



Combating Antimicrobial Resistance in the Food Chain Using Bioactive Compounds from Agricultural Waste

Ojo Samuel Adekanmi¹, Mfon Gladys Nkechi², Stanley Osazuwa Omobude³, Queen Amarachi Chibueze⁴, Comfort Adedayo Fatokun⁵, Motunrayo Racheal Owoyomi⁶

¹ University of Ibadan (adekanmisamuel4@gmail.com | ORCID: 0009-0002-8197-807X)

² Delta State University Abraka (gladyscelestine1@gmail.com | ORCID: 0009-0007-4614-7779)

³ Ambrose Alli University (stanomobude@gmail.com | ORCID: 0009-0002-7940-0818)

⁴ Kaduna State Polytechnic (chibuezequeen822@gmail.com | ORCID: 0009-0004-9082-8051)

⁵ Ladoke Akintola University (comfortingday7@gmail.com | ORCID: 0009-0002-6840-7440)

⁶ Kogi State Univeristy Ayingba (benjaminmotunrayoracheal@gmail.com | ORCID: 0009-0002-3035-5331)

DOI : <https://doi.org/10.55248/gengpi.07.0926.2916>

ABSTRACT :

The rise of antimicrobial-resistant bacteria across the food chain threatens public health and medical treatments globally. This problem is heavily driven by the routine use of synthetic antibiotics in livestock farming and chemical preservatives in food processing. Simultaneously, the agricultural sector struggles to manage massive volumes of organic waste, including seeds, peels, and pomace, which contribute to environmental degradation. This research addresses both issues by examining how agri-food waste can be converted into natural antimicrobial agents. By utilizing advanced laboratory techniques to extract bioactive compounds, specifically polyphenols and natural antioxidants, from these waste streams, the food industry can produce highly effective biopreservatives and functional animal feed additives. Replacing synthetic chemicals with these natural extracts significantly limits the proliferation of resistant pathogens in agricultural settings and finished food products. The study concludes that valorizing agricultural waste fits directly into a circular economy model, drastically reducing environmental pollution while providing a sustainable and scientifically backed strategy to protect consumers from antimicrobial resistance.

Keywords: Antimicrobial resistance; Bioactive compounds; Agricultural waste; Food safety; Circular economy.

1. Introduction

Antimicrobial resistance ranks among the most severe global public health threats of the modern era. A primary driver of this crisis is the widespread misuse of synthetic antibiotics within livestock farming and aquaculture systems. These chemical agents are routinely administered to promote animal growth and prevent infections in crowded environments. However, this constant exposure creates immense selection pressure, allowing bacteria to mutate, develop resistance, and spread antibiotic resistance genes rapidly. Walsh (2018) highlighted that the widespread application of antibiotics in animals for growth promotion directly drives the transmission of clinically dangerous drug resistance genes across farms [1]. These resistant pathogens systematically travel through the food chain, ultimately compromising human health when contaminated products are consumed [2].

Simultaneously, the global agricultural sector generates millions of metric tons of organic waste every year. Discarded materials such as fruit peels, vegetable stalks, and seed husks are typically dumped in landfills, where they decompose and contribute heavily to environmental pollution and greenhouse gas emissions. Despite being treated as refuse, these agricultural by-products are highly concentrated sources of bioactive compounds, particularly phenols and flavonoids, which naturally possess powerful antibacterial properties. Di Maro et al. (2024) demonstrated that agri-food wastes from pomace, peels, and seeds contain dense antimicrobial profiles that can be successfully recovered for sustainable, commercial applications [3]. This study evaluates the scientific and economic viability of extracting these compounds to serve as a sustainable alternative to synthetic antibiotics in the food supply chain.

1.1 Statement of the Problem

The food production industry faces a dual crisis: the unchecked spread of drug-resistant bacteria due to synthetic antibiotic reliance, and the massive environmental burden of unmanaged organic waste. While synthetic preservatives and drugs offer short-term agricultural gains, they cause long-term failures in human medical treatments. Without integrating natural, waste-derived antimicrobial alternatives, the rate of resistant infections will continue to climb, and agricultural waste will continue to degrade the environment.

2. Literature Review

2.1 The Burden of Antimicrobial Resistance in Agriculture

The link between standard agricultural practices and the decline of human medical efficacy is heavily documented in recent literature. When livestock are fed sub-therapeutic doses of antibiotics, their gastrointestinal tracts adapt, becoming breeding grounds for highly resistant bacteria strains. Zalewska et al. (2021) documented that synthetic antibiotic residues, resistance genes, and living resistant bacteria are frequently detected in animal manure and the soils where that manure is applied [2]. Consequently, manure acts as an active hotspot for the horizontal gene transfer of resistance traits. These bacteria contaminate groundwater via soil runoff and contaminate meat during slaughterhouse processing, drastically multiplying the risk vectors for human exposure.

2.2 Valorization of Agricultural Waste

Recent advancements in food technology highlight how circular economy principles can solve this resistance issue. Organic waste materials, specifically citrus peels, mango seeds, and grape pomace, are proven to be rich in bioactive compounds. Polyphenols, in particular, function by physically disrupting the cell walls of harmful bacteria and preventing their cellular reproduction, all without leaving the toxic chemical residues associated with synthetic drugs. Bouarab-Chibane et al. (2019) tested the antibacterial activity of 35 different polyphenols against six major foodborne pathogenic bacteria, confirming that polyphenols structurally damage bacterial cell membranes and completely halt their growth [4]. Ullah et al. (2022) expanded on this by demonstrating that natural polyphenols effectively preserve meat and dairy products by inhibiting spoilage bacteria [5]. Repurposing these extracts as natural food preservatives or organic livestock feed additives presents a highly effective method to break the agricultural sector's reliance on synthetic chemicals.

3. Methodology

3.1 Waste Identification and Sourcing

This research utilized a descriptive and analytical framework based on recent laboratory extraction data and food safety efficacy trials. The first stage involved categorizing high-yield agricultural waste products common in developing regions. Focus was placed on fruit peels and seed extracts that contain abundant natural polymers and phenolic compounds. Di Maro et al. (2024) identified that peels, pomace, and seeds resulting from citrus, mango, grape, and pomegranate processing are exceptionally rich in recoverable antimicrobial agents [3].

3.2 Extraction Techniques and Efficacy Evaluation

The second stage reviewed efficient, green laboratory extraction methods used to isolate these bioactive compounds without damaging their molecular structure. Chemat et al. (2017) demonstrated that ultrasound-assisted extraction drastically reduces processing time, toxic solvent usage, and energy consumption when compared to traditional methods [6]. Supercritical fluid extraction utilizing carbon dioxide is another highly effective, solvent-free technique that preserves heat-sensitive compounds [3]. Finally, the study analyzed in-vitro susceptibility test data to measure how well these organic extracts inhibit common foodborne pathogens like *Escherichia coli* and *Salmonella*. Bouarab-Chibane et al. (2019) found that polyphenols applied at a 1 g/L concentration successfully inhibited *E. coli*, *Salmonella* Enteritidis, *Listeria monocytogenes*, and *Staphylococcus aureus* [4].

4. Findings

4.1 Antimicrobial Efficacy of Waste Extracts

The analysis confirms that bioactive compounds extracted from everyday agricultural waste offer a robust and viable alternative to synthetic antimicrobials. Extracts highly concentrated with polyphenols consistently inhibit the growth of the most dangerous foodborne bacteria. Bouarab-Chibane et al. (2019) reported that over 45% of the tested polyphenols produced more than a 50% reduction in bacterial loads against *Salmonella* and *Listeria* [4]. Table 1 summarizes the specific efficacy of various waste extracts against targeted pathogens based on recent laboratory trials.

Table 1: Antimicrobial Efficacy of Selected Agri-Food Waste Extracts

Waste Source	Primary Bioactive Compound	Target Pathogens	Inhibition Level
Citrus Peels	Flavonoids / Ascorbic Acid	<i>Escherichia coli</i> , <i>S. aureus</i>	High (>60% reduction)
Grape Pomace	Phenolic Acids	<i>Salmonella</i> Enteritidis	Moderate to High
Mango Seeds	Tannins	<i>Listeria monocytogenes</i>	High (>70% reduction)
Pomegranate Peels	Punicalagin	<i>E. coli</i> , <i>Salmonella</i> spp.	Very High

Source: Compiled from Laboratory Susceptibility Data [3][4]

4.2 Implications for Animal Feed and Environment

Incorporating these natural extracts directly into livestock feed improves animal gut health naturally, which immediately reduces the need to administer synthetic antibiotics. The natural antimicrobial and antioxidant properties of dietary polyphenols actively support intestinal health and boost immune function in livestock [5]. Furthermore, repurposing agri-food waste into valuable antimicrobial products significantly lowers the financial costs, carbon emissions, and physical environmental damage associated with agricultural waste disposal. This practice perfectly aligns with circular economy principles by converting hazardous waste streams into highly valuable, health-protecting products [3].

5. Conclusion and Recommendations

5.1 Conclusion

Valorizing agricultural waste into bioactive compounds provides a highly effective dual solution to two separate global crises. It physically reduces the environmental burden caused by massive volumes of rotting organic waste, while simultaneously curbing the dangerous spread of antimicrobial resistance across the food chain. Extracts from citrus peels, mango seeds, and grape pomace provide safe, natural inhibition of pathogens like *Salmonella* and *E. coli*, proving that the agricultural sector can successfully transition away from synthetic antibiotics.

5.2 Recommendations

1. Food regulatory bodies and health ministries should actively promote the certification and usage of natural biopreservatives derived from plant waste to replace synthetic food chemicals.
2. Commercial livestock operators should be incentivized through government subsidies to replace synthetic growth-promoting antibiotics with functional feed additives made from polyphenol-rich agricultural waste.
3. Agricultural processing companies must invest in green extraction technologies, such as ultrasound-assisted extraction, to scale up the commercial production of these bioactive compounds efficiently.

REFERENCES

1. Walsh, T.R. (2018). A one-health approach to antimicrobial resistance. *Nature Microbiology*, 3, 854-855. DOI: 10.1038/s41564-018-0208-5
2. Zalewska, M., Błażejewska, A., Czapko, A., & Popowska, M. (2021). Antibiotics and Antibiotic Resistance Genes in Animal Manure - Consequences of Its Application in Agriculture. *Frontiers in Microbiology*, 12. DOI: 10.3389/fmicb.2021.610656
3. Di Maro, M., Gargiulo, L., Gomez d'Ayala, G., & Duraccio, D. (2024). Exploring Antimicrobial Compounds from Agri-Food Wastes for Sustainable Applications. *International Journal of Molecular Sciences*, 25(23), 13171. DOI: 10.3390/ijms252313171
4. Bouarab-Chibane, L., Forquet, V., Lantéri, P., et al. (2019). Antibacterial Properties of Polyphenols: Characterization and QSAR Models. *Frontiers in Microbiology*, 10, 829. DOI: 10.3389/fmicb.2019.00829
5. Ullah, H., Hussain, Y., Santarcangelo, C., et al. (2022). Natural Polyphenols for the Preservation of Meat and Dairy Products. *Molecules*, 27(6), 1906. DOI: 10.3390/molecules27061906
6. Chemat, F., Rombaut, N., Sicaire, A.G., et al. (2017). Ultrasound assisted extraction of food and natural products. Mechanisms, techniques, combinations, protocols and applications. A review. *Ultrasonics Sonochemistry*, 34, 540-560. DOI: 10.1016/j.ultsonch.2016.06.035
7. Panzella, L., Moccia, F., Nasti, R., Marzorati, S., Verotta, L., & Napolitano, A. (2020). Bioactive phenolic compounds from agri-food wastes: An update on green and sustainable extraction methodologies. *Frontiers in Nutrition*, 7, 60. DOI: 10.3389/fnut.2020.00060