioned. Table 3 gives the mineral compositions of coffee residues, revealing interesting values that emphasize their richness in vital minerals, particularly potassium. This abundance of essential minerals makes coffee residues valuable for agricultural applications. Coffee residues are remarkably diverse and rich in their composition, making them extremely deserving of being valued for a variety of uses. In the subsequent section, we will provide an overview of the broad applications of coffee residues, with a specific emphasis on their utilization within the field of biomedical applications.

**Table 2:** Elemental analysis, atomic ratios, and acidic groups between two distinct coffee residues, EC1 and EC2. (Pujol, et al. [7]).

| Elemental composition (%) | EC 1 | EC 2 |
|---|---|---|
| C | 57.16 | 59.77 |
| H | 7.17 | 7.57 |
| N | 1.18 | 1.32 |
| Atomic ratios | | |
| H/C | 1.51 | 1.52 |
| O/C | 0.45 | 0.39 |
| C/N | 56.51 | 52.83 |
| (O+N)/C | 0.47 | 0.41 |
| Acidic groups (mmolg-1) | | |
| all groups | 1.69 | 1.27 |
| strong carboxylic groups | 0.56 | 0.36 |
| weak groups | ~0 | ~0 |
| phenolic groups | 1.13 | 0.95 |

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**Table 3:** Mineral composition of coffee residue (Ballesteros, et al. [30]).

| Minerals | Composition (mg/kg dry material) |
|---|---|
| Potassium | 11,700 ± 0.01 |
| Calcium | 1,200± 0.00 |
| Magnesium | 1,900± 0.00 |
| Sulfur | 1,600± 0.00 |
| Phosphorus | 1,800± 0.00 |
| Iron | 52.00± 0.50 |
| Aluminum | 22.30± 3.50 |
| Strontium | 5.90± 0.00 |
| Barium | 3.46± 0.05 |
| Copper | 18.66± 0.94 |
| Sodium | 33.70± 8.75 |
| Manganese | 28.80± 0.70 |
| Boron | 8.40± 1.10 |
| Zinc | 8.40± 0.20 |
| Cobalt | 15.18± 0.05 |
| Iodine | <0.10 |
| Nickel | 1.23± 0.59 |
| Chromium | <0.54 |
| Molybdenum | <0.08 |
| Vanadium | <0.29 |
| Lead | <1.60 |
| Selenium | <1.60 |
| Gallium | <1.47 |
| Tin | <1.30 |
| Cadmium | <0.15 |

## Coffee Residues Waste Applications

Coffee residues possess a multitude of versatile applications, spanning from extracting bio components and colorants to crafting agglomerates and even contributing to building materials. Beyond these applications, its potential as a precursor for polymers/composites, catalysts, and as a nutrient-rich feed or food ingredient has been recognized due to its abundant nutrient content (Serna-Jiménez, et al. [12-14]). Furthermore, the agricultural sector has witnessed the benefits of incorporating coffee residues into cultivated soil. Its use has been associated with inhibiting the growth of weeds and exhibiting repellent properties against Spodoptera littorals larvae. Its nitrogen-rich composition also positions it as a valuable option for composting and fertilization, bolstering soil health and productivity (Hussein, et al. [15-17]). However, there are certain concerns associated with the direct use of coffee residues in soil without an appropriate treatment. This is primarily due to its composition, which includes tannins and caffeine. These compounds can have a toxic effect on the soil, leading to soil degradation over time. But the process of transforming coffee residue into biochar presents a solution to this issue. By subjecting the coffee residue to specific pyrolysis conditions, its toxicity can be eliminated. As a result, the resulting biochar can be safely incorporated into the soil, offering a way to enhance soil quality without any harm (Arya, et al. [18,19]). Notably, the value of coffee residues extends into the domain of biorefining. Optimal biorefining configurations have been explored, highlighting the potential to generate biodiesel and electricity on-site at coffee factories. This approach not only demonstrates a positive net value but also showcases reduced greenhouse gas emissions when compared to alternatives like landfilling or conventional biodiesel production (Yeoh and Ng [17]).

## Biomedical Applications of Coffee Residue

### Antioxidant Properties

Coffee residues are rich in antioxidants, such as chlorogenic acids and polyphenols. These antioxidants have been studied for their potential to counteract oxidative stress, which is linked to various health conditions including neurodegenerative diseases, cardiovascular diseases, and cancer (Choi and Koh [20]).

### Wound Healing

Coffee residues extracts have been investigated for their wound healing properties. Some studies suggest that these extracts can help in promoting cell proliferation, collagen synthesis, and tissue regeneration, which are essential processes for wound healing due to the content of coffee grounds in caffeine (Yuwono Ojeh, et al. [21,22]).

### Cosmetics

Coffee residues can also be used as a specific material in cosmetics, especially in skin lightening and anti-aging products (Kanlayavattanakul, et al.).

### Anti-Inflammatory Effects

Compounds found in coffee residues, such as caffeine and other bioactive molecules, have shown anti-inflammatory properties. It is a potential candidate for developing anti-inflammatory drugs or supplements (Ho, et al. [23]).

### Dermal and Hair Care

Coffee grounds contain exfoliating properties that can be utilized in skincare products. They can help remove dead skin cells while in hair care, coffee residues might be used in shampoos or treatments to promote scalp health and hair growth (Saewan [24]).

### Drug Delivery Systems

The porous nature of coffee residues can be leveraged for drug delivery systems also to the chemical composition of coffee residue such as polysaccharides. Researchers have explored the possibility of using coffee grounds as a carrier for drugs, allowing controlled release over time (Valente, et al. [25]).

### Dental Health

Some studies have indicated that coffee residues might have antibacterial properties that could be useful in oral care products. It might aid in fighting the germs that cause gum disease and dental plaque (Tsou, et al. [26]).

### Bone Health

Extracts derived from coffee waste might have applications in developing supplements for maintaining bone health (Coronado-Zarco [27]).

### Antimicrobial Applications

Coffee residues with natural antimicrobial properties could be harnessed for developing disinfectants, wound dressings, or other medical products aimed at preventing infections (Monente, et al. [28,29]) (Figure 1).

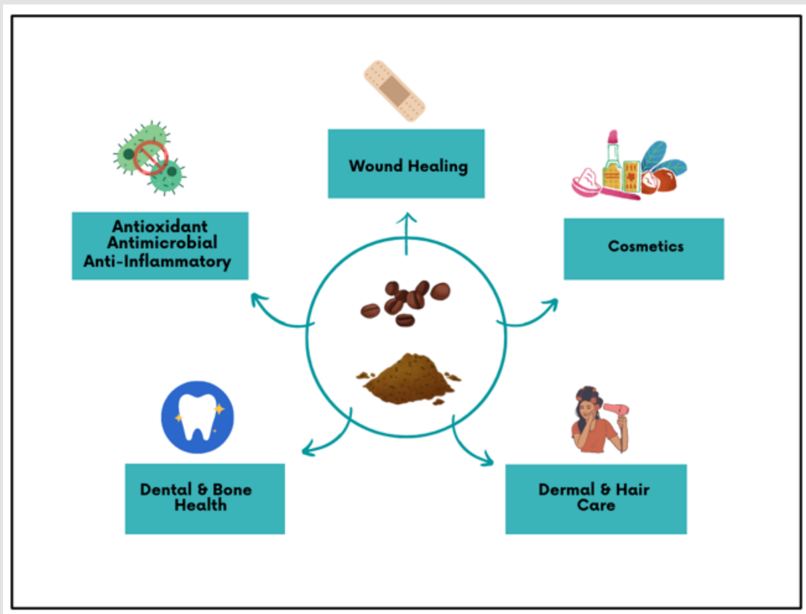


**Figure 1:** Biomedical applications of coffee residue.

## Conclusion

Food waste is a recognized catalyst of the ongoing climate change dilemma. As food waste decomposes in landfills or is incinerated, it releases greenhouse gases that contribute significantly to global warming [30,31]. To counteract this pressing environmental concern, the adoption of sustainable methodologies for food waste management is paramount. Repurposing food waste presents a promising solution. Instead of treating it as a disposable burden, the quest for extracting value from food waste holds the potential to mitigate its environmental impact while fostering economic and social benefits. An excellent example is the substantial waste generated by global coffee consumption. Particularly significant is the residues resulting from coffee bean processing, which possess remarkable potential for repurposing. Researchers have identified multiple applications for coffee residues. In the sector of biomedicine, the versatility of coffee residue has been explored for wound healing, drug delivery systems, and as a source of antioxidants. However, the viability and safety of these applications necessitate meticulous investigation and development. In biomedical pursuits, factors such as material purity, safety, and efficacy derived from coffee residue attain high importance. Thorough research is indispensable to comprehend the merits and risks of these applications, and regulatory benchmarks must be met before integrating coffee residues-based materials into medical or healthcare sectors. The agricultural domain also offers avenues for utilizing coffee residue, accompanied by inherent challenges.

While coffee residue contains beneficial minerals for plant growth, it also contains elements potentially detrimental to soil health. This contrast underscores the complexities of employing coffee residues in agriculture. In-depth research is obligatory to discern the precise repercussions of coffee residues on diverse soil types, plant species, and growth conditions. This depth of inquiry will pave the way for formulating guidelines and optimal practices for the secure and efficacious integration of coffee residue in agriculture. In conclusion, addressing the environmental repercussions of food waste, particularly in the context of coffee consumption, mandates a multifaceted strategy. Repurposing food waste, exemplified by coffee residue, harbors substantial cross-sector benefits. Nonetheless, it is serving upon thorough research, safety validation, and tailored consideration of unique application challenges to unlock the full potential of these waste materials in a sustainable manner.

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**ISSN: 2574-1241**

DOI: 10.26717/BJSTR.2023.52.008260

**May Issa.** Biomed J Sci & Tech Res