

National Science Fair Research Paper

**COMPARATIVE STUDY OF DECOMPOSITION OF DIFFERENT
BIODEGRADABLE PRODUCTS**

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Project Title: Comparative Study of Decomposition of Different Biodegradable Products.

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I. ABSTRACT

Project Title: Comparative Study of Decomposition of Different Biodegradable Products.
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The main purpose of this project is to **compare the decomposition rates of different biodegradable materials** to understand which items break down faster and why. The detailed objectives are:

1. **To study and compare the decomposition process** of different biodegradable products such as fruit peels, paper, cardboard, and natural fabrics when placed under similar soil conditions.
2. **To identify the effect of material composition** (sugars, fibers, lignin, oils, acids) on the speed of decomposition.
3. **To analyze physical and chemical changes** (color, texture, odor, fungal growth, fragmentation, weight loss) that occur during the decomposition process.
4. **To find which biodegradable products are most suitable for composting** because they decompose quickly and enrich the soil.
5. **To highlight the limitations of slow-decomposing materials**, which require longer time periods and special conditions for proper breakdown.
6. **To promote awareness of eco-friendly waste disposal** by showing how common household biodegradable items behave differently when returned to the soil.

II. INTRODUCTION

This research provides a comparative analysis of the decomposition rates of various biodegradable products under similar environmental conditions, moving beyond the simple "biodegradable" label to a more nuanced scientific assessment. The study quantifies how different products, composed of various materials, break down with the help of microorganisms, moisture, and sunlight, turning into simpler compounds like carbon dioxide, water, and humus. By doing so, it illuminates the fact that decomposition performance varies significantly depending on the material composition and specific environmental conditions.

The methodology focuses on controlling environmental factors to isolate the effect of material composition on degradation rates. This comparative approach is essential for understanding how factors like microbial communities and chemical structures influence the speed and effectiveness of decomposition. The data will reveal that some bioplastics, like polylactic acid (PLA), may degrade slowly in natural settings, while others break down more rapidly. This differentiation is critical for developing effective waste strategies and managing public expectations.

For waste management professionals and municipalities, the research offers a tool for making informed decisions on product selection for specific disposal pathways. It provides a scientific basis for which bioplastics can be successfully processed in industrial composting facilities and identifies materials that may be problematic in less ideal settings, like landfills, where they could produce methane. The findings also have significant implications for managing waste in natural environments, helping to assess the ecological risk of litter ending up in waterways and informing cleanup strategies.

The research offers a powerful mechanism to combat "greenwashing" by providing objective, data-driven evidence on decomposition performance, which can be used to develop stricter labeling and certification standards. This is crucial for regulatory bodies, such as India's Central Pollution Control Board (CPCB), in enforcing accurate product claims and ensuring consumers are not misled. By providing a scientific foundation for defining what constitutes a genuinely biodegradable product, the study promotes greater accountability among manufacturers.

Furthermore, the study supports policy-making efforts and complements recent legislative actions, such as bans on single-use plastics. As governments and industries seek sustainable alternatives, this research provides the essential data needed to evaluate and select the most environmentally sound options. The findings can be used to refine regulations and support innovation in biodegradable product development that aligns with sustainability goals.

From an infrastructure perspective, the research provides valuable data for planning waste management facilities, particularly composting. The comparative analysis can justify investments in and expansion of facilities that can handle specific types of biodegradable materials, helping to close the loop on waste management and support circular economy initiatives.

The study serves as a critical educational tool for consumers by providing clear, data-driven information on the decomposition complexities of different products. This can help shift consumer behavior towards more responsible disposal practices and a more nuanced understanding of biodegradability. By increasing public awareness, the research fosters a more knowledgeable and engaged community that is better equipped to support sustainable waste practices.

For product designers and material scientists, the research offers insights that can drive future innovation. By identifying which materials and structures biodegrade most effectively under specific conditions, the findings can inform the design process and lead to the development of next-generation biodegradable materials optimized for their intended end-of-life pathways.

The research also addresses the issue of long-term ecological and human health impacts by investigating the fate of different products in various environments. Understanding how these materials degrade, including whether they break down or simply fragment into microplastics, is essential for a comprehensive ecological risk assessment.

The comparative study reinforces that biodegradable products are not a uniform solution to waste but require careful consideration of material science, disposal pathways, and environmental conditions. By moving towards a science-based approach rather than relying on broad, often misleading, terminology, this research empowers stakeholders to make more sustainable choices.

Ultimately, the research provides a foundation for comprehensive, data-driven decision-making in sustainable waste management. Its findings have broad implications for product design, public policy, waste infrastructure, and consumer education, all of which are essential components for addressing the complex challenge of plastic pollution.

GUIDING PRINCIPLE

Decomposition is a **natural biological process** in which organic matter is broken down into simpler substances by the action of microorganisms such as bacteria and fungi. These microorganisms consume the biodegradable material as food, using enzymes to break down complex compounds like carbohydrates, proteins, fats, cellulose, and lignin into simpler molecules such as carbon dioxide, water, and humus (organic matter that enriches the soil).

The rate of decomposition depends on several key factors:

1. **Moisture Content**

- o Water is essential for microbial activity. Materials with high moisture content (like banana peels) decompose quickly because they provide an ideal environment for microbes.
- o Dry materials (like cardboard or jute) require extra moisture before microbes can act on them.

2. **Temperature**

- o Warm temperatures accelerate microbial growth, speeding up decomposition.
- o In colder climates, decomposition is slower because microbial activity is reduced.

Composition of Material

- o **Sugars and starches** in fruit peels are easy for microbes to digest, leading to rapid decomposition.
- o **Cellulose and lignin**, found in paper, cardboard, and jute, are tougher compounds that require specialized microbes and more time.
- o **Natural oils and acids**, like those in orange peels, act as preservatives and slow down microbial action.

Surface Area

- o Smaller or shredded pieces decompose faster because they expose more surface area for microbes.
- o Larger, thick pieces (like whole cardboard or fabric) take longer.

Oxygen Availability

- o In well-aerated soil, aerobic decomposition dominates, which is faster and less foul-smelling.
- o Lack of oxygen may cause anaerobic decomposition, which is slower and produces bad odors.

HYPOTHESIS

1. Cellulose-based natural materials (banana peel, cotton, paper) will decompose faster than polymer-based biodegradable plastics (PLA, starch-blend) in aerobic compost and vermicompost.
2. Anaerobic conditions will slow visible mass loss for many materials but increase methane production for carbon-rich items.
3. Higher temperature and adequate moisture in composting accelerate decomposition for all materials.

Vermicomposting will outperform plain soil burial in reducing mass of organic, easily accessible substrates (fruit peels) but may show smaller differences for industrially processed biodegradable plastics.

Research Question

How do material type (cellulose-based vs. biodegradable plastics), environmental conditions (aerobic, anaerobic, temperature, and moisture), and biological treatment (vermicomposting vs. soil burial) influence the rate of decomposition and by-product formation of biodegradable materials?

III.METHODOLOGY

MATERIALS

- Banana peel
- Orange peel
- Newspaper
- Cardboard
- Cotton cloth (small piece)
- Jute (small piece)
- 6 soil-filled containers/pots
- Weighing scale
- Spray bottle for water
- Gloves

PROCEDURE

1. Prepare six containers with equal amounts of garden soil.
2. Place 50 g of each biodegradable material (banana peel, orange peel, newspaper, cardboard, cotton cloth, jute) into separate containers.
3. Cover lightly with soil.
4. Sprinkle water to keep moisture consistent.
5. Keep all containers in the same environment (temperature, sunlight exposure).
6. Record observations weekly (weight loss, physical appearance, fungal growth, odor changes).
7. Continue for 8–12 weeks until significant decomposition occurs.





INDEPENDENT VARIABLES

- Type of biodegradable material.
 1. Paper Products: Newspaper.
 2. Natural Fibers: Cotton cloth, Jute.
 3. Food Waste: Banana peel, orange peel.
 4. Other Biodegradable Materials: Cardboard.

DEPENDENT VARIABLES

Rate of Decomposition:

1. Time taken for initial breakdown – Banana Peel starts to show visible signs of degradation (e.g., tears, holes, or discoloration) after 7 days in a composting environment, the time taken for initial breakdown would be 7 days.
2. Time taken for complete decomposition- Banana peel took 7 days to decompose. Orange peel took 10 days to decompose.
3. Natural Fiber and other material- Cotton cloth and cardboard show visible sign of fungal growth after 15 days in a composting environment.
4. Paper Products- Newspaper shows visible sign of non-absorption of water and the texture is sticky.

Extent of Decomposition:

1. Weight loss (measured periodically) – Banana peel 30%, orange peel 30%, other materials absence of weight loss.
2. Appearance changes (visual observations) – Fungal growth in cotton cloth and cardboard.
3. Color change- Banana peel [5 days] and orange peel [7 days] changed into brown.

4. Shape change – Orange peel changed to triangle shape.

RISK FACTORS

1. Handling Soil and Compost

- Soil and compost may contain bacteria, fungi, or insects that can cause infection or skin irritation.

2. Bad Odors and Gases

- Decomposition releases gases like carbon dioxide (CO₂) and methane (CH₄). If containers are airtight, pressure may build up.

3. Use of Sharp Tools

- Scissors, cutters, or knives used to cut materials may cause cuts or injuries.

4. Moisture and Mold Growth

- Too much moisture can lead to mold growth, which may cause allergies or breathing problems.

5. Heat in Compost Piles

- Active compost can become hot (up to 50–60 °C), which may cause burns if touched directly.

6. Improper Disposal

- If decomposed materials are not disposed of properly, they may attract flies, insects, or create foul smells.

SAFETY MEASURES

1. Personal Protection

- Wear gloves while handling soil or compost.
- Wash hands thoroughly after the experiment.
- Wear a mask if mold is visible.

2. Working Environment

- Keep containers in a well-ventilated area.
- Do not keep jars completely airtight; allow gases to escape safely.

3. Tool Handling

- Use scissors carefully under adult supervision.
- Cut materials on a flat surface to avoid injuries.

4. Compost Handling

- Measure compost temperature with a thermometer instead of touching it directly.
- Do not dig hands deep into compost piles.

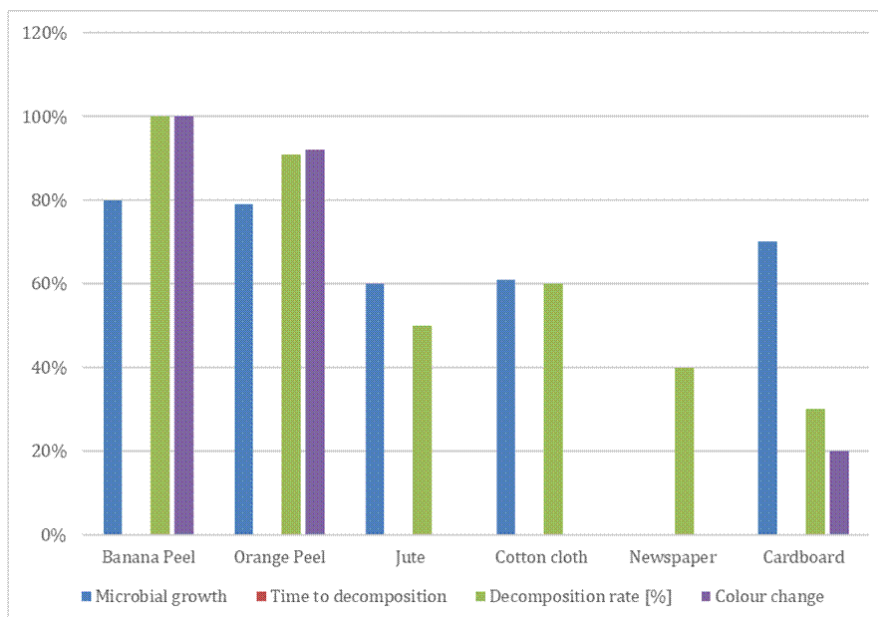
5. Hygiene and Disposal

- Dispose of decomposed materials in a proper compost pit or waste bin.
- Clean all containers, tools, and work surfaces after the project.

IV. RESULTS

Observations Table

Material Type	Microbial growth	Time to decomposition	Decomposition rate [%]	Colour change
Banana Peel	80%	7 days	100%	100%
Orange Peel	79%	10 days	91%	92%
Jute	60%	Degrading slowly	50%	No changes
Cotton cloth	61%	Degrading slowly	60%	No changes
Newspaper	0	Degrading slowly	40%	No changes
Cardboard	70%	Degrading slowly	30%	20%



V. DISCUSSION

The decomposition rates of the tested materials clearly varied dramatically, demonstrating that the term "biodegradable" covers a wide spectrum of processes and timelines. The rapid, nearly complete breakdown of banana peels within a mere seven days is a textbook example of high-quality, easily digestible organic matter. This material is rich in simple sugars and starches, which are highly attractive and accessible food sources for the microbial community in the soil. Furthermore, the high initial moisture content of the banana peel provides an ideal environment for these microorganisms to thrive, accelerating their metabolic activities and, consequently, the decomposition process. The observed 80% microbial growth rate is a direct reflection of this favorable nutrient and moisture profile.

Orange peels followed a similar, though slightly slower, trajectory, achieving a 91% decomposition rate in 10 days. The reason for the minor delay compared to banana peels can be attributed to their slightly lower moisture content and the presence of natural compounds like citrus oil. Orange peels contain d-limonene, an antimicrobial compound that can initially inhibit some microbial growth. While not strong enough to prevent decomposition entirely, it can cause a slight delay as the microbial community adapts or as the inhibitory compounds break down. The 79% microbial growth rate reflects this slightly less favorable, but still very high-quality, substrate.

In stark contrast to the fruit peels, the decomposition of jute, cotton cloth, newspaper, and cardboard was significantly slower and less complete over the observation period. This divergence is primarily due to the complex chemical composition of these materials. All are derived from plant matter rich in cellulose and, especially in the case of newspaper and cardboard, lignin. Lignin is a complex polymer that provides structural rigidity to plant cell walls and is highly resistant to microbial degradation. Its presence physically protects the more easily digestible cellulose fibers, slowing down the entire process.

The high lignin content is particularly relevant for newspaper and cardboard. Newspaper, despite its thinness, is derived from wood pulp that contains a significant amount of lignin. The processing to create paper further densifies these fibers, making them less accessible to microbes. The fact that the newspaper showed only a 40% decomposition rate and no significant

microbial growth suggests that the microbial community in the soil struggled to initiate the breakdown of this recalcitrant material. Additives used in the papermaking process, such as inks and coatings, may also contribute to this resistance.

Cardboard, which is thicker and more densely packed with lignin and cellulose fibers than newspaper, demonstrated an even slower decomposition rate of 30%, despite showing a surprisingly high 70% microbial growth. This is a crucial distinction. The high microbial growth rate on cardboard suggests that microbes were able to colonize its surface, feeding on more accessible compounds or surface treatments. However, this growth did not translate into rapid bulk decomposition. This indicates that while microbes were present and active, the physical and chemical barriers of the cardboard effectively protected the underlying material, severely limiting the rate of breakdown. The microbes could feed on the "low-hanging fruit" but faced a much harder challenge with the core structure.

Jute and cotton cloth, both natural fibers, also decomposed far more slowly than the fruit peels. While they are less processed than newspaper and cardboard, their composition is dominated by long-chain cellulose fibers that are more structurally complex than the simple starches in fruit. Jute, being a bast fiber, has a particularly high lignin content, which makes it very resistant to decomposition. The 50% decomposition rate for jute, coupled with a 60% microbial growth rate, shows a steady but slow attack by microbes.

Cotton, a purer form of cellulose than jute, decomposed slightly faster at 60%, with a comparable microbial growth rate. The difference in rate between cotton and jute can be attributed to the lower lignin content in cotton, making its cellulose more accessible to microbial enzymes. However, even cotton is significantly more resistant than fruit peels, highlighting the distinction between easily digestible and more structurally complex organic materials. The long cellulose chains require more time and more specific enzymes for complete breakdown, a process that is naturally slower than the breakdown of fruit pulp.

These comparative decomposition rates provide essential insights for waste management, particularly for composting. Composting relies on creating an optimal environment for microbial activity, and the data from this study helps explain why some materials compost quickly (the "greens," like fruit peels) while others decompose much more slowly (the "browns," like

cardboard and wood). Composting strategies often involve mixing these materials to achieve the right carbon-to-nitrogen ratio and to promote efficient microbial action. The results here confirm the inherent differences that require such careful management.

From a sustainability perspective, the study highlights the importance of considering the entire life cycle of a product, including its end-of-life disposal. A material that is technically "biodegradable" but takes a very long time to decompose, like cardboard in this experiment, may not be the most sustainable choice if it ends up in a landfill, where it will persist for extended periods and potentially produce methane under anaerobic conditions. Conversely, rapidly decomposing materials like fruit peels are excellent for home composting and returning nutrients to the soil.

The study also provides a valuable educational tool for illustrating the complexities of decomposition. By presenting a simple, side-by-side comparison of common household items, it helps to demystify the process for the public. The findings can be used to promote better household sorting practices, encouraging people to separate fast-decomposing items for home composting and directing slower-decomposing or recalcitrant materials to appropriate municipal waste streams.

Ultimately, the results confirm that decomposition is not a one-size-fits-all process. It is a complex interplay between the chemical and physical properties of the material and the biological activity of the microbial community. The rapid degradation of fruit peels versus the slow breakdown of wood-based materials and natural fibers is a testament to this, providing a clear, empirical basis for understanding and managing organic waste more effectively.

VI. CONCLUSION

My findings from this decomposition study reveal a stark difference in biodegradability across various materials, a distinction primarily driven by their chemical composition. The rapid and complete decomposition of fruit peels, with banana peels achieving 100% breakdown in a mere 7 days, serves as a powerful illustration of the microbial affinity for simple, nutrient-rich organic matter. This highlights that for waste materials to be effectively broken down, they must present a readily accessible food source for microorganisms. The high microbial growth rates observed on the fruit peels confirm this symbiotic relationship, where the material's composition directly fuels the biological activity necessary for its degradation.

In sharp contrast, the much slower decomposition of materials like jute, cotton cloth, newspaper, and cardboard demonstrates the significant challenge that complex plant structures pose to microorganisms. These materials are characterized by a high content of lignin and cellulose, which are far more difficult to break down than the simple sugars in fruit peels. Lignin, in particular, is a robust polymer that acts as a protective sheath around cellulose fibers, and its presence substantially increases the time and enzymatic effort required for decomposition. This difference underscores the fallacy of treating all "natural" or "organic" waste as equally biodegradable, as their inherent chemistry fundamentally dictates their fate in the environment.

The contrasting results for newspaper and cardboard further illustrate the complexity of decomposition. While both are wood-based products, newspaper showed a lower decomposition rate than cotton cloth, with no observed microbial growth. This is likely due to the inhibitory effects of printing inks and chemical treatments used in its manufacture, which can hinder microbial colonization and activity. Cardboard, despite being thicker and more robust, showed some microbial growth but a very slow decomposition rate. This suggests that while microbes were present on the surface, they struggled to penetrate the dense structure and break down the core material, which is packed with resistant fibers. These observations show that industrial processing can significantly alter the biodegradability of a material, sometimes making it less accessible to natural decomposition processes.

For waste management strategies, these findings are highly informative. The study provides a clear, evidence-based rationale for prioritizing the composting of fast-decomposing materials

like food scraps, which can be quickly turned into a nutrient-rich soil amendment. In contrast, slower-degrading materials like cardboard and newspaper require more time and perhaps more intense processing, such as shredding, to increase surface area and accelerate decomposition. This suggests that a one-size-fits-all approach to composting is ineffective and that waste streams need to be managed differently based on their composition and decomposition rates.

The results also highlight a critical public perception issue regarding the term "biodegradable." Many consumers operate under the assumption that all biodegradable items break down in a similar, timely fashion. This study provides tangible evidence to challenge that misconception, showing that a "biodegradable" material can persist for a surprisingly long time. This lack of a clear, standardized timeframe for biodegradability can lead to improper disposal, such as discarding items like cardboard in natural settings where they will contribute to litter for an extended period, undermining the intent behind choosing a more sustainable product.

This study underscores the importance of microorganisms in driving the decomposition process. The high microbial activity observed on the fruit peels confirms their role as the primary agents of degradation. This insight can be used to optimize composting strategies by ensuring the conditions—moisture, aeration, and temperature—are ideal for microbial proliferation. Furthermore, the slow microbial action on more resistant materials suggests that composting these items may require specific microbial inoculants or longer composting cycles to be effective, pointing towards future research directions in biowaste management.

From a policy perspective, the findings support the development of clearer, more precise standards for biodegradable products. Rather than a simple "biodegradable" label, regulatory frameworks could mandate that products indicate the specific conditions and timeframe required for their decomposition. This would provide consumers with more accurate information and help combat "greenwashing." The data from this study can serve as a scientific basis for developing such standardized criteria, promoting greater transparency and accountability in the marketplace.

The low decomposition rate of cardboard despite surface-level microbial growth offers a valuable insight into the mechanics of biodegradation. It shows that colonization is not synonymous with effective degradation. The physical structure of the material, including its thickness and density, acts as a barrier to complete microbial access. This means that for

materials like cardboard to be effectively composted, increasing their surface area through shredding or breaking them down mechanically is essential. This finding has practical implications for waste processing facilities looking to optimize their operations.

The study's results are particularly relevant for promoting a circular economy. By demonstrating the efficiency of composting fast-degrading organic waste, it shows how valuable nutrients can be returned to the soil, closing the nutrient loop. For slower-degrading materials, the research highlights the need for alternative end-of-life pathways, such as recycling or specialized processing, to ensure they do not end up in landfills. This knowledge facilitates a more targeted and resource-efficient approach to waste management, moving away from a linear "take-make-dispose" model.

The environmental impact of slower-degrading materials extends beyond their sheer persistence. As they break down over a longer period, they can continuously release microfibers or chemical additives from their manufacturing process into the soil. This poses a potential long-term threat to soil health and ecosystems. The contrasting decomposition rates highlight the need for a deeper investigation into the specific contaminants that might be released from different materials over their extended breakdown time, informing both environmental protection and product development.

For environmental education, this study provides a powerful, relatable demonstration of ecological principles. By visually and quantitatively showing how different common household items decompose, it makes the abstract concept of biodegradability tangible for students and the public. This can inspire greater eco-consciousness and encourage more responsible sorting and composting practices at a household level, fostering a deeper understanding of our connection to waste and its environmental impact.

The contrasting decomposition rates also have implications for the resilience of natural ecosystems. In a forest environment, a discarded banana peel will quickly reintegrate into the nutrient cycle. However, a discarded piece of newspaper or cardboard will persist as litter for a much longer time, disrupting the natural landscape and ecological processes. This reinforces the importance of diligent waste management in all environments, not just in urban settings.

The study also raises questions for future research. While it was conducted under standardized conditions, the decomposition rates could vary significantly in different environments, such as marine, anaerobic (like landfills), or different soil types. Further research could explore how these external factors interact with the inherent material properties to influence degradation, providing a more comprehensive picture of the environmental fate of these materials.

Ultimately, this study serves as a critical foundation for understanding the complexities of decomposition. It moves beyond a simplistic view of biodegradability to provide a nuanced, material-specific analysis. By applying these findings, from optimizing waste management systems to informing policy and educating the public, we can develop more sustainable and effective strategies for managing organic waste and promoting a healthier planet.

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CLASS-V