RESEARCH PAPER

Phytochemical and Biological Evaluation of Fruit and Vegetable Waste

Sriramani M., Sandhiya G., Janani P.R., Harikrishnaraj R., Nirmala M., Swetha M.S., Rasika G., Gayathri S., Preethi S., Deepika T., Sanofar B

Department of Microbiology, Padmavani Arts & Science College for Women, (Autonomous), Salem – 11

Corresponding author: *jananimicrobiology@gmail.com*

Abstract

The present study investigates the phytochemical composition and biological activities of fruit and vegetable waste peels, highlighting their potential as sustainable sources of natural bioactive compounds. Peels from mango, orange, banana, pomegranate, potato, and tomato were collected, cleaned, dried, powdered, and extracted separately using ethanol and hexane. The prepared extracts were subjected to qualitative phytochemical screening to identify major secondary metabolites. Biochemical characterization was carried out using Fourier Transform Infrared Spectroscopy (FT-IR) and Gas Chromatography–Mass Spectrometry (GC–MS) to characterize functional groups and identify bioactive compounds present in the extracts. The antibacterial activity of the extracts was evaluated against selected bacterial strains using the agar well diffusion method. Antioxidant activity was assessed using the DPPH radical scavenging assay, and the anti-larval activity of the extracts was evaluated against mosquito larvae by recording larval mortality after exposure. Overall, the study evaluates the phytochemical constituents and antibacterial, antioxidant, and anti-larval activities of fruit and vegetable waste extracts, supporting their potential value for the utilization and valorization of waste-derived bioactive compounds.

Keywords: Antibacterial activity, Antioxidant activity, Bioactive compounds, Fruit and vegetable waste peels, Phytochemicals

How to cite this article: Sriramani M, Sandhiya G, Janani PR, Harikrishnaraj R, Nirmala M, Swetha MS, Rasika G, Gayathri S, Preethi S, Deepika T, Sanofar B., Phytochemical and Biological Evaluation of Fruit and Vegetable Waste. Int J Drug Deliv Technol. 2026;16(88s): 878-888; DOI: 10.25258/ijddt.16.88s.89

Source of support: XX

Conflict of interest: XX

Introduction

Plants have long been recognized as one of the most valuable and affordable sources of therapeutic agents **(Jhumur Banerjee *et al.*, 2017)**. Their rich diversity of secondary metabolites—such as phenols, flavonoids, alkaloids, saponins, tannins, and glycosides—forms the basis of many traditional and modern medicines **(Hossam S. El-Beltagi *et al.*, 2022)**. In the human diet, fruits and vegetables play an essential role by supplying vitamins, minerals, and phytonutrients required for maintaining health, preventing diseases, and supporting physiological functions **(Swagata Biswas *et al.*, 2021)**. However, during harvesting, processing, transportation, storage, and consumption, a significant portion of fruits and vegetables is discarded in the form of peels, rinds, seeds, pomace, and other residues. Although commonly treated as waste, these materials are actually rich reservoirs of bioactive phytochemicals with substantial medicinal, nutritional, and industrial value **(Caterina Russo *et al.*, 2021; Jhumur Banerjee *et al.*, 2017)**.

Fruit and vegetable wastes are often overlooked despite containing higher concentrations of secondary metabolites than the edible portions **(Caterina Russo *et al.*, 2021; Anjali Kumari Sah *et al.*, 2025)**. Numerous studies have revealed that compounds such as phenolics, flavonoids, tannins, glycosides, carotenoids, and alkaloids are abundant in the discarded peels of pomegranate, orange, mango, banana, and other fruits, as well as in vegetable residues like tomato, potato, carrot, and onion skins **(Asma Adan *et al.*, 2020; Swagata Biswas *et al.*, 2021)**. These compounds serve as natural defense chemicals in plants and exhibit strong pharmacological properties including antioxidant, antibacterial, and anti-larvicidal activities **(Jefrillah Jebaseelan *et al.*, 2025; Subrata Mallick *et al.*, 2016)**.

Due to this diverse bioactivity, phytochemicals obtained from waste materials have received increasing attention in recent years, particularly as sustainable, cost-effective, and eco-friendly alternatives to synthetic drugs and chemical additives **(Caterina Russo *et al.*, 2021; Jhumur Banerjee *et al.*, 2017).**

**Author for Correspondence: jananimicrobiology@gmail.com*

Among these biological activities, antibacterial properties of fruit and vegetable waste extracts have become highly relevant in the context of rising antimicrobial resistance **(Muhammad Saleem *et al.*, 2023; Heena Bajaj *et al.*, 2024).** Pathogens including *Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, and Klebsiella pneumoniae* have developed resistance to multiple antibiotics, resulting in widespread clinical challenges. Extracts derived from mango peel, pomegranate rind, citrus waste, and tomato residues have demonstrated broad-spectrum antimicrobial activity due to their rich content of phenolic acids, tannins, flavonoids, and alkaloids **(Anjali Kumari Sah *et al.*, 2025; Muhammad Saleem *et al.*, 2023; Mohamed A. Salem *et al.*, 2023).** These phytochemicals inhibit bacterial growth through mechanisms such as disruption of cell wall integrity, alteration of membrane permeability, inhibition of protein and nucleic acid synthesis, and prevention of biofilm formation **(Arti Pandey *et al.*, 2018).** While Gram-positive bacteria are generally more susceptible due to their simpler cell wall structure, several fruit- and vegetable-based extracts have also proven effective against Gram-negative strains, suggesting their potential role as natural antimicrobial agents **(Li Fu *et al.*, 2016; Swagata Biswas *et al.*, 2021).**

Factors such as solvent polarity, extraction duration, temperature, and storage conditions significantly influence antibacterial potency, highlighting the importance of optimized and standardized extraction methods **(Muhammad Saleem *et al.*, 2023; Roudaina Abdel Samad *et al.*, 2023).**

Another major medicinal property associated with fruit and vegetable waste is their strong antioxidant potential **(Anjali Kumari Sah *et al.*, 2025; Caterina Russo *et al.*, 2021).** Oxidative stress, caused by an excess of reactive oxygen species (ROS), leads to the damage of cellular lipids, proteins, and DNA. Persistent oxidative stress promotes chronic diseases like cancer, cardiovascular disorders, diabetes, aging, inflammation, and neurodegenerative conditions such as Alzheimer's and Parkinson's disease. Phytochemicals such as polyphenols, flavonoids, carotenoids, anthocyanins, and vitamin-rich compounds from orange peels, carrot waste, mango peel, grape skin, and pomegranate rind exhibit exceptional antioxidant activity **(Tingjing Zhang *et al.*, 2016; Li Fu *et al.*, 2016; Swagata Biswas *et al.*, 2021).**

Standard assays such as DPPH radical scavenging and FRAP (Ferric Reducing Antioxidant Power) have repeatedly confirmed their ability to neutralize free radicals, donate hydrogen atoms or electrons, chelate metal ions, and enhance endogenous antioxidant enzymes including superoxide dismutase (SOD) and catalase **(Li Fu *et al.*, 2016; Hossam S. El-Beltagi *et al.*, 2022).** Unlike synthetic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT), natural antioxidants from plant waste are biodegradable, non-toxic, and environmentally compatible, making them attractive for use in pharmaceuticals, nutraceuticals, and cosmetic formulations **(Caterina Russo *et al.*, 2021; Jhumur Banerjee *et al.*, 2017).**

Phytochemical screening is therefore an essential tool for assessing the medicinal significance of fruit and vegetable waste **(Anjali Kumari Sah *et al.*, 2025; Mohamed A. Salem *et al.*, 2023).**

Qualitative tests for flavonoids, tannins, saponins, alkaloids, terpenoids, and phenolic compounds help determine the presence and relative abundance of secondary metabolites **(Asma Adan *et al.*, 2020; Niloy Das *et al.*, 2023).** These phytochemicals are responsible for most of the biological effects, including radical scavenging, antimicrobial action, enzyme inhibition, and anti-inflammatory responses **(Hossam S. El-Beltagi *et al.*, 2022; Arti Pandey *et al.*, 2018).** By combining phytochemical profiling with advanced instrumental techniques such as UV-VIS spectroscopy, FTIR (Fourier Transform Infrared Spectroscopy), and chromatographic separation researchers can identify specific functional groups and compounds responsible for therapeutic properties **(Humaira Rizwana *et al.*, 2019; Mostafa H. Baky *et al.*, 2024; Preeti Singh *et al.*, 2023).** Such analytical approaches pave the way for isolating active molecules and enhancing the scientific and industrial utility of fruit and vegetable waste **(Jhumur Banerjee *et al.*, 2017; Caterina Russo *et al.*, 2021).**

Valorization of waste materials aligns with global sustainability goals by reducing environmental pollution, minimizing agricultural waste, and converting low-cost byproducts into high-value bioactive ingredients **(Jhumur Banerjee *et al.*, 2017; Caterina Russo *et al.*, 2021).** The transformation of biodegradable waste into useful biological extracts contributes not only to health benefits but also to eco-friendly waste management strategies **(Jhumur Banerjee *et al.*, 2016; Maran JP *et al.*, 2015).** Industries such as pharmaceuticals, nutraceuticals, cosmetics, food packaging, and biopesticides increasingly rely on natural compounds due to concerns over chemical toxicity, regulatory restrictions, and consumer preference for organic and plant-based products **(Caterina Russo *et al.*, 2021; Jhumur Banerjee *et al.*, 2017).** Extracts from fruit and vegetable wastes can be incorporated into antimicrobial coatings, antioxidant supplements, functional foods, herbal medicines, skincare formulations, and biodegradable films **(Swagata Biswas *et al.*, 2021; Mohamed A. Salem *et al.*, 2023).**

Given the medicinal, economic, and environmental importance of these materials, it is crucial to explore the phytochemical richness and biological activities of fruit and vegetable waste **(Caterina Russo *et al.*, 2021; Anjali Kumari Sah *et al.*, 2025).** The present study focuses on identifying, analyzing, and evaluating the bioactive potential of selected waste materials through phytochemical tests, spectral characterization, antibacterial assays, antioxidant assays, and anti-larval experiments **(Mohamed A. Salem *et al.*, 2023; Roudaina Abdel Samad *et al.*, 2023; Jefrillah Jebaseelan *et al.*, 2025).** By examining the relationship between phytochemical constituents and

biological functions, the research aims to uncover the therapeutic significance of waste-derived compounds and promote their efficient utilization **(Jhumur Banerjee *et al.*, 2017; Tingjing Zhang *et al.*, 2016).** This approach not only contributes to drug discovery and natural product research but also supports sustainable waste valorization practices that benefit both human health and environmental conservation **(Caterina Russo *et al.*, 2021; Jhumur Banerjee *et al.*, 2017).**

Materials and methods:

2.1 Sample Collection

Waste materials, including peels, seeds, and pomace from various fruits and vegetables, were collected from different sources **(Anjali Kumari Sah *et al.*, 2025; Asma Adan *et al.*, 2020).** The collected samples were thoroughly washed with water to remove adhering dirt and other impurities. The samples were then sun-dried properly to reduce moisture content and powdered into a fine form **(Swagata Biswas *et al.*, 2021; Muhammad Saleem *et al.*, 2023).** The powdered samples were stored at 4 °C until further extraction and analysis **(Mohamed A. Salem *et al.*, 2023).**

2.2 Extraction

Approximately 40 g of the powdered sample was extracted separately using ethanol and hexane as solvents for 72 h **(Muhammad Saleem *et al.*, 2023; Mostafa H. Baky *et al.*, 2024).** After the extraction period, the extracts were filtered to remove the solid residues **(Mohamed A. Salem *et al.*, 2023).** The obtained filtrates were concentrated and stored at 4 °C until further analysis **(Roudaina Abdel Samad *et al.*, 2023).**

2.3 Phytochemical Screening

The extracts were subjected to qualitative phytochemical screening to detect the presence of major secondary metabolites **(Anjali Kumari Sah *et al.*, 2025; Asma Adan *et al.*, 2020).** The tests confirmed the presence of saponins, tannins, phenols, glycosides, flavonoids, and alkaloids in the extracts **(Niloy Das *et al.*, 2023; Mohamed A. Salem *et al.*, 2023).**

2.4 Biochemical Characterization

The extracts were characterized using FT-IR and GC-MS techniques **(R. Hemalatha *et al.*, 2016; Humaira Rizwana *et al.*, 2019).**while FT-IR analysis was performed to detect the functional groups associated with key secondary metabolites **(Humaira Rizwana *et al.*, 2019).**GC–MS was used to identify the major bioactive compounds present in the extracts **(Mostafa H. Baky *et al.*, 2024; Preeti Singh *et al.*, 2023)**.

2.5 Antibacterial Activity

The antibacterial activity of the extracts was evaluated against selected bacterial strains, including *Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Streptococcus pyogenes,* and *Bacillus cereus*, using the agar well diffusion method **(Anjali Kumari Sah *et al*., 2025; Li Fu *et al*., 2016)**. The extracts were tested for their ability to inhibit bacterial growth, and the antibacterial activity was determined by measuring the zones of inhibition after 24 h **(Heena Bajaj *et al*., 2024; Swagata Biswas *et al*., 2021)**.

2.6 Antioxidant Activity

The antioxidant activity of the extracts was evaluated using the DPPH radical scavenging assay **(Li Fu *et al.*, 2016; Tingjing Zhang *et al.*, 2016).** The absorbance of the reaction mixture was measured at 517 nm, and the percentage inhibition was calculated **(Hossam S. El-Beltagi *et al.*, 2022).** The IC_{50} value was also determined to evaluate the antioxidant activity of the extracts **(Anjali Kumari Sah *et al.*, 2025).**

2.7 Anti-Larval Activity

The anti-larval activity of the extracts was evaluated against mosquito larvae **(Subrata Mallick *et al.*, 2016; Niloy Das *et al.*, 2023).** The extracts were tested at the selected concentrations, and the mortality of the larvae was recorded after 24 h of exposure **(Jefrillah Jebaseelan *et al.*, 2025; Senthilkumar P. *et al.*, 2025).**

3. Results

3.1 Sample Collection

Fruit and vegetable waste, including peels, seeds, pulp, and pomace, was collected from markets, homes, and juice shops to obtain a variety of samples. The collected waste materials were used for further extraction and analysis.

3.2 Extraction

Approximately 40 g of dried powder was extracted separately using hexane (non-polar) and ethanol (polar) as solvents by soaking for 72 h. Following extraction, the extracts were filtered to remove the solid residues and were subsequently concentrated for further analysis.

3.3 Phytochemical Analysis

Phytochemical analysis was performed to detect the presence of alkaloids, phenols, flavonoids, tannins, saponins, and glycosides. Various standardized qualitative chemical tests were used, which produced observable changes such as specific colour reactions or precipitate formation.

Test	Hexane	Ethanol
Saponins	Positive	Negative

Tannins	No colour change	Positive
Phenols	No colour change	Negative
Glycosides	Positive	Negative
Alakaloids	Positive	Negative
Flavonoids	Positive	Positive

Table 1.Phytochemical Analysis

3.4 Biochemical Characteristics

I. FT-IR Analysis

FT-IR analysis confirmed the presence of functional groups such as –OH, C=O, –NH, C–H, and C=C, indicating the presence of compounds such as phenols, flavonoids, glycosides, alkaloids, and saponins

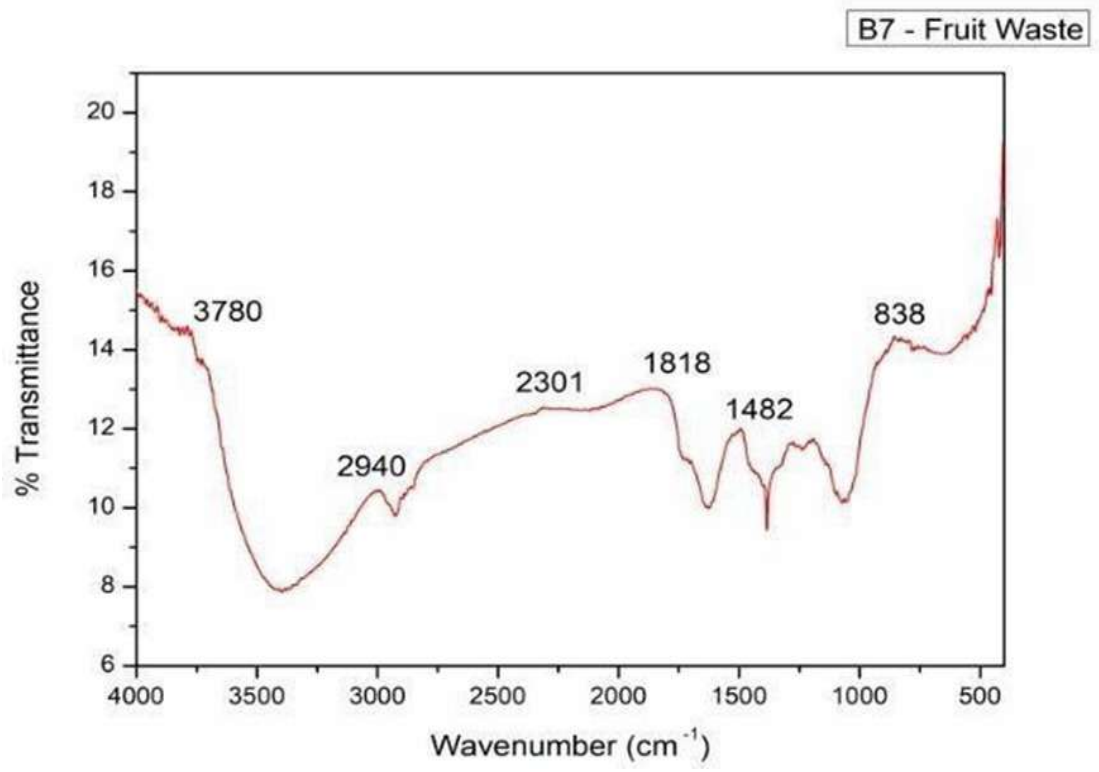


Fig: 1 FTIR Analysis

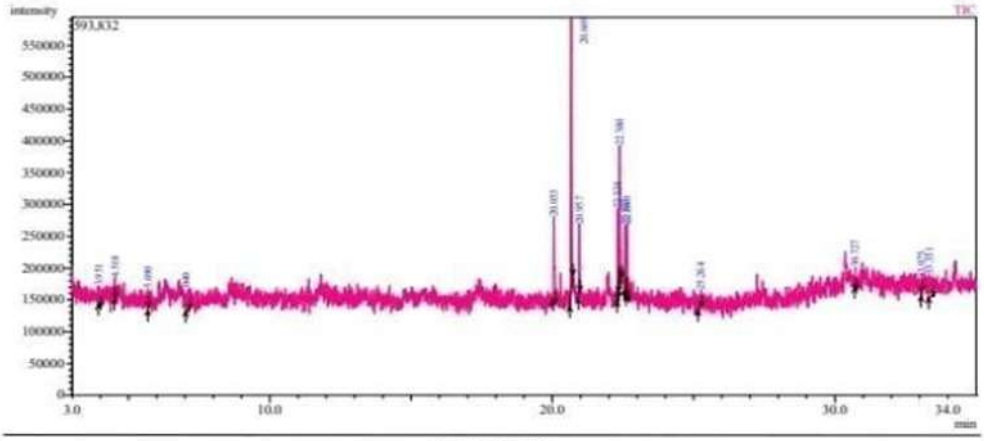
II. GC–MS Analysis

GC–MS analysis revealed hexadecanoic acid and its ethyl ester as the major identified compounds in the extract. Both compounds occurred in the highest relative amounts among the detected constituents. Their abundance suggests that they are important components of the extract and may contribute to its observed biological activity. Overall, the GC–MS profile confirms the presence of these compounds as major constituents of the extract.

CIMF-PERIYAR UNIVERSITY
GCMS (FUNDED BY RUSA)

Sample Information

Analyzed by	: Admin
Analyzed	: 10/7/2025 6:17:21 PM
Sample Name	: B7-E
Sample ID	: B7-E
Injection Volume	: 1.00uL
$EndIf$Data File	: D:\GCMS DATA\2025\OCTOBER\PADMAVANI\B7-E.qgd
Modified by	: Admin
Modified	: 10/7/2025 6:52:21 PM



Peak Report TIC

Peak#	R.Time	Area	Area%	Height	Height%	Name
1	3.951	79831	2.40	30075	2.01	
2	4.518	28855	0.87	32854	2.19	
3	5.690	24418	0.73	31954	2.13	
4	7.040	151444	4.56	26990	1.80	
5	20.053	285202	8.58	132482	8.85	Lidocaine
6	20.669	907987	27.32	429487	28.69	HEXADECANOIC ACID
7	20.957	168364	5.07	110596	7.39	HEXADECANOIC ACID, ETHYL ESTER
8	22.324	299496	9.01	137007	9.15	Pinolenic acid
9	22.380	525800	15.82	222544	14.87	Hexadecenoic acid, Z-11-
10	22.583	234326	7.05	105297	7.03	Linoleic acid ethyl ester
11	22.640	243820	7.34	115287	7.70	7-Tetradecenal, (Z)-
12	25.264	70729	2.13	26264	1.75	
13	30.727	43999	1.32	32976	2.20	5-Nitro-2,3-dimethyl-1,7-dimethyleneindole
14	33.075	36691	1.10	25803	1.72	1-[3,3-Dimethyl-2-(3-methyl-buta-1,3-dienyl)-cyclope
15	33.351	222844	6.70	37254	2.49	Glutaric acid, 2-(2-methyl-5-nitroimidazol-1-yl)ethyl o
		3323806	100.00	1496870	100.00	

Library

Hit#:2 Entry:183104 Library:WILEY8.LIB
SI:90 Formula:C16H32O2 CAS:57-10-3 MolWeight:256 RetIndex:0
CompName:HEXADECANOIC ACID $$ HEXADECANOATE $$ PALMITATE $$ PALMITIC ACID $$ 1-PENTADECANECARBOXYLIC ACID $$ A

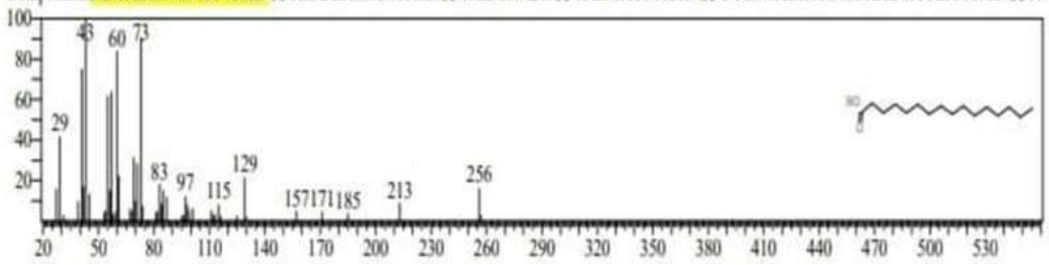


Fig: 2 GC-MS Analysis

3.5 Antibacterial Activity

The extracts showed stronger antibacterial activity at higher concentrations. The antibacterial effect increased with increasing extract concentration, as indicated by the larger zones of inhibition observed against the tested bacterial strains, including *Staphylococcus aureus, Bacillus subtilis, Escherichia coli, Streptococcus pyogenes,* and *Bacillus cereus.* Lower concentrations showed comparatively weaker inhibition. These results suggest that the extracts possess concentration-dependent antibacterial activity and may contain bioactive compounds capable of inhibiting bacterial growth.

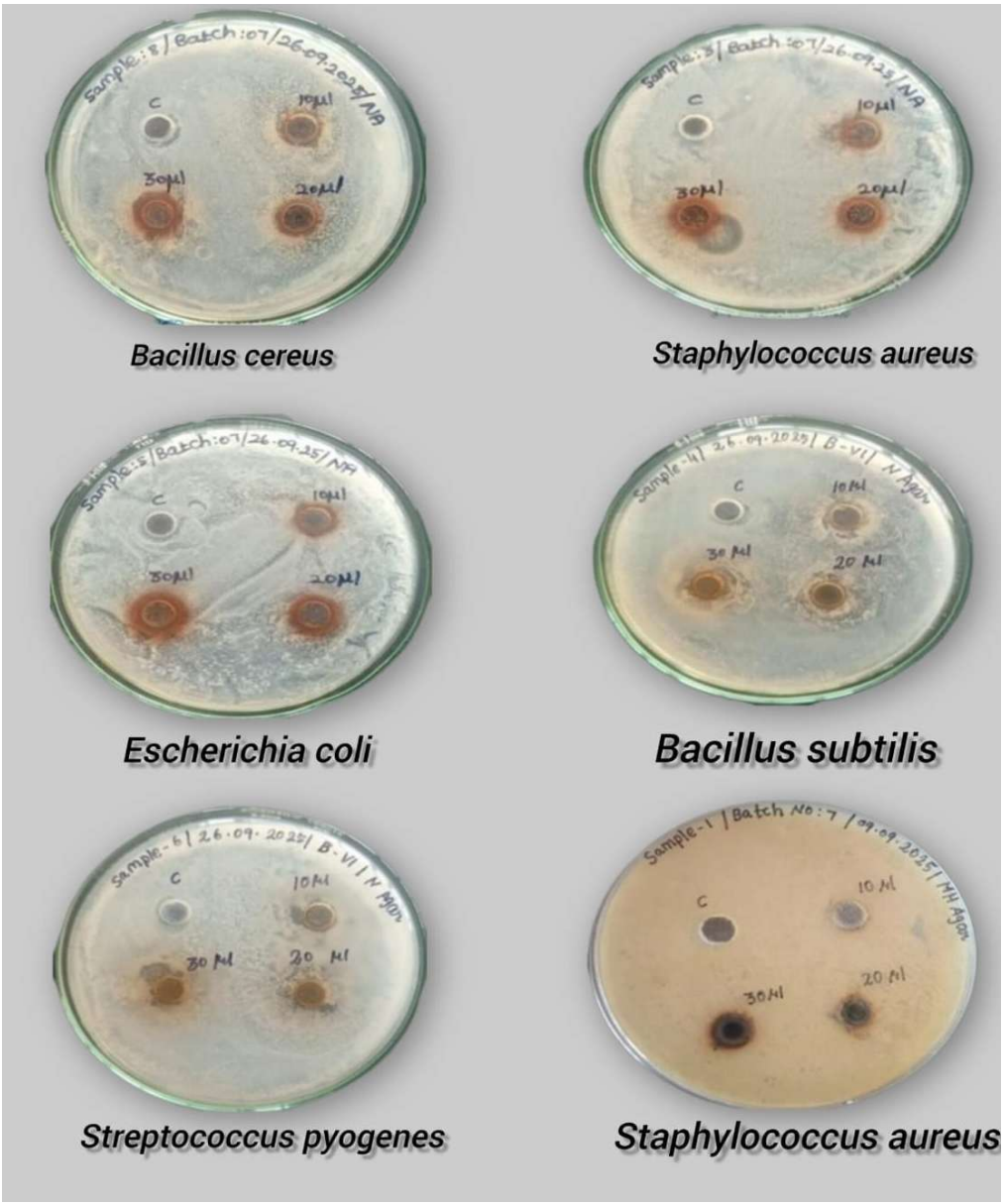


Fig :3 Antibacterial Activity

Plate	10µl	20 µl	30µl
Staphylococcusaureus(1)	0.4	0.5	0.5
Staphylococcusaureus(2)	0.5	0.7	1.0

Bacillussubtilis	0.4	0.5	0.5
Escherichiacoli	0.5	0.7	0.8
Streptococcuspyogenes	0.2	0.4	0.7
Bacilluscereus	0.5	0.6	0.8

Table 2. Antibacterial activity

3.6 Antioxidant Activity (DPPH)

The sample exhibited lower absorbance (0.946) compared with the control (1.072), indicating higher antioxidant activity.

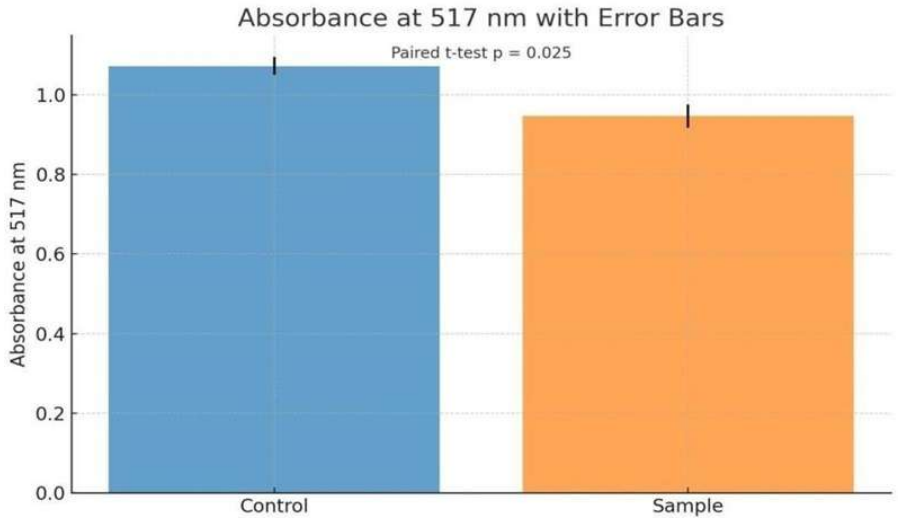


Fig: 4 Antioxidant Activity

Parameter	Mean	SD
Control	1.072	0.023
Sample	0.946	0.030

Table3.Antioxidant Activity

3.7 Anti-Larval Activity

Both 10 µL and 20 µL extract concentrations exhibited 100% larvicidal activity, resulting in complete mortality of mosquito larvae within 24 h, whereas no mortality was observed in the control group.



Fig 5.Antilarval activity

4. Discussion

The present study evaluated the biological properties of fruit and vegetable waste peels, including mango, orange, banana, pomegranate, potato, and tomato, with particular emphasis on their antibacterial, antioxidant, and larvicidal activities **(Anjali Kumari Sah *et al.*, 2025; Mohamed A. Salem *et al.*, 2023; Swagata Biswas *et al.*, 2021).** The findings indicate that these commonly discarded plant materials contain a diverse range of phytochemicals and bioactive constituents, demonstrating their potential biological significance **(Asma Adan *et al.*, 2020; Caterina Russo *et al.*, 2021; Muhammad Saleem *et al.*, 2023).** The utilization of fruit and vegetable waste as a source of bioactive compounds also highlights its potential value in waste valorization and sustainable biotechnological applications **(Jhumur Banerjee *et al.*, 2017; Caterina Russo *et al.*, 2021).**

The phytochemical analysis of the peel extracts confirmed the presence of important secondary metabolites, including alkaloids, flavonoids, phenols, tannins, saponins, and glycosides **(Anjali Kumari Sah *et al.*, 2025; Asma Adan *et al.*, 2020; Hossam S. El-Beltagi *et al.*, 2022).** These phytochemical constituents are associated with various biological activities and may contribute to the observed antibacterial, antioxidant, and larvicidal properties of the extracts **(Li Fu *et al.*, 2016; Niloy Das *et al.*, 2023; Subrata Mallick *et al.*, 2016).** The presence of multiple classes of secondary metabolites suggests that the biological activity of the extracts may be attributed to the combined effects of different phytoconstituents rather than a single compound **(Caterina Russo *et al.*, 2021; Mohamed A. Salem *et al.*, 2023).**

The extracts obtained using hexane and ethanol showed differences in their biological activities, which may be related to the polarity of the solvents and their ability to extract different classes of phytochemicals **(Muhammad Saleem *et al.*, 2023; Mostafa H. Baky *et al.*, 2024).** Ethanol extracts exhibited stronger antibacterial and antioxidant effects compared with the hexane extracts **(Anjali Kumari Sah *et al.*, 2025; Muhammad Saleem *et al.*, 2023).** This observation suggests that the ethanol solvent was effective in extracting polar bioactive constituents that may contribute to the observed biological activities **(Li Fu *et al.*, 2016; Hossam S. El-Beltagi *et al.*, 2022).** The antibacterial activity also increased at higher extract concentrations, indicating a concentration-dependent inhibitory effect on bacterial growth **(Heena Bajaj *et al.*, 2024; Syed Ali Raza Naqvi *et al.*, 2020).**

The antioxidant activity of the extracts was evaluated using the DPPH radical-scavenging assay **(Li Fu *et al.*, 2016; Tingjing Zhang *et al.*, 2016).** The sample exhibited lower absorbance compared with the control, indicating higher antioxidant activity **(Anjali Kumari Sah *et al.*, 2025).** The observed antioxidant potential may be associated with the presence of phenolic and flavonoid compounds detected during phytochemical screening **(Hossam S. El-Beltagi *et al.*, 2022; Asma Adan *et al.*, 2020).** These compounds are known to contribute to antioxidant activity through their ability to interact with free radicals **(Arti Pandey *et al.*, 2018; Syed Ali Raza Naqvi *et al.*, 2020).** The findings therefore indicate that fruit and vegetable peels can serve as potential sources of naturally occurring antioxidant constituents **(Caterina Russo *et al.*, 2021; Swagata Biswas *et al.*, 2021).**

Characterization using GC–MS and FT-IR further supported the presence of bioactive compounds and functional groups in the extracts **(Mohd Fahim *et al.*, 2019; R. Hemalatha *et al.*, 2016).** FT-IR analysis confirmed functional groups such as –OH, C=O, –NH, C–H, and C=C, which are associated with different classes of bioactive compounds, including phenols, flavonoids, glycosides, alkaloids, and saponins **(Humaira Rizwana *et al.*, 2019; Mostafa H. Baky *et al.*, 2024).** GC–MS analysis further supported the identification of major bioactive compounds present in the extracts **(Preeti Singh *et al.*, 2023; Roudaina Abdel Samad *et al.*, 2023).** These analytical findings provide additional support for the phytochemical composition of the selected fruit and

vegetable waste materials **(Anjali Kumari Sah *et al.*, 2025; Muhammad Saleem *et al.*, 2023).**

Overall, the findings demonstrate that fruit and vegetable waste peels possess notable antibacterial, antioxidant, and larvicidal properties **(Anjali Kumari Sah *et al.*, 2025; Mohamed A. Salem *et al.*, 2023; Jefrillah Jebaseelan *et al.*, 2025).** The presence of diverse phytochemicals and bioactive compounds highlights the potential of these waste materials as valuable natural resources **(Caterina Russo *et al.*, 2021; Asma Adan *et al.*, 2020).** Their biological activities may support future applications in the development of natural drugs, nutraceutical products, and eco-friendly biocontrol agents **(Swagata Biswas *et al.*, 2021; Subrata Mallick *et al.*, 2016).** Thus, the utilization of fruit and vegetable waste peels can contribute to the recovery of valuable bioactive compounds while supporting sustainable approaches to waste management and biotechnology **(Jhumur Banerjee *et al.*, 2017; Jhumur Banerjee *et al.*, 2016).**

5. Conclusion

Fruit and vegetable waste peels represent an underutilized and biologically valuable source of naturally occurring bioactive compounds. Although these materials are commonly discarded as household, agricultural, or food-processing waste, their chemical composition indicates considerable potential for biological applications. The present study demonstrated that fruit and vegetable peel extracts possess appreciable antibacterial, antioxidant, and larvicidal activities, confirming that these waste-derived materials can serve as promising sources of multifunctional bioactive agents. Among the different extraction systems evaluated, ethanol extracts exhibited comparatively greater biological effectiveness, suggesting that ethanol may facilitate the efficient recovery of a broad range of biologically active phytoconstituents from the peel matrix.

The observed biological activities can be associated with the presence of diverse phytochemical constituents, including phenolic compounds, flavonoids, tannins, alkaloids, terpenoids, glycosides, saponins, and other secondary metabolites. These compounds are known to exhibit a wide range of biological functions through different mechanisms, including microbial growth inhibition, free-radical scavenging, membrane disruption, enzyme modulation, and interference with essential cellular processes. The antioxidant potential of the extracts further indicates their ability to neutralize reactive oxygen species and reduce oxidative stress, while the antibacterial activity highlights their possible application as natural

Alternatives to conventional antimicrobial agents.Similarly, the larvicidal activity suggests that selected peel-derived compounds may have potential for environmentally compatible vector-management strategies.

The findings are particularly significant from the perspective of waste valorization and sustainable resource utilization. Converting fruit and vegetable peels into biologically active extracts provides an alternative to conventional disposal practices and simultaneously generates value from an otherwise discarded biomass. Such an approach supports the principles of the circular bioeconomy by transforming organic waste into useful bioresources with potential applications in pharmaceutical, agricultural, environmental, and biotechnological sectors. The utilization of peel-derived bioactive compounds could therefore reduce the environmental burden associated with organic waste accumulation while promoting the development of renewable and naturally derived products.

Furthermore, the multifunctional nature of these extracts provides opportunities for their incorporation into value-added products such as natural antimicrobial formulations, antioxidant-based preparations, eco-friendly agricultural inputs, and botanical larvicidal agents. However, the practical application of these extracts requires further investigation to identify and characterize the specific compounds responsible for the observed activities, determine their mechanisms of action, evaluate dose-dependent responses, and establish their safety and stability profiles. Advanced analytical approaches such as chromatographic and spectroscopic techniques may be employed to identify the major bioactive constituents and correlate their chemical composition with biological activity.

Overall, the present findings support the concept that fruit and vegetable waste peels should not be regarded merely as disposable residues but as renewable sources of biologically active compounds with considerable functional potential. Their systematic recovery, characterization, and application could contribute to sustainable waste management, natural product development, resource recovery, and green biotechnology. Further in-depth studies, including compound-level characterization, toxicity assessment, formulation development, and in vivo or field-based validation, are warranted to translate the demonstrated biological potential of these waste-derived materials into safe, effective, and commercially viable value-added products.

6. Reference

1. Anjali Kumari Sah, Kripa Pandey, Aaraju Khadka, Surjina Shrestha, Sagar Kandel, Sudip Bhandari, Era Tuladhar. 2025. Phytochemical Analysis, Antioxidant, and Antibacterial Properties of Waste Fruit Peels (Orange, Banana, Apple, and Lemon). DOI: 10.54796/njb.v13i1.387.

2. Arti Pandey, Pradeep Singh Negi. 2018. Phytochemical composition, in vitro antioxidant activity and antibacterial mechanisms of Neolamarckia cadamba fruits extracts. DOI: 10.1080/14786419.2017.1323209.

3. Asma Adan, Redemtor Awuor Ojwang, Edward Kirwa Muge, B.K. Mwanza. 2020. Phytochemical composition and essential mineral profile, antioxidant

and antimicrobial potential of unutilized parts of jackfruit. DOI: 10.26656/fr.2017.4(4).326

4. Caterina Russo, Alessandro Maugeri, Giovanni Enrico Lombardo, Laura Musumeci, Davide Barreca, Antonio Rapisarda, Santa Cirmi, Michele Navarra. 2021. The Second Life of Citrus Fruit Waste: A Valuable Source of Bioactive Compounds. DOI: 10.3390/molecules26195991.

5. Heena Bajaj, Sonia Kaushal, Anu Kalia, Vishaldeep Kaur. 2024. Unraveling the chemical composition, antibacterial, antioxidant and cytotoxic potential of Citrus reticulata Blanco dropped fruit extracts. DOI: 10.1016/j.bcab.2024.103104.

6. Hossam S. El-Beltagi, Abeer E. El-Ansary, Mai A. Mostafa, Teba A. Kamel, Gehan Safwat. 2022. Evaluation of the Phytochemical, Antioxidant, Antibacterial and Anticancer Activity of Prunus domestica Fruit. DOI: 10.15835/nbha47111402.

7. Humaira Rizwana, Fatimah Al Otibi, Nouf Al-Malki. 2019. Chemical Composition, FTIR Studies and Antibacterial Activity of Passiflora edulis f. edulis (Fruit). DOI: 10.22207/JPAM.13.4.64.

8. Jefrillah Jebaseelan, Umamaheswari Kopula Ganesh, Prince Leeban Johnwilmet, Rajalakshmi Anbalagan, Jayalakshmi Krishnan, Anand Setty Balakrishnan. 2025. Exploring the Antibacterial, Antioxidant and Larvicidal Effects against Culex quinquefasciatus of Nigella sativa Seeds and its Silver Nanoparticles. DOI: 10.1007/s11686-025-01096-x.

9. Jhumur Banerjee, R. Vijayaraghavan, Amit Arora, Douglas R. MacFarlane, Antonio F. Patti. 2016. Lemon Juice Based Extraction of Pectin from Mango Peels: Waste to Wealth by Sustainable Approaches. DOI: 10.1021/acssuschemeng.6b01342.

10. Jhumur Banerjee, Ramkrishna Singh, R. Vijayaraghavan, Douglas MacFarlane, Antonio F. Patti, Amit Arora. 2017. Bioactives from fruit processing wastes: Green approaches to valuable chemicals. DOI: 10.1016/j.foodchem.2016.12.093.

11. Li Fu, WenQing Lu, XiaoMin Zhou. 2016. Phenolic Compounds and In Vitro Antibacterial and Antioxidant Activities of Three Tropic Fruits: Persimmon, Guava, and Sweetsop. DOI: 10.1155/2016/4287461.

12. Maran JP, Swathi K, Jeevitha P, Jayalakshmi J, Ashvini G. (2015). Microwave-assisted extraction of pectic polysaccharide from waste mango peel. DOI: 10.1016/j.carbpol.2014.11.072.

13. Mohamed A. Salem, Osama G. Mohamed, Esraa M. Mosalam, Aya Ibrahim Elberri, Hend Mohamed Abdel-Bar, Mariam Hassan, Ahmed A. Al-Karmalawy, Ashootosh Tripathi, Shahira M. Ezzat, Hend E. Abo Mansour. 2023. Investigation of the phytochemical composition, antioxidant, antibacterial, anti-osteoarthritis, and wound healing activities of selected vegetable waste. DOI: 10.1038/s41598-023-38591-y.

14. Mohd Fahim, Mohammad Ibrahim, Sultan Zahiruddin, Rabea Parveen, Washim Khan, Sayeed Ahmad, Birendra Shrivastava, A.K. Shrivastava. (2019). TLC-bioautography identification and GC–MS analysis of antimicrobial and antioxidant active compounds in Musa paradisiaca L. fruit pulp essential oil. Phytochemical Analysis. DOI: 10.1002/pca.2816

15. Mostafa H. Baky, Eman M. El-Taher, Dina M. Y. El Naggar, Mostafa B. Abouelela. 2024. Phytochemical investigation of the n-hexane-extracted oil from four umbelliferous vegetables using GC/MS analysis in the context of antibacterial activity. DOI: 10.1038/s41598-024-60631-4.

16. Muhammad Saleem, Arjumand Iqbal Durani, Asnuzilawati Asari, Mahmood Ahmed, Muhammad Ahmad, Numan Yousaf, Muhammad Muddassar. (2023). Investigation of antioxidant and antibacterial effects of citrus fruits peels extracts using different extracting agents: Phytochemical analysis with in silico studies. Heliyon. DOI: 10.1016/j.heliyon.2023.e15433

17. Niloy Das, Sonali Saha, Utpal Singha Roy. (2023). Studies on Phytochemical Analysis, Antioxidant, Antibacterial and Larvicidal Properties of the Acacia nilotica Fruit Extracts. Mapana Journal of Sciences. DOI: 10.12723/mjs.63.3

18. Preeti Singh, Jyotika Dhankhar, Rajeev Kumar Kapoor, Asha Sharma. (2023). A comparative study on GC–MS analysis and antimicrobial activity of bioactive compounds present in aerial parts (leaf and fruit) of Ficus benghalensis L. Journal of Applied and Natural Science. DOI: 10.31018/jans.v15i2.4618

19. R. Hemalatha, P. Nivetha, C. Mohanapriya, G. Sharmila, C. Muthukumaran, M. Gopinath. 2016. Phytochemical composition, GC-MS analysis, in vitro antioxidant and antibacterial potential of clove flower bud (Eugenia caryophyllus) methanolic extract. DOI: 10.1007/s13205-016-0398-x.

20. Roudaina Abdel Samad, Nada El Darra, Alissar Al Khatib, Hadi Abou Chacra, Adla Jammoul, Karim Raafat. (2023). Novel dual-function GC/MS aided ultrasound-assisted hydrodistillation for the valorization of Citrus sinensis by-products: phytochemical analysis and anti-bacterial activities. Scientific Reports. DOI: 10.1038/s41598-023-38130-9

21. Senthilkumar P., Thavamurugan S., Annamalai A., Kolandhasamy P., Muthunarayanan V., Selvaraj N., Azhagiyamanavalan L., Vinayagam R. (2025). Exploration of Secondary Metabolites in Platostoma menthoides (L.) Using Ethyl Acetate Extract and Its

Antibacterial, Antioxidant, and Larvicidal Activities. Toxics. DOI: 10.3390/toxics13010051

22. Subrata Mallick, Utpal Adhikari, Anjali Rawani, Goutam Chandra. 2016. Phytochemical Analyses and Larvicidal Potentiality of Fruit Peel Extracts of Citrus limetta against Filarial Vector Culex quinquefasciatus. DOI: 10.5376/jmr.2016.06.0022.

23. Swagata Biswas, Pranabesh Ghosh, Alolika Dutta, Maitrayee Biswas, Sirshendu Chatterjee. 2021. Comparative Analysis of Nutritional Constituents, Antioxidant and Antimicrobial Activities of Some Common Vegetable Wastes. DOI: 10.12944/CRNFSJ.9.1.07.

24. Syed Ali Raza Naqvi, Shafaqat Ali, Tauqir A. Sherazi, Atta-Ul Haq, Muhammad Saeed, Muhammad Sulman, Muhammad Rizwan, Saad Alkahtani, Mohamed M. Abdel-Daim. 2020. Antioxidant, Antibacterial, and Anticancer Activities of Bitter Gourd Fruit Extracts at Three Different Cultivation Stages. DOI: 10.1155/2020/7394751.

25. Tingjing Zhang, Xinyuan Wei, Zhuang Miao, Hamada Hassan, Yunbo Song, Mingtao Fan. 2016. Screening for antioxidant and antibacterial activities of phenolics from Golden Delicious apple pomace. DOI: 10.1186/s13065-016-0195-7.

26. Xinyu Yuan, Tao Wang, Liping Sun, Zhu Qiao, Hongyu Pan, Yujie Zhong, Yongliang Zhuang. 2024. Recent advances of fermented fruits: A review on strains, fermentation strategies, and functional act.DOi.org/10.1016/j.fochx.2024.101482.