REVISTA CEREUS
ISSN: 2175-7275

DOI 10.18605/2175-7275/cereus.v18n1p462-477

Recebido em 18/01/2026
Aceito em 25/03/2026

ARTIGO

Saccharomyces cerevisiae: Implications for Fermentative Efficiency and Sustainable Bioeconomy

Saccharomyces cerevisiae: Implicações para a Eficiência Fermentativa e a Bioeconomia Sustentáve

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RESUMO

sustentável, baseada em sistemas circulares e no uso de *Saccharomyces cerevisiae*, desempenhando papel estratégico na economia de baixo carbono. Nesse contexto, este estudo avaliou o efeito da temperatura sobre o crescimento e a viabilidade celular das linhagens industriais Fleischmann®, Barra Grande e Catanduva-1, bem como o potencial de aplicação da biomassa excedente de leveduras na bioeconomia e sua contribuição para os Objetivos do Desenvolvimento Sustentável (ODS). As leveduras foram cultivadas em meio Yeast Extract Peptone Dextrose (YPD 2%) e posteriormente inoculadas em caldo de cana (22 °Brix; pH 5,0), seguido de incubação a 30, 35 e 40 °C. O crescimento celular foi avaliado qualitativamente em meio Potato Dextrose Agar (PDA), e a viabilidade foi determinada pelo método de coloração com azul de metileno. Os resultados evidenciaram respostas adaptativas distintas entre as linhagens, com a Fleischmann® apresentando desempenho ótimo a 30 °C, a Barra Grande exibindo maior estabilidade térmica a 40 °C e a Catanduva-1 demonstrando elevada robustez em todas as condições avaliadas. Esses achados reforçam o papel das leveduras como plataformas biotecnológicas versáteis e indicam que linhagens adaptadas ao estresse térmico oferecem vantagens estratégicas para aplicações industriais sustentáveis.

Palavras-chave: Otimização de processos; Biocombustíveis sustentáveis; Resposta ao estresse.

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ABSTRACT

Ethanolic fermentation in Brazil represents a model of clean and sustainable technology, based on circular systems and the use of *Saccharomyces cerevisiae*, playing a strategic role in the low-carbon economy. Accordingly, this study evaluated the effect of temperature on the growth and cellular viability of the industrial strains Fleischmann®, Barra Grande and Catanduva-1, as well as the potential application of surplus yeast biomass within the bioeconomy and its contribution to the Sustainable Development Goals (SDGs). The yeasts were cultivated in Yeast Extract Peptone Dextrose medium (YPD 2%) and subsequently inoculated into sugarcane juice (22 °Brix; pH 5.0), followed by incubation at 30, 35 and 40 °C. Cell growth was qualitatively assessed on Potato Dextrose Agar (PDA), and viability was determined using the methylene blue staining method. The results revealed distinct adaptive responses among the strains, with Fleischmann® showing optimal performance at 30 °C, Barra Grande exhibiting greater thermal stability at 40 °C, and Catanduva-1 demonstrating high robustness across all tested conditions. These findings reinforce the role of yeasts as versatile biotechnological platforms and indicate that thermally adapted strains offer strategic advantages for sustainable industrial applications.

Keywords: Process optimisation. Sustainable biofuels. Stress response.

1. INTRODUCTION

The intensification of climate change, increasing pressure for the decarbonisation of economies, and the progressive depletion of fossil fuel reserves have driven the search for cleaner, renewable, and more sustainable energy alternatives. In this context, biofuels have emerged as key drivers of the global energy transition, with particular emphasis on ethanol, whose production and use lead to significant reductions in greenhouse gas (GHG) emissions and promote the development of resilient agro-industrial systems (Melendez et al., 2022). This biofuel is predominantly obtained through the fermentation of sugars present in plant biomass (Tropea, 2022).

In Brazil, sugarcane is the main feedstock for ethanol production due to its agronomic suitability and high energy yield, and since the implementation of the National Alcohol Programme (Proálcool) in the 1970s, the country has become a global leader in fuel ethanol through an integrated production chain, advanced logistics, and public policies such as RenovaBio (Grangeia et al., 2023; Grandis et al., 2024). Beyond serving as an alternative to petrol, Brazilian ethanol is a strategic pillar of the bioeconomy, which is based on the sustainable use of renewable biological resources to produce energy, food, materials, and value-added compounds (Solarte-Toro and Alzate, 2021).

Ethanol production constitutes a central strategy within the bioeconomy paradigm, as it incorporates sustainable practices that combine technological innovation with environmental preservation. This approach is based on the valorisation of renewable biomass, the reuse of agro-industrial residues, and the promotion of resource circularity, thereby reducing dependence on fossil fuels and mitigating GHG emissions (Kumar Sarangi et al., 2023). By converting plant-derived by-products into clean energy, ethanol enables wealth generation with a lower environmental impact, reinforcing its role as a driver of energy transition and sustainable development (Sarkar et al., 2023; Raihan et al., 2022).

At the core of this process lies alcoholic fermentation, one of the most relevant technological pillars of the ethanol production chain. This stage is carried out by yeasts of the genus *S. cerevisiae*, microorganisms widely used in industry due to their high fermentative efficiency, robustness, and adaptability to different operational conditions (Fernandes et al., 2023; Chen et al., 2024). These yeasts are essential for process success, as they catalyse the conversion of simple sugars such as glucose and fructose into ethanol and carbon dioxide through rapid and economically viable biochemical reactions (Topaloğlu

et al., 2023). Consequently, the fermentative performance of the strains employed directly affects yield, productivity, and the sustainability of industrial ethanol production.

Over recent decades, the use of selected industrial strains of *S. cerevisiae* has led to major advances in fermentation processes, as these strains are optimised for industrial conditions, exhibiting high fermentation rates, tolerance to ethanol and temperature variations, and resistance to osmotic and inhibitory stresses, resulting in increased productivity, reduced fermentation time, and improved process stability (Chen et al., 2024). Additionally, yeast metabolism generates surplus cellular biomass during fermentation, which, although often treated as a by-product, represents an important technical and environmental advantage due to its potential reuse within circular economy systems in the production facility (Elhalis, 2024).

The reuse of surplus yeast primarily occurs through biomass recycling across successive fermentation cycles, reducing the need for fresh inoculations and optimising microbial utilisation (Van Aalst et al., 2022). In industrial systems, yeast cells are recovered by centrifugation, subjected to acid washing, and reinoculated, which lowers biological input costs and enhances process sustainability (De Góes-Favoni et al., 2022). Residual biomass can also be valorised as a protein supplement in animal feed after thermal inactivation, contributing to by-product valorisation and diversification of the ethanol value chain (Patsios et al., 2020). In addition, residual yeast biomass presents potential for bioconversion processes aimed at producing bioactive compounds, including enzymes and proteins (Łukaszewicz et al., 2024).

In ethanol production, this approach seeks to maximise the use of sugarcane and microbial resources while reducing environmental impacts and creating economic opportunities, in line with circular economy principles that promote the reuse of residues as inputs for new production cycles (Kirchherr et al., 2023). Additionally, selected yeast strains play a critical role in adapting production systems to climate change, particularly in tropical regions where high temperatures can impair yeast viability and fermentation efficiency, making thermotolerant strains essential for maintaining industrial resilience (Gomes et al., 2021; Eardley & Timson, 2020).

Furthermore, fermentation processes operate continuously and intensively, requiring strains capable of withstanding cumulative stresses such as high osmotic load, toxic compounds, and pH fluctuations (Elhalis, 2024). Selected yeasts not only tolerate these

conditions but also exhibit improved metabolic performance, reduced formation of undesirable by-products, and greater reusability across successive cycles. From an environmental perspective, ethanol production strategies that incorporate the reuse of surplus yeast biomass contribute significantly to reducing water, energy, and external input consumption (Meng et al., 2021).

Brazilian ethanol production exemplifies clean and sustainable technology based on circular systems and biotechnology. The reuse of surplus yeast biomass highlights the efficiency and innovation of the sugar-energy sector, which relies on selected *S. cerevisiae* strains with high performance and resistance to adverse conditions. In a global scenario oriented towards a low-carbon economy, Brazilian ethanol produced through sustainable practices and intelligent use of by-products stands out as one of the most promising biofuels. The consolidation of this model requires continuous investment in research, innovation, and public policies that recognize its environmental, economic, and social benefits. In this context, the present study aimed to investigate the effect of temperature on the growth and cellular viability of three industrial *Saccharomyces cerevisiae* strains cultivated in sugarcane juice-based medium, as well as to analyse the utilisation of surplus yeast biomass within the framework of the bioeconomy.

2. MATERIALS AND METHODS

2.1. Place of study development

The study was developed in the Biotechnology, Biochemistry and Biotransformation Laboratory of the Centro de Estudo em Recursos Naturais – CERNA, Universidade Estadual do Mato Grosso do Sul, Dourados/MS.

2.2. Microorganisms and inoculum preparation

The yeast strains used in this study were industrial strains of *S. cerevisiae*: Fleischmann®, Barra Grande and Catanduva-1. For the pre-inoculum, 125 mL Erlenmeyer flasks containing 2% Yeast Extract Peptone Dextrose (YPD) liquid medium were used. The medium consisted of 1.0% (w v^{-1}) yeast extract, 1.0% (w v^{-1}) peptone and 2.0% (w v^{-1}) glucose, and was sterilised by autoclaving at 120 °C for 20 min. Subsequently, 0.10 g of lyophilised yeast was inoculated into each flask. The cultures were incubated at 30 °C for 10 h under agitation at 200 rpm. After growth, the cells were harvested by centrifugation

(800 × g for 20 min), resuspended and washed three consecutive times with sterile saline solution (0.85%, w v^{-1}). The resulting wet biomass concentration was adjusted to 10 mg mL^{-1} and used for the fermentative experiments.

2.3. Fermentation conditions

Fermentation was carried out in 125 mL Erlenmeyer flasks containing 50 mL of sterilised sugarcane juice at 22 °Brix and pH 5.0, into which the yeast biomass was inoculated. The flasks were incubated at 30, 35 and 40 °C under agitation at 200 rpm. After 8 h of fermentation, aliquots were collected for subsequent analyses.

2.4. Analytical methods

Cell growth analyses were performed using Petri dishes previously prepared with solid Potato Dextrose Agar (PDA). Aliquots of 5 µL were spotted onto the plates using a micropipette and incubated at 30 °C until colony development. Growth was assessed qualitatively by photographic documentation, followed by comparison among the different treatments.

Cell viability was determined using the methylene blue staining method according to Lee, Robinson and Wang (1981), in which viable cells remain unstained while non-viable cells appear blue. Briefly, 10 µL of each sample was mixed with 90 µL of methylene blue solution in test tubes. After 5 min under agitation, cell counting was performed in a Neubauer chamber using a light microscope.

2.5. Data analysis

The results were analysed using Excel 2019 and expressed as mean values ± standard deviation. All experimental analyses were performed in triplicate.

2.6. Biotechnological application of yeast-derived compounds and alignment with the Sustainable Development Goals (SDGs)

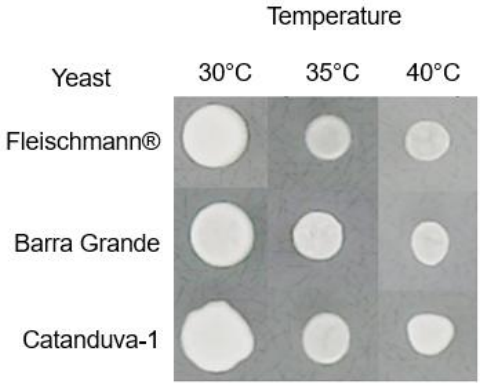
A literature survey was conducted to investigate studies addressing compounds produced by yeasts and their biotechnological applications, as well as the potential contribution of these products to the Sustainable Development Goals (SDGs). Searches were performed in national and international databases, considering publications from 2010

to 2025. After selection and critical analysis of the studies, the results were organised into tables and discussed in terms of trends and perspectives for the sustainable bioeconomy.

3. RESULTS AND DISCUSSION

The analysis of colony growth of the *S. cerevisiae* strains showed that all strains exhibited greater cellular development at 30 °C, as evidenced by the larger colony diameters. The Fleischmann® strain displayed pronounced growth at this temperature but showed a progressive reduction at 35 °C and 40 °C, indicating sensitivity to increased thermal stress. The Barra Grande strain exhibited a similar pattern; however, it maintained slightly larger colonies than Fleischmann® at higher temperatures, suggesting a somewhat greater degree of thermal tolerance. In contrast, the Catanduva-1 strain stood out by producing dense and well-developed colonies at 30 °C and, even under elevated temperatures, maintaining visible and relatively robust growth at 40 °C. These results indicate that Catanduva-1 demonstrated greater resistance to thermal stress, a trait that is advantageous for industrial applications, particularly in fermentative processes conducted under conditions with limited temperature control (Figure 1).

Figure 1. Cellular growth of *S. cerevisiae* strains at different temperatures after 8 h of fermentation.



Source: Research data.

In fermentation vats, different factors may act synergistically and induce stress in yeasts, including the presence of contaminants, pH fluctuations, unfavourable osmotic conditions, accumulation of organic acids, and increased temperature ((Tobias; Mascarenhas and Batistote, 2025). Thermal stress, in particular, exerts a strong influence

on cellular physiology by triggering changes in metabolic pathways that redirect energy towards the synthesis of protective molecules, such as trehalose, which plays an important role in stabilising the plasma membrane (Da Silva Santos et al., 2018).

Adequate fermentative performance is directly associated with the adaptive capacity of yeasts in response to these stressors. In this context, tolerance to thermal stress is an essential trait for maintaining structural integrity and cellular viability throughout the process. According to Coertjens et al. (2022), fermentation is characterised as an exothermic reaction; therefore, maintaining temperature control below 34 °C is crucial to ensure efficient fermentative metabolism and optimal ethanol production.

The analysis of cell viability revealed distinct response patterns to thermal stress, demonstrating the strain-specific adaptive capacity of S. cerevisiae. The Fleischmann® strain initially showed the highest viability at 30 °C (88%) but exhibited progressive sensitivity to increasing temperatures, declining to 62% at 40 °C. Although the Barra Grande strain started with lower viability values (74%), it maintained greater stability as temperature increased, reaching 67% at 40 °C. In contrast, Catanduva-1 exhibited consistently high viability, ranging from 82% to 80% across the three temperatures, indicating a more efficient short-term adaptation to thermal stress (Table 1).

Table 1. Cell viability of S. cerevisiae strains at different temperatures after 8 h of fermentation.

Yeast	Cell viability **(%)**		
	30 °C	**35 °C**	**40 °C**
Fleischmann®	88	75	62
Barra Grande	74	72	67
Catanduva-1	82	83	80

Source: Research data.

Studies by Tobias et al. (2025) demonstrated that the industrial strains Catanduva-1 and Pedra-2 maintained high viability (~98%) during the first 10 h of fermentation in sugarcane juice at 15 °Brix across temperatures of 30, 35 and 40 °C; however, after prolonged fermentation (40 h) at 40 °C, Pedra-2 retained approximately 60% viability, while Catanduva-1 declined to below 40%. Similarly, Santos et al. (2021) reported higher viability for the Pedra-2 and FT858 strains at 30 °C (76–79%) in sugarcane juice at 22 °Brix, with a

marked reduction at 40 °C due to thermal stress. Overall, these results highlight Catanduva-1 as a robust strain for fermentations under adverse conditions, whereas the Fleischmann® strain is more suitable for processes conducted under moderate and controlled temperatures.

The versatility of yeasts as biotechnological platforms is reflected in their application in the production of biofuels, bioplastics, foods and supplements, as well as in the valorisation of agro-industrial residues. Yeasts are also widely used in bioremediation, in the production of pharmaceuticals and vaccines, and in metabolic engineering processes, further highlighting their relevance to the circular economy. In this context, the adoption of S. cerevisiae strains with enhanced tolerance to thermal stress becomes strategically important in light of climate change, as elevated temperatures can compromise the efficiency of bioindustrial processes. More robust yeasts enable continuous fermentations with reduced dependence on cooling systems and fewer chemical adjustments, thereby lowering energy, water and additive consumption. This characteristic ensures greater production stability under adverse conditions and strengthens the principles of the bioeconomy by optimising renewable resources and promoting circularity and sustainability in fermentative systems (Table 2).

Table 2. Potential of yeasts as biotechnological platforms.

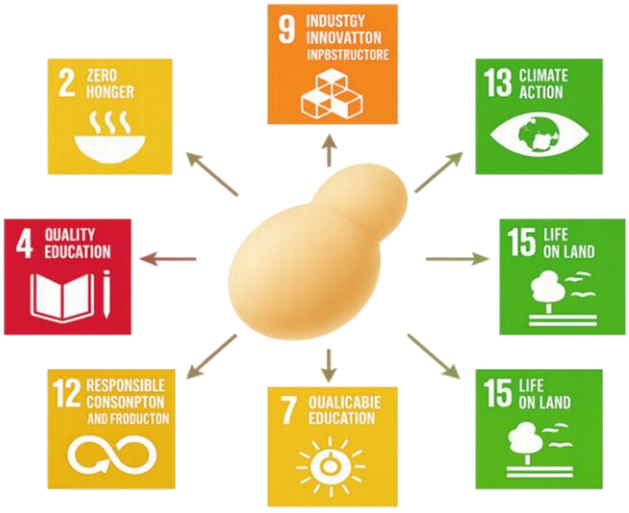
Biotechnological application	Description	Process type	Reference
Biofuel production	Ethanol, biodiesel and biobutanol from biomass or residues.	Alcoholic fermentation, anaerobic fermentation	Turner et al. (2018); De Oliveira Gonçalves et al. (2023); Tönjes et al. (2023)
Bioproducts and bioplastics synthesis	Production of organic acids, PHA and other compounds by yeasts.	Lactic acid fermentation, aerobic fermentation, metabolic engineering	Ali et al. (2023); Ospina-Betancourth et al. (2022); Zhang et al. (2023)
Agro-industrial waste valorisation	Use of vinasse, molasses and other residues as substrates.	Waste fermentation, co-fermentation, biorefinery	Coimbra et al. (2021); Montiel-Rosales et al. (2022); Carrilho and Soares (2024)
Food and supplement production	Protein-rich biomass, vitamins (e.g. B12), probiotics.	SCP (single-cell protein) production, submerged cultivation	Silva et al. (2023); Kessi-Pérez et al. (2022); Pang et al. (2022)
Environmental remediation and biosorption	Removal of heavy metals and pollutants from water and soil by yeasts.	Biosorption, bioremediation, static or suspended cultivation	Shao et al. (2025); Nicula et al. (2023); Li et al. (2023)

Pharmaceutical and vaccine production	Insulin, vaccines and therapeutic proteins produced by recombinant yeasts.	Heterologous expression, controlled fermentation, protein purification	Kulagina et al. (2021); Srivastava et al. (2023); Paul, Kumari and Siddiqui (2023)
Metabolic engineering and circular economy	Yeasts optimised for the production of natural and sustainable compounds.	Genetic engineering, modular metabolic expression	Ullah, Shahzad and Wang (2021); Shi, Chen and Nielsen (2025); Sousa et al. (2024)

Source: Compiled by the authors.

Yeasts, particularly *S. cerevisiae*, stand out as versatile eukaryotic microorganisms with broad potential for application in modern biotechnology. Their ability to operate in diverse processes, including industrial fermentations, protein-rich biomass production, bioremediation of contaminated environments and renewable energy generation, makes them strategic tools for the development of sustainable solutions. In this context, the biotechnological use of yeasts directly contributes to the promotion of more efficient, environmentally responsible and socially inclusive production systems (Figure 2).

Figure 2. Potential applications of yeasts in contributing to the achievement of the Sustainable Development Goals through biotechnology



Source: Prepared by the authors (2026).

The diverse biotechnological applications of yeasts, particularly *Saccharomyces cerevisiae*, are closely aligned with the United Nations 2030 Agenda and its Sustainable Development Goals (SDGs). Due to their metabolic versatility, robustness, and long history

of safe use, yeasts serve as key biological platforms for sustainable production across multiple industrial sectors, extending beyond traditional fermentation to areas such as food and feed, biofuels, biochemicals, bioplastics, environmental remediation, and human health. Recent studies have emphasized that yeast-based biotechnologies contribute directly to multiple SDGs by promoting resource efficiency, waste valorisation, and the transition from fossil-based to bio-based economies, according to Nirmal et al. (2025); Balakrishnan et al. (2025); Trujillo-Cayado et al. (2025), including:

• SDG 2 (Zero Hunger): addressed through the ability of yeasts to produce single-cell protein (SCP) from agro-industrial residues, thereby contributing to food security in vulnerable regions.

• SDG 4 (Quality Education): supported by the incorporation of yeasts into teaching, research and extension projects in biotechnology, promoting scientific and technical training.

• SDG 7 (Affordable and Clean Energy): highlighted by the role of *S. cerevisiae* in ethanol production, offering alternatives to fossil fuels.

• SDG 12 (Responsible Consumption and Production): promoted through the valorisation of residues as substrates for fermentative processes, fostering circular economy practices and waste reduction.

• SDG 13 (Climate Action): addressed by replacing polluting industrial processes with biotechnological routes that generate lower greenhouse gas emissions.

• SDG 15 (Life on Land): supported by the use of yeasts in bioremediation practices and sustainable waste management, contributing to environmental recovery and ecosystem conservation.

These examples demonstrate the potential of yeasts as key tools for integrating technological innovation, environmental sustainability and socioeconomic development. Furthermore, the valorisation of microorganisms adapted to Brazilian regional conditions enhances technological autonomy and adds value to national scientific knowledge. The bioeconomy is also strengthened by integrating climate mitigation strategies with technological innovations in biofuel production systems.

4. FINAL CONSIDERATIONS

Temperature plays a decisive role in the performance of *S. cerevisiae* strains, with 30 °C representing the most favourable condition for cellular growth. Cell viability varied

according to temperature, revealing distinct adaptive strategies among the evaluated strains.

Among the strains analysed, Catanduva-1 stood out for its stability under all tested conditions, demonstrating greater thermal resilience and strong potential for industrial applications in fermentative processes subject to temperature fluctuations.

The wide range of biotechnological applications highlights the versatile role of yeasts as cellular platforms capable of meeting strategic demands across different sectors. Their high innovative potential, combined with their ability to participate in bioremediation processes and to be genetically optimised, further expands their industrial prospects. These attributes reinforce the contribution of yeasts to the achievement of the Sustainable Development Goals and to the consolidation of the bioeconomy.

ACKNOWLEDGEMENTS

The authors acknowledge the Universidade Estadual de Mato Grosso do Sul (UEMS), the Programa de Pós-Graduação em Recursos Naturais (PGRN), the Fundação de Apoio ao Desenvolvimento do Ensino, Ciência e Tecnologia do Estado de Mato Grosso do Sul (FUNDECT), the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), the Financiadora de Inovação e Pesquisa (FINEP), and the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil for financial support to VCMT and MSM.

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