

Banana Peel as a sustainable substrate for microbial enzyme production: A review

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Abstract

Banana peel, a readily available lignocellulosic agro waste, has gained increasing attention as a low-cost and environmentally sustainable substrate for microbial enzyme production. This review emphasizes current scientific advances in utilizing banana peel for the biosynthesis of industrially significant enzymes, including pectinase, cellulase, amylase, lipase, catalase, protease, peroxidase and L-asparaginase, through fungal and bacterial fermentation systems. The influence of banana varietal composition, ripeness stage, and substrate pretreatment on enzyme yield, along with comparing fermentation methods such as solid-state and submerged fermentation, is assessed. Prominent microbial strains—including *Aspergillus niger*, *A. japonicus*, *Trichoderma reesei*, *Paenibacillus lactis*, and *Yarrowia phangngaensis*—are highlighted for their enzyme efficiency. Industrial applications are discussed in the context of biofuel generation, food processing, textile treatment, and environmental remediation. Despite scale-up limitations and variability in substrate composition, integrating banana peel bioprocessing with circular bioeconomy frameworks can transform food waste into valuable bioproducts, contributing to sustainable development goals (SDGs).

Keywords: Banana peel, enzyme production, pectinase, cellulase, microbial fermentation, agro-waste, sustainability

Introduction

The global food industry generates vast quantities of agro-waste, much of which is improperly disposed of, leading to environmental degradation and the loss of potential economic value. Among these, banana peels constitute a significant proportion of fruit waste, accounting for approximately 30–40% of the fresh weight of the banana. According to the Food and Agriculture Organization (FAO, 2024)^[6], global banana production exceeded 179 million metric tons in 2022. Given this volume, it is estimated that between 36 and 42 million metric tons of banana peel waste are generated annually worldwide.

Banana peel is rich in structural carbohydrates such as cellulose and hemicellulose, as well as soluble sugars, pectin, proteins, polyphenols, and minerals. These attributes

make it a desirable lignocellulosic feedstock for microbial fermentation processes (Fig. 1). In particular, the peel's polysaccharide content supports microbial growth and enzyme secretion, offering a renewable and economical substrate for enzyme bioproduction (Singh *et al.*, 2023; Tang *et al.*, 2024)^[19, 21].

The demand for microbial enzymes in the food, textile, detergent, pharmaceutical, and bioenergy sectors has surged, driven by the need for sustainable and cost-effective biocatalysts. Traditional enzyme production methods often rely on refined carbon sources, which are expensive and environmentally taxing. Thus, utilizing banana peel for enzyme synthesis aligns with the global pursuit of green technologies and waste valorization (Jayasekara *et al.*, 2023; Sahay *et al.*, 2022)^[10, 18].

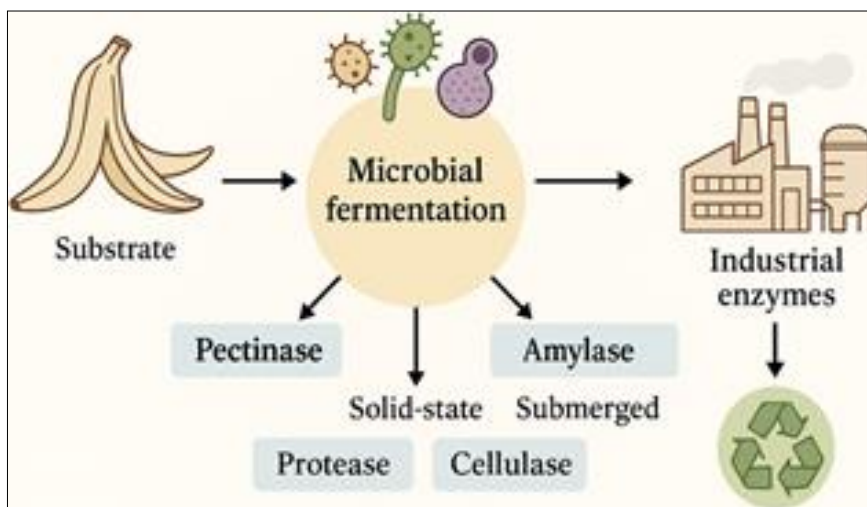


Fig 1: Banana peel as a sustainable substrate for fungal enzyme production (created using dall-e (open ai, 2025))

Recent studies (Dion *et al.*, 2021; Sulaiman *et al.*, 2020)^[4, 22] have explored banana peel in submerged and solid-state fermentations using various microbial strains,

revealing promising yields of industrially relevant enzymes such as pectinase, cellulase, amylase, and protease. This review consolidates current evidence on the composition,

microbial compatibility, enzyme yield potential, and industrial relevance of banana peel-based fermentations.

Biochemical Composition and Varietal Impact

Banana peel comprises cellulose (10–15%), hemicellulose (5–10%), pectin (10–21%), protein (6–9%), and polyphenols (0.9–3%). Banana cultivars vary in

composition, texture, and peel traits, influencing fermentative potential. Varieties such as *Musa balbisiana*, with higher cellulose and pectin, may support more robust enzyme secretion. Phenolic content also varies, potentially affecting microbial growth and enzyme production (Fig. 2). Future work should involve standardized fermentation trials across cultivars.

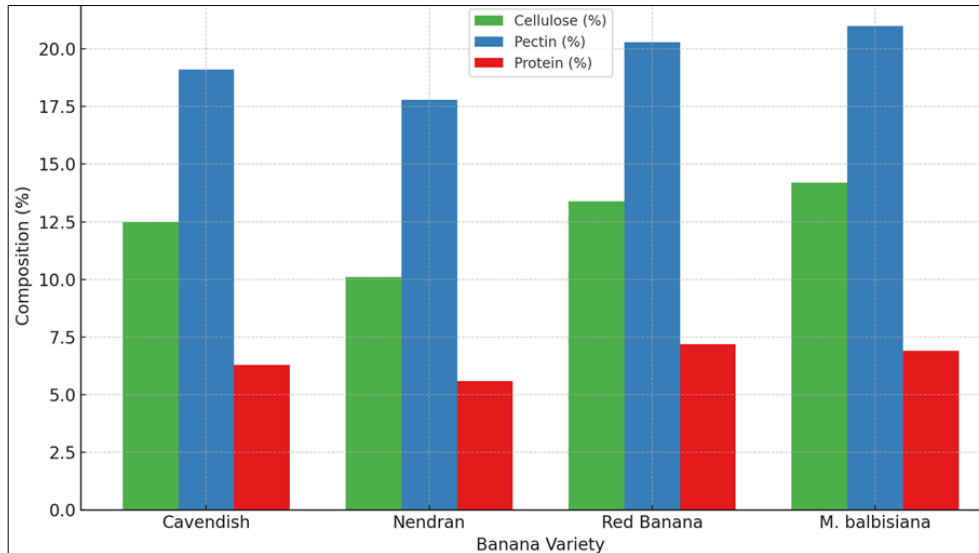


Fig 2: Comparative composition of banana peel by variety.

Microbial Enzymes Produced from Banana Peel

Banana peel is abundant lignocellulosic agro-waste rich in carbohydrates, fiber, and minor proteins, which supports the growth of a wide range of microorganisms. Various microbial enzymes have been successfully produced using banana peel as a carbon source, including hydrolytic and oxidative enzymes, many of which have significant industrial relevance.

Cellulase

Cellulases are a group of enzymes (endoglucanases, exoglucanases, and β -glucosidases) responsible for breaking down cellulose into glucose. Banana peel, rich in cellulose and hemicellulose, is ideal for cellulase production, especially under solid-state fermentation (SSF). *Aspergillus niger* and *Trichoderma reesei* have been widely studied for cellulase production from banana peel. Jain *et al.* (2017)^[9] reported maximum cellulase activity of 5.6 U/g dry substrate using *A. niger* under SSF conditions (pH 5.5, 30 °C, 72 h). *Penicillium citrinum* also demonstrated considerable cellulase productivity using banana peel with FPase and CMCase activities (Kumar *et al.*, 2014).

Pectinase

Pectinases degrade pectic substances in plant cell walls and are vital in fruit juice clarification, textile processing, and wastewater treatment. Patil & Dayanand (2006)^[16] observed high pectinolytic activity in *Aspergillus sp.* using banana peel with pectinase activity of 2.15 U/mL under optimized conditions.

Amylase

Amylases hydrolyze starch into sugars and are used in baking, brewing, and detergents. Banana peel contains residual starch and sugars that can serve as a carbon source

for amylase-producing microbes. *Aspergillus oryzae* and *Bacillus subtilis* have been reported to yield up to 1.98 U/mL of amylase using banana peel under submerged fermentation (SmF) (Oliveira *et al.*, 2011)^[13].

Protease

Proteases break down proteins and are widely used in leather processing, food industries, and pharmaceuticals. Though banana peel has relatively low protein content, supplementation enhances protease production. *Aspergillus flavus* and *Bacillus licheniformis* have been reported to yield 2.3 U/mL protease when grown on banana peel mixed with peptone or casein (Haq *et al.*, 2006)^[8].

Lipase

Lipases catalyze the hydrolysis of lipids and are crucial in biodiesel production, dairy processing, and cosmetics. *Candida rugosa* grown on banana peel plus olive oil produced 0.95 U/mL lipase under SmF (Saxena *et al.*, 2003).

L-asparaginase

L-asparaginase converts L-asparagine into aspartic acid and ammonia, used as a chemotherapeutic agent against acute lymphoblastic leukemia. Screening of banana peel as a substrate showed potential for L-asparaginase production by *Aspergillus niger*, *Fusarium spp.*, and *Aspergillus japonicus*.

Catalase and Peroxidase

These enzymes detoxify reactive oxygen species and are useful in textile bleaching and environmental cleanup. Studies showed banana peel fermentation induced catalase activity due to its phenolic content and oxidative stress response (Benassi *et al.*, 2013)^[3].

Challenges and Limitations

Notably, the variability in substrate characteristics such as ripeness and banana variety, which can significantly influence fungal growth and enzyme production. Contamination risks were heightened under unsterile conditions, limiting the reproducibility of results. Furthermore, the lack of scale-up data restricts industrial translation, and the absence of variety-specific fermentation profiles hinders process optimization across different banana types.

Conclusion and Discussion

The current body of research underscores the substantial potential of banana peel as a sustainable and versatile substrate for microbial enzyme production. The diversity of enzymes ranging from pectinase and cellulase to protease and amylase demonstrates biochemical richness and functional adaptability of banana peel across microbial taxa. However, most existing work remains confined to laboratory-scale investigations, with few studies exploring industrial translation or economic feasibility. Emerging evidence suggests that yield optimization through statistical modeling (e.g., RSM, ANN) and substrate formulation (e.g.,

co-substrates, pretreatment) can significantly enhance enzyme productivity. *Yarrowia phangngaensis* cultured on banana peel showed an ~182% increase in pectinase activity following nutrient optimization. Yet, reproducibility across banana varieties and geographical contexts remains a challenge due to variability in peel composition. The impact of peel maturity, genotype, and storage condition on microbial metabolism requires deeper exploration.

Furthermore, while fungal strains such as *A. niger* and *T. reesei* are well-established for enzyme secretion, there is growing interest in less conventional microbes such as *Paenibacillus lactis* and *Yarrowia phangngaensis* which demonstrate superior thermostability or specificity in enzyme output. Their performance on banana peel substrates invites broader screening and strain engineering.

A clear research gap exists in the scale-up of these fermentation systems. Pilot-scale bioreactor studies, techno-economic assessments, and life cycle analysis (LCA) of banana peel valorization processes are urgently needed. Additionally, policy frameworks supporting waste-to-resource pipelines and industry-academia partnerships can accelerate the commercial adoption of such systems.

Table 1: Summary of enzyme yields and applications

Enzyme	Microorganisms	Fermentation Type	Yield (approx.)	Applications	Reference
Cellulase	<i>A. niger</i> , <i>T. reesei</i> , <i>P. citrinum</i>	SSF	3.1–5.6 U/g	Biofuel production, paper & textile industries, animal feed	Jain <i>et al.</i> , 2017; Kumar <i>et al.</i> , 2014 ^[9]
Pectinase	<i>A. japonicus</i> , <i>A. carbonarius</i> , <i>Fusarium spp.</i>	SSF/Plate assay	2.15 U/mL	Fruit juice clarification, textile processing, wastewater treatment	Patil & Dayanand, 2006 ^[16]
Amylase	<i>A. oryzae</i> , <i>B. subtilis</i>	SMF	~1.98 U/mL	Baking, brewing, starch liquefaction, detergent industries	Oliveira <i>et al.</i> , 2011 ^[13]
Protease	<i>A. flavus</i> , <i>B. licheniformis</i>	SMF/SSF	2.3 U/mL	Leather industry, meat tenderization, pharmaceuticals, detergents	Haq <i>et al.</i> , 2006 ^[8]
Lipase	<i>Candida rugosa</i>	SMF (oil induced)	0.95 U/mL	Biodiesel production, dairy industry, bioremediation, cosmetics	Saxena <i>et al.</i> , 2003
L-asparaginase	<i>A. japonicus</i> , <i>Fusarium spp.</i>	Plate assay	Qualitative halo zone	Chemotherapy (anti-leukemia), food acrylamide reduction	Gulati <i>et al.</i> , 1997 ^[7]
Catalase	<i>A. niger</i> , <i>A. flavus</i>	SmF/SSF	Detected (semi-quant)	Textile bleaching, biosensors, oxidative stress protection	Benassi <i>et al.</i> , 2013 ^[3]

In summary, banana peel valorization for enzyme production represents a scientifically robust and ecologically sound strategy (Table 1). Realizing its full industrial potential will depend on multidisciplinary efforts encompassing microbiology, process engineering, agricultural science, and sustainability policy.

Future Prospects

Looking ahead, genetic and metabolic engineering offer promising avenues to enhance enzyme yields in fungal strains. Bioreactor scale-up studies are essential to bridge the gap between lab-scale and industrial applications. Additionally, developing standardized pretreatment protocols can ensure consistency in substrate preparation. Integrating these approaches into a circular bioeconomy model holds great potential, particularly in banana-producing countries, by transforming waste into value-added bioproducts.

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