STM JOURNALS

Journal of
Energy, Environment & Carbon Credits

ISSN: 2249-8621
Volume 16, Issue 2, 2026
May–August
DOI (Journal): 10.37591/JoEECC

https://journals.stmjournals.com/joeecc

Review JoEECC

Recent Research Trends in Bioethanol Production – An Indian Context

Kritin Srinivas R.[1], Aditya Suravarjhula[2], Haritha SR[1], Indra Neel Pulidindi[3,*]

Abstract

Biofuels production is indeed a research hotspot. Prevention is better than cure. A paradigm shift from fossil based to bio-based fuels gives health, wealth and happiness. Among various biofuels, after biodiesel, bioethanol is next to and close to commercialization. The use of bioethanol is countries like Brazil and US is a success story. In India there is significant progress taking place in the transportation sector to use bioethanol as fuel and petroleum alternative. To meet the growing demand for bioethanol, the usually slow process of the fermentation of glucose to bioethanol has to be accelerated. The current review article is a serious attempt in this direction to accelerate the appearance of bioethanol in the market in the service of mankind. Fermentation of carbohydrates is the key biochemical reaction used for bioethanol production. The current developments in fermentation technology, microbial strain enhancement, metabolic engineering techniques, and process optimization tactics targeted at increasing bioethanol production are all thoroughly examined in this study. Innovative bioreactor designs, enzyme-assisted saccharification, and effective feedstock utilization are highlighted as ways to lower production costs and increase conversion efficiency. Additionally, a critical analysis is conducted on the effects of operational factors on fermentation performance, including temperature, pH, substrate concentration, and nutrient supplementation. The study highlights the potential contribution of large-scale bioethanol production to energy security, environmental sustainability, and the reduction of greenhouse gas emissions. It also addresses current trends, problems, and future possibilities.

Keywords: Bioethanol, sonication, solar reactor, solar energy, carbon nanomaterials, carbon nanodots

***Author for Correspondence**
Indra Neel Pulidindi
E-mail: indraneelp.smc@saveetha.com

[1]MBBS Student, Department of Medicine, Saveetha Medical Collage and Hospital, Saveetha Institute of Medical and Technical Sciences Deemed University, Chennai, Tamil Nadu, India.
[2]M. Tech Student, Department of Molecular Medicine, Saveetha Medical College (SMC) and Saveetha Institute of Medical and Technical Science (SIMATS), Saveetha Nagar, Thandalam, Tamil Nadu, India,
[3]Professor, Department of ENT, Saveetha Medical College and Hospital, Saveetha Institute of Medical and Technical Sciences Deemed University, Chennai, Tamil Nadu, India.

Received Date: June 13, 2026
Accepted Date: June 15, 2026
Published Date: June 18, 2026

Citation: Kritin Srinivas R., Aditya Suravarjhula, Haritha SR, Indra Neel Pulidindi. Recent Research Trends in Bioethanol Production – An Indian Context. Journal of Energy Environment and Carbon Credits. 2026; 16(2): 6–13p.

INTRODUCTION

There is growing global research activity on bioethanol production, conversion, and application [1-4]. A Web of Science search with the keyword bioethanol yields, 16, 954 papers in total. During the past 10 years (2016-2025) enormous advances have been made in the field of bioethanol production. On average, 1111 papers were produced on the subject of "bioethanol" globally (Figure 1). This number translates to "161" for India (Figure 2).

A paradigm shift from the use of first-generation (corn/sugar; food-based) to third-generation (algal biomass; both micro and macro) feedstock for bioethanol production has occurred.

Diverse feedstocks belonging to the first (corn, sugarcane, and other edible sugar-based feedstocks), second (lignocellulosic agricultural

© STM Journals 2026. All Rights Reserved

wastes), and third (algal biomass, both fresh water microalgae and marine macroalgae) generations have been extensively used for the production of bioethanol. Therefore, feedstock diversity is another challenge facing the upcoming biorefinery. This challenge can be overcome by adopting suitable biomass pretreatment methods.

Biomass Pretreatment

The work of Professor Tae Hyun Kim can be consulted for biomass pretreatment, especially those methods where ammonia is used as a chemical pretreating agent for the delignification of biomass [5-7]. Pretreatment is one of the cost-incurring steps in the biomass conversion of fuels and chemicals, including bioethanol production. Efforts are ongoing globally to make this process cost-effective and greener.

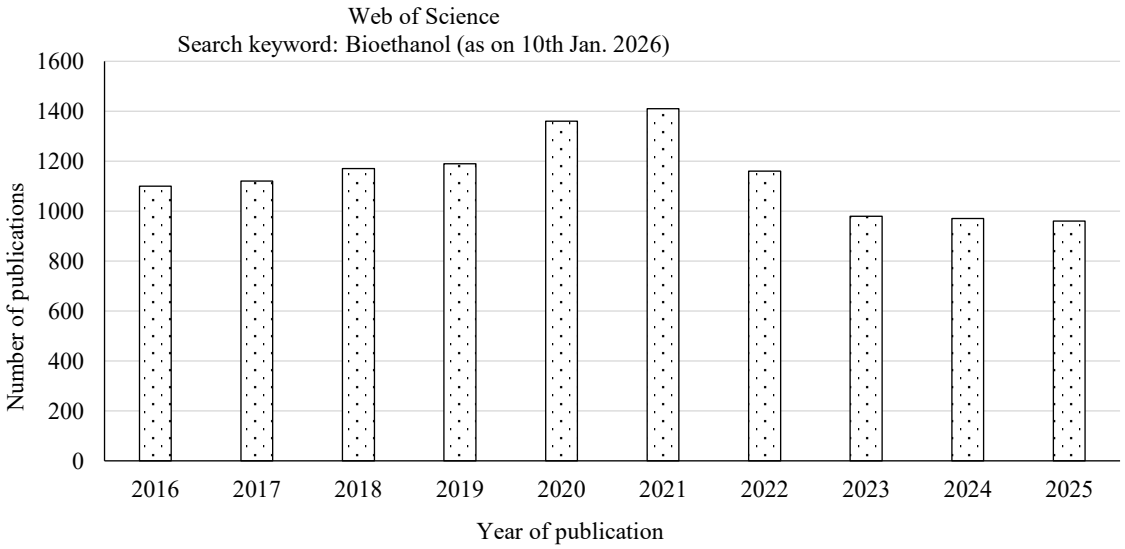


Figure 1. Global research trend in bioethanol production during the past decade (2016-2025)

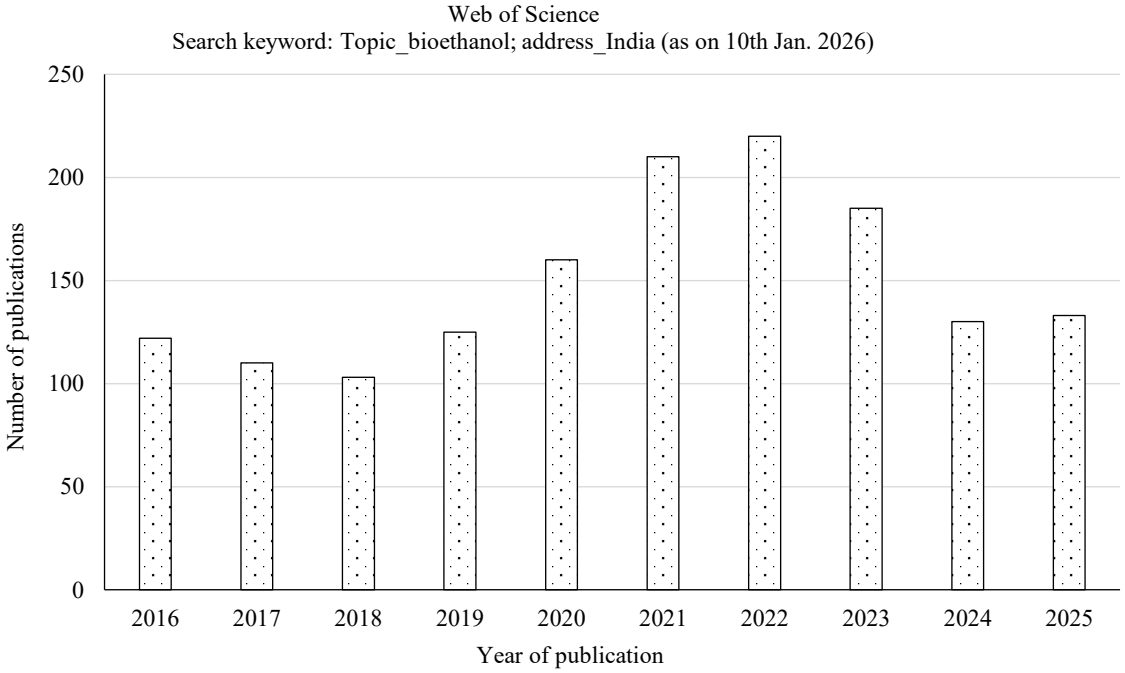


Figure 2. Research trend in bioethanol production in India during the past decade during the past decade (2016-2025).

© STM Journals 2026. All Rights Reserved

Methods for Acceleration of Kinetics of Glucose Fermentation

The stoichiometric biochemical reaction of glucose fermentation is shown in Figure 3. For every mole of glucose metabolized by yeast, two moles of ethanol (liquid) and two moles of CO_2 (gas) are produced. The CO_2 gas escaped from the fermentation broth contained in the Erlenmeyer flasks closed with a cotton plug, as shown in Figure 2. As a result, there will be a loss of weight as the fermentation process advances. This weight loss was exploited by Turkish researchers as an authentic marker for evaluating the progress of fermentation.

The weight loss during fermentation can be translated to the conversion of glucose, and the reaction rate constant can be calculated according to the following equations [8]:

$$\text{Conversion of glucose (wt\%)} = \frac{\text{Observed decrease in weight}}{\text{Total decrease in weight expected}} \times 100 \quad (1)$$

$$k = \frac{2.303}{t} \log\left(\frac{a}{a-x}\right) \quad (2)$$

In reality, glucose fermentation is a complex reaction. The scheme shown in Figure 3 is far from reality as many facts, such as the formation of the inevitable secondary metabolite, namely glycerol, and its subsequent hydrogenolysis to 1, 3 propanediol are totally ignored. Many hidden and unknown aspects of fermentation glucose are yet to be discovered, as there is a revolution in analytical and electroanalytical techniques, providing new insights into the products that are formed, as shown in Figures 4-7.

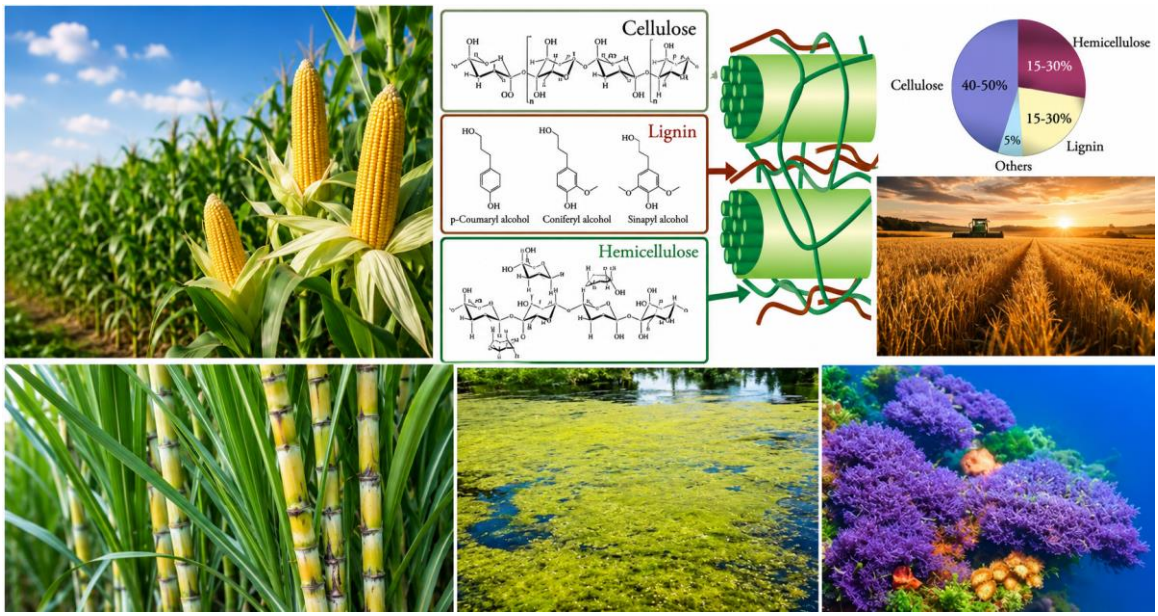


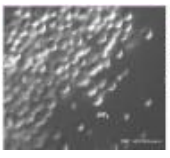
Figure 3. First, second and third generation feedstock for the production of bioethanol.

Glucose fermentation to ethanol

Yeast (Saccharomyces cerevisiae)
Fungal strain: Baker' yeast or Instant dry yeast from supermarket

Theoretical yield of ethanol:

$C_6H_{12}O_6$
D-glucose
Theoretical yield of ethanol:
1 g glucose yields 0.51 g ethanol
1 g sucrose yields 0.54 g ethanol



Experimental ethanol yield is always lower than 50 wt.% because of the formation of glycerol secondary as metabolite

Figure 4. Stoichiometric reaction for the conversion of glucose to bioethanol.

© STM Journals 2026. All Rights Reserved

As shown in Figure 4, ^{13}C NMR can be used as an elegant tool to evaluate the kinetics of glucose fermentation. Moreover, NMR in general and ^{13}C NMR, in particular, provide fundamental information on the fingerprint signals of organic compounds at specific chemical shift values. However, the chemical shift values are slightly altered by the use of solvents, and it is necessary to state the solvent used whenever a spectrum is reported. In the present instance, all through the paper, the NMR spectra were recorded using D_2O as the solvent. Under these conditions, two signals at approximately 17 and 56 are characteristic of ethanol. Likewise, two signals at 62 and 72 are typical of glycerol [8-12]. Thus, in addition to ethanol, as shown in Figure 3, the formation of the secondary metabolite glycerol is inevitable in the glucose fermentation process.

Moreover, recent studies have shown that the secondary metabolite glycerol is converted to 1, 3-propanediol by yeast [2]. Usually, the hydrogenolysis of glycerol to 1,3-propanediol is accomplished using noble metal catalysts. The product distribution during the biocatalytic conversion of glycerol is shown in Figure 6, wherein anaerobic conditions appear to be the best. As high as 42 wt.% yield of 1, 3-propanediol is achieved under modest reaction conditions. There are many such surprises in store when exploring the classical fermentation process [13].

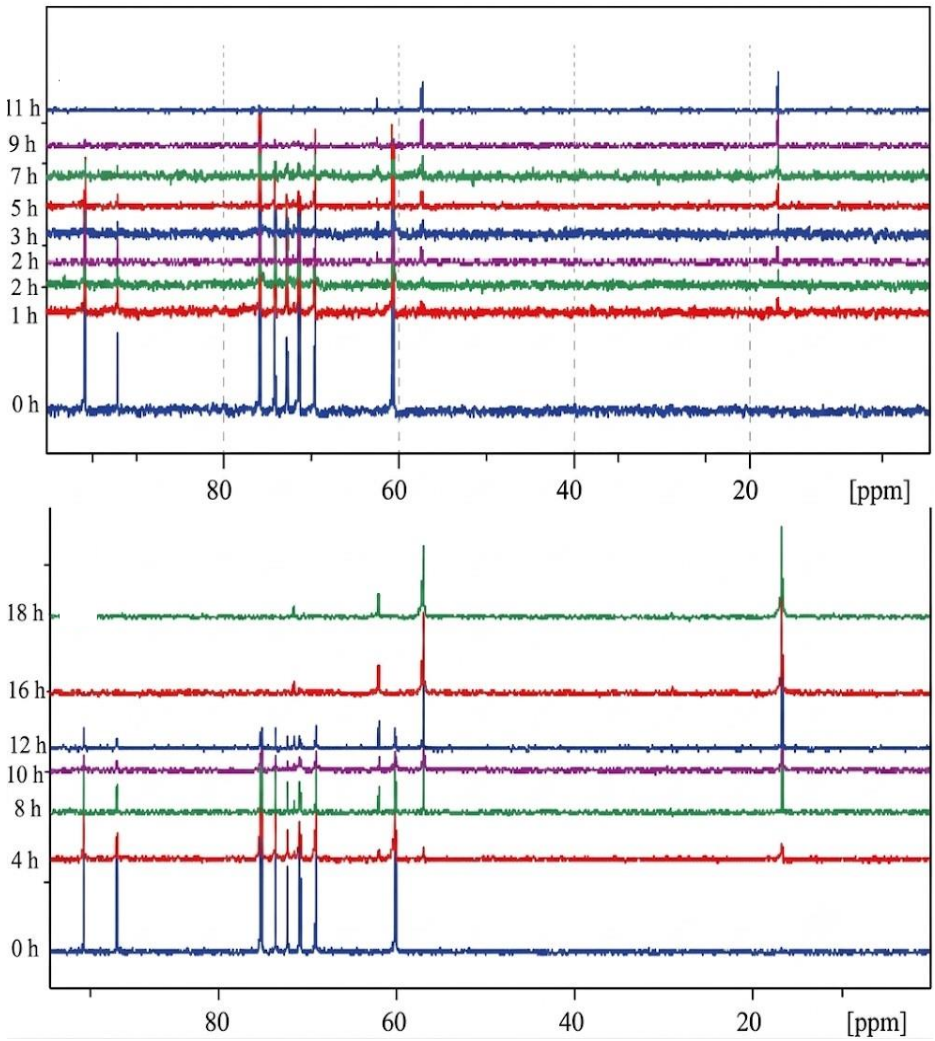


Figure 5. ^{13}C NMR of aliquot of products from fermentation broth (glucose fermentation in the presence of the yeast, Saccharomyces cerevisiae) as a function of reaction time under (A) bath sonication (40 kHz ultrasound) and under (B) regular stirring on a magnetic stirrer (control) [12]. [Adatpted with permission from the American Chemical Society]

© STM Journals 2026. All Rights Reserved

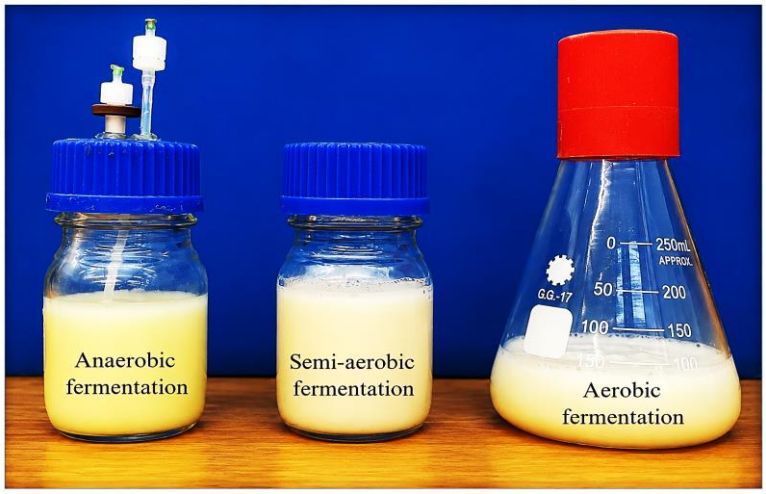


Figure 6. Biocatalytic conversion of glycerol to 1,3-propanediol using yeast fungal strain (Saccharomyces cerevisiae) [2]. Adapted with permission from the Royal Society of Chemistry.

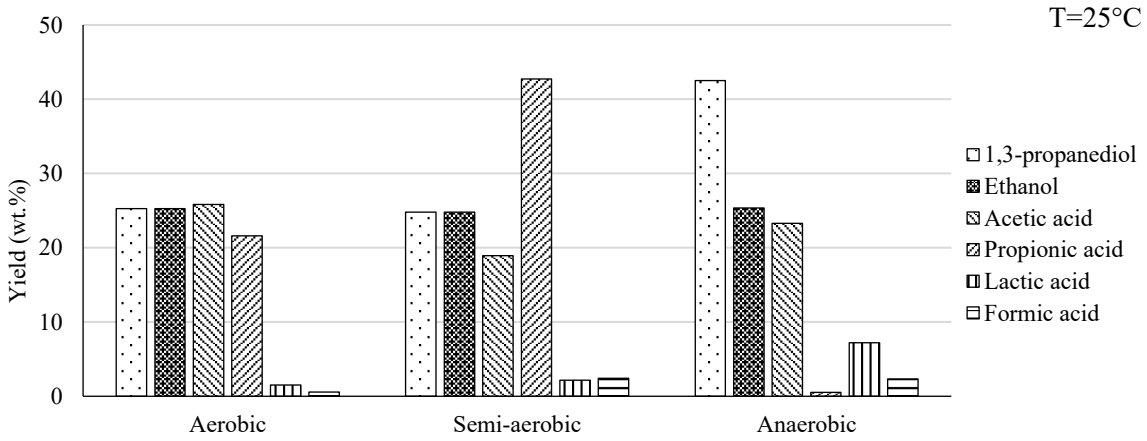


Figure 7. Product distribution in the biocatalytic conversion of glycerol to 1,3 propanediol using Baker' yeast as the biocatalyst [2]. Adapted with permission from the Royal Society of Chemistry.

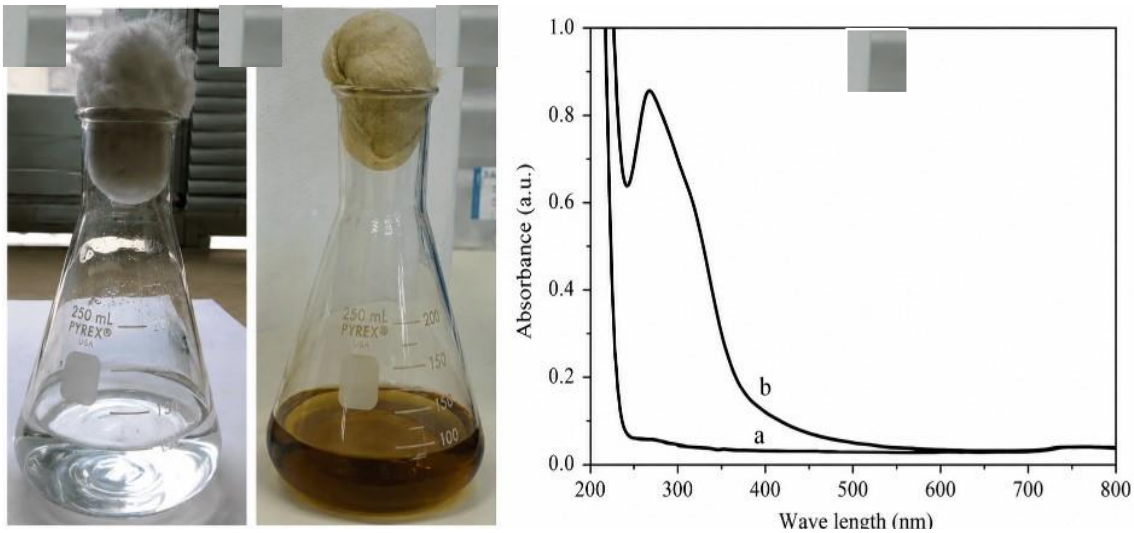


Figure 8. A. Erlenmeyer flasks with glucose (2 wt. %) and urea (0.2 wt.%) (a) before and (b) after the hydrothermal treatment; B. UV-Vis spectrum of the solution of glucose (2 wt. %) and urea (0.2 wt.%) before and after the hydrothermal reaction.

© STM Journals 2026. All Rights Reserved

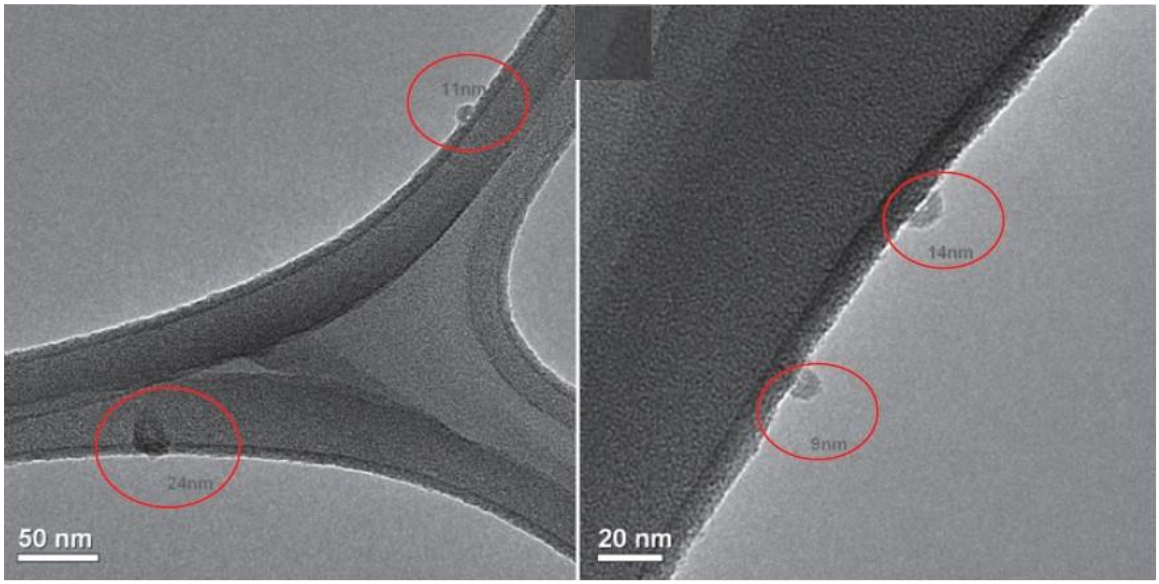


Figure 9. HRTEM images of the nitrogen doped carbon nanodots produced from the reaction of gluose (2 wt.%) and urea (0.2 wt.%) upon hydrothermal reaction at 120 C for 20 min. TEM images of N-CNDs (a) fresh and (b) after 3 months shelf life.

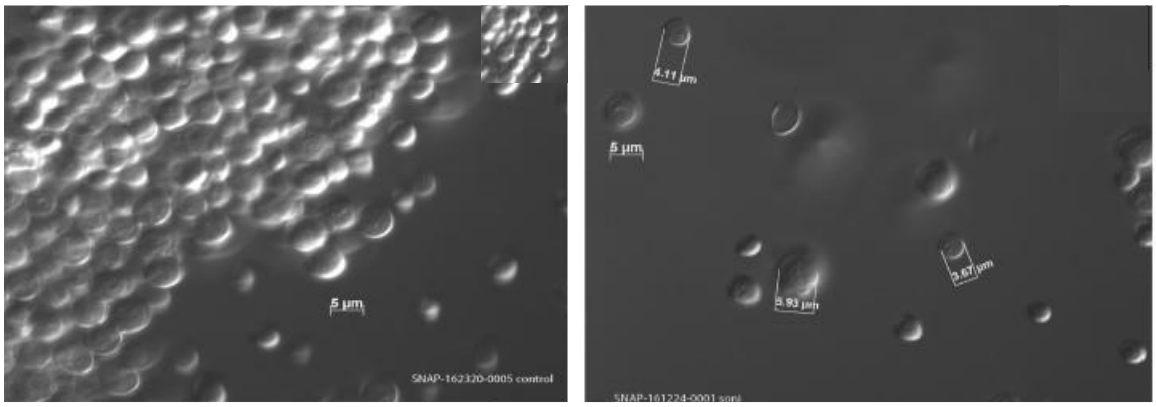


Figure 10. SEM images of the yeast particles (A) under stirring on a magnetic stirrer in a fermentation broth and (B) from the fermentation broth kept in a bath sonicator (40 kHz) [8].

Several innovative strategies have been developed to accelerate the slow fermentation process. Some of them include the use of mil sonication (40 kHz) and the use of solar energy for driving the fermentation process, wherein the formed ethanol is removed from the broth continuously. As a result, the yeast will not experience the presence of ethanol throughout the course of fermentation but will only be exposed to glucose. Recently, the potential of exotic nanostructures of carbon, namely, heteroatom-doped carbon nanodots, has been explored for accelerating the kinetics of glucose fermentation. Carbon nanodots (CNDs) are the newest allotropic form of carbon nanomaterials. While all known carbon nanostructures are hydrophobic, carbon nanodots are hydrophilic. The hydrophilicity is due to the extensive surface functionalization of the carbon nanodots. Activated carbon materials (ACMs) are extensively surface-functionalized. However, ACMs are hydrophobic, similar to other known forms of carbon. Therefore, it is not only the extensive surface functionalization but also the ultra-small size of the spherical carbon nanodots that renders them with the unique property of hydrophilicity. Like any other nanomaterials, CNDs are produced using either bottom-up or top-down approaches. A variety of feedstocks, namely, glucose, citric acid, xylose, cellulose, lignin, and algal biomass, are extensively utilized for CNDs production as the application domain of these novel materials is expanding rapidly. The hydrophilicity of CNDs makes them applicable for biomedical applications such as bioimaging and biosensing. Their high crystallinity with specific defects by the doping of heteroatoms (N/B/S/P) makes

© STM Journals 2026. All Rights Reserved

them ideal candidates for a variety of fundamental catalytic reactions, such as hydrolysis, dehydration, esterification, and etherification. Recently, the potential of doped and undoped CNDs for accelerating the kinetics of glucose fermentation has been widely investigated from Figure 8-10.

CONCLUSION

Biochemical pathways, via the metabolism of monomeric (glucose and fructose) and dimeric (sucrose) sugars to glucose by the fungal strain, yeast, *Saccharomyces cerevisiae*, yield bioethanol. However, the performance of the biocatalyst, yeast, is rate-determining and time-demanding, and the process is slow. Several attempts have been made in the recent past to enhance yeast performance. Conducting the fermentation process in the presence of nutrient-rich conditions is one of the classical methods used by biochemists to accelerate yeast performance. Alternate and new technologies for the acceleration of fermentation kinetics include conducting the biochemical reaction in the presence of sonication (40 KHz ultrasound) and conducting the fermentation process under sunlight. Herein, we propose a novel approach for using nitrogen-enriched carbon nanodots produced from an unconventional and sustainable feedstock, namely, microcrystalline cellulose. Climate change and its catastrophic results are major challenges facing mankind. The paradigm shift from fossil-based to bio-based fuels leads to the alleviation of suffering of mankind as a result of growing environmental pollution. Among various biofuels, biodiesel and bioethanol are much sought after as their energy density is close to that of gasoline, and they operate on a closed carbon cycle. Recent trends in bioethanol production include the integration of fermentation/simultaneous saccharification and fermentation (SSF) processes with solar energy and fuel cells. Biotechnological inventions that facilitate the acceleration of the kinetics of carbohydrate fermentation to bioethanol are much sought after, as the fermentation process is a key and enabling technology in biorefinery operations. Novel water-soluble carbon nanomaterials have been explored to accelerate the performance of yeast in glucose metabolism to bioethanol. The image of the CNDs formed from the glucose – urea reaction in an autoclave at 120°C for 20 min.

The conversion of the colorless solution to golden yellow is a visible indication of the conversion of glucose to carbon nanodots via the dehydration, carbonization, and polymerization reactions for the aromatic core and with extensive surface functionalization. As such, the glucose-urea solution is not expected to show any absorption. Upon hydrothermal treatment, where urea decomposes to ammonia and creates alkaline conditions conducive to the formation of CNDs, the golden yellow solution shows a characteristic absorption band with a λ_{max} of 275 nm and a shoulder at 310 nm. These features are due to the $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions. These carbon nanodots are spherical in shape and less than 10 nm in size, making them easily accessible to the cellular structure of the yeast microparticles.

When carried out under bath sonication conditions (mild sonication, 40 kHz), the yeast particles (baker's yeast; *Saccharomyces cerevisiae*) were well dispersed. As a result of continuous sonication, the CO_2 formed in the fermentation broth was separated from the broth and escaped via the porous cotton plug. As a result, ideal pH conditions are maintained, which is conducive to the performance of yeast. Moreover, the yeast surface is dynamic and exposed to glucose molecules, facilitating their migration of the glucose molecules to the cell membrane. Sonication also facilitates the transport of formed ethanol from the cellular compartment to the outside of the yeast cell. These important processes contribute to the acceleration of glucose metabolism to bioethanol. The presence of CNDs is surmised to hasten the aforementioned steps.

NMR is an elegant analytical tool that can be used to monitor the product distribution in the fermentation broth and evaluate the kinetics of glucose fermentation to bioethanol. Sample preparation for NMR analysis is relatively simple compared to that for gas chromatography or HPLC. As the fermentation broth and the products of fermentation are in the aqueous medium, D_2O is the ideal solvent for NMR analysis (Figure 10). NMR tubes are another requirement. However, the regular analysis of the fermentation products by NMR is much simpler, and the interpretation of the results by analysis of spectra can be accomplished with the help of the SDBS database, wherein the spectral (UV, FT IR,

© STM Journals 2026. All Rights Reserved

NMR, and MS) information of most of the organic compounds is stored. When CNDs are used as additives to accelerate the kinetics of fermentation, features typical of CNDs appear in both the aliphatic and aromatic regions, and they do not interfere with the useful fermentation product, bioethanol, or the secondary metabolite, glycerol. Moreover, the appearance of CNDs will be entirely at different chemical shift values as that of glucose, either in the ^{1}H or the ^{13}C NMR, making their identification easier.

REFERENCES

1. Tabah B, Pulidindi IN, Chitturi VR, Arava LM, Varvak A, Foran E, et al. Solar-energy-driven conversion of biomass to bioethanol: a sustainable approach. J Mater Chem A. 2017;5(30):15486-506.
2. Yoo CG, Lee CW, Kim TH. Effect of low-moisture anhydrous ammonia (LMAA) pretreatment on biomass quality and enzymatic hydrolysis for long-term storage. Appl Biochem Biotechnol. 2014;174(7):2639-51.
3. Kim TH, Yoo CG, Lamsal BP. Front-end recovery of protein from lignocellulosic biomass and its effects on chemical pretreatment and enzymatic saccharification. Bioprocess Biosyst Eng. 2013;36(6):687-94.
4. Park YC, Kim TH, Kim JS. Effect of organosolv pretreatment on mechanically pretreated biomass by use of concentrated ethanol as the solvent. Biotechnol Bioprocess Eng. 2017;22(4):431-9.
5. Yoo CG, Nghiem NP, Hicks KB, Kim TH. Pretreatment of corn stover using low-moisture anhydrous ammonia (LMAA) process. Bioresour Technol. 2011;102(21):10028-34.
6. Parisutham V, Kim TH, Lee SK. Feasibilities of consolidated bioprocessing microbes: from pretreatment to biofuel production. Bioresour Technol. 2014;161:431-40.
7. Caylak B, Sukan FV. Comparison of different production processes for bioethanol. Turk J Chem. 1998;22(4):351-60.
8. Sulaiman AZ, Ajit A, Yunus RM, Chisti Y. Ultrasound-assisted fermentation enhances bioethanol productivity. Biochem Eng J. 2011;54(3):141-50.
9. Qiao C, Zhou J, Luo H, Ma Y, Qin H, Zhang S, et al. Boosting ethanol fermentation with carbon dot nanozyme. ACS Appl Nano Mater. 2025;8(11):5399-411.
10. Pulidindi IN, Hakim MR, Mayer P, Gedanken A. Isosaccharinic acid mediated fine chemicals production from cellulose. J Fundam Renew Energy Appl. 2014;4(143):2.
11. Kim TH, Kim JS, Sunwoo C, Lee YY. Pretreatment of corn stover by aqueous ammonia. Bioresour Technol. 2003;90(1):39-47.
12. Goryacheva IY, Sapelkin AV, Sukhorukov GB. Carbon nanodots: mechanisms of photoluminescence and principles of application. TrAC Trends Anal Chem. 2017;90:27-37.
13. Mokoloko LL, Forbes RP, Coville NJ. The transformation of 0-D carbon dots into 1-, 2- and 3-D carbon allotropes: a minireview. Nanomaterials (Basel). 2022;12(15):2515.

© STM Journals 2026. All Rights Reserved