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Biodegradation potentials of husk-based low-density polyethylene composites by *Actinomyces appecies*, *Clostridium cellulolyticum*, and their synergistic interaction

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Abstract

The environmental durability of conventional low-density polyethylene (LDPE) poses a significant challenge for waste management, prompting extensive research into more biodegradable alternatives and biologically driven degradation methods. The aim of this study, was to assess the biodegradation behavior of various *Zea mays* husk-polymer composites to evaluate their environmental degradability and potential for sustainable material applications. Four composites, delignified (D5P5), de-hemicellulolised (H5P5), bleached (B5P5), and untreated (U5P5), were exposed to *Actinomyces appecies* and *Clostridium cellulolyticum* for a 12-week period. The results revealed that the de-hemicellulolised composite (H5P5) and bleached composite (B5P5) exhibited higher degradation rates compared to their untreated and delignified counterparts. This enhanced biodegradability was attributed to structural modification during pre-treatment, which increased microbial accessibility and enzyme penetration. The synergistic action of *Actinomyces appecies* and *Clostridium cellulolyticum* further promoted cellulose breakdown, indicating their effectiveness in composite degradation. In contrast, the result also showed that the low-density polyethylene (LDPE) demonstrated minimal degradation (0.25%) after nine weeks, confirming its resistance to microbial activity. The findings demonstrate that pre-treatment of maize husk fibers significantly improves the biodegradability of polymer composites. De-hemicellulolised and bleached composites showed the highest microbial decomposition, making them promising candidates for eco-friendly applications. It is recommended that future studies focus on optimizing pre-treatment processes and extending the biodegradation period to enhance microbial performance. The development of maize husk-based composites could serve as a viable alternative to non-biodegradable plastics in packaging and other industrial uses.

Keywords: Biodegradation; *Actinomyces appecies*; *Clostridium cellulolyticum*; *Zea mays* husk; composites.

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INTRODUCTION

Plastics, particularly low-density polyethylene (LDPE), are among the most pervasive synthetic polymers used globally due to their excellent flexibility, durability, and low production cost (Debele et al., 2024). However, these same traits render them resistant to environmental degradation and contribute significantly to plastic pollution (Law & Narayan, 2022). With growing awareness of the ecological and health impacts of plastic accumulation, there is urgent demand for novel materials and strategies that facilitate polymer degradation (Kanwal et al., 2025). One promising approach is incorporation of natural fillers such as agricultural husk (Alichó et al., 2026), which can enhance biodegradability by both altering the composite's physical properties (e.g. increasing hydrophilicity, porosity) and serving as an accessible substrate for microorganisms (Sholokhova et al., 2024). Microbial degradation of polymers is an area of active research, some bacterial and fungal species produce enzymes capable of breaking down polymeric chains, particularly when the polymer is made more accessible, through pre-treatment or formulation with biofillers (Panigrahi et al., 2025). *Clostridium cellulolyticum* is notable for its cellulolytic (cellulose-degrading) capabilities and well-characterized "cellulose degradome," making it a strong candidate for decomposing composites that contain cellulose or other lignocellulosic materials (Xu et al., 2013). Meanwhile, *Actinomyces* *appecies* contributes distinct enzymatic activities that complement those of *C. cellulolyticum* (Xia et al., 2021). Synergistic interactions among microbial species hold potential to improve degradation rates beyond what each species achieve alone (Wu et al., 2023). A growing body of research has explored LDPE (and other polyolefins) composites filled with natural materials, cellulose, starch, husk, straw, etc. to improve biodegradability and reduce environmental persistence (Sharma et al., 2025). For example, Halimatuddahlia & Rambe (2014) evaluated LDPE composites filled with cellulose and cellulose acetate (10 wt%) and found that weight loss and surface degradation were significantly greater in cellulose-filled composites than in LDPE alone under soil burial or open environmental exposure (Halimatuddahlia & Rambe, 2014). Similarly, composites of LDPE with rice straw fillers have been characterized: increasing filler load and reducing particle size often increase tensile modulus and stiffness, though typically at the expense of elongation at break and impact strength. The same studies often find that natural fillers enhance water uptake, which may facilitate microbial ingress and enzymatic attack (Zhou et al., 2024). The present study investigates the biodegradation potential of husk-based LDPE composites by *A. appecies*, *C. cellulolyticum*, and their combined action over 12 weeks. Four composites, delignified (D5P5), de-hemicellulolised (H5P5), bleached (B5P5), and untreated (U5P5), were compared in terms of weight loss, surface degradation, and morphological changes. Particular attention

was given to how the inclusion of husk affects microbial colonization and structural alteration and whether the combined microbial inoculation leads to enhanced composite breakdown.

Materials and methods

Collection, identification and processing of *Z. mays* husk

The *Z. mays* husk utilized in this study was acquired from an agricultural site located at Adokasa, Karu LGA of Nasarawa state in Nigeria. The husk was identified as *Poaceae* and a voucher NIPRD/H/7317 was assigned. The husk was oven dried at 100 °C for 4 hours before being processed into powder. LDPEs were gathered from selected dump sites, washed, dried, and chopped into 50µm size using USHA Mixer Electric Grinder (MG2053N, India).

Sample preparation

The husk was oven dried at 100 °C for 4 hours and ground into powder (Okere et al., 2015) using USHA Mixer Electric Grinder (MG2053N, India). The husk was reduced to 50 mesh particle size using American Society for Testing and Materials (ASTM) standard sieves. The powdered husk was then stored in moisture free and air tight plastic container

Formulation of cellulosic-low density polyethylene composites

Cellulosic LDPE composites were formulated by mixing different mass ratios of husk and LDPE as shown in Table 1.

Mixing

According to the formulation protocol, the composites samples were produced by a mixing process involving the introduction of the LDPE while the two rolls mill machine were in counter clockwise motion and soften for a period of 5 min at a temperature of 170 °C. Upon achieving a band and bank formation of the LDPE on the front roll, the prepared husk was introduced gradually to the bank, cross mixed and allowed to mix for 3 min to achieve homogeneity. The composites were sheeted out and labeled accordingly.

Hot pressing

The various mixes obtained from the mixing process was placed into a metal mould of dimensions 120 mm x 100 mm x 3.2 mm and was placed on the hydraulic hot press for shaping at 150 °C and 2.5 MPa for 5min. The composites were then cooled under same pressure on a cool press plate for 5 min, removed and labelled accordingly (Wilkinson, 2018).

Degradation assessment of the composites

The selected composites with the superior mechanical properties were cut into sizes, cleansed with distilled water, sterilized using absolute ethanol, weighed, and stored in clean tubes for future utilization. Nutrient agar (NA) was prepared

as the chosen medium for microorganism culture. Exactly 28 g of NA was dissolved in 1000 mL of distilled water, autoclaved at 121 °C for 15 minutes, and stored in the laboratory refrigerator. *A. appecies* (A), *C. cellulolyticum* (C) and a mixture of both (AC) were sub-cultured in nutrient agar (NA) culture media, separately. The organisms, *A. appecies*, and *C. cellulolyticum*, were utilized due to their efficient cellulose degradation capability with optimum growth temperature of 15–35 °C (Fosses et al., 2017). Control samples were also included, consisting of LDPE without husk filler. Nutrient agar media, sub-cultured with 0.5 ml of *A. appecies*, *C. cellulolyticum* and a mixture of the two organisms. The composites and LDPE, with known weights, were added to the media at 35°C. The weight loss was recorded every 3 weeks over a period of 12 weeks. After each period of three-week of incubation, the composites and LDPE surfaces were washed with a 0.5% sodium hypochlorite solution and 70% v/v ethanol (Park & Kim, 2019). The initial weight as well as the final weight of the composites were

measured in triplicate (Aftab et al., 2023). The weight loss (%) was determined according to equation 1

$$\text{Biodegradation (\%)} = \frac{\text{Initial Weight (w1)} - \text{Final Weight (w2)}}{\text{Initial Weight (w1)}} \times 100.. (1)$$

Statistical analysis of data obtained

All measurements were performed in triplicate, and mean values ± SEM were recorded. Results were analyzed statistically using descriptive method.

Results and Discussion

Biodegradation potentials of composites

Figures 1(a and b), show the biodegradation of D₅P₅ and H₅P₅ composites after 12 weeks of exposure to the organisms. It indicated that H₅P₅, Figure 1 (b) was the most degraded composite under the activities of *A. appecies* and *C. cellulolyticum* compared to D₅P₅, Figure 1 (a).

Table 1: Formulation of composites

| ZH (%) | DH(%) | HH(%) | BH(%) | LDPE(%) |
|--------|-------|-------|-------|---------|
| 10 | 10 | 10 | 10 | 90 |
| 20 | 20 | 20 | 20 | 80 |
| 30 | 30 | 30 | 30 | 70 |
| 40 | 40 | 40 | 40 | 60 |
| 50 | 50 | 50 | 50 | 50 |
| 60 | 60 | 60 | 60 | 40 |
| 70 | 70 | 70 | 70 | 30 |
| 80 | 80 | 80 | 80 | 20 |
| 90 | 90 | 90 | 90 | 10 |

Key: ZH = *Z. mays* husk, DH = Delignified husk; HH = De- hemicellulolised husk; BH = Bleached husk, and LDPE = Low density polyethylene

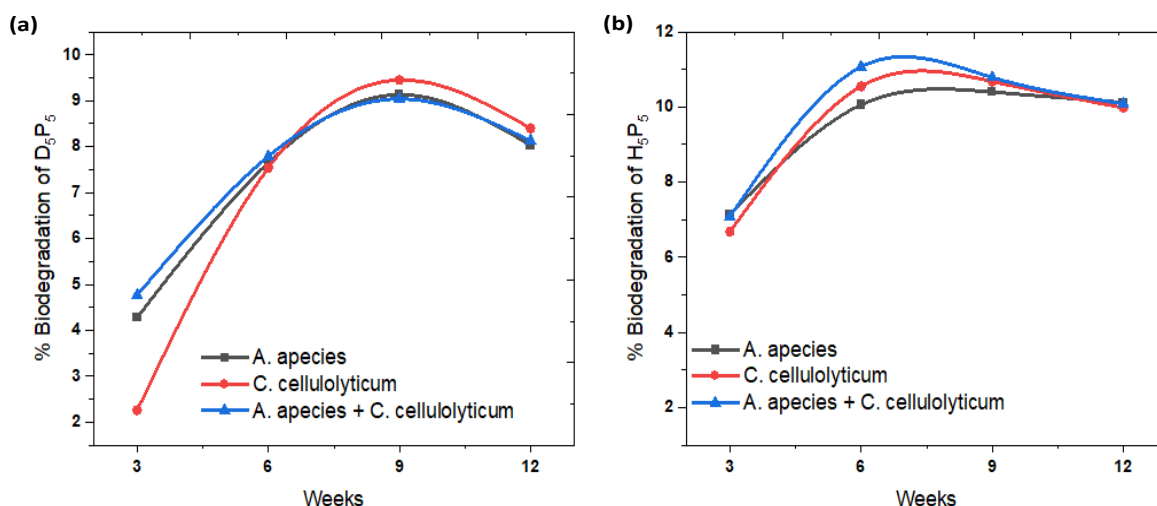


Figure 1: Percentage biodegradation of the (a) delignified (D₅P₅) and (b) de-hemicellulolised (H₅P₅) husk composites within a study period of 3 - 12 weeks (Figure 1 [a and b]), showed the biodegradation of B₅P₅ and U₅P₅ composites after 12 weeks of exposure to the organisms, in which B₅P₅, Figure 2(a), degraded more and under the influence of synergetic organisms, *A. appecies* and *C. cellulolyticum* compared to U₅P₅, Figure 2(b).

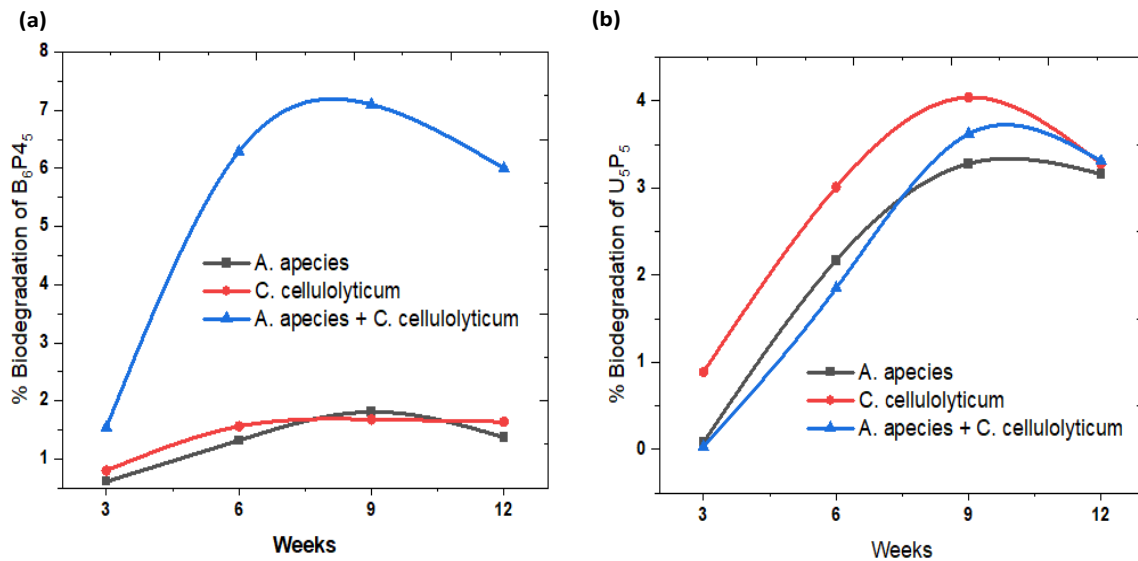


Figure 2: Percentage biodegradation of the (a) bleached (B₅P₅) and (b) untreated (U₅P₅) husk composites within a study period of 3 - 12 weeks.

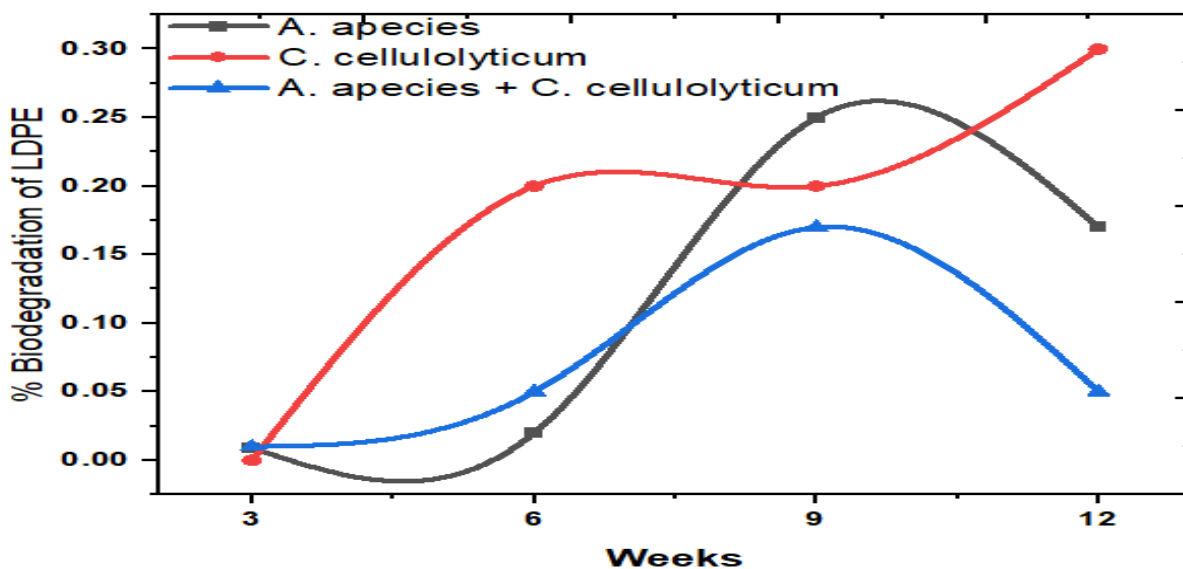


Figure 3: Percentage biodegradation of LDPE within a study period of 3 - 12 weeks. After 12 weeks of exposure to the organisms, LDPE had a minimal biodegradation, with (0.25 %) of it being degraded at the 9th week under the action of *A. species*.

Percentage biodegradation of the composites

Figures 1 illustrates the typical growth phase (lag, exponential, and stationary phases) exhibited by *A. species*, *C. cellulolyticum*, and the synergistic organisms (*A. species*, and *C. cellulolyticum*) as they cleave to the surface of the composite material (Li et al., 2018). The lag phase of each was observed between weeks 3 to 6, as the organisms require time to cleave to the surface of the composite material and also adapt to the new carbon source resulting in the initially slow degradation due to biooxidation observed as weight loss at week 4. At the exponential growth phase (week 6 to 9) of

the organisms, there was an increase in the % degradation with a corresponding weight loss peak, suggesting a rapid consumption of the composites during cell growth resulting in polymer fragmentation, due to potential utilization of the composites as carbon source for growth (da Silva et al., 2019). At the stationary growth phase, (week 9 to 12) there was a decrease in degradation process which can be attributed to the potential bio-assimilation of the microorganism to the composite that resulted in more composite bio-fragmentation, leading to stationary growth phase. Comparably, the percentage of D₅P₅ degradation with regard

to *A. appecies*, *C. cellulolyticum*, and the synergistic organisms (*A. appecies* and *C. cellulolyticum*) is depicted in Figure 1(a). The organisms exhibit comparable activity, peaking at the ninth week when *C. cellulolyticum* had the highest percentage of D₅P₅ degradation (9.8 %), followed by *A. appecies* (9.2 %) and the synergistic organisms (8.8 %). However, comparing the activities of the organisms on D₅P₅, it shows that *C. cellulolyticum* was the most effective for its degradation. The observed degradation could be due to the removal of lignin, which agrees with da Silva et al. (2019) report on Effect of lignin as accelerator of the biodegradation process of poly (lactic acid)/lignin composites, Materials Science and Engineering: B 251. Generally, both organisms show decline in their activities at the 12th week of exposure, which can be attributed to the complete utilization of the nutrients required by the organisms. However, comparing the percentage degradation of H₅P₅ with respect to the organisms as illustrated in Figure 1 (b), the organisms showed resemblance in activities on H₅P₅, displaying optimal degradation between the 6th and 7th week of exposure. The synergistic organisms had the highest degradation (11.5%), followed by *C. cellulolyticum* (10.8%) and *A. appecies*, (10.2%). This revealed that de-hemicellulisation, rendered the composite more susceptible to degradation by the synergistic organisms. Further, comparing the percentage degradation of D₅P₅ with H₅P₅, as shown in Figures 1 (a and b), it was evident that H₅P₅ degraded more, 11.5%, compared to D₅P₅ (8.8%) with respect to the synergistic organisms. Additionally, H₅P₅ had the highest degradation (10.8%), under the activity of *C. cellulolyticum*, Figure 1(b), compared to D₅P₅ (9.8%), Figure 1 (a). *A. appecies* also degraded H₅P₅ more (10.2%), Figure 1 (b) compared to D₅P₅ (9.4%), Figure 1 (a). This is attributed to high carbon content due to the removal of hemicellulose from the husk, that renders the composite material more prone to organisms' activities, this concurs with Banik et al. (2017) work on an overview of lignin and hemicellulose effect upon biodegradable bamboo fiber composites due to moisture. The percentage biodegradation of B₅P₅ and U₅P₅ after 12 weeks of exposure as shown in Figures 2 (a-b) however, indicated that B₅P₅ had the highest degradation (7.5%) within 8 weeks by the activity of synergistic organisms. Additionally, based on the exposure time, specifically at the 9th and 12th week, the activity of the organism declined, which is an indication that the organisms required nutrient for continuous action would have been exhausted. The result further revealed that *A. appecies*, and *C. cellulolyticum* had similar action on B₅P₅, degrading 1.7 and 1.5 % within the 6th and 9th week of exposure, Figure 1 (a). However, Figure 2 (b), showed that U₅P₅ had the greatest degradation (4.5%), by *C. cellulolyticum*, and followed by synergistic organisms (3.7%) and *A. appecies* (3.3 %) within 9 weeks of exposure. Meanwhile, comparing the percentage degradation of the pre-treated and untreated composites with respect to the organism's activity, the results illustrate that the pre-treated composites, D₅P₅, H₅P₅ and B₅P₅ were better degraded,

Figures 1 (a - b) and 1.1(a), compared to the untreated, U₅P₅, figure 2(b). Furthermore, considering degradation of the pre-treated composites with respect to their exposure, H₅P₅, was the most degraded (11.5 %), Figure 1 (b), followed by D₅P₅, (8.5 %), Figure 1 (a), and B₅P₅ (7.2 %), Figure 2 (a), under the activity of the synergistic organisms as well as *C. cellulolyticum*. Generally, LDPE showed very minimal degradations (0.25 %) by *A. appecies*, (0.20 %), *C. cellulolyticum*. and (0.16 %) by the synergistic action, as illustrated in Figure 3 compared to the percentage degradations observed in Figures 1 (a-b) and 2 (a-b). The findings on degradation aligns with that of Łukawski et al (2022), which revealed that as a result of absorbed water, microorganisms may be able to thrive and cause biological assaults as well as the eventual breakdown of composite structures.

Conclusion

Importantly, the biodegradation potential of the produced composites was performed using *A. appecies*, *C. cellulolyticum*, and their synergistic combination. The results indicated that *C. cellulolyticum* predominantly degraded delignified composite (D₅P₅) (9.5%) while *A. appecies* and the synergistic organisms degraded it by 9.2% and 9.0% respectively. Conversely, the synergistic organisms exhibited highest degradation of de-hemicellulolised composite (H₅P₅) (11.5%) compared to *A. appecies* (10.2%) and *C. cellulolyticum* (10.5%). Furthermore, the percentage degradation of bleached composite (B₅P₅) indicated that the synergistic organisms were the most effective agents, breaking down 7.5% of its components within 7 weeks. In addition, the percentage degradation of untreated composite (U₅P₅), indicated that *C. cellulolyticum* was the best degradation organism, capable of degrading up to 4.5% of its components in 9 weeks. In contrast, LDPE exhibited only minimal degradation by the respective organisms, with *A. appecies* degrading LDPE by only 0.25 % in the 10th week of exposure.

Conflict of Interest

The authors have declared that there is no conflict of interest.

Authors Contribution

JOA and FKO conceptualized the study; JOA performed the methodology; MDA and SMG did the validation; PI did the formal analysis, resources and supervision; MDA and FKO performed the data investigation; SMG handled the data curation; JOA wrote the original draft; SMG and FKO performed writing review and editing; JOA did project administration. All authors read and agreed to the final version of the manuscript.

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