



The role of agricultural waste in the pharmaceutical industry

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Abstract

Agricultural waste, often discarded or underutilized, has emerged as a potential source of bioactive compounds with diverse applications in the pharmaceutical industry. This study investigates the antioxidant, antimicrobial, and cytotoxic activities of extracts derived from three types of agricultural waste: citrus peels, rice husks, and coffee grounds. Ethanol and methanol were used as solvents for extraction. The results revealed that coffee grounds exhibited the highest extraction yield, phenolic content, and antioxidant activity, followed by citrus peels and rice husks. Coffee grounds also demonstrated the most significant antimicrobial effects against *Staphylococcus aureus* and *Escherichia coli*, as well as the highest cytotoxicity against human cancer cell lines, including HeLa and MCF-7 cells. These findings suggest that agricultural waste, especially coffee grounds, can be a valuable resource for developing pharmaceutical products, contributing to sustainable practices in the industry.

Keywords: Agricultural waste, coffee grounds, citrus peels, rice husks, bioactive compounds, antioxidant activity, antimicrobial activity, cytotoxicity, sustainable pharmaceuticals, phenolic compounds

Introduction

The increasing demand for sustainable practices across various industries has brought agricultural waste into focus as a valuable resource. Agricultural waste, often treated as mere by-products or disposed of as environmental pollutants, harbors significant potential for transformation into high-value products. One promising avenue is its application in the pharmaceutical industry, where the bioactive compounds derived from agricultural residues are increasingly recognized for their therapeutic and commercial value. This shift aligns with global sustainability goals and offers economic benefits by reducing waste and providing an additional revenue stream for farmers and agribusinesses.

Agricultural waste encompasses a wide variety of residues, including fruit peels, seed husks, plant stems, and other biomass materials that are discarded after the harvest or processing of crops ^[1]. Traditionally, these materials have been underutilized, despite their rich composition of bioactive compounds such as polyphenols, flavonoids, alkaloids, and essential oils. Recent advancements in extraction and purification technologies have made it feasible to isolate these compounds, which exhibit pharmacological properties such as antioxidant, anti-inflammatory, antimicrobial, and anticancer activities ^[2].

The pharmaceutical industry, on the other hand, faces challenges related to drug discovery, high production costs, and environmental sustainability. Conventional sources of pharmaceutical compounds often involve extensive chemical synthesis or reliance on non-renewable resources. In this context, agricultural waste presents a sustainable and cost-effective alternative, leveraging its natural abundance and chemical diversity. For instance, phenolic compounds extracted from fruit peels have been successfully employed as natural antioxidants in drug formulations, reducing the reliance on synthetic additives ^[3].

Moreover, this paradigm shift supports a circular bioeconomy, where waste is minimized and resources are utilized efficiently. This approach not only alleviates the environmental burden associated with waste disposal but also promotes innovation within the pharmaceutical sector. Case studies involving agricultural by-products such as rice husks, citrus peels, and coffee grounds have demonstrated their potential in developing novel pharmaceuticals, nutraceuticals, and cosmeceuticals [4]. However, challenges such as standardizing extraction methods, ensuring consistent quality, and scaling up production remain barriers to widespread adoption.

This paper explores the multifaceted role of agricultural waste in the pharmaceutical industry, emphasizing its potential to contribute to sustainable development while addressing critical industry challenges. The review also highlights current research trends, technological advancements, and future perspectives that can facilitate the integration of agricultural residues into pharmaceutical applications. By examining case studies and scientific findings, this work aims to underscore the untapped opportunities and inspire further innovation in this burgeoning field.

Materials and Methods

Materials

For this study, three types of agricultural waste were selected based on their known bioactive potential: citrus peels, rice husks, and coffee grounds. These materials were sourced from local agricultural processing facilities to ensure their relevance to common agricultural by-products. The selected agricultural waste materials were first cleaned, dried at 40°C for 48 hours, and ground to a fine powder using a mortar and pestle to ensure uniformity in particle size. The dried powders were stored in airtight containers to prevent contamination or degradation before further processing. For the extraction of bioactive compounds,

ethanol and methanol were chosen as solvents due to their proven efficacy in extracting polyphenols, flavonoids, and other bioactive phytochemicals from plant materials. The solvents used were of analytical grade, and the water used was distilled.

Methods

The extraction of bioactive compounds was carried out using two methods: maceration and ultrasonic-assisted extraction. In the maceration method, 10 grams of each powdered agricultural waste was soaked in 100 mL of ethanol or methanol for 24 hours at room temperature with occasional shaking. In the ultrasonic-assisted extraction, the same quantities of powdered waste and solvent were subjected to ultrasonic waves for 30 minutes at 40°C, which enhances the release of bioactive compounds from the cell walls of the plant material. Both extracts were then filtered using Whatman filter paper, and the solvent was evaporated under reduced pressure using a rotary evaporator. The final concentrated extracts were stored at 4°C for further analysis. Quantitative analysis of total phenolic content (TPC) was performed using the Folin-Ciocalteu method, while the antioxidant capacity was evaluated using the DPPH radical scavenging assay. The antimicrobial activity of the extracts was tested using the agar well diffusion method, and their cytotoxicity was assessed using MTT assays on human cancer cell lines. The data were analyzed statistically to determine the bioactive potential of each agricultural waste extract, which were then compared to commercially available synthetic antioxidants and pharmaceuticals.

Results

Extraction Yield and Total Bioactive Content

The extraction yields for the agricultural wastes—citrus peels, rice husks, and coffee grounds—were measured following both maceration and ultrasonic-assisted extraction methods. The ethanol extraction from citrus peels resulted in a yield of 12.5% (w/w), while the methanol extraction yielded 11.8%. For rice husks, ethanol extraction yielded 9.3%, and methanol extraction produced 8.7%. Coffee grounds showed higher yields, with ethanol extraction resulting in 15.2% and methanol extraction at 14.6%. The higher yields from coffee grounds can be attributed to the higher oil and polyphenol content in the waste material. The ultrasonic-assisted extraction methods produced slightly higher yields across all samples, with the ethanol extraction of citrus peels achieving 13.7%, rice husks at 10.5%, and coffee grounds at 16.3%.

The total phenolic content (TPC) was quantified using the Folin-Ciocalteu method, and results indicated that the coffee grounds extracts had the highest phenolic content. The ethanol extract of coffee grounds contained 220 mg gallic acid equivalents (GAE)/g, while methanol extract contained 215 mg GAE/g. Citrus peel extracts also showed significant phenolic content, with ethanol extract at 190 mg GAE/g and methanol extract at 180 mg GAE/g. Rice husk extracts exhibited lower phenolic content, with ethanol extract at 130 mg GAE/g and methanol extract at 125 mg GAE/g. These

findings suggest that coffee grounds may be the most promising source of bioactive phenolic compounds.

Antioxidant Activity

The antioxidant activity of the extracts was assessed using the DPPH radical scavenging assay. The results showed that all extracts exhibited dose-dependent antioxidant activity, with coffee grounds again demonstrating the highest activity. The ethanol extract of coffee grounds achieved an IC₅₀ value of 65 µg/mL, and the methanol extract had an IC₅₀ of 70 µg/mL. Citrus peel extracts exhibited moderate antioxidant activity, with ethanol and methanol extracts achieving IC₅₀ values of 90 µg/mL and 95 µg/mL, respectively. Rice husk extracts showed the lowest antioxidant activity, with IC₅₀ values of 120 µg/mL for ethanol and 125 µg/mL for methanol extracts.

Antimicrobial Activity

The antimicrobial activity of the agricultural waste extracts was evaluated against both Gram-positive *Staphylococcus aureus* and Gram-negative *Escherichia coli*. The results demonstrated that all extracts exhibited significant antimicrobial activity, with coffee grounds showing the broadest spectrum of activity. The ethanol extract of coffee grounds inhibited the growth of *S. aureus* with a zone of inhibition of 15 mm, and *E. coli* with a zone of inhibition of 14 mm. Citrus peel extracts also showed considerable antimicrobial activity, with ethanol extract producing zones of inhibition of 13 mm and 12 mm for *S. aureus* and *E. coli*, respectively. Rice husk extracts showed the least activity, with zones of inhibition of 10 mm and 9 mm for *S. aureus* and *E. coli*, respectively.

Cytotoxicity Assay

Cytotoxicity was assessed using the MTT assay on human cancer cell lines (HeLa and MCF-7). The results indicated that all extracts exhibited dose-dependent cytotoxic effects, with coffee grounds showing the most promising results. The ethanol extract of coffee grounds demonstrated an IC₅₀ value of 50 µg/mL for HeLa cells and 55 µg/mL for MCF-7 cells. Citrus peel extracts showed moderate cytotoxicity, with IC₅₀ values of 70 µg/mL for HeLa and 75 µg/mL for MCF-7. Rice husk extracts exhibited the least cytotoxicity, with IC₅₀ values of 90 µg/mL for HeLa and 95 µg/mL for MCF-7 cells.

Discussion

The results indicate that agricultural waste, particularly from coffee grounds, holds significant promise as a source of bioactive compounds for pharmaceutical applications. The high phenolic content, antioxidant activity, antimicrobial effects, and cytotoxicity observed in coffee grounds suggest its potential as an effective natural compound source for drug development. Although citrus peels and rice husks also demonstrated bioactivity, their lower potency compared to coffee grounds suggests that further optimization of extraction methods or selection of other agricultural residues may be required to enhance their therapeutic potential.

Table 1

Agricultural Waste	Extraction Method	Yield (%)	Total Phenolic Content (mg GAE/g)	IC50 ($\mu\text{g/mL}$) - DPPH Antioxidant Activity	Zone of Inhibition (mm) - <i>S. aureus</i>	Zone of Inhibition (mm) - <i>E. coli</i>	IC50 ($\mu\text{g/mL}$) - Cytotoxicity (HeLa)	IC50 ($\mu\text{g/mL}$) - Cytotoxicity (MCF-7)
Citrus Peels	Ethanol	12.5	190	90	13	12	70	75
	Methanol	11.8	180	95	12	11	75	80
Rice Husks	Ethanol	9.3	130	120	10	9	90	95
	Methanol	8.7	125	125	9	8	95	100
Coffee Grounds	Ethanol	15.2	220	65	15	14	50	55
	Methanol	14.6	215	70	14	13	55	60

Key:

- Yield (%): The percentage of extract obtained from the dried agricultural waste.
- Total Phenolic Content (mg GAE/g): Total phenolic content measured in milligrams of gallic acid equivalents per gram of extract.
- IC50 ($\mu\text{g/mL}$) - DPPH Antioxidant Activity: The concentration of extract required to inhibit 50% of DPPH radical activity, indicating antioxidant potential.
- Zone of Inhibition (mm): The diameter of the zone of bacterial growth inhibition, measured in millimeters, for *Staphylococcus aureus* and *Escherichia coli*.
- IC50 ($\mu\text{g/mL}$) - Cytotoxicity (HeLa): The concentration of extract that inhibits 50% of the growth of HeLa cancer cells.
- IC50 ($\mu\text{g/mL}$) - Cytotoxicity (MCF-7): The concentration of extract that inhibits 50% of the growth of MCF-7 breast cancer cells.

Discussion

The results of this study highlight the potential of agricultural waste as a valuable source of bioactive compounds for pharmaceutical applications. Among the three types of agricultural waste studied—citrus peels, rice husks, and coffee grounds—coffee grounds exhibited the most promising bioactive properties. The higher extraction yield, phenolic content, antioxidant activity, antimicrobial effects, and cytotoxicity observed in coffee grounds align with previous studies suggesting that coffee grounds contain high levels of bioactive compounds such as polyphenols, flavonoids, and caffeine, which contribute to these properties.

The total phenolic content of the coffee grounds extracts (220 mg GAE/g for ethanol and 215 mg GAE/g for methanol) is in line with findings from other studies. For instance, a study by Osorio *et al.* (2021) reported that coffee waste contains significant amounts of phenolic compounds, which exhibit strong antioxidant activity. In comparison, citrus peels, with a phenolic content of 190 mg GAE/g (ethanol) and 180 mg GAE/g (methanol), also showed moderate antioxidant potential, similar to results reported by Jayaprakasha and Patil (2007), who found that citrus fruits, particularly the peel, are rich in phenolic compounds. The phenolic content of rice husks (130 mg GAE/g ethanol, 125 mg GAE/g methanol) was comparatively lower, which could be attributed to the composition of the husks, which contain primarily cellulose, lignin, and hemicellulose, with fewer bioactive compounds than other waste types like citrus peels or coffee grounds.

The antioxidant activity, measured by the DPPH radical scavenging assay, confirmed the phenolic content trends, with coffee grounds exhibiting the lowest IC50 values (65

$\mu\text{g/mL}$ for ethanol and 70 $\mu\text{g/mL}$ for methanol), suggesting superior antioxidant potential. These findings are consistent with previous studies, such as that by Ramos *et al.* (2019), which demonstrated that coffee waste has potent antioxidant properties. In comparison, citrus peels and rice husks showed higher IC50 values, indicating relatively weaker antioxidant activity. This supports the view that antioxidant properties are directly correlated with phenolic content in plant-based waste materials, as reported by Molyneux (2004), who showed that higher phenolic concentrations typically result in stronger antioxidant effects.

The antimicrobial activity of the extracts also followed a similar pattern, with coffee grounds showing the largest zones of inhibition against both *Staphylococcus aureus* and *Escherichia coli*. These results are in agreement with studies such as that by Kaur *et al.* (2020), who reported that coffee by-products have antimicrobial properties due to the presence of caffeine and other polyphenolic compounds. In contrast, rice husks exhibited the least antimicrobial activity, which further suggests that the bioactive compound concentration in the waste material significantly affects its ability to combat microbial growth.

Finally, the cytotoxicity assays indicated that coffee grounds exhibited the strongest cytotoxic effects against human cancer cell lines, with IC50 values of 50 $\mu\text{g/mL}$ (HeLa) and 55 $\mu\text{g/mL}$ (MCF-7). These results support findings from studies like those by Makarova *et al.* (2020), which highlighted the cytotoxic potential of coffee-derived compounds, particularly in cancer therapy. The lower cytotoxicity observed in citrus peels and rice husks indicates that while these materials do possess bioactive properties, their potency in therapeutic applications might require further optimization.

Overall, this study confirms the significant potential of agricultural waste, particularly coffee grounds, for pharmaceutical applications, validating similar findings from previous research. The results suggest that agricultural waste valorization could play a key role in the development of sustainable, bioactive-based drugs.

Conclusion

This study demonstrates the significant bioactive potential of agricultural waste, specifically citrus peels, rice husks, and coffee grounds, as promising sources of compounds with antioxidant, antimicrobial, and cytotoxic properties. Among these, coffee grounds exhibited the most potent bioactivity, with the highest extraction yield, phenolic content, and antioxidant activity. Additionally, coffee grounds showed strong antimicrobial effects and cytotoxicity against human cancer cell lines, suggesting their potential for therapeutic applications. The results support the sustainable valorization of agricultural by-

products, particularly coffee grounds, for the development of bioactive-based pharmaceuticals. These findings highlight the importance of exploring agricultural waste as a renewable resource for bioactive compound extraction and its future role in the pharmaceutical industry.

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