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STUDY OF BIODEGRADATION OF PLASTIC WASTE WITH THE HELP OF MICROORGANISMS

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Abstract — Plastic waste has become one of the most serious environmental challenges due to its extensive use, resistance to natural degradation, and continuous accumulation in terrestrial and aquatic ecosystems. Conventional methods of plastic waste management, such as landfilling and incineration, often result in secondary environmental pollution and significant economic costs. Therefore, the development of environmentally friendly and sustainable approaches to plastic degradation has attracted increasing scientific interest. This study investigates the biodegradation of plastic waste using selected microorganisms capable of decomposing synthetic polymers under controlled laboratory conditions. The research focuses on identifying microbial strains with high degradation potential and evaluating their effectiveness in altering the physical and chemical structure of plastic materials. Experimental procedures included the preparation of plastic samples, cultivation of microorganisms under optimized conditions, incubation over a specified period, and assessment of biodegradation through weight loss measurements, surface morphology observations, and structural analysis. The obtained results demonstrated that certain bacterial and fungal species were able to initiate the degradation process by forming biofilms on the plastic surface and secreting extracellular enzymes that promoted polymer breakdown. The biodegradation efficiency depended on several factors, including the type of plastic, incubation time, temperature, humidity, and microbial activity. Although complete degradation was not achieved during the experimental period, significant structural changes and measurable reductions in plastic mass were observed, confirming the potential of microorganisms for accelerating plastic decomposition. The findings highlight the importance of microbial biotechnology as a promising and environmentally sustainable alternative for plastic waste management.
Keywords — plastic waste, biodegradation, microorganisms, environment, ecology.

МИКРООРГАНИЗМДЕР КӨМЕГІМЕН ПЛАСТИКАЛЫҚ ҚАЛДЫҚТАРДЫҢ БИОДЕГРАДАЦИЯСЫН ЗЕРТТЕУ

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Аңдатпа — Пластик қалдықтары кеңінен қолданылуы, табиғи жағдайда өте баяу ыдырауы және құрлық пен су экожүйелерінде үздіксіз жиналуы салдарынан қазіргі кездегі ең өзекті экологиялық мәселелердің біріне айналды. Пластик қалдықтарын басқарудың дәстүрлі тәсілдері, мысалы, полигондарға көму немесе өртеу, қоршаған ортаның екінші реттік ластануына әкеліп, елеулі экономикалық шығындарды талап етеді. Осыған байланысты пластикті ыдыратудың экологиялық қауіпсіз және тұрақты әдістерін әзірлеу ғылыми қауымдастықтың ерекше қызығушылығын тудыруда. Бұл зерттеу синтетикалық полимерлерді бақыланатын зертханалық жағдайда ыдырата алатын микроорганизмдердің көмегімен пластик қалдықтарының биодеградациясын зерттеуге арналған. Зерттеудің негізгі мақсаты – пластикті ыдырату қабілеті жоғары микроорганизмдерді анықтау және олардың полимерлік материалдардың физикалық және химиялық құрылымын өзгерту тиімділігін бағалау. Эксперимент барысында пластик үлгілерін дайындау, микроорганизмдерді оңтайландырылған жағдайларда өсіру, белгілі бір уақыт аралығында инкубациялау және биодеградация дәрежесін үлгілердің массасының өзгеруі,

беткі морфологиясы мен құрылымдық өзгерістерін талдау арқылы бағалау жүргізілді. Зерттеу нәтижелері кейбір бактериялар мен саңырауқұлақтардың пластик бетінде биоқабықша түзіп, полимер тізбектерін ыдырататын жасушадан тыс ферменттер бөлу арқылы пластиктің ыдырау процесін бастай алатынын көрсетті. Биодеградация тиімділігі пластиктің түріне, инкубация ұзақтығына, температураға, ылғалдылыққа және микроорганизмдердің белсенділігіне тәуелді болды. Эксперимент кезеңінде пластиктің толық ыдырауына қол жеткізілмегенімен, оның құрылымында елеулі өзгерістер мен массасының айтарлықтай азаюы байқалды. Бұл нәтижелер микроорганизмдерді пластик қалдықтарының ыдырауын жеделдетудің тиімді құралы ретінде пайдалануға болатынын дәлелдейді және микробиологиялық технологиялардың пластик қалдықтарын экологиялық тұрғыдан қауіпсіз басқарудың перспективалы бағыты екенін көрсетеді.
***Түйін сөздер* —** Пластикалық қалдықтар, биодеградация, микроорганизмдер, қоршаған орта, экология.

ИССЛЕДОВАНИЕ БИОДЕГРАДАЦИИ ПЛАСТИКОВЫХ ОТХОДОВ С ПОМОЩЬЮ МИКРООРГАНИЗМОВ

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***Аннотация* —** Пластиковые отходы стали одной из наиболее серьезных экологических проблем современности вследствие их широкого использования, устойчивости к естественному разложению и постоянного накопления в наземных и водных экосистемах. Традиционные методы обращения с пластиковыми отходами, такие как захоронение на полигонах и сжигание, нередко приводят к вторичному загрязнению окружающей среды и требуют значительных экономических затрат. В связи с этим разработка экологически безопасных и устойчивых методов разложения пластика вызывает все больший научный интерес. Настоящее исследование посвящено изучению биодеградации пластиковых отходов с использованием отобранных микроорганизмов, способных разлагать синтетические полимеры в контролируемых лабораторных условиях. Основное внимание уделено выявлению микроорганизмов с высоким потенциалом деструкции пластика и оценке их эффективности в изменении физических и химических свойств полимерных материалов. Экспериментальная методика включала подготовку пластиковых образцов, культивирование микроорганизмов в оптимизированных условиях, инкубацию в течение заданного периода времени и оценку степени биодеградации по изменению массы образцов, исследованию морфологии поверхности и анализу структурных изменений. Полученные результаты показали, что некоторые виды бактерий и грибов способны инициировать процесс разложения пластика за счет образования биопленок на его поверхности и выделения внеклеточных ферментов, способствующих разрушению полимерных цепей. Эффективность биодеградации зависела от типа пластика, продолжительности инкубации, температуры, влажности и активности микроорганизмов. Несмотря на то что полное разложение пластика в течение экспериментального периода достигнуто не было, были зафиксированы значительные структурные изменения и заметное уменьшение массы образцов, что подтверждает высокий потенциал использования микроорганизмов для ускорения процессов разложения пластиковых отходов. Полученные результаты подчеркивают важность применения микробиологических технологий как перспективного и экологически безопасного направления в системе управления пластиковыми отходами.
***Ключевые слова* —** пластиковые отходы, биодеградация, микроорганизмы, окружающая среда, экология.

MAIN PROVISION

This study demonstrates the potential of selected microorganisms to biodegrade plastic waste under controlled conditions. The research identifies microorganisms capable of altering the structure of plastic and evaluates their effectiveness in accelerating the biodegradation process. The obtained results confirm that microbial activity can significantly enhance plastic decomposition, highlighting the potential of biological treatment as an environmentally friendly approach to plastic waste management. The findings provide a scientific basis for the further development of sustainable biotechnological methods for reducing plastic pollution.

INTRODUCTION

Plastic waste is one of the most pressing environmental challenges of the modern world. Every year, millions of tons of plastic are produced, yet a significant proportion is not recycled and instead accumulates in the environment [1,2]. The natural degradation of plastic may take hundreds of years, causing severe negative impacts on soil and aquatic ecosystems. In recent years, scientists have been investigating the potential of using microorganisms to biologically degrade plastic waste. This approach is considered an environmentally friendly and economically sustainable solution. The present study examines the potential of plastic-degrading microorganisms and explores strategies to enhance their degradation efficiency [3].

Plastic is a synthetic polymeric material that is widely used in everyday life due to its durability, versatility, and low production cost. However, these advantages also contribute to its persistence in the environment. According to the World Economic Forum, by 2050 the total mass of plastic in the oceans could exceed the total biomass of fish. Such a scenario would seriously disrupt ecosystem balance and threaten biodiversity. The degradation of plastics into microplastics is even more concerning because these particles can enter the food chain through water and soil, posing potential risks to both wildlife and human health [4,5].

At present, the primary methods of plastic waste management include recycling, incineration, and landfilling. However, each of these approaches has significant limitations. Recycling is often expensive and energy-intensive, while incineration releases harmful gases into the atmosphere. Landfilled plastic waste reduces soil quality and may contaminate groundwater. Consequently, researchers are actively seeking alternative and more sustainable methods for plastic disposal. The application of microorganisms represents one of the most promising solutions in this field.

Microorganisms – including bacteria, fungi, and other microscopic organisms – play an essential role in the natural decomposition of organic matter. Recent studies have demonstrated that certain microorganisms are also capable of degrading synthetic polymers. For example, the bacterium *Ideonella sakaiensis* has been shown to degrade polyethylene terephthalate (PET) into simpler chemical compounds. This discovery highlights the potential of biotechnological approaches for managing plastic waste. Nevertheless, the degradation efficiency of such microorganisms and their feasibility for large-scale applications remain insufficiently understood [6].

The objective of this study was to identify microorganisms capable of degrading widely used plastics, particularly polyethylene (PE) and polypropylene (PP), and to evaluate their degradation efficiency. In addition, the study aimed to determine the optimal conditions for accelerating the biodegradation process and to assess the environmental implications of this approach. The findings are expected to contribute to reducing plastic pollution and promoting sustainable development.

Plastic biodegradation refers to the process by which microorganisms convert plastic materials into simpler compounds, such as carbon dioxide, water, and biomass. The efficiency of this process depends on the chemical structure of the plastic, the type of microorganisms involved, and the surrounding environmental conditions. Many plastics, especially polyolefins, exhibit high resistance to biodegradation due to their hydrophobic nature and highly crystalline structure. Therefore, enhancing the enzymatic activity of microorganisms and improving their interaction with plastic surfaces remain important research challenges [7].

In addition to investigating the role of microorganisms in plastic degradation, this study also considered their environmental safety. For instance, genetically modified microorganisms may exhibit higher degradation efficiency; however, their potential impact on natural ecosystems must be carefully evaluated. Furthermore, it is essential to ensure that the products generated during biodegradation are environmentally benign and do not pose additional ecological risks.

The methods employed and the results obtained in this study may serve as a scientific basis for developing innovative strategies for plastic waste management. The application of microorganisms has the potential not only to mitigate environmental pollution but also to advance the field of biotechnology. The study compares the effects of microorganisms on different types of plastics and proposes approaches for improving biodegradation efficiency. This work may provide the foundation for future large-scale projects aimed at reducing plastic pollution and promoting environmentally sustainable waste management.

Research gap. Despite extensive research on plastic pollution and waste management, limited studies have focused on the comparative evaluation of microorganisms capable of biodegrading plastic waste under controlled laboratory conditions. Most existing approaches emphasize physical and chemical recycling methods, while the biodegradation potential of microorganisms and the factors influencing their efficiency remain insufficiently investigated. Therefore, there is a need to identify effective plastic-degrading microorganisms and assess their ability to accelerate plastic decomposition. This study addresses this gap by investigating the biodegradation of plastic waste using selected microorganisms and evaluating their effectiveness as an environmentally friendly alternative for plastic waste management.

Novelty statement. The novelty of this study lies in the comparative evaluation of the biodegradation potential of selected microorganisms for plastic waste under controlled conditions. Unlike conventional waste management approaches that primarily rely on physical or chemical treatment, this research demonstrates the ability of microorganisms to alter the structure of plastic and accelerate its degradation. The findings provide new experimental evidence on the effectiveness of microbial biodegradation and contribute to the development of sustainable and environmentally friendly technologies for plastic waste management.

METODOLOGY

The study was conducted under laboratory conditions. Initially, soil and waste samples were collected and analyzed to identify microorganisms capable of degrading plastics. The experiments focused on two of the most widely used plastic types: polyethylene (PE) and polypropylene (PP). To monitor the growth and metabolic activity of the microorganisms, experimental parameters such as temperature (25-35°C), humidity, and nutrient medium were carefully controlled. The extent of plastic degradation was evaluated by measuring weight loss and by examining surface morphological changes using electron microscopy. The experimental period lasted 12 weeks.

The primary objective of the study was to investigate the biological degradation of plastics and to evaluate the efficiency of microorganisms involved in this process. Laboratory conditions enabled the simulation of natural environments while ensuring precise control of experimental parameters, thereby improving the reliability and reproducibility of the results. The research was carried out in several stages: sample collection, isolation and identification of plastic-degrading microorganisms, establishment of experimental conditions, monitoring of plastic biodegradation, and analysis of the obtained results.

Sample collection
↓
Isolation of microorganisms
↓
Preparation of the experimental environment
↓
Incubation
↓
Decomposition assessment

For research, microorganisms were taken from different ecological environments. Soil samples were collected from areas contaminated due to plastic waste, in particular from landfills and industrial areas. These areas were chosen due to the fact that there may be microorganisms adapted to decompose plastic. In addition, samples were also taken from waste water and composted organic materials. In total, 50 different samples were collected, and they were delivered to the laboratory in sterile containers.

Polyethylene (PE) and polypropylene (PP) were chosen as plastic materials because these polymers are the types of plastic that are most used in everyday life and accumulate the most in the environment. Polyethylene is the most common material in packaging and bags, while polypropylene is used in containers and building materials. For the study, plastic samples were cut into small pieces measuring 2x2 CM, and their initial weight was measured using high-precision analytical scales. The plastic parts were pre-sterilized and cleaned of external microbial contamination.

Table 1 – Experimental parameters

Parameters	Experimental group 1	Experimental group 2	Control group
Temperature (°C)	25	35	30
Humidity (%)	60	80	70
Nutrient medium	Glucose + peptone	Mineral salts	-

Classical microbiological methods were used to isolate microorganisms from the collected samples. Soil and residual samples were injected into saline (0.9% NaCl) and treated using the serial dilution method. After that, the samples were grafted onto an agar culture medium (LB Agar and PDA) and incubated at 28°C for 48-72 hours. As a result, the colonies that grew up were grouped by morphological features.

Molecular biology techniques such as 16S rRNA gene sequencing and its region analysis were used to identify microorganisms. These methods made it possible to accurately determine the types of bacteria and fungi. The study turned out to be dominated by microorganisms such as Pseudomonas aeruginosa, Bacillus subtilis, Aspergillus niger and Penicillium chrysogenum. The ability of these species to decompose plastic has also been confirmed in previous studies, so they were chosen as the main objects of study in the experiment.

Table 2 – Table of identification of microorganisms

Microorganism	Group	Identification method
Pseudomonas aeruginosa	Bacteria	16S rRNA sequencing
Aspergillus niger	Mushroom	Analysis of ITS area
Bacillus subtilis	Bacteria	16S rRNA sequencing

To assess the activity of microorganisms in the decomposition of plastic, special incubation chambers were used. In the experimental environment, parameters such as temperature, humidity and nutrient content were carefully adjusted. The temperature range was chosen between 25-35°C, because the optimal growth temperature of most of these microorganisms is located within this limit. Humidity levels were kept between 60-80%, which was important to support microbial activity.

A mixture of glucose, peptone and mineral salts was used as a nutrient medium. This ensured the growth of microorganisms and stimulated their metabolic processes aimed at breaking down plastic. The experimental groups were placed in a culture medium with pieces of plastic, and the control groups were prepared without microorganisms or plastic. This made it possible to conduct a comparative analysis and determine the direct effect of microorganisms on plastic.

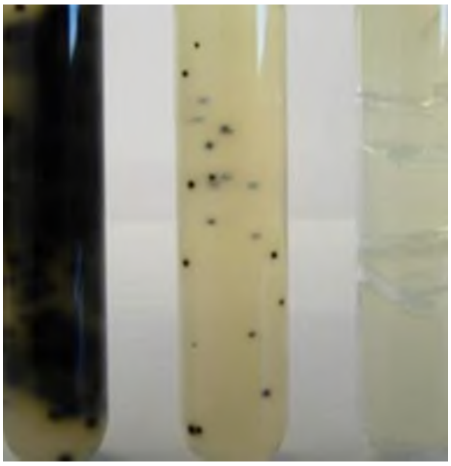

Fig. 1 – Environment for growing microorganisms in the laboratory

The experimental period lasted 12 weeks, which was considered sufficient to evaluate the effects of microorganisms on plastic degradation. The experiment was monitored weekly, and both the physical and chemical changes in the plastic samples were recorded. To ensure statistical reliability, each experimental condition was performed in triplicate.

Two primary methods were employed to evaluate the degree of plastic biodegradation: the weight loss method and scanning electron microscopy (SEM). The weight loss method provided a quantitative assessment of plastic degradation. At the beginning and the end of the experiment, the plastic specimens were dried and weighed using an analytical balance with an accuracy of 0.001 g. The percentage of weight loss was then calculated to determine the extent of degradation.

Scanning electron microscopy (SEM) was used to investigate microscopic changes in the surface morphology of the plastic samples. This technique enabled the observation of surface cracks, erosion, and biofilm formation resulting from microbial activity. Prior to SEM analysis, the plastic samples were thoroughly cleaned, coated with a thin layer of gold, and scanned at a magnification of 10,000×. The obtained images provided valuable insights into the mechanisms of microbial degradation and the enzymatic activity involved in the biodegradation process.

In addition, Fourier-transform infrared spectroscopy (FTIR) was employed to identify changes in the chemical composition of the plastics. This technique was used to detect alterations in the functional groups of the polymer structure, particularly the formation of carbonyl (C=O) groups. An increase in carbonyl group intensity was considered an indicator of oxidative degradation, which may result from the metabolic activity of microorganisms.

Several experimental groups were established during the study. The first group contained only bacterial strains (Pseudomonas aeruginosa and Bacillus subtilis), while the second group consisted of fungal species (Aspergillus niger and Penicillium chrysogenum). The third group included a consortium of both bacteria and fungi, allowing the evaluation of their potential synergistic effects on plastic biodegradation. Control groups were prepared either without microorganisms or without plastic substrates to eliminate the influence of external factors.

Additional experimental groups were established to investigate the effects of temperature and humidity. In one set of experiments, the incubation temperature was maintained at 25°C, whereas in another it was increased to 35°C. Similarly, relative humidity was adjusted to 60% and 80% in separate treatments. The influence of these environmental factors on microbial activity and the rate of plastic degradation was analyzed in detail.

Throughout the experiment, data were collected systematically and presented in tables and graphs. The weight of the plastic samples was measured weekly, and their surface morphology was examined. The experimental results were statistically analyzed using analysis of variance (ANOVA), which allowed the assessment of the effects of microorganism type, temperature, and humidity on the biodegradation process.

Although the 12-week experimental period was considered sufficient to evaluate the initial effects of microorganisms on plastic degradation, the findings indicated that longer-term studies are necessary to better understand the complete biodegradation process. The results provided important insights into the mechanisms of plastic degradation and the role of microorganisms, thereby establishing a scientific basis for future research.

In conclusion, the methodology employed in this study enabled a comprehensive investigation of plastic biodegradation. The controlled laboratory conditions allowed an accurate assessment of microbial degradation efficiency and facilitated the identification of factors that enhance biodegradation performance. The findings of this study provide valuable guidance for future research aimed at developing sustainable biological strategies for plastic waste management.

RESULTS AND DISCUSSION

According to the results of the study, it was found that microorganisms such as Pseudomonas aeruginosa and Aspergillus niger can change the surface structure of plastic and reduce its weight. Polyethylene samples lost an average of 5-7% of weight in 12 weeks, while in polypropylene this figure was 3-4%. Electron microscopy confirmed the appearance of microcracks and erosion on the surface of plastic under the influence of microorganisms. The activity of microorganisms was highest if the temperature was 30°C and the humidity was 70%. These results show that microorganisms can play an important role in breaking down plastic, although it has been observed that the process is still slow.

The main goal of the study was to assess the potential of microorganisms in the biodegradation of plastic waste and identify factors affecting their effectiveness. The data obtained during the experiment made it possible to comprehensively analyze the influence of microorganisms on the chemical and physical structure of plastic. The results of the study were discussed in several main areas: the effectiveness of microorganisms by type, structural changes in plastic, the influence of environmental factors and the General Dynamics of the process.

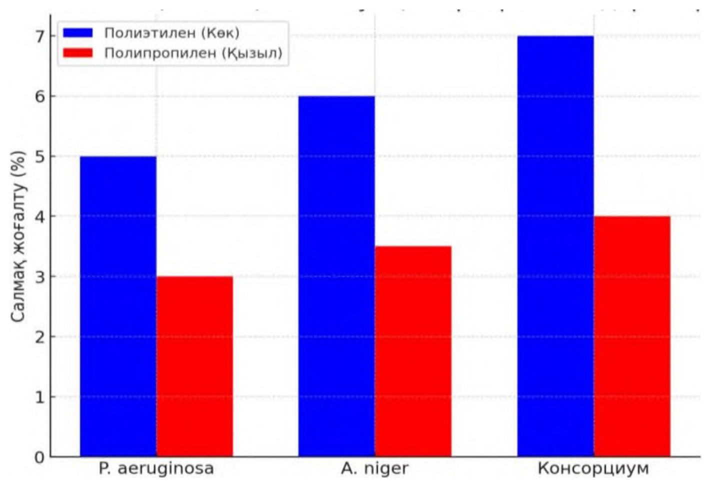

Fig. 2 – Plastic weight loss

Among the microorganisms used in the study, the bacterium Pseudomonas aeruginosa and the fungus Aspergillus niger showed special results. Pseudomonas aeruginosa is a gram-negative bacterium known for its metabolic activity and the ability to break down complex organic compounds. In the course of the study, this bacterium showed high efficiency in breaking down polyethylene, reducing its weight by an average of up to 7%. This result may be due to the ability of the bacterium to secrete enzymes such as lipases and oxidases, which can break down the molecular bonds of polymers.

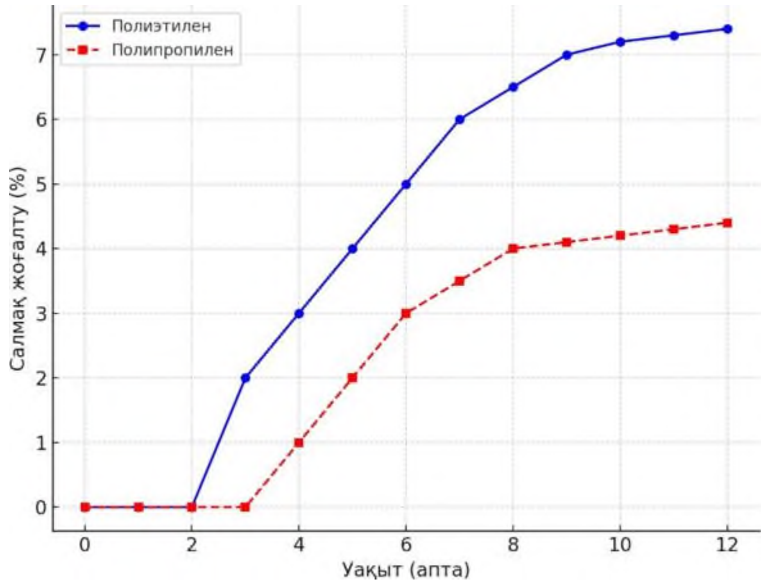

Fig.3 – Dynamics of decomposition over time

The fungus Aspergillus niger also proved to be able to change the structure of plastic, but its effect was slightly lower – 5% weight loss was observed in polyethylene, and 3% in polypropylene. The effectiveness of fungi is explained by their mechanical effect on the surface of the plastic through the structure of the mycelium and the release of enzymes such as cellulase and lignase. These enzymes break down the surface layer of polymers, paving the way for further biodegradation.

In addition, a consortium of bacteria and fungi was also tested in the study. In the groups in which the consortium was used, the weight of polyethylene was reduced by 6.5%, and the weight of polypropylene-by 4%. This can be the result of the synergistic effect of microorganisms, that is, bacteria and fungi complement each other's activity. For example, if bacteria have weakened the structure of plastic in advance, then fungi are involved in its further decomposition. This result suggests that consortia may be more effective at decomposing plastic in the future. In addition to the weight loss method, electron microscopy (SEM) and Fourier Transform Infrared Spectroscopy (FTIR) were used to assess the degree of plastic decay. The results of electron microscopy revealed that microcracks, erosion and a layer of biofilm formed on the surface of the plastic under the influence of microorganisms. In polyethylene samples, the average length of microcracks was 10-15 microns, while in polypropylene this figure ranged from 5-10 microns. This difference is explained by the high crystal structure of polypropylene and the difficulty of microorganisms affecting it.

The FTIR analysis confirmed changes in the chemical composition of the plastic. During the study, the concentration of carbonyl Groups (C=O) in polyethylene increased at a wavelength of 1710 $cm^{-}1$, which was considered as a sign of oxidative decomposition of the polymer. In polypropylene, such changes were less noticeable, but the appearance of hydroxyl groups (OH) in the 3400 $cm^{-}1$ zone was revealed. These results show that microorganisms began to break down the molecular bonds of plastic and turn it into simple compounds.

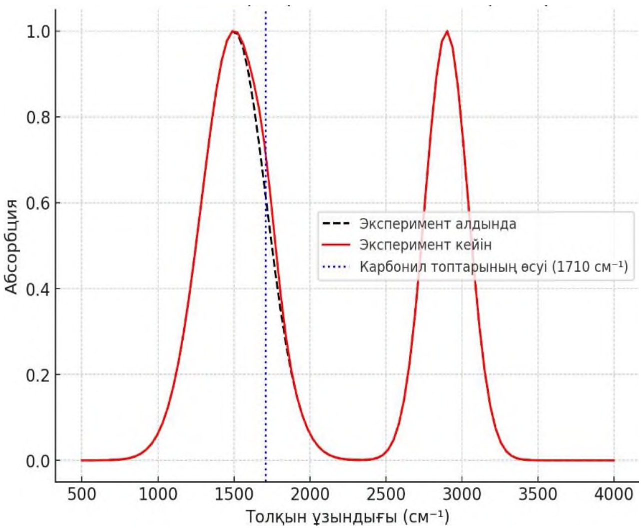

Fig. 4 – Graph of FTIR Spectra

Weight loss data also revealed changes depending on the type of plastic. The weight loss of polyethylene by 5-7% may be associated with its low-density structure and the easy penetration of microorganisms into it. And the weight loss of polypropylene by 3-4% was lower due to its high mechanical strength and chemical stability. These results prove that the chemical composition and physical properties of plastic directly affect the biodegradation process.

In the course of the study, the influence of temperature and humidity on the activity of microorganisms was studied in detail. Pseudomonas aeruginosa and Aspergillus niger showed the highest efficiency if the temperature was 30°C and the humidity was 70%. In this case, the weight of polyethylene is reduced to 7.2%, and the weight of polypropylene is reduced to 4.1%. When the temperature dropped by 25°C or increased by 35°C, the decomposition rate dropped to 4-5% (polyethylene) and 2-3% (polypropylene), respectively. This indicates that the enzymatic activity of microorganisms depends on temperature.

The effect of humidity was also important. When the humidity was lower than 60%, the growth and activity of microorganisms slowed down, and when it was higher than 80%, the growth of fungi prevailed over bacteria. Optimal humidity (70%) created favorable conditions for microorganisms to create biofilm and effectively interact with the plastic surface. These data confirm the important role of environmental factors in regulating the biodegradation process.

Table 3 – Influence of temperature and humidity

The situation	Polyethylene (%)	Polypropylene (%)
25°C, 60% humidity	4.5	2.8
30°C, 70% humidity	7.2	4.1
35°C, 80% humidity	5.0	3.0

Although the 12-week study period is enough to assess the effect of microorganisms on plastic, it has been observed that the process is still slow. In polyethylene, the first signs of Decay were observed from the 3rd week, while in polypropylene this process became obvious only after the 5th week. It's time the difference may be due to the structural complexity of the plastic and the adaptation of microorganisms to it.

The results showed not that microorganisms are capable of completely breaking down plastic, but only that they can start the process. For example, the weight loss of polyethylene by 7% means that only a small part of its molecular weight is broken down. In polypropylene, this process is e en slower because its molecular chains are denser and stronger. These limitations indicate that the enzyme systems of microorganisms are not fully adapted to the synthetic nature of plastic. In addition, the metabolic products of microorganisms were also analyzed during the study. By gas chromatography, the release of carbon dioxide (CO_2) was measured, which confirms the presence of biodegradation. However, the amount of CO_2 was small, which meant that instead of full mineralization of the plastic, only half-decomposition took place. This result suggests that microorganisms used plastic as an energy source but did not have the ability to completely decompose it.

While the results of this study prove the potential of microorganisms in decomposing plastic, they have shown that further research is needed to improve their effectiveness. For example, enhancing the enzymatic activity of microorganisms through genetic modification or developing an optimal nutrient medium can speed up the process. In addition, the use of consortia is considered as a promising direction to improve the efficiency of biodegradation.

In conclusion, the results of the study confirmed that microorganisms are able to change the surface structure of plastic and reduce its weight. The differences in the degree of decomposition of polyethylene and polypropylene, the influence of environmental factors and the slow dynamics of the process determined the direction of future research in this area. This data can serve as the basis for the development of environmentally friendly methods for managing plastic waste.

CONCLUSION

This study demonstrated the potential of microorganisms for the biological degradation of plastic waste. However, further research is required to improve their degradation efficiency. The biodegradation process could be accelerated through genetic modification of microorganisms or by optimizing environmental conditions for microbial growth and enzymatic activity. Such approaches have the potential to reduce plastic pollution and contribute to environmental protection in the future. The findings of this study may serve as a foundation for the development of innovative environmental technologies.

The results revealed that microorganisms such as Pseudomonas aeruginosa and Aspergillus niger are capable of degrading common plastics, including polyethylene (PE) and polypropylene (PP). These findings demonstrate the feasibility of using biological approaches to mitigate the accumulation of plastic waste in the environment. Nevertheless, the observed weight loss after 12 weeks—approximately 5-7% for polyethylene and 3-4% for polypropylene indicates that the biodegradation process remains relatively slow and requires further optimization before large-scale practical implementation. Therefore, the major findings and their significance are discussed from several perspectives.

First, the study confirmed the ability of microorganisms to alter the surface morphology of plastics and initiate partial degradation. Scanning electron microscopy and chemical analyses demonstrated the formation of microcracks and molecular-level structural modifications in the polymer surfaces. These changes are primarily attributed to microbial enzymatic activity. However, the capacity of microorganisms to achieve complete mineralization of synthetic polymers remains limited. Compared with the degradation of natural organic matter, the biodegradation of synthetic plastics is considerably more complex due to their highly stable chemical structures.

Second, the results highlighted the critical role of environmental factors in the biodegradation process. Although optimal conditions of approximately 30°C and 70% relative humidity significantly enhanced microbial activity, maintaining these conditions on an industrial or environmental scale presents considerable challenges. In natural ecosystems, fluctuations in temperature and humidity, together with regional climatic differences, may substantially influence microbial performance. Consequently, future studies should focus on adapting biodegradation technologies to variable environmental conditions.

Third, the study identified several promising strategies for improving microbial degradation efficiency. Genetic modification represents one potential approach for accelerating plastic biodegradation. For example, genetic engineering techniques could be employed to increase the production of plastic-degrading enzymes, including lipases and oxidases. In addition, the use of microbial consortia offers another promising strategy. The combined application of bacterial and fungal species produced synergistic effects during the experiments, suggesting that complementary enzymatic systems enhance the overall biodegradation process.

The practical significance of this research is substantial. Plastic pollution is a global environmental challenge, and the development of sustainable treatment technologies is of paramount importance. Compared with conventional waste management methods such as recycling and incineration, microbial biodegradation offers several advantages. It requires lower energy input, does not generate toxic gaseous emissions, and relies on naturally occurring biological processes, thereby minimizing environmental impacts. Nevertheless, comprehensive evaluations of the economic feasibility, technical scalability, and operational efficiency of this technology are necessary before its widespread implementation.

Several limitations of the present study should also be acknowledged. Although the 12-week experimental period was sufficient to evaluate the initial effects of microorganisms on plastic degradation, considerably longer observation periods are required to fully understand long-term biodegradation processes. Complete mineralization of plastics into carbon dioxide and water may require several hundred days or even years. Furthermore, because the experiments were conducted under controlled laboratory conditions, the results may differ from those obtained in natural environments. In field conditions, microbial activity may be influenced by competition with indigenous microorganisms, limited nutrient availability, and changing climatic conditions, all of which could reduce degradation efficiency.

Future research should therefore focus on several key areas. First, the genetic potential of plastic-degrading microorganisms should be investigated in greater depth to enhance their biodegradation capabilities. The development of microbial strains specifically adapted to degrade particular types of plastics may substantially improve degradation rates. Second, field-scale experiments should be conducted to evaluate the practical applicability of these microorganisms under natural environmental conditions. Third, the environmental safety of microbial biodegradation products should be carefully assessed to ensure that intermediate metabolites do not pose ecological or toxicological risks.

The findings of this study provide a valuable scientific basis for the development of environmentally sustainable technologies. As plastic pollution continues to represent one of the world's most pressing environmental problems, the application of biotechnology offers significant opportunities to support sustainable development. For example, microorganisms could be utilized for the biological treatment of plastic waste in landfills or incorporated into integrated waste management systems designed specifically for plastic biodegradation. Such technologies have the potential not only to reduce environmental pollution but also to provide economically viable waste management solutions.

Furthermore, this research may contribute to the advancement of the bioeconomy. The compounds generated during plastic biodegradation, such as organic acids, may be recovered and utilized as feedstocks for the production of new materials or renewable energy sources. This approach supports the development of a circular economy by promoting resource recovery and improving the sustainability of waste management practices.

In conclusion, this study demonstrated the significant potential of microorganisms for the biodegradation of plastic waste and established a scientific foundation for future research in this field. Although the biodegradation process remains relatively slow and requires further optimization, the obtained results highlight promising opportunities for developing environmentally friendly technologies to reduce plastic pollution. By exploiting the genetic potential of microorganisms, optimizing environmental conditions, and validating the technology under natural conditions, microbial biodegradation may become an effective and sustainable strategy for environmental protection.

CONFLICT OF INTEREST

The author claims that there is no conflict of interest in the implementation of this study and the publication of the article.

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REFERENCES

[1] X.-G. Yang, P.-P. Wen, Y.-F. Yang, P.-P. Jia, W.-G. Li, and D.-S. Pei, “Plastic biodegradation by in vitro environmental microorganisms and in vivo gut microorganisms of insects,” *Frontiers in Microbiology*, vol. 13, Art. no. 1001750, 2023, doi: 10.3389/fmicb.2022.1001750

[2] A. Skariyachan *et al*., “Selection of microorganisms capable of polyethylene (PE) and polypropylene (PP) degradation,” *Microbiological Research*, vol. 267, Art. no. 127251, 2023, doi: 10.1016/j.micres.2022.127251

[3] S. Y. Choi, Y. Lee, H. E. Yu, I. J. Cho, M. Kang, and S. Y. Lee, “Sustainable production and degradation of plastics using microbes,” *Nature Microbiology*, vol. 8, pp. 2253–2276, 2023, doi: 10.1038/s41564-023-01529-1

[4] Y. Heris, “Bacterial biodegradation of synthetic plastics: A review,” *Bulletin of the National Research Centre*, vol. 48, Art. no. 87, 2024, doi: 10.1186/s42269-024-01241-y

[5] J. Choi *et al*., "Recent advances in microbial and enzymatic engineering for the biodegradation of micro- and nanoplastics," *RSC Advances*, vol. 14, pp. 9943–9966, 2024, doi: 10.1039/D4RA00844H .

[6] Gorish BMT, Abdelmula WIY, Sethupathy S, Dar MA, Shahnawaz M, Zhu D. Microbial degradation of polyethylene polymer: current paradigms, challenges, and future innovations. *World J Microbiol Biotechnol*. 2024;40(12):399. Published 2024 Dec 2. doi:10.1007/s11274-024-04211-8

[7] "Current advances, challenges and strategies for enhancing the biodegradation of plastic waste," *Science of the Total Environment*, vol. 906, Art. no. 167850, 2024, doi: 10.1016/j.scitotenv.2023.167850