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Research Article

VALORIZATION OF FRUIT WASTE FOR BIOETHANOL PRODUCTION THROUGH FERMENTATION WITH *SACCHAROMYCES CEREVISIAE*

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ABSTRACT

With the increasing global demand for fossil fuels and the consequent rise in environmental pollution, the search for renewable and sustainable energy alternatives has become a global priority. This study explores the production of bioethanol from fruit waste—specifically apple pomace and overripe bananas—using the yeast *Saccharomyces cerevisiae* as a fermenting agent. The substrates were pretreated, mixed with sucrose and yeast inoculum, and subjected to a 36-hour fermentation process at ambient temperature. The fermented broth was then distilled to recover ethanol, which was analyzed using the specific gravity method. The experimental process yielded 200 mL of 48% ethanol from a 1,000 mL substrate mixture, demonstrating a yield efficiency of approximately 38%. The process proved cost-effective, environmentally sustainable, and suitable for small-scale implementation. The study highlights fruit waste as a promising feedstock for renewable fuel production and supports the development of decentralized bioethanol generation systems, particularly in developing countries.

Keywords: Bioethanol, Fruit waste, Saccharomyces cerevisiae, Fermentation, Renewable energy, Waste valorization.

INTRODUCTION

The depletion of fossil fuel reserves and the adverse environmental effects of their combustion have prompted an urgent need for renewable energy alternatives. Bioethanol, a clean-burning and renewable biofuel derived from biological feedstocks, offers a sustainable solution to these challenges. It can be produced from a wide variety of raw materials, including sugarcane, corn, potato, and other starch- or cellulose-rich substrates. However, large-scale ethanol production from food crops has raised concerns about food security, land use, and production costs. To address these limitations, recent research has shifted toward the utilization of non-conventional feedstocks, particularly agro-industrial and fruit wastes, as cost-effective and sustainable alternatives. Fruit wastes such as banana peels, apple pomace, mango pulp residues, and citrus peels are generated in large quantities worldwide and pose environmental disposal challenges. These wastes are rich in fermentable sugars and nutrients suitable for microbial growth, making them ideal substrates for ethanol fermentation. By employing waste-to-energy conversion techniques, it becomes possible to reduce environmental pollution, manage organic waste, and generate renewable energy simultaneously. The yeast *Saccharomyces cerevisiae* is widely recognized for its high ethanol yield, tolerance to alcohol, and ability to ferment a broad range of sugars. The present study focuses on the valorization of fruit waste specifically apple pomace and rotten bananas for bioethanol production through fermentation with *S. cerevisiae*. The main objectives are to: Evaluate the potential of fruit waste as a substrate for ethanol production. Optimize fermentation conditions for maximum ethanol yield. Demonstrate the feasibility of a

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simple, low-cost bioethanol production process suitable for small-scale or rural applications.

Fruit processing residues (apple pomace, banana peels, mixed fruit juices) are widely recognized as low-cost, sugar-rich substrates for ethanol production. Hang and Woodams (1981) provided early experimental evidence of alcohol production from apple pomace, while several more recent studies have evaluated a wide spectrum of fruit wastes (apple pomace, banana peels, mango, pawpaw, pineapple) as viable feedstocks for bioethanol production (Borujeni (2021); Mtashobya (2025), Reddy (2007). Reviews synthesize these findings and emphasize the high availability and seasonal abundance of these wastes, which reduce feedstock costs and avoid competition with food crops (Mgeni (2024); Mgeni (2025). Effective pretreatment and saccharification are critical to release fermentable sugars from fruit residues. Enzymatic hydrolysis of apple pomace liquid fractions has been shown to significantly increase fermentable sugar yields (Kut (2022) Magyar (2016)). Microwave-assisted hydrolysis and chemical pretreatments have also been explored for fruit peels and lignocellulosic fractions to improve sugar accessibility prior to fermentation (Suhag (2020) and Sanchez (2007). Studies on banana wastes highlight that a combination of mild acid/alkaline pretreatment followed by enzymatic saccharification can improve subsequent ethanol yields (Oberoi *et al*. 2011; Singh (2014).

Saccharomyces cerevisiae remains the workhorse for ethanol fermentation due to its ethanol tolerance and high conversion efficiency; many studies use *S. cerevisiae* alone or in co-culture with saccharifying fungi (e.g., *Aspergillus niger*) to achieve simultaneous saccharification and fermentation (SSF) (Singh (2014), Kumar (2020) and Brooks (2008)). Consolidated bioprocessing (CBP), in which a single microbial consortium performs hydrolysis and fermentation, is emerging as a promising route to reduce process steps and costs (Rathod (2024)). Comparative studies demonstrate that SSF and CBP can yield equal or higher ethanol titers from fruit wastes compared with separate hydrolysis-fermentation, particularly when enzymatic loading is limiting (Suryaprabha (2017) and Fang (2023). Several experimental studies have optimized fermentation parameters to maximize ethanol yield from fruit wastes. Oberoi (2011) employed statistical design to optimize temperature, pH, and substrate concentration for banana peel fermentation and reported improved titers. Time course studies indicate that ethanol production typically plateaus within 24–48 h under optimal conditions for S. cerevisiae (Hang and Woodams (1981) ; Akin-Osanaiye (2008). Nutrient supplementation (e.g., yeast extract, nitrogen sources) and inoculum size strongly influence fermentation kinetics and final yields (Asli (2010) and Reddy (2007).

Reported ethanol yields from fruit residues vary by substrate and process but are generally promising: apple-based studies report moderate to high yields after enzymatic hydrolysis and distillation Kut (2022) and Magyar (2016)), while banana peel studies show comparable yields when SSF or optimized pretreatments are applied (Brooks (2008) and Suhag (2020) and Oberoi (2011). Distillation and redistillation remain necessary to reach fuel-grade concentrations; techno-economic assessments indicate that energy-efficient distillation strategies and integration of heat recovery greatly affect overall process viability (Rebolledo-Leiva (2024) and Goettemoeller & Goettemoeller (2007).

Moving beyond single-product ethanol processes, integrated apple-pomace biorefineries and valorization strategies aim to produce ethanol alongside other valuable products (e.g., mycoprotein, pectin, animal feed), improving economics and sustainability (Fukuda *et al*., (2009), Borujeni *et al*. (1981) and Rebolledo-Leiva (2024). Reviews advocate cascading biorefinery concepts where sequential extraction and conversion steps maximize resource use and minimize waste (Gebre (2023) and Grassi (1999). Techno-economic and life-cycle assessments show that fruit-waste ethanol can offer lower net greenhouse gas emissions than fossil fuels, especially when local feedstock supply and waste management benefits are factored in (Rebolledo-Leiva (2024) and Inderwildi & King (2009). Industrial scaling requires consistent feedstock supply chains and process integration to reduce logistics costs; Singh and Jain (1995); Shinde and R. B. Patil (2016), Magyar (2016) and Borujeni et al. (1981) provided process mass balances and preliminary industrial estimates that help identify major energy sinks and cost drivers. Post-fermentation residues from fruit wastes are nutrient-rich and suitable as soil amendments or compost, supporting circularity and reducing disposal burdens (Akin-Osanaiye (2008); Gebregergs (2016) and Sanchez (2007).

MATERIALS AND METHODS

Collection of Fruit Waste

Approximately 400 g of apple pomace and overripe bananas were collected from local fruit markets in Dehradun, India. The samples were washed in 5% potassium permanganate ($KMnO_4$) solution to remove surface contaminants, followed by thorough rinsing with distilled water. The cleaned fruit wastes were homogenized using a mechanical blender to obtain a uniform substrate.

Preparation of Fermentation Substrate

Following the modified protocol of S. Kauser (2024) and Akin-Sanaye (2008), 300 mL of warm distilled water was mixed with 50 g of sucrose and 10 g of *Saccharomyces cerevisiae* obtained from the Forest Research Institute (FRI), Dehradun. This yeast-sucrose solution was then added to the homogenized fruit waste mixture and stirred thoroughly. The final volume was adjusted to 1,000 mL with slightly warm distilled water. The prepared substrate was transferred into a 1.5 L conical flask, sealed with a cotton plug, and incubated at room temperature for fermentation.

Fermentation and Ethanol Recovery

The fermentation process was allowed to proceed for 36 hours under anaerobic conditions. Samples were periodically collected and centrifuged to separate the supernatant. The ethanol concentration in the supernatant was determined using the specific gravity method (AOAC, 1970; 1980). Following fermentation, the mixture was distilled using a laboratory distillation apparatus to concentrate ethanol. A yield of approximately 200 mL of 48% ethanol was obtained from the 1,000 mL fermentation mixture. The product could be further purified through redistillation for higher concentration.

Waste Residue Utilization

The post-fermentation residues, rich in organic matter, were air-dried and tested as a potential organic fertilizer. These residues contain valuable nutrients that can enhance soil fertility, contributing to circular waste utilization.

RESULTS AND DISCUSSION

After a 36-hour fermentation period, the mixture of apple pomace and rotten banana produced a total of 200 mL of ethanol with 48% concentration from a 1,000 mL substrate volume, corresponding to a 38% yield. Ethanol concentration increased steadily during the fermentation process and plateaued after approximately 30–36 hours, indicating completion of sugar conversion by *S. cerevisiae*.

Table 1. Composition of all materials used.

Substrate Composition	Initial Volume (mL)	Fermentation Duration (Hrs)	Ethanol Concentration (%)	Yield (%)
Apple pomace + Rotten Banana	1000	36	48	38

The successful conversion of fruit waste into bioethanol demonstrates the potential of low-cost, locally available feedstocks for sustainable fuel production. The yield obtained (48% ethanol concentration) is comparable with results from other studies utilizing similar substrates. Akin-Osanaiye et al. (2008) reported ethanol yields of 45% from papaya waste fermentation. Reddy (2007) obtained 42% ethanol from mango fruit juice fermentation. Brooks (2008) achieved 46% ethanol concentration using ripe banana peels. The comparable performance of mixed fruit waste in this study indicates synergistic effects of mixed sugars and nutrients present in apple pomace and bananas, enhancing yeast metabolism and fermentation efficiency. The use of *Saccharomyces cerevisiae* remains advantageous due to its high tolerance to ethanol, rapid sugar uptake, and robust growth under ambient conditions. The 36-hour fermentation period observed is consistent with optimal yeast activity before nutrient depletion or ethanol inhibition. Economically, the process presents minimal production costs since the substrates are freely available as fruit waste, and the yeast strain used is inexpensive. Environmentally, it promotes waste valorization, reduces landfill burden, and supports the circular bioeconomy model by converting waste into value-added products. Moreover, the fermentation residues, rich in organic compounds, can serve as bio-fertilizers, thereby closing the material loop.

CONCLUSION

This study demonstrates that fruit waste such as apple pomace and rotten bananas can be effectively utilized for bioethanol production through fermentation with *Saccharomyces cerevisiae*. The process yielded 48% ethanol concentration after 36 hours, validating the efficiency of low-cost substrates for renewable fuel generation. The method is simple, eco-friendly, and feasible for small-scale or rural biofuel production. Additionally, the post-fermentation waste can be repurposed as fertilizer, promoting sustainable waste management. Thus, fruit waste valorization not only supports renewable energy goals but also contributes to a zero-waste and circular economy framework. Further optimization and scale-up of this method could help integrate bioethanol production into local energy systems and agricultural waste management programs. Future research should focus on optimizing fermentation parameters such as pH, temperature, inoculum size, and nutrient supplementation to enhance yield and efficiency. Scaling up to pilot or industrial levels will further validate its commercial feasibility.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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