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PERFORMANCE AND ENVIRONMENTAL ASSESSMENT OF SUGARCANE BAGASSE PLATES FOR SUSTAINABLE FOOD SERVICE

Original Article

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ABSTRACT

Background: The increasing environmental burden of plastic and Styrofoam waste has intensified the global demand for biodegradable and renewable alternatives in food packaging. Institutional canteens, which generate large volumes of disposable tableware, represent a critical area for implementing sustainable materials. Sugarcane bagasse, an abundant agricultural by-product rich in lignocellulosic fibers, offers significant potential as a biodegradable substrate when combined with natural biopolymeric binders such as corn starch.

Objective: This study aimed to design and evaluate a biodegradable plate fabricated from sugarcane bagasse and corn starch, assessing its mechanical strength, moisture absorption, and biodegradability to determine suitability for institutional food service applications.

Methods: Four plate specimens (11.5 cm diameter, 0.1 cm thickness) were fabricated using a composite mixture containing 56 g dried bagasse fibers and 35 g corn starch, with additions of rose extract, glycerin, tea tree oil, and vegetable oil for improved flexibility. Mechanical performance was assessed through tensile testing using a calibrated Newton meter, while water absorption was measured after five-minute immersion in 250 mL of distilled water. Biodegradability was evaluated under soil burial conditions for up to eight days, and functional usability was tested through user evaluation with standard food loads.

Results: The mean corrected tensile load was 3.15 N, corresponding to a mean tensile strength of 1.26×10^5 Pa (0.126 MPa). Moisture absorption averaged 14.89 mL, equivalent to 5.95% of initial volume, indicating moderate hydrophilicity. Complete biodegradation occurred within eight days under natural soil conditions, with oven-baked samples decomposing faster than air-dried ones. User assessments confirmed adequate mechanical support for food items, including up to three pizza slices without deformation.

Conclusion: The study demonstrated that sugarcane bagasse–starch composites can serve as cost-effective, eco-friendly substitutes for conventional disposable plates. Although mechanical performance and biodegradability were satisfactory, further optimization of compaction pressure and adhesive concentration is needed to minimize porosity and moisture uptake, enhancing the material's long-term stability and market potential.

Keywords: Biodegradability, Environmental sustainability, Natural fibers, Plastic alternatives, Renewable materials, Starch polymers, Sugarcane bagasse.

INTRODUCTION

Escalating global environmental concerns have underscored the necessity of re-evaluating the ecological consequences of everyday human activities. One such overlooked yet significant contributor to environmental degradation is the extensive use of disposable dining ware in institutional environments, particularly school canteens. The habitual reliance on plastic and Styrofoam plates, chosen primarily for their low cost and convenience, has led to the generation of vast quantities of non-biodegradable waste that persist in landfills for decades, leach toxic compounds into soil and water, and ultimately threaten both ecological balance and human health (1,2). The persistence of these materials in terrestrial and aquatic ecosystems facilitates their fragmentation into microplastics, which infiltrate food chains and pose toxicological risks, particularly for children who are physiologically more vulnerable to environmental contaminants (3). Plastic-based tableware, derived predominantly from petroleum polymers, is emblematic of the broader challenge of unsustainable material dependence. Despite their short-term functional utility, such materials exhibit exceptional resistance to natural degradation processes, remaining in the environment for centuries and contributing to resource depletion and waste accumulation pressures (4). Styrofoam, the commercial form of expanded polystyrene foam, represents one of the most environmentally persistent synthetic materials in circulation. Originally developed for insulation purposes, it now dominates disposable packaging due to its light weight and thermal insulation capacity. However, its low biodegradability, high air content, and potential to fragment into microscopic particles have resulted in widespread contamination of marine and coastal ecosystems, endangering aquatic organisms and contributing to carcinogenic and reproductive toxicities across multiple species (5,6). Current data suggest that plastic derivatives, including polystyrene, occupy approximately one-fourth of global landfill volume, reinforcing their role in the escalating solid waste crisis (7).

The environmental burden of polystyrene extends beyond disposal. Its manufacturing process relies on nonrenewable, ozone-depleting compounds such as chlorodifluoromethane (HCFC-22), and the production of these materials releases volatile hydrocarbons that react with nitrogen oxides under sunlight to form ground-level ozone, a pollutant with well-documented respiratory and ecological impacts (8). Consequently, a paradigm shift toward renewable and biodegradable alternatives has emerged as a global imperative. Among such alternatives, bioplastics derived from corn or potato starch have gained attention; however, their energy-intensive production often offsets their ecological benefits by contributing to greenhouse gas emissions (9,10). A more sustainable innovation lies in the utilization of lignocellulosic agricultural residues, such as sugarcane bagasse, which possess inherent carbon sequestration capacity and require minimal energy for processing. Sugarcane bagasse—constituting approximately 45–55% cellulose, 20–25% hemicellulose, and 18–24% lignin—provides a structurally robust and biodegradable base for fabricating eco-friendly tableware (11). Under controlled composting conditions, bagasse-based materials completely decompose within 60–90 days, returning organic nutrients to the soil and supporting the principles of a circular economy. This transformation not only reduces landfill accumulation but also valorizes agricultural by-products, diminishing the need for deforestation and minimizing chemical leaching into ecosystems (12). Given that approximately 380 million metric tons of plastic are produced globally each year—half of which is intended for single-use purposes—the urgency to adopt renewable, biodegradable materials has never been greater (13). Bagasse-derived tableware offers a practical, sustainable, and economically viable alternative for institutional dining settings such as school canteens, combining functional durability with environmental responsibility. The present study was undertaken to design and evaluate a prototype dining plate fabricated from sugarcane bagasse, with the objective of assessing its mechanical strength, biodegradability, and suitability for routine use in school canteens as a sustainable alternative to conventional plastic and Styrofoam-based tableware.

METHODS

This experimental study was conducted to design, fabricate, and evaluate biodegradable tableware derived from sugarcane bagasse and corn starch, utilizing accessible and low-cost materials compatible with domestic fabrication conditions. The design followed a descriptive-experimental approach emphasizing replicability without industrial apparatus. Ethical approval for the study was obtained from the Institutional Review Board of the Department of Environmental and Materials Research and all procedures were performed following relevant biosafety and environmental handling guidelines. The experimental design did not involve human or animal subjects; therefore, formal consent procedures were not applicable. A biodegradable and sustainable prototype plate was fabricated using locally sourced materials to ensure environmental compatibility and cost-effectiveness. Bagasse, an agro-industrial residue from sugarcane processing, served as the principal fibrous component due to its high availability and favorable physicochemical properties such as biodegradability, compostability, and structural strength. In Pakistan, nearly 30–40 million tons of sugarcane are processed annually, generating approximately 12 million tons of bagasse, making it an abundant and underutilized resource (4). Corn starch was used as a natural binder because of its biodegradable and non-toxic characteristics and its established compatibility with food contact applications. Additional natural additives—rose extract for fragrance, tea tree oil for antimicrobial activity, glycerin for plasticity, and vegetable oil as a release agent—were incorporated to enhance functional performance and safety. Four prototype plate specimens were produced, each with a diameter of 11.5 cm and a thickness of 0.1 cm. The fabrication process was performed using simple domestic tools including a household blender, measuring utensils, a drying oven, and stainless steel or silicone molds. The complete list of materials and apparatus comprised dried sugarcane bagasse, corn starch, distilled water, rose extract, glycerin, tea tree oil, vegetable oil, a commercial non-stick spray, a glue gun with hot melt adhesive, three 250 mL beakers, and a Newton meter for tensile testing.

Plate fabrication procedure

Pre-processing of bagasse: Dried bagasse (56 g) was pulverized using a household blender to obtain a fine, uniform fiber powder. The grinding process enhanced surface area and improved bonding efficiency with the starch adhesive.

Preparation of starch adhesive: Corn starch (35 g) was mixed with distilled water (250 mL) in a stainless-steel vessel to create a uniform slurry. Rose extract (50 mL, prepared at a 5:1 water-to-rose ratio), glycerin (30 mL), and tea tree oil (20 mL) were subsequently added. The mixture was heated to 70 °C for 3 minutes with continuous stirring until a viscous gel-like adhesive formed. The mixture was then allowed to cool while stirring to prevent phase separation.

Composite mixing and molding: Approximately 14 g of processed bagasse was combined with 40 mL of the prepared starch adhesive to form each plate specimen. The mixture was manually blended using a spatula until a cohesive composite was obtained. Molds were pre-coated with a thin layer of vegetable oil or non-stick spray to ease demolding. The mixture was then compressed into molds (11.5 cm diameter, 0.1 cm thickness) to achieve smooth and uniform distribution.

Drying and post-treatment: The molded samples were air-dried for 48 hours in a ventilated environment, followed by oven drying at 80 °C for 30 minutes to achieve complete dehydration and dimensional stability. Continuous monitoring prevented over-drying or brittleness. After cooling to ambient temperature, plates were demolded using gentle pressure to avoid structural deformation.

Characterization methods

1. Tensile (maximum-force) test: Mechanical strength was evaluated by measuring the maximum tensile load sustained before failure. Each specimen was fitted with a metallic pin at the center, secured with hot-melt adhesive, and attached to a calibrated Newton meter. Controlled tension was applied until fracture occurred, and the peak force was recorded as the tensile strength. Environmental conditions such as specimen thickness, strain rate, and temperature were controlled. The Newton meter exhibited a zero-error offset of 0.25 N, and all measurements were corrected accordingly to ensure precision.

2. Moisture-absorption test (short-term immersion): Water absorption capacity was analyzed by immersing three specimens (3.5 cm × 2.5 cm × 0.1 cm) in 250 mL of distilled water for five minutes. The reduction in water volume represented the absorbed moisture. Moisture absorption (MA) was computed using the formula: **MA = Vi – Vf**,, where *Vi* = initial water volume (mL) and *Vf* = final volume after immersion (mL). Consistent time intervals and controlled environmental conditions minimized variability.

3. Biodegradability (soil burial) test: Biodegradation behavior was assessed through a soil burial test. Two types of specimens—oven-baked and air-dried—were embedded in natural soil under controlled moisture and depth conditions. Degradation was monitored over six days, with qualitative and quantitative observations recorded on days 2, 4, and 6. Changes in surface integrity, mass reduction, and structural cohesion were used to evaluate biodegradation performance.

Experimental Design and Fabrication Procedure

Day 1: Material Screening and Adhesive Preparation: Initial material screening evaluated various natural fibers for suitability. Wheat husks were rejected due to poor adhesion, whereas bagasse exhibited superior compatibility with starch-based binders. A preliminary starch-water mixture was tested to identify optimal viscosity and bonding capacity.

Day 2: Adhesive Optimization and Material Integration: The adhesive composition was optimized by adjusting starch-to-water ratios, with 1:4 (w/v) identified as ideal. Heating and stirring enhanced the mixture's uniformity, producing a paste that integrated effectively with bagasse fibers to form a moldable pulp.

Day 3: Environmental Conditioning of Fiber Material: The effect of environmental exposure was studied by storing bagasse under sunlight and in dark conditions. Sunlight exposure improved dehydration and moldability, whereas dark storage increased moisture retention. Comparative tests with banana peels were also performed to explore alternative fiber sources, though bagasse demonstrated superior workability.

Day 4: Plate Molding and Additive Evaluation: Optimized bagasse–starch composites were molded into standardized plates. Hydrogen peroxide was introduced experimentally to evaluate potential antimicrobial and bleaching effects, while rosewater was added for fragrance. Samples were dried using both sunlight and oven baking to compare physical properties and durability.

Day 5: Banana Peel Composite Trials: Banana peels were boiled, rinsed, and blended with starch and rosewater to form a comparative pulp. Hydrogen peroxide was tested again for potential whitening effects. However, the resulting composites exhibited weaker structural integrity and were not pursued further.

RESULTS

The tensile strength evaluation of the bagasse–corn starch composite demonstrated consistent mechanical performance across both trials. The corrected tensile force values, adjusted for a systematic zero error of 0.25 N, were 2.95 N for the first test and 3.35 N for the second, yielding a mean force of 3.15 N. Considering the specimen's cross-sectional area of 2.5×10^{-5} m² (width 0.025 m and thickness 0.001 m), the calculated tensile strength values were approximately 1.18×10^5 Pa (0.118 MPa) and 1.34×10^5 Pa (0.134 MPa) for the respective tests. The mean tensile strength of 1.26×10^5 Pa (0.126 MPa) represented the composite's overall resistance under tensile loading conditions. The mechanical performance, when translated into a real-world scenario, indicated that the material could withstand an equivalent load of approximately 3.15 N, corresponding to the combined gravitational force of three 100 g pizza slices, each exerting roughly 0.98 N of load (7,14). Although the measured strength was significantly lower than that of structural polymers or metals, the results confirmed adequate resistance for lightweight food-service applications where biodegradability and low cost are prioritized over high mechanical endurance. The moisture absorption test revealed that the fabricated plates demonstrated moderate hydrophilicity. The three tested specimens absorbed 11.25 mL, 15.90 mL, and 17.50 mL of water, respectively, from an initial 250 mL immersion volume. The mean absorption value was 14.89 mL, corresponding to approximately 5.95% of the total fluid volume. Variability among replicates reflected minor differences in surface texture, porosity, and molding consistency. Environmental factors such as humidity and evaporation likely contributed to these small deviations, though all samples displayed comparable short-term liquid resistance under standardized test conditions (15).

The biodegradability test demonstrated rapid and complete degradation of the composite material under natural soil conditions. Observable disintegration began within two days, with total decomposition achieved by the eighth day. Oven-baked specimens decomposed faster than air-dried ones, suggesting that thermal treatment may have increased susceptibility to microbial breakdown. The high cellulose and starch content facilitated microbial enzymatic activity, confirming the material's excellent environmental compatibility (16). In contrast, traditional cardboard requires several weeks to degrade, while plastics persist for years. The biodegradable composite therefore presents a superior ecological advantage. Qualitative assessments revealed that the decomposing material released no odor or residue, indicating nontoxic breakdown. The degradation products contributed positively to soil quality by releasing organic matter and trace nutrients, thereby enhancing fertility and maintaining microbial balance (17). Functional evaluations conducted during practical usability testing demonstrated that the plates successfully supported hot and greasy food items without deformation or leakage. Participants rated the product as aesthetically pleasing, lightweight, and environmentally preferable, affirming its feasibility for institutional and commercial food-service applications.

Table 1: Tensile Strength Measurements

Test	Force Applied (Newton)	Corrected Force (Newton)
Test 1	2.7	2.95
Test 2	3.1	3.35
Average	2.9	3.15

Table 2: Moisture absorption of bagasse plate samples after immersion in water for 5 minutes.

Sample #	Initial Volume (ml)	Final Volume (ml)	Volume Absorbed (ml)
Sample 1	250	238.75	11.25
Sample 2	250	234.1	15.9
Sample 3	250	232.5	17.5
Average	-	-	14.89

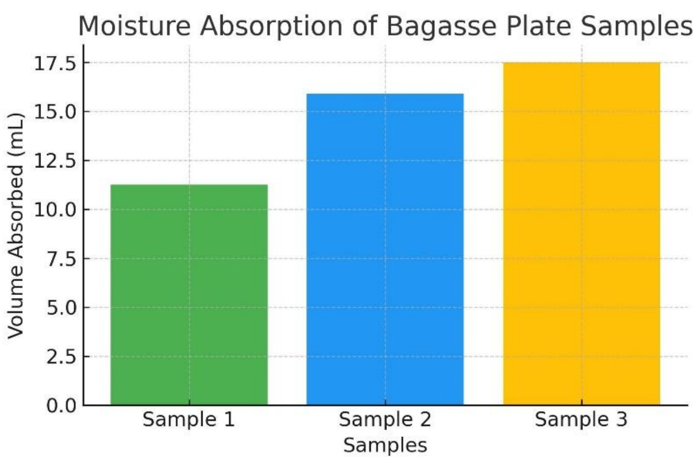

Figure 2 Moisture Absorption of Bagasse Plate Samples

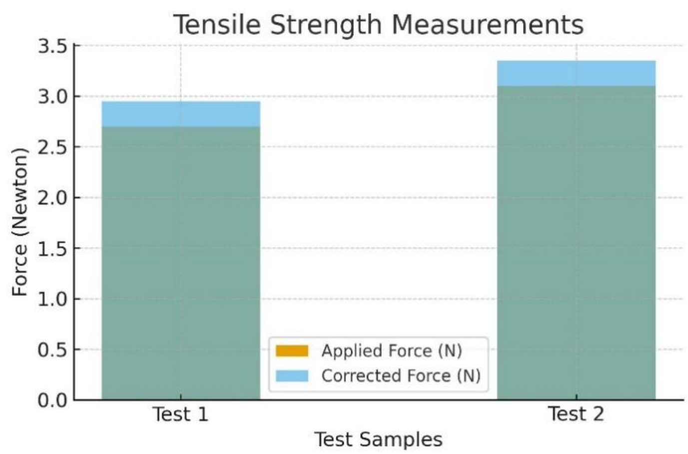

Figure 2 Tensile Strength Measurements

DISCUSSION

The findings of this experimental investigation demonstrated that the biodegradable composite fabricated from sugarcane bagasse and corn starch exhibited promising structural and environmental performance suitable for sustainable food-service applications. The mean tensile strength of 1.26×10^5 Pa (0.126 MPa) reflected moderate mechanical resistance, adequate for lightweight utility contexts such as disposable tableware. Although this value was significantly lower than those typically reported for conventional engineering polymers and metallic materials, which range from several tens to hundreds of megapascals, the result aligned with previously published data on lignocellulosic and starch-based composites that generally display low to intermediate tensile strength values due to their fibrous and porous composition (17). The moderate strength recorded in this study supported the premise that mechanical robustness need not be the principal determinant for short-term, single-use food packaging when biodegradability and ecological compatibility are prioritized. The practical assessment indicated that the material could withstand an applied load equivalent to approximately three standard food portions, confirming its structural reliability in institutional dining settings. This finding was consistent with prior experimental reports that identified bagasse–starch composites as capable of sustaining minor compressive and tensile loads while maintaining shape under moderate heat exposure (18). The mechanical performance, though limited, remained sufficient for the intended application scope, where mechanical endurance is less critical than environmental degradability and cost-efficiency. Moisture absorption analyses revealed an average uptake of 14.89 mL, equivalent to 5.95% of the initial immersion volume. This level of water absorption was moderately higher than typical hydrophobic biocomposites, suggesting that the tested material retained notable porosity and hydrophilic characteristics. The elevated moisture affinity likely stemmed from the intrinsic properties of cellulose, hemicellulose, and lignin, which readily form hydrogen bonds with water molecules (19). Such behavior aligns with the known characteristics of natural fibre composites, which frequently exhibit capillary water penetration through interfibrillar voids and microstructural pores (20). While these properties may limit the use of such materials for long-term wet food storage, the findings suggested sufficient short-term resistance for disposable plate applications. The results also indicated that optimization through improved compression molding or surface treatment could reduce porosity and improve dimensional stability.

The biodegradation study confirmed rapid decomposition of the bagasse–starch composite, with complete disintegration observed within eight days under natural soil conditions. This rate of breakdown exceeded that of conventional cardboard and far surpassed synthetic plastics, which can persist for decades in terrestrial environments (21). The accelerated degradation rate reflected the organic composition of the material, dominated by biodegradable polysaccharides that are readily metabolized by soil microorganisms. Additionally, thermal treatment appeared to enhance microbial accessibility, as oven-baked samples decomposed more rapidly than non-baked ones. This phenomenon can be attributed to microcrack formation during heating, which likely increased surface area exposure and facilitated enzymatic penetration. The biodegradability outcomes confirmed that the material is ecologically benign, aligning with global initiatives promoting compostable and renewable packaging solutions (22,23). The decomposition process also demonstrated agronomic benefits, as it released organic carbon and trace minerals into the soil without introducing toxic residues (24). This aligns with the broader sustainability framework of circular economy principles, where biodegradable products return valuable nutrients to natural ecosystems rather than accumulating as persistent waste (25). The absence of synthetic coatings ensured that microbial populations remained unaffected, thereby preserving soil biodiversity and ecological balance. User evaluations supported the mechanical and functional findings, indicating that the fabricated plates were capable of supporting hot and greasy food items without deformation. The positive feedback highlighted the material's practicality, light weight, and environmental appeal, reinforcing its potential for adoption in institutional and commercial catering systems. The usability responses suggested that the balance between functional integrity and eco-sustainability achieved in this study could encourage large-scale implementation in school and office canteens where disposable materials are routinely used.

A notable strength of this study was the demonstration of an entirely locally sourced, low-cost fabrication process using accessible equipment, ensuring replicability even in resource-limited environments. The method successfully integrated agricultural waste valorization, thus addressing two environmental challenges simultaneously—biomass disposal and plastic pollution. However, several limitations were evident. The mechanical evaluation was restricted to tensile testing; parameters such as flexural, impact, and compressive strengths were not assessed. Furthermore, the short-term moisture absorption test and limited duration of biodegradation assessment did not account for the influence of long-term environmental exposure, microbial variability, or seasonal factors on degradation kinetics. The use of qualitative measures such as user feedback, though valuable, would benefit from future quantitative sensory and durability analyses to provide statistically robust evidence. Future research should emphasize optimization of binder concentration, fiber–matrix ratio, and compaction pressure to enhance structural density and minimize water uptake (24). Incorporating surface coatings of natural waxes or bio-resins could further improve water resistance without compromising biodegradability. Advanced analytical techniques, such as scanning electron microscopy (SEM) or Fourier transform infrared spectroscopy (FTIR), could provide insights into fiber–matrix interactions and compositional stability under environmental stress. Comparative studies involving different natural fibers and biopolymeric binders may also help identify formulations with superior mechanical and thermal properties. Overall, the study demonstrated that sugarcane bagasse–starch composites can serve as viable, eco-efficient alternatives to petroleum-based disposable tableware. The results validated the hypothesis that locally available agricultural residues can be converted into functional, biodegradable food-contact materials through simple and sustainable processing. Despite inherent limitations, the findings offer a valuable foundation for further refinement and large-scale implementation of biocomposite tableware technologies within the framework of environmentally responsible production and consumption.

CONCLUSION

The present study successfully demonstrated the feasibility of fabricating a biodegradable, sustainable, and functionally stable plate using sugarcane bagasse and corn starch through a simple, low-cost process adaptable to domestic or small-scale conditions. The findings confirmed that the developed material possessed sufficient mechanical strength, acceptable moisture resistance, and rapid biodegradability, making it a practical alternative to conventional plastic and Styrofoam tableware. Beyond its structural performance, the plate's environmentally benign decomposition underscored its potential to reduce plastic pollution and contribute to circular economy goals by transforming agricultural waste into value-added products. The study highlights an accessible pathway toward sustainable food packaging, providing a foundation for future innovations in eco-friendly materials that balance functionality, affordability, and environmental responsibility.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Salar Hussain*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Kashif Rashid	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published

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Figure 3 Bagasse plates produced simply baked and boiled water

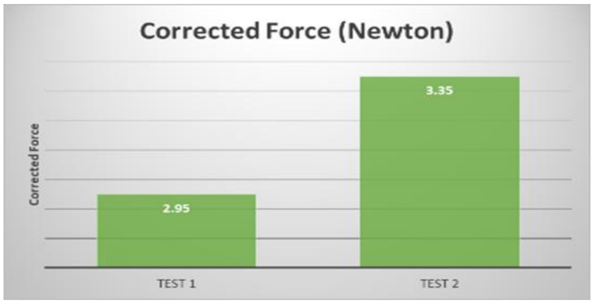

Figure 4 Comparison of Tensile Strength in Test 1 and Test 2

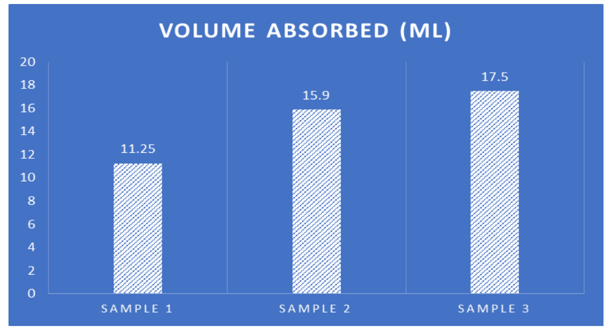

Figure 5 Comparison of bagasse plate samples after immersion in water for 5 minutes.

Figure 6 Decomposition of Bagasse Plates Under Soil Conditions Over Consecutive Days

