Degradable Cutlery Using Renewable Resources: An Alternative Source for Plastic

Jeba Mettilda J[1], Priya R Iyer[2]
[1,2]*PG and Research Department of Biotechnology*
Women's Christian College
Chennai- 600006
(An Autonomous Institution Affiliated to the University of Madras)

***Abstract*—Plastic waste from single-use cutlery is a major environmental concern due to its persistence and ecological hazards. This study reports the development of biodegradable cutlery from agricultural waste groundnut shell, corn husk, watermelon rind, orange peel, lemon peel, and flaxseed using natural binders. Raw materials were dried, powdered, and subjected to aqueous and ethanolic extraction for phytochemical analysis, confirming the presence of phenols, flavonoids, tannins, saponins, and glycosides. Cutlery was molded, baked, and characterized through FTIR, SEM, tensile, hardness, moisture, and water absorption tests. FTIR confirmed lignocellulosic and bioactive functional groups, while SEM showed uniform fiber distribution. Biodegradability was evaluated through soil burial, followed by microbial isolation and identification of degrading species.**

Functional analysis revealed antimicrobial activity against Klebsiella pneumoniae, Staphylococcus aureus, and Candida albicans, strong antioxidant capacity, and anti-inflammatory effects. The developed cutlery exhibited good mechanical strength, effective biodegradation, and functional bioactivity, highlighting its potential as an eco-friendly alternative to plastic utensils and promoting agricultural waste valorization.

I. INTRODUCTION

Plastic pollution from single-use products has become a critical global environmental challenge, with conventional petroleum-based plastics persisting for hundreds of years and releasing toxic microplastics into ecosystems (Thompson et al., 2021; Smith & Johnson, 2020). In the food service industry alone, billions of plastic utensils are discarded annually, contributing significantly to landfill accumulation and marine debris (Brown et al., 2019; Davis & Lee, 2022). Biodegradable cutlery, made from renewable plant-based materials such as cornstarch, bamboo, and agricultural residues, offers a sustainable alternative by decomposing naturally
under suitable environmental conditions (Rujnić-Sokele & Pilipović, 2017; Lee & Chen, 2022). However, challenges such as higher production costs, limited durability, and the need for proper composting infrastructure hinder large-scale adoption (Mazhandu et al., 2023). This study focuses on developing biodegradable cutlery from agricultural waste including groundnut shell, corn husk, watermelon rind, orange peel, lemon peel, and flaxseed leveraging their lignocellulosic composition and bioactive compounds to achieve durable, eco- friendly products. The work also investigates their physicochemical properties, biodegradability, and functional activities, promoting agricultural waste valorization within a circular economy framework.

II. MATERIALS AND METHODOLOGY

Materials: Groundnut shell, corn husk, watermelon rind, orange peel, lemon peel, flaxseed; ethanol; distilled water.
Glassware: Conical flasks, beakers, glass pipettes, micropipettes, Petri dishes, test tubes, crucibles, molds. Equipment: Grinding machine, hot air oven, weighing balance.

Methodology Collection and extraction of sample extract
Sample Collection and Preparation: Raw agricultural wastes were collected from local markets, chopped, sun- dried for 5 days, and ground into fine powder

Phytochemical tests Qualitative analysis

- Test for tannins done by ferric chloride test
- Test for flavonoids done by ferric chloride test
- Test for alkaloids by Wagner's test
- Test for Saponins by foam test
- Test for Phenol by Ferric chloride test
- Test for Carbohydrates by Molisch's test
- Test for Protein by Nitric acid test
- Test for amino acids by Ninhydrin test
- Test for Terpenoid by Salkowski test
- Test for Steroids by Liebermann-Burchard test
- Test for Glycosides
- Test for oils
- Test for resins

Quantitative analysis

- Test for alkaloid
- Test for protein
- Test for flavonoid
- Test for glycoside
- Test for phenols
- Test for amino acid
- Test for steroids
- Test for Tannins
- Test for saponins
- Test for Terpenoids
- Test for Carbohydrate Characterization of Biodegradable Cutlery

Characterization of Biodegradable Cutlery

- Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy (FTIR) was performed to identify functional groups and biomolecules present in the biodegradable cutlery. The spectra confirmed the presence of characteristic peaks corresponding to cellulose, lignin, and other bioactive compounds from the agricultural waste-based materials (Zhang et al., 2020).

- Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) (JSM-6480 LV) was used to analyze the surface morphology of the cutlery. SEM images revealed fiber distribution, porosity, and structural integrity, which are crucial for understanding the biodegradability and mechanical strength (Sharma et al., 2019).

- Tensile Strength Testing

The tensile strength of the cutlery was measured to determine its resistance to applied stress. This analysis ensured that the biodegradable cutlery possessed sufficient durability for practical usage conditions (Sharma et al., 2019)

- Hardness Testing

Hardness of the cutlery was evaluated to assess resistance against deformation and breakage. The results
confirmed the material's structural robustness and suitability for food applications (Zhang et al., 2020).

- Absorption Test

The water absorption capacity of the biodegradable cutlery was determined by immersing samples in distilled water for varying time intervals (10 min, 30 min, 1 hr, 3 hr, and 24 hr). Weight gain was recorded, and absorption percentage was calculated. This test assessed the resistance of the cutlery to liquid penetration under real-world food handling conditions.

- Moisture Content

Moisture content was evaluated using oven drying at 110°C. The percentage of weight loss was calculated to determine the cutlery's stability and shelf life. Lower moisture content indicated higher stability and reduced risk of microbial growth during storage.

- Biodegradability Test

Biodegradability of the cutlery was studied by burying samples in garden soil at a depth of 30 cm under natural environmental conditions. Physical changes such as cracking, disintegration, and loss of structural integrity were monitored at regular intervals. The results confirmed natural degradation of the product, proving its eco-friendly nature.

- Isolation of Microorganisms

Microorganisms degrading cutlery were isolated from soil using the serial dilution and spread plate method. Soil suspensions (10^{-1}–10^{-10}) were prepared, and aliquots from higher dilutions (10^{-9} and 10^{-10}) were spread on nutrient agar plates. Plates were incubated at 30–37°C for 24 hours, and distinct colonies were selected for further characterization.

- Identification of Microorganisms

Isolated colonies were purified by repeated sub-culturing on nutrient agar. Preliminary identification was based on colony morphology and Gram staining
Biological Activity of Biodegradable Cutlery

- Antibacterial Activity

The antibacterial properties of the biodegradable cutlery were tested against Klebsiella pneumoniae and Staphylococcus aureus using the agar well diffusion method on Mueller-Hinton Agar. Distinct inhibition zones indicated strong antibacterial activity of the formulated cutlery.

- Antifungal Activity

Antifungal activity was determined against Candida albicans using Mueller Hinton Agar supplemented with ampicillin. The results confirmed antifungal potential, indicating the cutlery's ability to resist fungal contamination.

- Antioxidant Activity

The antioxidant capacity of the cutlery was assessed using the DPPH free radical scavenging assay. A reduction in DPPH absorbance confirmed the presence of bioactive compounds capable of neutralizing free radicals (Braca et al., 2001).

- Anti-inflammatory Activity

The anti-inflammatory activity of the cutlery was determined by protein denaturation assay using Bovine Serum Albumin (BSA). Inhibition of protein denaturation demonstrated significant anti-inflammatory potential when compared with the standard acetylsalicylic acid (Liu et al., 2021).

III. COLLECTION AND EXTRACTION OF SAMPLES

Groundnut shell, corn husk, and watermelon rind were collected, washed, shade dried, and ground into fine powders. Extracts were prepared using aqueous and ethanolic solvents in a 1:10 ratio and filtered through Whatman No.1 filter paper. The filtrates retained their natural colour and odour, similar to observations in earlier studies (Diem et al., 2014).

Figure 1. Groundnut shell

Figure 2. Corn husk

Figure 3. Watermelon rind

Figure 4. Powdered samples

IV. QUALITATIVE ANALYSIS

Phytochemical screening revealed the presence of important bioactive compounds including alkaloids, tannins, flavonoids, phenols, proteins, amino acids, saponins, glycosides, terpenoids, polyphenols, and resins. Oils were absent in all samples.

TEST	ETHANOL EXTRACT	AQUEOUS EXTRACT
Alkaloids	+	+
Tannins	+	+
Flavonoids	+	+
Phenols	+	+
Proteins	+	+
Amino acids	+	+
Saponins	+	+
Glycosides	+	+
Terpenoids	+	–
Carbohydrates	+	+
Oils	–	–

Table 1. Qualitative phytochemical analysis of Groundnut shell extract

TEST	ETHANOL EXTRACT	AQUEOUS EXTRACT
ALKALOIDS	+	+
PROTEINS	+	+
AMINO ACIDS	+	-_
CARBOHYDRATES	+	+
TANNINS	+	+
GLYCOSIDES	+	+
TERPENOIDS	+	+
FLAVONOIDS	+	+
STEROIDS	+	_-_
PHENOLS	+	_ -
SAPHONINS	+	+
POLYPHENOLS	+	+
QUINONES	+	-_
OILS	_	-_
RESINS	+	+

Table 2. Qualitative phytochemical analysis of Corn husk extract

TEST	ETHANOL EXTRACT	AQUEOUS EXTRACT
ALKALOIDS	+	+
PROTEINS	+	+
AMINO ACIDS	+	_
CARBOHYDRATES	+	+
TANNINS	+	+
GLYCOSIDES	+	+
TERPENOIDS	+	+
FLAVONOIDS	+	+
STEROIDS	+	_
PHENOLS	+	_
SAPHONINS	+	+
POLYPHENOLS	+	+
QUINONES	+	_
OILS	-	_
RESINS	+	+

Table 3. Qualitative phytochemical analysis of Watermelon rind extract

These findings agree with previous reports confirming that plant residues such as groundnut shells, corn husks, and watermelon rinds contain flavonoids, tannins, phenols, and glycosides (Ajali et al., 2007; Arawande et al., 2024)

V. QUANTITATIVE ANALYSIS

Quantitative estimations revealed differences in solvent extraction efficiency. Aqueous extracts showed higher carbohydrate content, while ethanolic extracts yielded higher phenols and flavonoids.

Phytoconstituents	Groundnut shell (mg/100ml)	Corn husk (mg/100ml)	Watermelon rind (mg/100ml)
Carbohydrates	12.5 (aq) / 8.3 (eth)	15.2 (aq) / 9.1 (eth)	10.4 (aq) / 6.8 (eth)
Phenols	6.9 (aq) / 10.8 (eth)	5.7 (aq) / 9.5 (eth)	7.1 (aq) / 11.2 (eth)
Flavonoids	4.8 (aq) / 7.6 (eth)	5.2 (aq) / 8.4 (eth)	4.5 (aq) / 7.1 (eth)
Tannins	2.5 (aq) / 3.1 (eth)	3.0 (aq) / 3.8 (eth)	2.2 (aq) / 2.9 (eth)

Table 4. Quantitative analysis of phytochemicals (Aq = aqueous, Eth = ethanolic)

These results confirm solvent dependency of phytoconstituent solubility, consistent with earlier findings (Do et al., 2014; Sim et al., 2012)

VI. FORMULATION OF BIODEGRADABLE CUTLERY

Powders of groundnut shell, corn husk, and watermelon rind were blended with flaxseed gel and small amounts of orange and lemon peel powder. The dough was molded and baked at 230 °C for 15 minutes. Flaxseed mucilage enhanced structural strength, in agreement with its reported natural binding capacity (Nowak et al., 2023).

Figure 5. Prepared biodegradable cutlery

VII. ABSORPTION TEST

The cutlery showed gradual increase in weight due to water absorption at different time intervals. Flaxseed gel minimized swelling, providing acceptable water resistance.

Sample	10 MIN	30 MIN	1 HOUR	3 HOUR	24 HOUR
Groundnut shell	120%	136%	140%	152%	176%
Corn husk	135%	167.9%	182%	200%	257.14%
Watermelon rind	107%	122.2%	140.7%	144.4%	192.5%

Table 5. Water absorption (%) at different time intervals

These values confirm hydrophilic nature of plant composites but acceptable resistance for practical use (Babar et al., 2024).

VIII. MOISTURE CONTENT:

SAMPLE	MOISTURE CONTENT%
Groundnut shell	10%
Corn husk	12.19%
Watermelon rind	13.33%

Table 6. Moisture content of the cutlery samples

The average moisture content of the cutlery samples was low suggesting longer shelf life and prevention of microbial spoilage (Sharma et al., 2019).

IX. SHELF LIFE:

The product remained in good condition without any contamination for more than 60 days and is still in good condition to date.

X. DEGRADATION TEST:

Soil burial is the best method for the degradation of renewable resources because it provides natural environmental conditions, including microbial activity, moisture, and temperature fluctuations, that accelerate decomposition. This method is widely used to assess the biodegradability of organic and polymeric materials. (Shah, A. A., et al.,2008)

In just over two weeks, the sample fully degraded, indicating high susceptibility to microbial or environmental breakdown. Enzymatic activity from soil microbes likely drove the process, breaking down organic components through structural weakening and biochemical decomposition. This rapid biodegradation highlights the material's potential for sustainable applications.

Figure 6. Degraded product after 2 weeks

XI. ISOLATION AND IDENTIFICATION OF MICROORAGNISM FROM THE SOIL WHICH DEGRATED THE CUTLERY:

Serial dilution was employed to reduce microbial concentration, ensuring countable colonies (30–300) for accurate quantification and isolation of dominant microbes (Ben-David et al., 2014).

Microscopic analysis revealed Gram-positive, rod-shaped bacteria under 100x oil immersion, indicating potential involvement in the biodegradation of complex plant polymers such as lignin, pectin, cellulose, and polysaccharides.

Notably, Bacillus spp., including Bacillus subtilis, have been reported to degrade lignin effectively, utilizing it as a sole carbon source (Abd-Elsalam & El-Hanafy, 2009).

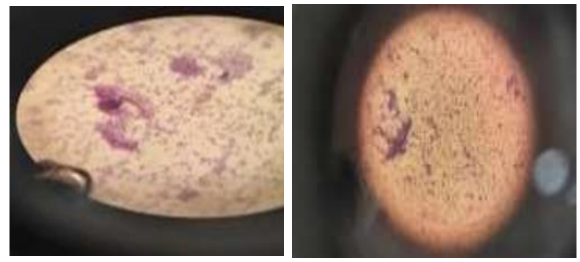

Figure 7. Microscopic view of Gram postive - purple rods were viewd under 100x oil immersion

XII. ANTIMICROBIAL TESTS

Sl. No.	ORGANISM	GROUND NUT SHELL (mm)	CORN HUSK (mm)	WATERMELON RIND (mm)
1.	Staphylococcus spp.	10	4	8
2.	Klebsiella spp.	8	9	8
3.	Candida spp.	10	-	-

Table 6. Antimicrobial Tests

The antimicrobial efficacy of agro-waste extracts was evaluated against selected pathogens. Against Staphylococcus sp., groundnut shell exhibited the highest zone of inhibition (10 mm), followed by watermelon rind (8 mm) and corn husk (4 mm). Against Klebsiella sp., corn husk showed the greatest inhibition (9 mm), with watermelon rind and groundnut shell both demonstrating moderate activity (8 mm). Against Candida sp., groundnut shell again exhibited the highest inhibition (10 mm), while inhibition values for watermelon rind and corn husk were not recorded.

These results suggest varying degrees of antimicrobial potential among the agro-waste materials tested, possibly due to differences in their bioactive compound composition. Supporting this, previous research by Athanasiadis et al. (2023) confirmed the antimicrobial activity of watermelon (Citrullus lanatus) rind against common pathogens such as Escherichia coli, Salmonella typhi, and Staphylococcus aureus

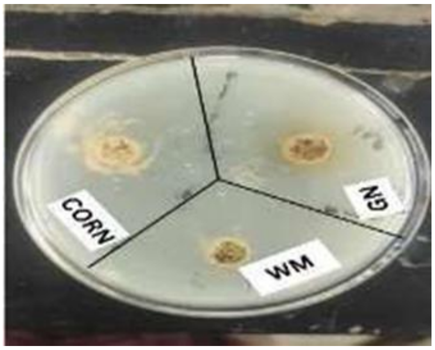

Figure.8 Staphylococcus spp.

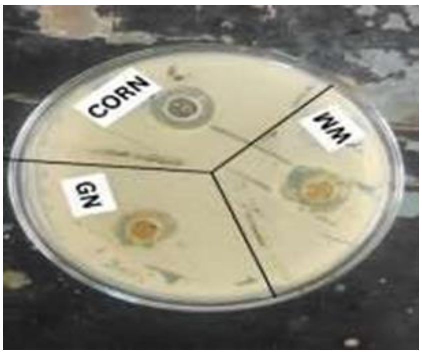

Figure.9 Klebsiella spp.

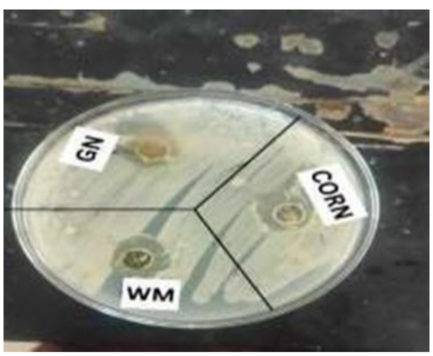

Figure.10 Candida spp

XIII. ANTIOXIDANT ACTIVITY:

% Inhibition= (Absorbance of control−Absorbance of test/Absorbance of control) ×100
Control - 0.03

SAMPLE	ANTIOXIDANT ACTIVITY
GROUNDNUT SHELL	20%
CORN HUSK	80%
WATERMELON RIND	30%

Table 7. Antioxidant activity

Corn Husk (80%) exhibited the highest antioxidant activity, likely due to its rich content of phenolic compounds, flavonoids, and tannins, which are known for their potent antioxidant properties (Ogunbusola et al., 2020).

Watermelon Rind (30%) demonstrated moderate activity, attributed to its flavonoids, vitamin C, and carotenoid content, though in lower concentrations compared to corn husk (Rao et al., 2019).

Groundnut Shell (20%) showed the lowest activity, which may be due to its lignocellulosic composition, limiting the availability of active antioxidant compounds (Ajali et al., 2007).

XIV. ANTI-INFLAMTORY ACTIVITY:

% Inhibition = 100 - [(A_1 / A_0) × 100] A_0 = 1.09

SAMPLE	ANTI INFLAMATORY
GROUNDNUT SHELL	94.5%
CORN HUSK	90%
WATERMELON RIND	99%

Table 8. Anti-inflammatory activity

The anti-inflammatory effects of bioactive compounds were assessed in plant-based materials, with findings aligning with previous studies. Watermelon Rind (99%) exhibited the highest anti-inflammatory activity, attributed to its rich content of flavonoids, carotenoids, and vitamin C, known for modulating inflammatory pathways (Rao et al., 2019). Lycopene and citrulline may also contribute to its potency.

Groundnut Shell (94.5%) showed strong anti-inflammatory activity, likely due to its phenolic compounds, tannins, and lignins (Ajali et al., 2007).

Corn Husk (90%) demonstrated slightly lower activity, but still significant, with polyphenols, flavonoids, and ferulic acid contributing to its effects (Ogunbusola et al., 2020).

XV. FTIR ANALYSIS GROUNDNUT SHELL:

The spectra showed broad O–H stretching peaks (3600–3900 cm^{-1}), which decreased after degradation, indicating a reduction in hydroxyl content. Aliphatic C–H stretching bands at 2923 cm^{-1} and 2854 cm^{-1} shifted to ~2860 cm^{-1} and 2337 cm^{-1}, suggesting oxidation of aliphatic groups. A carbonyl (C=O) peak at 1745 cm^{-1} decreased in intensity post-degradation, confirming partial breakdown of ester and carboxyl groups.

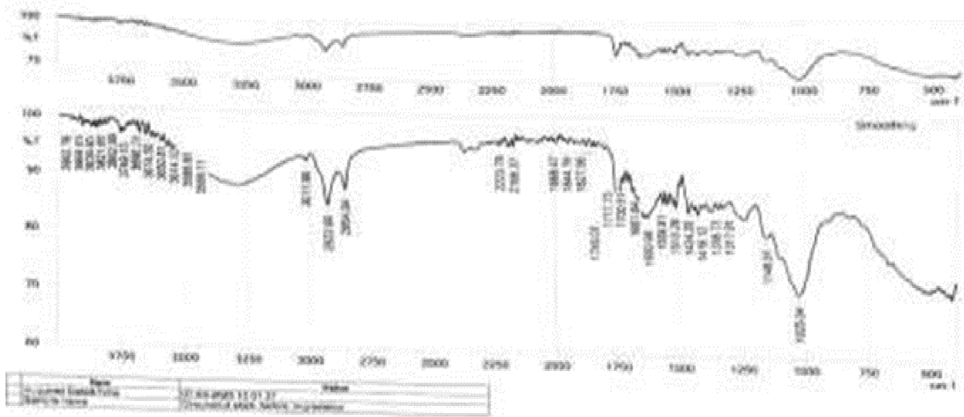

Figure. 11 FTIR for Groundnut shell sample before degradation

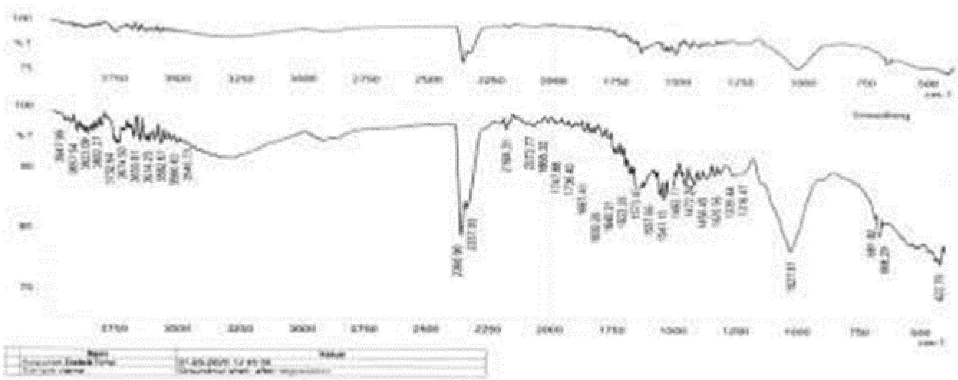

Figure.12 FTIR for Groundnut shell sample after degradation

Corn Husk:

Before degradation, O–H groups (3600–3750 cm^{-1}), aliphatic C–H stretching (2924, 2854, 3013 cm^{-1}), and carbonyl groups (1742 cm^{-1}) were prominent. After degradation, these peaks showed reduced intensity and slight shifts, indicating microbial hydrolysis and oxidation of cellulose, hemicellulose, and pectin. Lignin- associated aromatic C=C peaks (1595, 1559 cm^{-1}) also decreased, while C–O stretching bands (1031, 1157 cm^{-1}) weakened, signifying polysaccharide degradation.

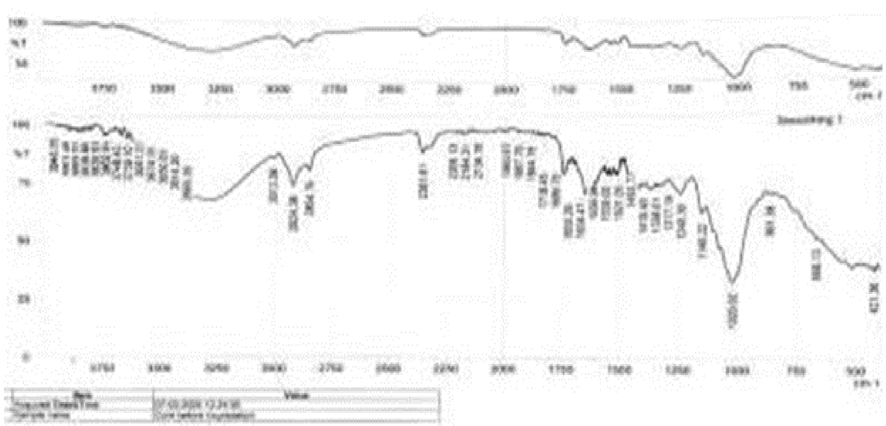

Figure 13 FTIR for Corn husk sample before degradation

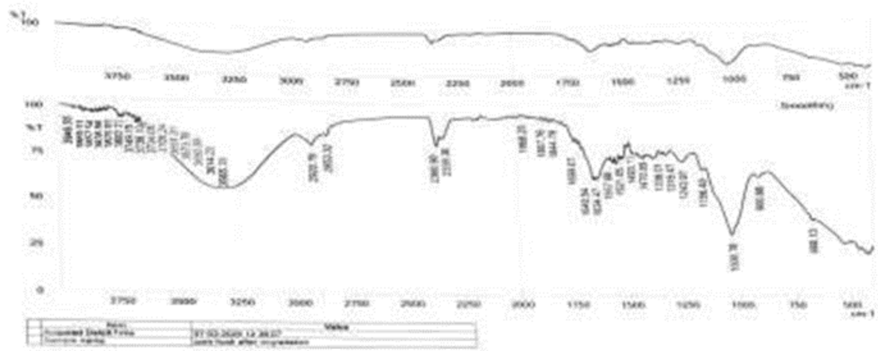

Figure 14 FTIR for Corn husk sample after degradation

Watermelon Rind:

Strong O–H stretching bands (3902–3649 cm⁻¹) were observed before degradation, which shifted with reduced intensity post-treatment, suggesting hydroxyl group breakdown. Aliphatic C–H peaks (3012, 2923, 2853 cm⁻¹) showed decreased intensity after degradation. The carbonyl peak at 1742 cm⁻¹ shifted slightly (1745 cm⁻¹), confirming ester and carboxyl group modification. Aromatic C=C bands (1595, 1559 cm⁻¹) weakened, while C– O stretching peaks (1031, 1157 cm⁻¹) reduced, indicating structural degradation of lignin and polysaccharides.

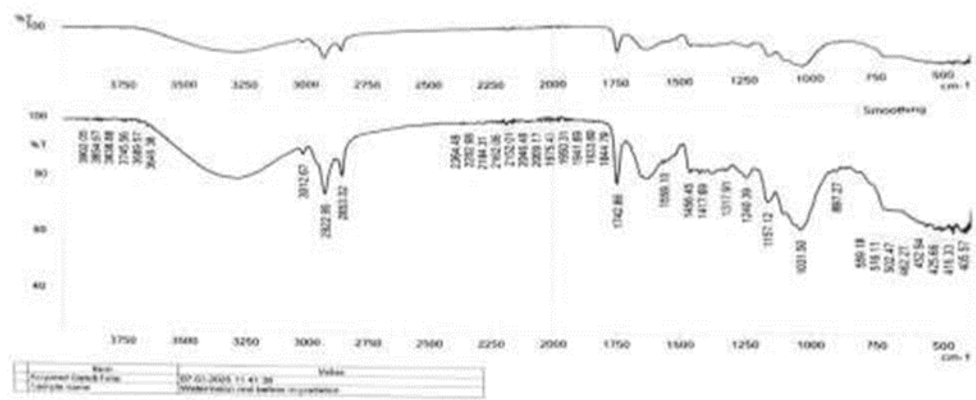

Figure 15 FTIR for Watermelon rind sample before degradation

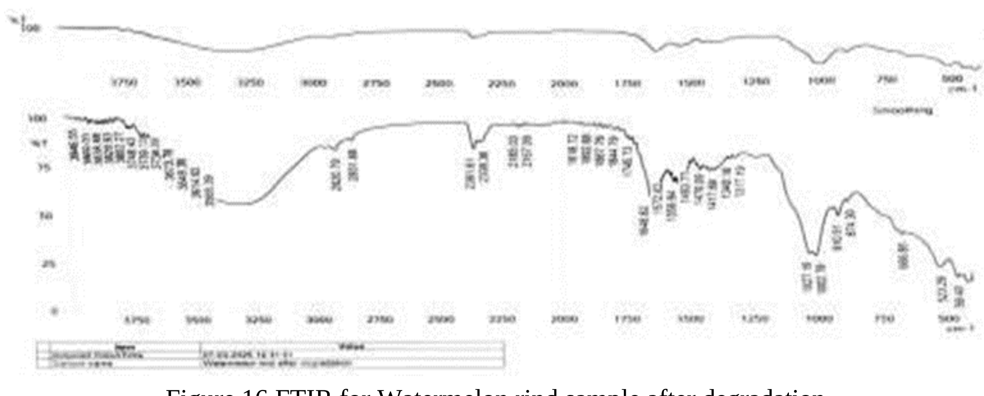

Figure 16 FTIR for Watermelon rind sample after degradation

XVI. SEM ANALYSIS

Groundnut Shell Cutlery:

SEM revealed a highly porous, rough, and fibrous structure with large voids, which enhances biodegradability but compromises mechanical strength. The non-uniform distribution of fibers indicates brittleness, suggesting the need for stronger binding or reinforcement.

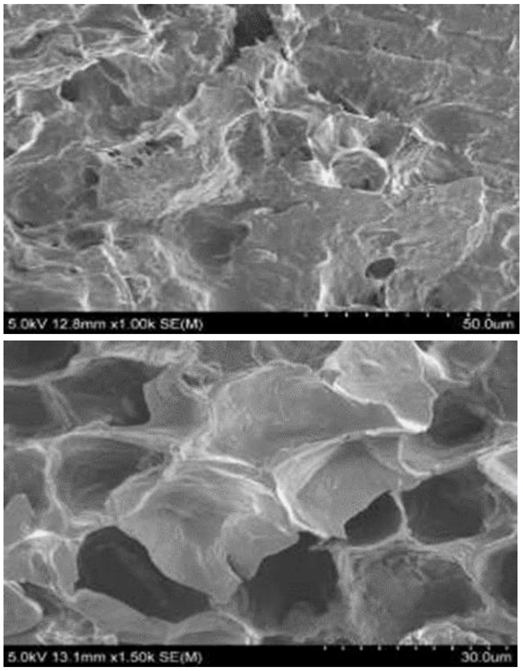

Figure 17 SEM image for Groundnut shell cutlery

Corn Husk Cutlery:

Compared to groundnut shell, corn husk cutlery exhibited a more compact and uniform morphology with moderate pores and fewer voids, contributing to improved structural integrity and durability. However, microcracks and irregular pores were observed, which may affect water resistance.

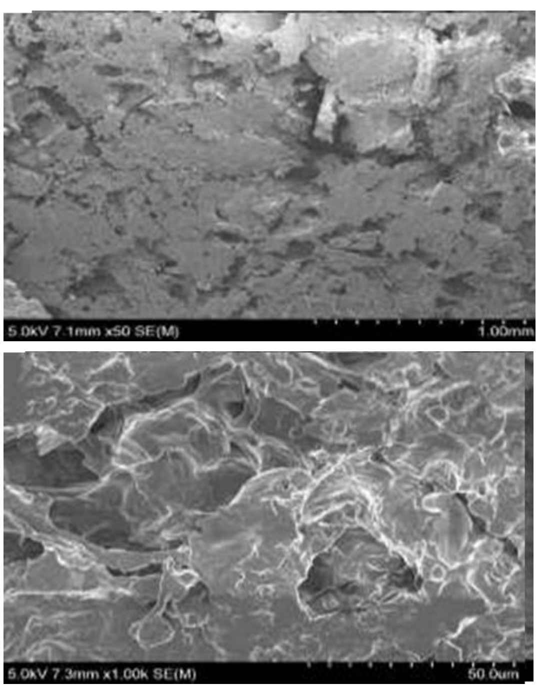

Figure 18 SEM image for Corn Husk Cutlery

Watermelon Rind Cutlery:

This sample showed the smoothest and most compact surface with minimal pores, indicating higher mechanical strength and lower water absorption. The relatively continuous morphology suggests better compaction, although some fibrous regions were still visible.

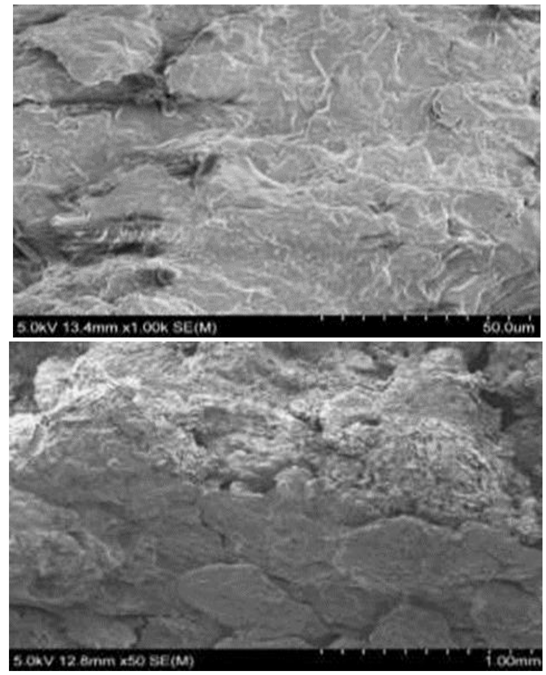

Figure 19 SEM image for Watermelon Rind Cutlery

HARDNESS TEST:

The hardness of the cutlery samples was measured using the Shore A scale, and the results showed notable differences among the materials. Groundnut shell cutlery recorded the lowest hardness values (55.5–57.0), making it the softest sample with reduced mechanical strength and higher susceptibility to deformation. Corn husk cutlery exhibited moderate hardness (75.5–77.0), indicating a balance between flexibility and durability. Watermelon rind cutlery demonstrated the highest hardness values (88.5–89.5), suggesting superior rigidity, resistance to indentation, and overall enhanced durability compared to the other samples.

XVII. CONCLUSION:

Biodegradable cutlery was developed using organic waste-derived powders such as watermelon rind, flax seed, orange peel, lemon peel, corn husk, and groundnut shell, providing an eco-friendly alternative to conventional plastic cutlery. The degradation

potential was evaluated by burying the cutlery samples in soil, followed by microbial analysis using serial dilution and spread plate techniques to assess microbial activity during degradation. Bacterial isolates from the degraded soil were identified as key contributors to the biodegradation process. Characterization of the cutlery before and after degradation was performed using Fourier Transform Infrared (FTIR) spectroscopy to detect chemical changes and Scanning Electron Microscopy (SEM) to analyze surface morphological alterations. Additionally, water absorption behavior was assessed by immersing the samples for different time intervals (10 min, 30 min, 1 h, 3 h, and 24 h) to evaluate water uptake and material stability. The findings confirm that the biodegradable cutlery decomposes efficiently in soil while maintaining sufficient structural integrity for practical applications. Further optimization of material composition and microbial treatments may accelerate the degradation rate. Overall, this eco-friendly, cost-effective, and
sustainable cutlery offers a promising alternative to plastic, contributing to reduced environmental pollution and supporting a greener future.

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