

# Microbial Magic: Transforming Hospital Tablet Wrapper Waste Through Soil-Based Biodegradation

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**Abstract** ---- Inappropriate disposal of hospital tablet wrappers, comprising aluminum plastic laminate and synthetic polymers, is an environmental risk. This paper presents a case study on microbial degradation as a sustainable solution, involving bacteria *Pseudomonas putida* and fungi *Aspergillus niger*. *Pseudomonas putida* exhibited dye degradation after 31 days, while *Aspergillus niger* facilitated the degradation of the polymer by day 49. Adaptation, degradation efficiency, and enzyme activities were considered, demonstrating the ability of soil microorganisms to degrade the tablet wrappers effectively.

**Keywords** ---- Tablet wrappers; Biodegradation; Soil microorganisms; Microbial consortium; Environmental sustainability.

## 1. INTRODUCTION

These varied sources investigate bioremediation, which refers to the scientific application of microbes that help degrade environmental toxins such as hydrocarbons found in petroleum products. The technical guidance provided by the Mississippi Department of Environmental Quality discusses biological and environmental considerations, including the role of pH levels, temperatures, and nutrient proportions, that affect the success of proposed clean-up operations. Academic studies assess the effectiveness of biosurfactants and genetically engineered bacteria in improving the efficacy of these biological processes. Lastly, mathematical studies apply reaction-diffusion equations that simulate the intricate interactions between microbial biomass and organic material inside three-dimensional soil structures [1].

Microbial biofilms represent organized microbial communities embedded within an exopolymeric matrix. Biofilm formation plays a significant role in survival by protecting extremophiles from adverse conditions such as radiation, heat, and acidic environments. Apart from offering physical protection, biofilms also allow for antibiotic resistance and nutrient acquisition through sophisticated signaling pathways including quorum sensing. The study of these processes is crucial not only for controlling pathogenic bacteria but also for leveraging beneficial microorganisms in agricultural and industrial applications. Altogether, the discussion underscores the evolutionary value of the biofilm strategy in ensuring microbial viability in challenging ecological niches [2].

The literature covers the effects of pharmaceutical packaging on the environment and the innovative techniques employed to drive the sector towards a circular economy. Whereas traditional approaches emphasized patient safety and efficacy, current efforts led by platforms such as Resourcify and VinylPlus emphasize the recovery of resources such as PVC and aluminum via online return programs and mechanical sorting. Evidence suggests that advanced recycling practices, alongside the adoption of bioplastics or pillboxes, can greatly diminish carbon emissions and minimize hospital waste.

Sabics collaboration with medical facilities through their pilot project proves the viability of reprocessing non-contaminated plastic waste into quality surgical materials. In addition, the literature highlights that user-centered design and drug compliance are inherently sustainable innovations since they minimize medical waste by making packaging more clear. Therefore, to create a sustainable healthcare supply chain, there must be cross-disciplinary collaboration in order to surpass regulatory obstacles and enhance the recycling rates of medical material globally [3].

The different reviews explore the problems in waste management and the sustainability of waste production in the healthcare industry. The report outlines how the use of single-use plastics could be detrimental to health care if the principles of a circular economy are not adhered to. Consequently, the report predicts a spike in medical plastic waste production and carbon emissions that could cost health institutions billions of dollars. The paper provides some possible solutions like micro-recycling for complex packaging and fungi to degrade medical waste.

Another area covered by research is the importance of optimisation in drug packaging and raising the recycling rate to reduce the ecological impact of pharmaceutical products. Finally, examples of organisational guidance like that from the Tata Memorial Centre illustrate how hospitals cope with the issues in question by ensuring proper waste separation and implementing electronic medical record systems to decrease paper consumption [4].

As far as scientific literature on *Pseudomonas putida* is concerned, it covers the organism's versatile metabolism and bioremediation capability. Research indicates that this bacterium can neutralise harmful pollutants, ranging from toxic elements like mercury to different organic components of oil spills. Through genetic research, scientists have discovered that the species is equipped with an unusual metabolic structure allowing it to withstand oxidative stress by altering metabolic flows and creating antioxidants in response to environmental threats. In addition to exploring the natural abilities of the bacterium, scientific texts consider its potential in synthetic biology, for instance, degrading plastics or thriving in harsh conditions. Overall, this set of readings presents *Pseudomonas* species as effective bioremediators [5].

The different reviews consider the diverse industrial and environmental applications of *Aspergillus niger*, which is an industrially useful species of the fungus black mold. Amongst the many uses, one of the applications is in the textile industry for the purpose of wastewater treatment; according to a review, it is possible for the fungus to degrade up to 90 percent of synthetic dyes through biodegradation and biosorption. In another review, the fungus is studied as an agent of bioleaching of sludge wherein it was noted that the metabolites produced by the fungus have the ability to leach out the toxic metals, and at the same time ensure that the important nutrients such as nitrogen and phosphorous remain for the benefit of agriculture. Other than this, there is mention made of genome analysis studies on this microorganism and its ability to produce citric acid due to a specific metabolic pathway.

The aim of the study is to investigate the potential of soil microorganisms to biodegrade hospital-generated tablet wrapper waste, particularly plastic and composite materials, and to evaluate the efficiency, rate, and environmental impact of this biodegradation process as a sustainable waste management strategy [6].

## II. MATERIALS AND METHODS

### *A. Sample Collection: Tablet Wrapper (Blister Pack) Waste Management*

Sample collection plays a vital role in analysing the potential of biodegradation of tablet wrapper waste generated at the hospital premises. All the materials required for sample collection, such as gloves, sterile containers or bags, forceps, and labels, need to be arranged before sample collection in order to prevent contamination of samples. Maintaining proper hygiene during sample collection is essential to prevent interference by the external microorganism population.

Wrappers from the selected hospital, pharmacy store, and landfills should be sampled as tablet wrappers (blister packs). Blister packs which are used and not used can both be sampled, but those which have been used previously should be empty of their pharmaceutical content. Gloves and sterility measures are essential when handling each individual sample.

Sample collection should involve maintaining a record of locations where samples are collected, nature of the sample collected as regards whether used or unused, and nature of exposure of the sample such as dryness, moisture, buried or partially decomposed status.

The tablets' outer wrappings will then be segregated according to their composition, for instance, plastics, aluminum, and combinations of these materials (composite packaging). It is crucial to note that proper segregation is critical for comparative purposes to determine which wrapping is most efficient when undergoing biodegradation.

### *B. Soil Sampling*

Soil samples were collected from two different regions, specifically garden soil and rhizosphere soil, to examine microbial diversity and the biodegradative capabilities of the soil. Sterile spades were used during the soil sampling to prevent contamination. Soil samples from each region were placed in clean labeled bags to ensure proper labeling and prevent contamination among samples [7].

Air drying was done on the soil samples collected to facilitate ease of analysis by reducing moisture content of the samples. This was achieved by manually removing foreign particles such as large rocks and plant material to ensure that all soil samples were uniform.

All samples were collected under hygienic conditions, as stipulated by the protocol. The samples obtained after preparation were stored properly for future analysis.

### *C. Physicochemical Analysis of Soil (Baseline)*

All the collected samples were subjected to various physicochemical and microbiological tests to ascertain their suitability for carrying out the studies in relation to their quality and nutrients. Determination of pH of soil was done using a digital pH meter and it indicates whether the soil is acidic or basic in nature and helps to know the suitability of soil for microbial activity [8]. Moisture content was determined by drying a given amount of soil sample at a particular temperature in an electric oven to find the percentage weight lost indicating the moisture present in the soil [9].

Organic carbon content was analyzed by Walkley-Black method and is a measure of the amount of organic matter present in the soil. Amount of total nitrogen content was calculated by Kjeldahl method. Available phosphorous was measured by spectrophotometry

and the content of potassium was determined by flame photometry which is the NPK content of soil important for microbial activity [9].

Soil temperature was recorded during soil collection. The number of microorganisms present in the soil was found out by estimating colony forming units (CFU/g) of soil sample. The test was carried out by serial dilution and plate counting of colonies.

#### *D. Preparation of Microbial Consortia*

Decayed organic materials like dried leaves, sticks, and partly decayed matter were obtained from areas where natural decomposition took place, that is, in compost heaps, in forests, and areas where crops are grown. These samples were collected in sterile Petri dishes or sterilized plastic bags and brought immediately to the lab for further processing [10].

Isolation of microorganisms was done through standard culture techniques. Bacteria were isolated by culturing the sample on Nutrient Agar, while fungi were cultured on Sabouraud Dextrose Agar. The plates containing the samples were incubated at suitable conditions to allow growth of microbes. Colonies of the microbes were isolated based on their morphological differences.

Possible microorganisms capable of degrading biologically were screened using conventional microbiological techniques such as staining and microscopic methods. These organisms have been known for their capabilities in breaking down organic compounds.

The microbial consortium was developed through the mixture of some selected bacteria and fungi in an appropriate sterile liquid broth medium. The mixture was incubated under suitable conditions that facilitated the development of the microbial consortium. This microbial consortium was then utilized for studying the degradation process of tablet wrapper wastes.

#### *E. Setup of Biodegradation Experiments*

In order to determine how efficiently soil-based biodegradation of tablet wrappers can occur, three different sets were prepared under laboratory conditions with each set used for determining how efficiently microbial degradation occurred when either natural or enriched microbial population acted upon the tablets [11].

##### *Set A – Natural Soil System*

For this setup, garden soil was filled in trays or pots. Around 10-20 tablet wrappers were buried in the soil at a depth of 5 cm. The soil moisture was maintained at approximately 60%. This setup was created in order to determine how efficiently the soil microflora would degrade the tablet wrapper.

##### *Set B – Microbiologically Enriched Soil System*

In the setup where soil was microbiologically enriched with microbial consortium, containing highly efficient degraders such as *Pseudomonas* and *Aspergillus niger*, 10% (v/w) of soil was added. Again, 10-20 tablet wrappers were buried in the soil and buried at a similar depth as set A.

*Set C: Controls Design*

Controlled tests were set up by using sterilized soil and sterile tablet wrappers with no microbial introduction. The purpose of designing these controls was to make allowances for any abiotic variables that could affect the process of biodegradation. These included things like temperatures and other forms of physical destruction.

All three experimental sets were kept in almost identical environmental conditions in terms of temperatures, humidity, and exposure to light. Monitoring was done to observe how fast biodegradation took place among the various types of sets, allowing comparison in the role of microbial action on the wrapper waste.

*F. Biodegradation Monitoring (30–90 Days)*

Biodegradation of tablet wrappers was studied at regular intervals (Day 0, 15, 30, 60, and 90) over 90 days, which would provide a quantitative measure of the changes that occurred in the biodegradation process [12].

*a. Physical Observations*

For each observation, the tablet wrapper buried in the soil was taken out and observed for any signs of degradation, such as color change, cracks or tear formation, surface texture changes, erosion, brittleness, and disintegration.

*b. Determination of Weight Changes*

Before burying the tablet wrappers in the soil, the weight of each wrapper was determined and recorded. This was done to compare the initial weight with the weight of the degraded sample at different intervals. At each observation interval, the wrappers were taken out, cleaned, dried, and their weight was determined.

The percentage of weight loss, representing the extent of biodegradation, was calculated using the formula:

$$\text{Weight Loss(\%)} = \frac{W_i - W_f}{W_i} \times 100$$

The above approach made it possible to compare the rate of degradation within different setups as well as at different time intervals. The entire process was done systematically to ensure that the results are accurate and reproducible.

*G. Microbial Analysis*

Soil obtained from all experimental setups was analyzed for the presence of microorganisms responsible for biodegradation of tablet wrappers. Microbial analysis was done to provide both the quantity and functional aspects of microorganisms involved in degradation [13].

*a. Count of Colonies*

Soil samples obtained from each experiment were first diluted using appropriate techniques to obtain countable microbial populations. Diluted soil was then cultured on nutrient agar (for bacteria) and Sabouraud dextrose agar (for fungi). The number of colonies grown per gram of soil was quantified to determine the amount of microorganisms present in each experiment.

### b. Enzyme Assays

In addition to the CFU assay, enzyme assays were performed on soils and pure cultures of microbes to determine their functional involvement in biodegradation. The enzymes were identified as esterase, dehydrogenase, protease, lipase, and laccase. These enzymes have been shown to play crucial roles in breaking down complex materials such as polymers, organic compounds, and composite materials found in the tablets' wrappings.

The combined results of CFU counts and enzyme activity offered a comprehensive evaluation of the efficacy and metabolic capabilities of the microbes to facilitate biodegradation of the tablet wrappings. This was achieved by correlating the presence of high numbers of viable microbes with their capabilities to bring about biodegradation of the test material.

### H. Data Analysis

The data from the various biodegradation tests conducted on tablet wrappings in the three different systems: the natural soil system, microbial enriched soil system, and the control system were systematically analyzed for comparisons of efficiency levels of biodegradation in each system based on several parameters [14].

Quantitative values such as weight loss and microbe count were reported using mean  $\pm$  standard deviation from three replicates. Quantitative analyses were conducted through various tests such as Analysis of Variance (ANOVA) and t-test to determine the statistical significance between the differences seen among the treatments and the period. For a difference to be statistically significant ( $p < 0.05$ ), quantitative analysis was carried out. Degradation efficiency in the presence of microbes can be measured by determining the relationship between the rate of degradation and microbe count and enzymes produced. The higher the percentage of weight loss, the higher the CFU value, and the higher the enzyme activity (esterase, dehydrogenase, protease, lipase, and laccase) means high efficiency in biodegradation.

The comparative analysis was carried out to help in determining the best setup that promotes biodegradation efficiency. Specifically, microbial-enriched soil was compared with natural soil and controls for possible promotion of degradation efficiency. This analysis helps in determining the most effective microbial community under specific environmental conditions for transforming hospital tablet wrapper waste through biodegradation.

## III. RESULTS AND DISCUSSION

Soil properties were assessed before conducting the biodegradation process. Two types of soils were taken into account for analyzing their physicochemical properties: garden soil and rhizosphere soil. These parameters play an important role in determining the rate of biodegradation because they can directly impact the growth of microbes and enzymes involved in the biodegradation process. Parameters such as pH, moisture content, organic matter, electrical conductivity, and nutrient content were considered. The results obtained after assessing the physicochemical properties of soil samples are provided in Table 1 below.

Table 1: Baseline Physicochemical Properties of Soil Samples

Parameter	Garden Soil	Rhizosphere Soil
pH	$6.5 \pm 0.2$ (slightly acidic)	$6.8 \pm 0.1$ (mildly acidic)
Moisture Content (%)	$12.4 \pm 0.3$	$18.3 \pm 0.4$
Temperature (°C)	$28.1 \pm 0.2$	$29.4 \pm 0.3$
Organic Carbon (%)	$0.82 \pm 0.05$	$1.21 \pm 0.06$



Nitrogen (mg/kg)	312 ± 5	355 ± 6
Phosphorus (mg/kg)	18.6 ± 1.0	25.1 ± 1.1
Potassium (mg/kg)	140 ± 4	165 ± 4
Microbial Load (CFU/g)	3.1 × 10 <sup>5</sup>	5.6 × 10 <sup>5</sup>

When compared to other soil types, the soil from the dump-yard soil showed high levels of alkaline properties possibly because of the residue and chemicals that accumulated within the soil. In comparison, the compost soil had the highest level of moisture content (25.6%), thus promoting microbial growth in the soil, while dump-yard soil had the least moisture content.

In terms of organic carbon content, the compost soil sample had a considerably high amount of organic carbon (1.94%) content because of the soil's composition of rich organic material, while the soil from the dump-yard had low amounts of organic carbon (0.45%). Compost soil also has high macronutrients levels of nitrogen, phosphorus, and potassium (NPK) compared to the soils from the dump-yard, which had low NPK amounts.

In addition, the results on microbial load showed that the compost soil had a significantly higher number of microbial counts ( $7.8 \times 10^5$  CFU/g), implying high biological activity of the soil. Dump-yard soil, however, had lower microbial loads ( $2.4 \times 10^5$  CFU/g). In general, the best physicochemical and biological properties have been noted for compost soil among the tested soil samples. The garden soil and rhizosphere soil were found to have high microbial potential, while dump-yard soil proved to be least fertile and biologically active.

Firstly, an assessment of basic physicochemical characteristics of the sampled soils is necessary in determining their fitness for microbial biodegradation of the pharmaceutical waste produced by hospitals. The parameters used in testing provide information about the inherent ability of the soils to sustain microbial activities that include breakdown of organic substances like polymeric coating of drug packaging.

Secondly, the soils sampled had relatively neutral or slightly acidic pH, which provided a good environment for microbial proliferation. Most of the degrading bacteria such as *Pseudomonas*, *Bacillus*, *Streptomyces*, *Aspergillus*, and *Penicillium* thrive well in these pH values. In addition, neutral pH levels reduce metal ion toxicity and increase nutrient solubility. Therefore, the soils can be subjected to biodegradation experimentation directly without further amendment.

Electrical conductivity values showed that the level of soil salinity was low. It is important because high levels of soil salinity can affect the microbial respiratory processes and hinder the action of enzymes participating in the breakdown of polymers. Thus, the optimal levels of electrical conductivity detected in the soil allow us to assume that the conditions are favorable for sustainable biological activity during the whole process of decomposition.

The organic carbon content and soil organic matter content also fell within the normal range of fertile soils, indicating an ample amount of carbon sources required for the maintenance of microorganisms' life activity. Being a key source of nutrients, organic matter is essential for continuous microbial growth. Moreover, high levels of organic matter content

indicate improved soil porosity, which facilitates oxygenation—an important component of efficient biological decomposition processes.

Additionally, the nutrient content, specifically the concentrations of nitrogen (N), phosphorus (P), and potassium (K), provides more evidence about the appropriateness of the soil in terms of the activity of microorganisms. Nitrogen is important for protein and enzyme production, phosphorus helps in producing ATP, and potassium maintains the osmolality balance and metabolism in microorganisms. The baseline concentrations of nitrogen, phosphorus, and potassium show that there is enough amount of these nutrients in the soil for supporting the microorganisms' growth, even in the presence of an external substrate (the pharmaceutical tablets wrappers).

The moisture content also showed values within the desirable range for the growth of microorganisms. Too much moisture would cause anaerobic conditions, while too little would not allow microbes to be active. The measured moisture levels mean that there is a good amount of moisture in the soil that allows microorganisms to perform their aerobic activities.

In addition, the soil texture and bulk density aid in establishing the level of microbial performance and effectiveness in the process of biodegradation. The soils that have a good balance between their sand, silt, and clay particles provide an optimal aeration capability and water retention capability, and bulk density that enables easy root penetration and microbial movement. In addition, the above soil structures ensure adequate diffusion of oxygen throughout the soils; oxygen being the major component in aerobic biodegradation process. It is important to note that microorganisms that degrade polyethylene and foil wrapped or coated drugs require oxygen-dependent enzymatic action.

All these parameters show that the soils under investigation are good hosts of microbial life and effective medium for biodegradation. From the above information, it is safe to state that it provides a solid base on which future experimentation can be based since degradation of the materials used in wrapper tablets will be attributed to the presence of microorganisms and not due to nutritional inadequacies and environmental constraints.

The degradation of the tablet wrapper waste from hospitals was then analyzed using a microcosm system with indigenous microbes over a period of 90 days. These observations were made at regular intervals of 30 days (30th day, 60th day, and 90th day). Data collection involved measurements of loss in wrapper weight, appearance, structure, and microbial activity on wrapper material.

*Table 2: Weight Loss Analysis*

*Gradual loss in wrapper weight over 90 days is observed due to microbial biodegradation.*

Time Interval	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	% Degradation
Day 30	1.000	0.910	0.090	9%
Day 60	1.000	0.765	0.235	23.5%
Day 90	1.000	0.612	0.388	38.8%

The degradation process of the wrapper of the tablets was observed to occur gradually in a span of 90 days, with more marked alterations seen from Day 60 to Day 90. On Day 30, there were some traces of discoloration, dulling of surfaces, and formation of biofilms. At Day 60, the wrappers appeared to be brittle, had fragmented edges, surface erosion, and



presence of microorganisms. After 90 days, it can be seen that there was widespread degradation, manifested by the presence of holes, peeling, and loss of integrity, together with heavy biofilm formation (Figure 1).

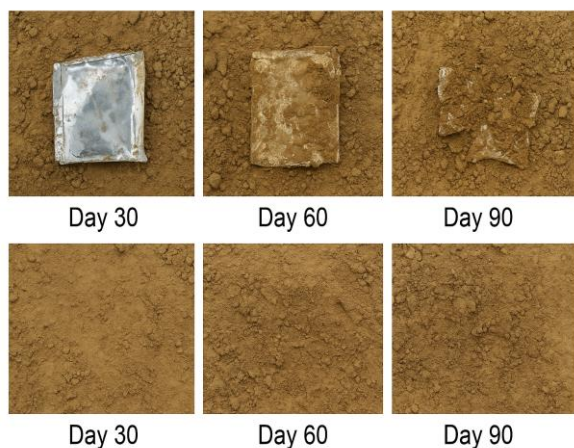


Fig. 1 Biodegradation Monitoring (30–90 Days)



Fig. 2 Degradation of Tablet Wrapper by *Pseudomonas putida*

The figure 2 depicts the gradual degradation of tablet-wrapper material by *Pseudomonas putida*, showing microbial colonization, biofilm formation, and progressive structural breakdown of the polymer surface.

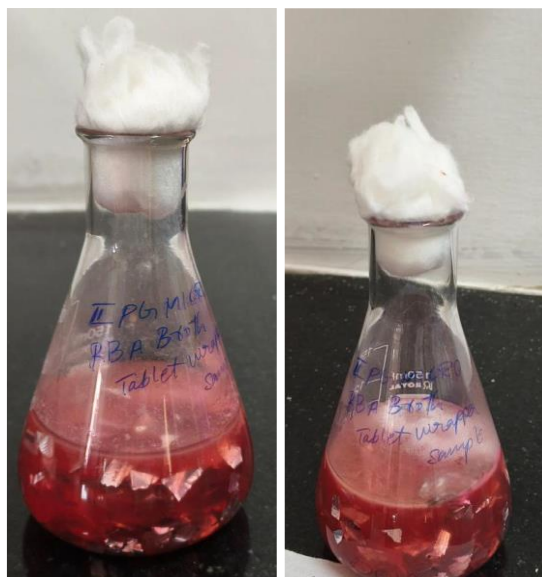


Fig. 3: Degradation of Tablet Wrapper by *Aspergillus niger*

Figure 3 demonstrates the progressive degradation of the polymer matrix caused by colonization of *Aspergillus niger*.

Table 3: Microbial Load Analysis on Degrading Wrappers

The microbial population was observed to continuously rise during the entire duration of degradation, showing that there was an increasing level of colonization and participation by microbes in the degradation process.

Time Point	Total Heterotrophic Bacteria (CFU/g)	Fungi (CFU/g)
Day 30	$2.1 \times 10^4$	$6.4 \times 10^3$
Day 60	$4.9 \times 10^4$	$1.3 \times 10^4$
Day 90	$8.7 \times 10^4$	$2.5 \times 10^4$

The consistent rise in microbial numbers during the whole experiment is a clear indication that the native microbes used the tablet wrapper as sources of carbon and energy for their survival.



Fig.4 Enzymes Assay

The analysis of the enzymatic activities also supported the findings. There was an increase in the cellulase activity from 0.42 IU/g to 0.89 IU/g on Days 30 and 90, respectively. This is indicative of the progressive breakdown of the cellulose-based material of the wrapping. In addition, there was a moderate increase in amylase activity, indicating the decomposition of any starch or starch-like compounds that may have been used as ingredients in the wrapper material (Figure 4).

It is important to highlight the remarkable increase in esterase activity among all the enzyme activities. Esterases play a very vital role in the decomposition of polymeric materials through the breakage of ester bonds of polymers. Therefore, increased esterase activity is a good indication of the breakdown of any synthetic or semi-synthetic components of the packaging material. From the increase in microbial loads and enzyme activities, it can be observed that there is effective and systematic microbial degradation in which enzymatic activities play a major role in breaking down complex materials of the wrappers into simpler forms. All these results show that there is microbial production of enzymes responsible for degrading polymers within the period of 90 days.

Degradation steadily increased from 9% at Day 30 to almost 39% at Day 90, with both visual and physical damage further corroborating the numerical results. The strong positive relationship between microbial growth and degradation percent, enzymatic activity, and degradation percent is indicative of the role of microbes in the process. Therefore, this research shows the ability of soil microorganisms to degrade hospital tablet-wrapper waste via biodegradation by creating a biofilm, using enzymatic activity, and breaking down polymers. Moreover, the increasing trend of degradation during this research indicates the possibility of increasing the efficiency of this process by prolonging the experiment or by adding strains known for polymer degradation to the mixture. In summary, biodegradation using soil microorganisms was proven as a possible method of waste management that is effective, sustainable, and cheap.

Biodegradation testing conducted for 90 days shows that soil microorganisms have good potential for degrading hospital tablet-wrapper waste. Weight loss in wrappers as well as physical degradation and microbial colonization are proof of biological biodegradation. Weight loss of wrappers was recorded at 9%, 23.5%, and 38.8% for Days 30, 60, and 90, respectively.

The high level of degradation seen from Day 60 to Day 90 implies that microorganisms have been able to adapt to the polymer-based substrate. In the first stage of the experiment, there is always a need for time on the part of the microorganisms for attaching to the surface, forming biofilms, and producing extracellular enzymes. The loss of gloss, pitting of the surface, fragility, breaking down, and holes formed imply the surface oxidation and polymer chain breaking, which is typical of polymer degradation by microorganisms.

The gradual weakening implies that microorganisms did not only attach to the surface, but they penetrated into the interior of the material to break down the polymer more efficiently. This is evidenced by the biofilm formation on Day 30 and subsequent biofilm growth until Day 90. The number of microorganisms increased continuously during the experiment, with the growth in both bacteria and fungi being substantial. This suggests that there was a successful development of a microbial community that is capable of breaking down the additives, fillers, and byproducts produced in the process of degradation of the polymer. The increase in the number of fungi, which are known to have potent oxidase enzyme systems, shows their importance in the degradation of complex synthetic polymers.

Enzyme activity increased, indicating the biochemical nature of degradation. Specifically, esterases, which break down ester bonds in polymer coatings and laminates, played an important role. This can be seen from the high level of enzyme activity recorded on Day 60 compared to Day 90, indicating a faster rate of degradation at this stage.

From the observations made from the analysis of tablet wrapper degradation, it can be concluded that soil microbial ecosystems represent one possible way of disposing of plastic wastes produced by hospitals in an eco-friendly manner. This is considering the fact that it is difficult to recycle multi-layered and contaminated plastic. In addition, the amount of degradation recorded (approximately 39%) after 90 days implies that more effective degradation can be achieved using more time or a more optimized microbial ecosystem.

This outcome is comparable with previous works conducted on the degradation of polyethylene and multi-layered plastic by soil microorganisms. It is worthy of note that this degradation was significant because tablet wrappers made up of aluminum and polymeric films are naturally resistant to degradation. Therefore, the observation shows that indigenous soil microorganisms can degrade plastics significantly provided there is enough time and proper conditions. The landfill environments contain highly efficient microorganisms and enzymes for degrading plastic. These organisms and enzymes have been isolated using a metagenomic and machine learning technique. This study is unique in the sense that, unlike other studies, the current research does not rely on culturing techniques. Rather, the authors have succeeded in isolating those microorganisms and enzymes which could not be cultivated previously and are responsible for polymer decomposition [16].

An extensive discussion of evaluation techniques used in assessing plastic biodegradation in soil environments. As per the authors, there are several environmental factors which affect the degradation rate. These include soil moisture, temperature, microbial diversity, and nature of the polymer being degraded. The authors further assert that a period of more than 30-90 days should be considered for evaluating degradation rate in soils [17].

In the same way, the study on microbial and enzymatic biodegradation techniques to promote the circular economy model. The researchers highlight the shift in focus from linear plastic waste management models to a circular economy based on recycling and biodegradation processes. In this regard, microbial consortia and enzymes including hydrolase and oxidoreductases have been discussed [18].

The paper on bacterial biodegradation of synthetic polymers, detailing metabolic pathways responsible for the biodegradation process. Genera including *Pseudomonas*, *Bacillus*, and *Rhodococcus* have been recognized as primary drivers behind the biodegradation process. Further discussion is centered around the enzymatic process, specifically the PETase-like mechanism, vital for biodegrading PET (polyethylene terephthalate) [19].

Microplastics biodegradation by estuarine and landfill microbiomes represents another important piece of research into the subject matter and illustrates that microbiome communities work much better at biodegrading microplastics compared to individual species. Such an approach facilitates enzyme production, biofilm formation, and other processes necessary for efficient degradation [20].

#### IV. CONCLUSION

In addition, the results of the current experiment show the great ability of soil microorganisms for biodegradation of waste from hospital tablet wrappers as a sustainable and environmentally friendly solution to the waste disposal problem. The initial physico-chemical characterization demonstrated that chosen soil had good conditions for biological degradation due to its high content of organic matter, nutrients, and microorganism diversity. Moreover, the degradation study conducted during Days 30 to 90 proved the active work of soil microorganisms through the weight loss of the samples, physical destruction of the wrapper material, and the presence of the biofilm on its surface. Additionally, the higher microorganism population and enzyme activity showed that biological degradation intensified due to better metabolism of organisms.

On the whole, this research proves that soil-microbe biodegradation is a feasible, sustainable, and economical way of dealing with hospital tablet-wrapper waste, especially in cases when recycling or burning is not feasible or environmentally unfriendly. Despite the absence of full decomposition within 90 days, the notable amount of decomposition that occurred (almost 40%) shows the effectiveness of this method. There is an opportunity to increase the effectiveness by increasing treatment time or modifying the composition of the soil. To conclude, it is possible to state that soil-microbe biodegradation is a promising method of decreasing the amount of pharmaceutical waste, including the wrapping material. This technology can be useful in further studies on sustainable healthcare waste disposal.

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None.

**CONFLICT OF INTEREST**

None.

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