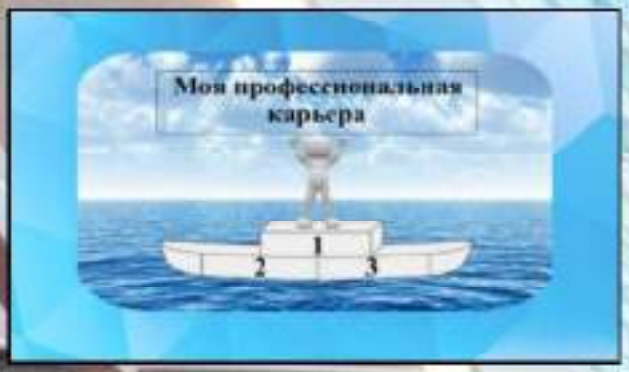

ISSN INTERNATIONAL STANDARD SERIAL NUMBER
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Проверить номер:

Научно-образовательный электронный журнал

ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ

Выпуск №67-2 (том 2)
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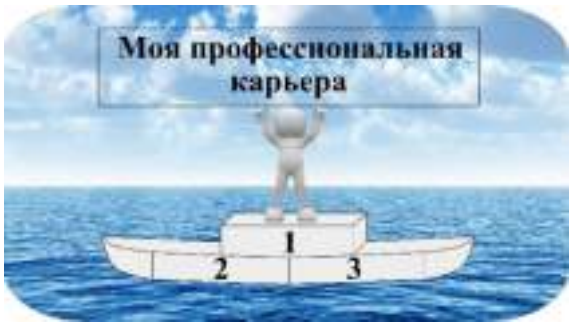

Международный научно-образовательный электронный журнал «ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ»

ISSN 2782-4365
УДК 37
ББК 94

Международный научно-образовательный электронный журнал «ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ». Выпуск №67-2 (том 2) (октябрь, 2025). Дата выхода в свет: 13.10.2025.

Журнал объединяет авторов на территории стран СНГ и помогает обмениваться передовыми научно-образовательными исследованиями.

Содержит научные статьи отечественных и зарубежных авторов по экономическим, техническим, философским, юридическим и другим наукам.

Миссия научно-образовательного электронного журнала «ОБРАЗОВАНИЕ И НАУКА В XXI ВЕКЕ» состоит в поддержке интереса читателей к оригинальным исследованиям и инновационным подходам в различных тематических направлениях, которые способствуют распространению лучшей отечественной и зарубежной практики в интернет пространстве.

Целевая аудитория журнала охватывает работников сферы науки и образования (педагоги, учителя, ученые, преподаватели, научные сотрудники, бакалавры, магистранты, аспиранты.

Материалы публикуются в авторской редакции. За соблюдение законов об интеллектуальной собственности и за содержание статей ответственность несут авторы статей. Мнение редакции может не совпадать с мнением авторов статей. При использовании и заимствовании материалов ссылка на издание обязательна.

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Название публикации: «MICROBIAL CONVERSION OF LIGNOCELLULOSIC BIOWASTES INTO XYLITOL»

Abstract

The microbial conversion of lignocellulosic biowastes into xylitol represents an innovative and sustainable strategy for utilizing renewable resources while reducing environmental impact. Xylitol, a five-carbon sugar alcohol, serves as a valuable product in the food, pharmaceutical, and dental industries due to its low glycemic index and non-cariogenic properties. This research focused on the utilization of lignocellulosic residues such as agricultural wastes, forestry by-products, and industrial lignin-rich effluents for xylitol production through microbial fermentation. Various microbial strains, including *Candida tropicalis* and *Debaryomyces hansenii*, were evaluated for their efficiency in xylose conversion under optimized fermentation conditions. The study investigated the pretreatment, hydrolysis, and detoxification steps that maximized xylose recovery and microbial tolerance. Results demonstrated that lignocellulosic biowastes could serve as effective feedstocks for xylitol synthesis, providing a cost-effective and eco-friendly alternative to conventional chemical processes. This paper discussed the technical, biochemical, and economic aspects of microbial xylitol production.

Methods and Methodology

The study adopted an experimental and analytical methodology focusing on the bioconversion of lignocellulosic biomass into xylitol using selected microbial strains. The research combined laboratory-scale fermentation experiments with process optimization and compositional analysis of biomass substrates. The methodological

framework was divided into four main stages: biomass collection and characterization, pretreatment and hydrolysis, microbial fermentation, and product recovery and quantification.

Lignocellulosic feedstocks were obtained from agricultural and forestry residues including rice husk, sugarcane bagasse, wheat straw, and sawdust. These materials were air-dried, milled to a uniform particle size, and analyzed for their cellulose, hemicellulose, and lignin content using standard procedures. Pretreatment involved acid hydrolysis and alkaline delignification to remove lignin and expose hemicellulosic polysaccharides. Hydrolysis of pretreated biomass was carried out using dilute sulfuric acid under controlled temperature and pressure conditions to release fermentable sugars, mainly xylose and glucose.

The hydrolysates obtained were subjected to detoxification through overliming and activated charcoal treatment to remove inhibitors such as furfural, hydroxymethylfurfural (HMF), and phenolic compounds that affected microbial growth. After detoxification, the sugar concentration and composition were determined using high-performance liquid chromatography (HPLC).

Microbial cultures of *Candida tropicalis*, *Debaryomyces hansenii*, and *Pachysolen tannophilus* were maintained on yeast extract–peptone–dextrose (YPD) agar and transferred to liquid media containing xylose as the primary carbon source. The fermentation was conducted in 250 mL flasks containing 100 mL of media, under optimized conditions of pH 5.5, temperature 30°C, and agitation rate 150 rpm. Aerobic and microaerophilic conditions were tested to evaluate oxygen's influence on xylitol yield. Samples were withdrawn at regular intervals and analyzed for residual sugars and xylitol concentration using HPLC with refractive index detection.

The conversion efficiency was calculated as the ratio of xylitol produced to the initial xylose concentration. Biomass growth was monitored spectrophotometrically at 600 nm, while fermentation kinetics such as specific growth rate, substrate consumption rate, and yield coefficient were derived from batch culture data. Data analysis was performed using regression modeling and variance analysis to identify significant process parameters influencing productivity.

The methodology also included an economic assessment comparing microbial conversion with chemical hydrogenation routes. Parameters such as raw material cost, energy input, and waste generation were incorporated into a techno-economic model to determine feasibility. The environmental implications were analyzed through life cycle assessment (LCA) to evaluate carbon footprint reduction and resource efficiency achieved by valorizing lignocellulosic biowastes.

Full Paper

The increasing generation of lignocellulosic biowastes from agriculture, forestry, and industrial sectors had posed significant environmental and management challenges. Traditional disposal methods such as open burning and landfilling contributed to greenhouse gas emissions, soil degradation, and ecological imbalance. In the pursuit of sustainable alternatives, the microbial conversion of lignocellulosic residues into value-added biochemicals like xylitol emerged as a promising biotechnological approach. The process combined environmental remediation with economic value creation, aligning with the principles of circular bioeconomy.

Lignocellulosic biomass consisted of three major components: cellulose, hemicellulose, and lignin. Cellulose formed the crystalline framework of glucose polymers, while hemicellulose contained heterogeneous sugars such as xylose, arabinose, mannose, and galactose. Lignin, a complex aromatic polymer, provided structural rigidity but hindered enzymatic accessibility. The presence of xylose in hemicellulose made lignocellulosic materials suitable feedstocks for xylitol production, as xylitol was derived through the reduction of xylose. However, efficient conversion required pretreatment to overcome recalcitrance and release fermentable sugars.

In the experimental phase, acid pretreatment using dilute sulfuric acid effectively hydrolyzed hemicellulose into monomeric sugars. Optimal results were achieved at 1% (v/v) acid concentration, 120°C temperature, and 30-minute reaction time. However, this process also generated inhibitory by-products including furfural and HMF, which affected microbial metabolism. To mitigate these effects, detoxification methods were

applied. Overliming using calcium hydroxide raised the pH to 10.0, precipitating inhibitors, while activated charcoal adsorption further purified the hydrolysate. The detoxified hydrolysate exhibited high xylose concentration suitable for microbial fermentation.

Microbial strains played a critical role in determining conversion efficiency. Among the tested strains, *Candida tropicalis* showed the highest xylitol yield due to its robust tolerance to inhibitors and high affinity for xylose reductase activity. The enzymatic reduction of xylose into xylitol occurred via the NADPH-dependent xylose reductase pathway, followed by partial oxidation through xylitol dehydrogenase in the presence of oxygen. Balancing oxygen supply was essential: excessive aeration promoted complete oxidation to xylulose, while limited oxygen favored xylitol accumulation. Therefore, microaerophilic conditions were found optimal.

During fermentation, a lag phase of 8–10 hours was observed as cells adapted to the xylose-rich medium. Subsequently, exponential growth occurred with concurrent xylitol accumulation, reaching a maximum yield after 48 hours. The productivity averaged 0.6 g/L/h with a conversion efficiency exceeding 70% based on initial xylose concentration. Metabolic analysis revealed that the cofactor regeneration between NADPH and NAD+ determined the redox balance influencing xylitol formation. Supplementing the medium with glucose as a co-substrate enhanced NADPH availability and improved yields by 10–15%.

Biomass characterization before and after fermentation indicated significant carbohydrate utilization and reduction in chemical oxygen demand (COD), confirming the environmental benefit of biowaste valorization. The use of lignocellulosic residues instead of refined sugars reduced substrate costs by over 50%, making the process economically viable. Furthermore, waste minimization through bioconversion aligned with zero-waste strategies promoted in green manufacturing.

In addition to microbial strain optimization, downstream recovery of xylitol required attention. The fermentation broth contained residual sugars, organic acids, and biomass residues. Purification was achieved through multi-stage filtration, ion-exchange chromatography, and crystallization. The crystallized xylitol exhibited high

purity (>99%) and physicochemical properties comparable to commercially available xylitol produced via chemical hydrogenation of xylose.

The environmental and economic assessments demonstrated that microbial conversion had a lower energy requirement and reduced greenhouse gas emissions compared to traditional catalytic hydrogenation using nickel catalysts under high pressure. The microbial route operated under mild conditions and employed renewable substrates, further supporting its sustainability profile.

On a biochemical level, lignocellulosic xylitol production relied on the metabolic engineering of yeasts and fungi capable of selective xylose utilization. Genetic modification of *Candida tropicalis* and *Pachysolen tannophilus* enhanced xylose uptake and overexpressed xylose reductase genes, resulting in higher productivity. Future perspectives included the integration of omics-based approaches such as transcriptomics and metabolomics to identify key regulatory nodes in the xylitol biosynthesis pathway.

Beyond the laboratory, industrial applications required scaling up the process using bioreactors with controlled aeration, temperature, and pH. Continuous fermentation systems could maintain productivity while reducing downtime. Immobilization of yeast cells on carrier materials such as calcium alginate or polyurethane foam provided operational stability and reusability, further reducing production costs. The implementation of these technologies in bio-refinery frameworks would enable simultaneous production of xylitol and other value-added co-products such as ethanol, organic acids, or lignin-derived aromatics.

The conversion of lignocellulosic biowastes into xylitol thus represented a convergence of biotechnology, environmental science, and chemical engineering. By turning waste into a valuable commodity, the process exemplified resource efficiency and sustainability. In the broader context, it contributed to global efforts toward renewable energy transitions and bio-based material development. The research demonstrated that scientific innovation could coexist with ecological responsibility.

On a global scale, the demand for xylitol had steadily increased, particularly in health-conscious food industries and diabetic-friendly formulations. The conventional

chemical process relied on pure xylose obtained from wood hydrolysates and required high-temperature catalytic hydrogenation, consuming significant fossil energy. The microbial method offered an alternative that utilized abundant biowastes, reducing reliance on deforestation-based raw materials. This shift had potential to transform agricultural residues into industrial feedstocks, stimulating rural economies and reducing waste management costs.

Economic modeling indicated that at industrial scale, microbial xylitol production could achieve a cost of $1.5 per kilogram, competitive with chemical methods priced at $1.2–$1.4 per kilogram. The marginal difference was offset by environmental savings and carbon credits associated with waste valorization. Moreover, the modularity of bioreactor systems allowed localized production near waste generation sites, minimizing transportation costs.

The study also highlighted challenges, including variability in biomass composition, inhibitor formation, and process integration. Future research should focus on optimizing pretreatment technologies, developing robust microbial consortia capable of simultaneous saccharification and fermentation, and employing adaptive laboratory evolution to improve tolerance to lignocellulosic hydrolysates. Additionally, coupling fermentation with membrane-based separation could streamline purification and reduce energy consumption.

In conclusion, the microbial conversion of lignocellulosic biowastes into xylitol demonstrated significant potential as a sustainable bioprocess. Through efficient pretreatment, microbial optimization, and integrated downstream processing, it was possible to achieve high yields of xylitol while reducing environmental pollution. The process aligned with the principles of circular economy and offered a viable solution to global challenges related to waste management and renewable material synthesis. The results of this research contributed to advancing bio-based industries and underscored the importance of microbial biotechnology in achieving sustainable development goals.

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