Production of Bio-Ethanol from Cafeteria Food Waste

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Project Title (mention project title here)

Sustainable Development Goals

(Please tick the relevant SDG(s) linked with FYDP)

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	**SDG 12**	**Responsible Consumption and Production**
SDG 5	Gender Equality	**SDG 13**	**Climate Change**
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	**Affordable and Clean Energy**	SDG 15	Life on Land
SDG 8	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving

	Attribute	Complex Problem	
1	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	Yes
2	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	Y
3	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	Y
4	Familiarity of issues	Involve infrequently encountered issues	Y
5	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
6	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	Y
7	Consequences	Have significant consequences in a range of contexts.	
8	Interdependence	Are high level problems including many component parts or sub-problems	

Range of Complex Problem Activities

	Attribute	Complex Activities	
1	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	Y
2	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	Y
3	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	Y
4	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	Y
5	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	Y

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1. Abstract

The twin challenges of efficient waste management and the generation of clean and cost-effective energy are paramount in our societies. Now a days, food waste has emerged as a significant economic, social, and environmental concern. This research tackles contemporary challenges in waste management and sustainable energy by focusing on the intricate issue of food waste. It explores the conversion of food waste into ethanol through the utilization of Saccharomyces cerevisiae. The study reveals that, with a 10% solid load, Saccharomyces cerevisiae efficiently converts 80% of food waste into ethanol in just 72 hours, yielding 20.99 g/l ethanol with a productivity of 0.29. Furthermore, it identifies the optimum 72-hour timeframe for maximizing ethanol production from glucose. This innovative approach offers a sustainable solution for waste management and the generation of clean energy, addressing both food waste and environmental concerns.

2. Introduction

The challenges of waste management and the pursuit of clean and affordable energy sources are critical issues faced by societies worldwide (Savita, 2018). In Jakarta, Indonesia, a substantial portion of municipal solid waste (MSW), approximately 6,000 tons per day out of a total of 8,000 tons, finds its way to landfills (Putra et al., 2020). The United States harnesses 11% of the biological fraction of MSW for electricity generation through waste-to-energy (WTE) facilities, underlining the potential of converting waste to power (*Pakistan Environmental Protection Agency*, n.d.). Meanwhile, China grapples with the monumental challenge of managing around
130 million tons of MSW, with a diverse composition, necessitating comprehensive waste management strategies (Pheakdey et al., 2022).

The Organization for Economic Co-operation and Development (OECD) estimates that MSW typically comprises 5% metal, 7% glass, 10% plastic, 28% paper, and a significant 35 -40% organic waste (OCDE, 2013). The substantial portion of organic waste, including food scraps, underscores the need for sustainable management practices. Food waste, recognized as a significant economic, social, and environmental concern, has prompted global initiatives such as the Food and Agriculture Organization's goal to reduce food waste by 50% by 2030 (“FAO Publ. Cat. 2022,” 2022). Furthermore, addressing the energy crisis and environmental impact, particularly from solid biomass and coal, is crucial, given that over 2.5 billion people lack access to clean cooking facilities globally (*IEA – International Energy Agency*, n.d.). Household air pollution, a consequence of inadequate cooking facilities, results in approximately 3.2 million annual deaths, with notable health implications (*World Health Organization (WHO)*, n.d.). However, the solution lies in transitioning to clean cooking fuels and technologies. In this context, food waste, often collected in substantial quantities from various sources, emerges as a valuable resource for bioprocess engineering. The University of Engineering and Technology Taxila, for example, generates around 60% of its waste as food waste, highlighting the potential for sustainable waste management. Food waste composition varies across regions due to cultural and habitual traditions. Globally, about one-third of food production, roughly 1.3 billion tons, is lost or wasted annually, necessitating innovative and sustainable approaches to address this challenge ("FAO Publ. Cat. 2022," 2022).

In Pakistan, the pressing issue of waste management is evident, with a daily generation of approximately 110 tons of solid waste, equating to a per capita rate of 0.337 kg/day. Among this substantial waste stream, an alarming 30% comprises food waste, amounting to a staggering 33 tons of discarded food annually (Blakeney, 2019). This situation calls for innovative and sustainable solutions. One promising avenue involves harnessing this food waste as a valuable raw material for ethanol fermentation, which not only addresses waste management concerns but also holds the potential to significantly reduce costs.

Taking a closer look at the University of Engineering and Technology Taxila, where waste management is a critical consideration, the institution grapples with a daily waste generation of around 250 kg/day. Astonishingly, 60% of this waste is constituted by food waste, signifying the substantial scope for enhancing waste utilization and management practices within the university.

3. Materials & Methods

3.1 Materials

In this research, food waste from the University of Engineering and Technology, Taxila's cafeterias was the primary material studied. The food waste was carefully processed, including sun-drying for two weeks, grinding to 1-3 mm particles, and storage at 4°C. Saccharomyces cerevisiae, a commercial yeast strain, was employed for biological experiments. Enzymes, such as cellulose and amylase, were naturally extracted from vegetable and fruit peels using a phosphate buffer. Chemical reagents like 98% sulphuric acid and sodium hydroxide solution were sourced from the department's chemistry lab. These materials and reagents played crucial roles in the research's methodology.

3.2 Methodology

Dilute acid pretreatment involved treating food waste samples with 1% and 3% dilute H_2SO_4 acid for 1 and 2 days, with a sample-to-acid ratio of 1:3. The samples were analyzed for reducing sugars using the DNS method. After analysis, the solid residue was dried at 50°C for 2 days. Simultaneous Saccharification & Fermentation (SSF) with natural enzymes was employed to convert complex carbohydrates to ethanol. Yeast was introduced to ferment these sugars into ethanol directly. This method improved efficiency and reduced processing time. Reducing sugar concentrations were determined using the DNS method. Absorbance was measured at 550 nm. Biomass concentration was determined through optical density measurements at 550 nm wavelength. Calibration curves were generated using yeast solutions. HPLC was used to determine ethanol and glucose concentrations. Samples were taken at intervals, diluted, and filtered.

3.3 Analytical Methods

This section details the analytical methods used to characterize the food waste sample. The sample was assessed for pH, moisture content, total solids, volatile solids, and ash content. For pH measurement, a sample was mixed with distilled water and measured with a pH meter. Moisture content was determined by weighing before and after drying the sample in a hot air oven. Total solids were calculated after drying the sample. Volatile solids were measured by heating the sample in a muffle furnace. Ash content was determined by burning the dried sample. Additionally, hemicellulose, lignin, and cellulose content were determined using specific chemical treatments and weight differences.

3.4 Experimental Setup

An experimental setup was devised for the small-scale production of bioethanol from cafeteria food waste, utilizing cost-effective materials and repurposed metals (Figure 1). The system consisted of a ferment tank with a total volume of 13L, accommodating a working volume of 10L, serving as the primary vessel for sustaining the volumes of both the cultivation and feedstock tanks. Notably, the system relied on a pumpless slurry flow mechanism, driven by gravitational force. To maintain a constant temperature of

30°C, essential for yeast fermentation, an aquarium heater (12 V) was employed during winter experiments, while it was unnecessary in the summer.

Additionally, within the ferment tank, a low-energy electric motor-operated stirrer facilitated uniform slurry mixing throughout the experimental process.

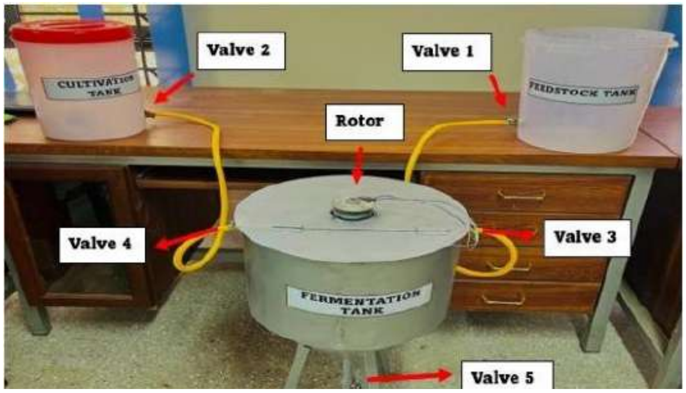


Figure 1: Bioethanol

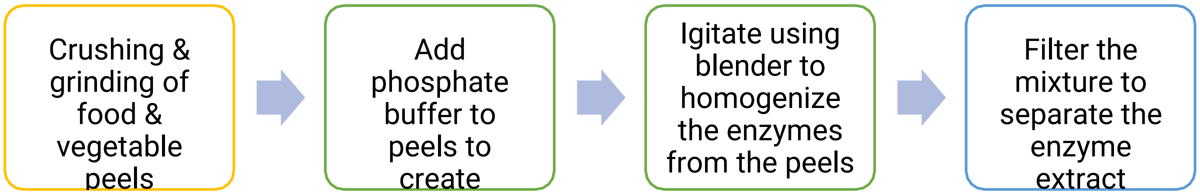
3.5 Bioethanol Yeilding Process

To produce bioethanol from food waste, the process began with sun-drying and grinding the waste into smaller pieces. The dried sample then underwent an acidic pretreatment before being boiled in a mixture of 4L of water and 550g of waste, with an additional 100g of powdered sugarcane added. After boiling, the slurry was cooled to around 30°C, filtered, and the resulting feedstock could be repurposed as poultry industry feed, reducing agricultural waste. Within the reactor system, feedstock was stored in the feedstock tank, while a yeast solution containing 200g of yeast in 2L of boiled water was placed in the cultivation tank. Valves 1 and 2 were opened to allow the flow of feedstock and yeast solution into the fermentation tank, maintaining a controlled temperature of approximately 30°C with a heater and rotor. Throughout this process, slurry samples were collected from Day 1 to Day 3 through Valve 3 for monitoring.

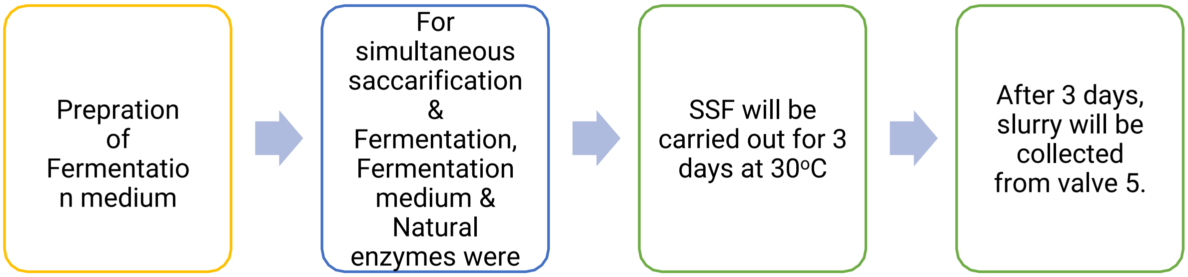
3.6 Design Methodology

1. Steps in Preparation of Sample

2. Steps in Extraction of Natural Enzymes for Hydrolysis



3. Steps in Fermentation



4. Results & Discussions

4.1 Characteristics of Food Waste

The composition of kitchen waste used in the study is summarized in Table 1. The total dry matter, an indirect indicator of available nutrients for yeast growth and maintenance, ranged from 30% to 40% (w/w) due to varying moisture content, which fell between 60% and 70% (w/w). Approximately 60% of the total dry matter consisted of carbohydrates, which are the primary focus for obtaining fermentable sugars, making kitchen waste a valuable raw material for ethanol production.

Table 1: Characteristics of food-waste

Constituent	Content (% w/w)
Moisture	63.4 ± 3.8
Total Solids	35.8 ± 3.7
Protein	4.4 ± 0.24
Ash	0.5 ± 0.84
Total CHO's	23.5 ± 6.63

4.2 Effect of Pretreatment Method on Glucose Production

According to the data given in Table 4.2, it was found that no pretreated samples had higher initial glucose concentrations than the acid pretreated samples.

Table 2: Pretreatment conditions and glucose concentrations after each pretreatment

Pretreatment conditions			**Glucose concentratio**
Temperature ˚C	**Time (hour)**	**Chemical**	
NPT	NPT	NPT	22.7
60	3	1%	13.1
60	3	3%	12.9

4.3 Behavior of Saccharomyces Cerevisiae in Kitchen Waste

From the results obtained by kitchen waste fermentations performed at 30˚C, pH 4.5, 150 rpm and initial cell concentration of 1g/L (corresponding 10% (v/v) inoculum of Saccharomyces cerevisiae), it can be seen that the cell biomass concentration reached high values in waste medium fermentation.

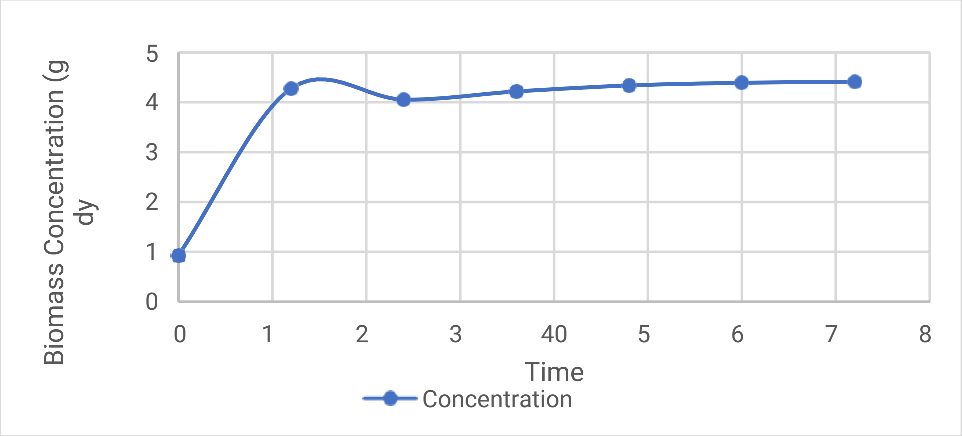


Figure 2: Growth of Saccharomyces Cerevisiae in Waste Medium

4.4 Glucose-Ethanol Trends and Determination of Fermentation Time

This study investigated kitchen waste fermentation at 30˚C and pH 4.5 with 150 rpm agitation. It achieved an average 80% glucose conversion, with 79% conversion at a 10% solid load. The highest ethanol yield was 1.66 g ethanol/g glucose after 72 hours, with a productivity of 0.29 g ethanol/L.h. Glucose concentrations consistently declined, highlighting active fermentation via hydrolysis by S. cerevisiae. These findings offer insights for optimizing kitchen waste fermentation for ethanol production.

During fermentation, glucose concentration consistently decreased, starting from an initial 51.3 g/L and dropping notably after 12 hours. This decline was attributed to S. cerevisiae's efficient glucose utilization for ethanol production via hydrolysis under anaerobic conditions, confirming active fermentation.

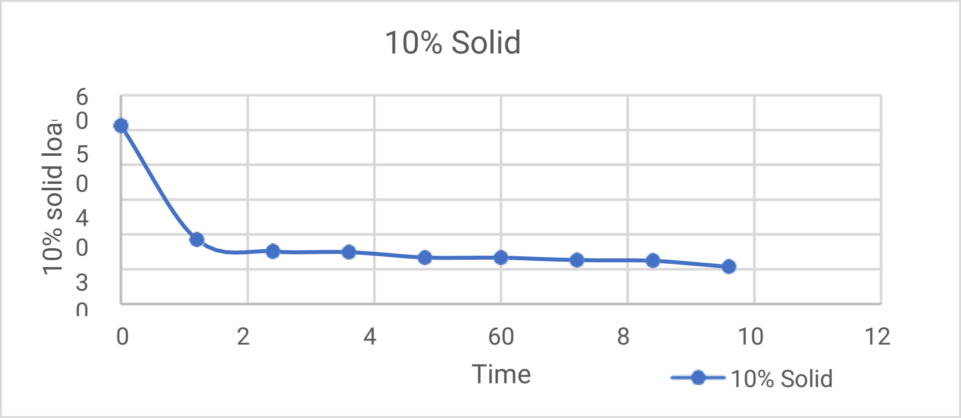


Figure 3: Concentration of Glucose during Fermentation

The fermentation process exhibited a distinct ethanol accumulation pattern. Ethanol concentration rapidly increased from zero at the start, reaching 20.99 g/L by 72 hours, representing peak efficiency. Beyond 72 hours, ethanol production declined, possibly due to limiting glucose availability or the accumulation of inhibitory compounds, with stabilization observed from 84 to 96 hours, indicating a metabolic equilibrium.

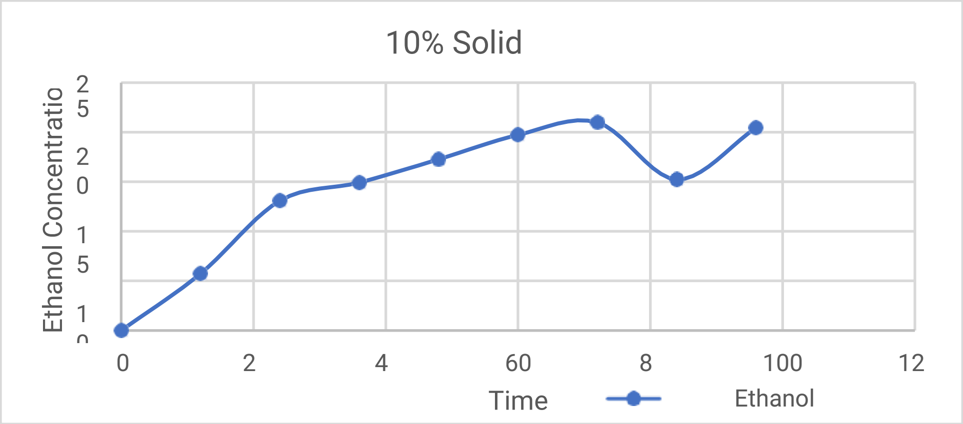


Figure 4: Concentration of Ethanol during Fermentation

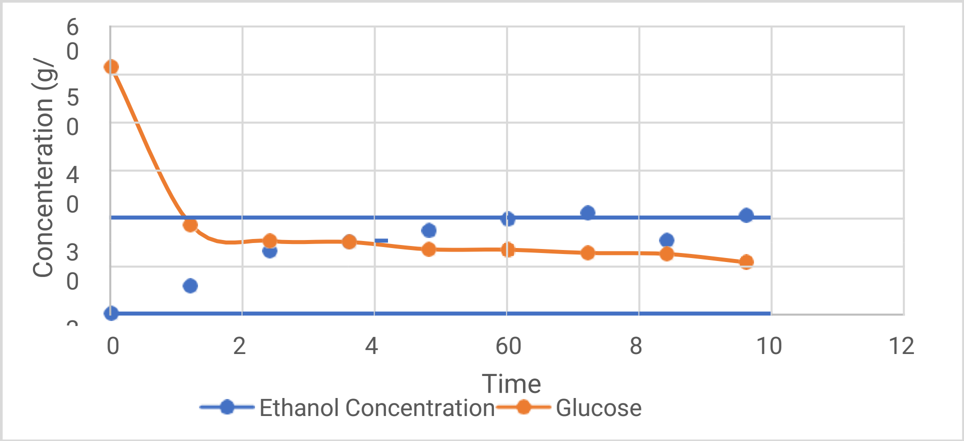


Figure 5: Waste medium fermentation with 10% solid load.

Figure 5 illustrates the dynamic relationship between ethanol and glucose concentrations, showing efficient fermentation with rising ethanol levels and decreasing glucose levels.

5. Conclusion

The experimental results highlight the promising feasibility and efficiency of producing ethanol from mixed kitchen waste, presenting cost-saving and sustainability opportunities. Using mixed kitchen waste as a raw material streamlines the process, eliminating the need for carbohydrate fraction segregation and simplifying waste management. Notably, the absence of pretreatment before enzymatic hydrolysis results in high glucose levels, potentially reducing energy consumption and enhancing bioethanol yields. Additionally, the natural nutrient composition of Food waste eliminates the need for a separate fermentation medium, offering a more economically viable and sustainable approach to ethanol production.

Reference

Blakeney, M. (2019). Food loss and food waste: Causes and solutions. In *Food Loss and Food Waste: Causes and Solutions*. https://doi.org/10.4337/9781788975391

FAO publications catalogue 2022. (2022). *FAO Publications Catalogue 2022*. https://doi.org/10.4060/CC2323EN

IEA – International Energy Agency. (n.d.). Retrieved September 18, 2023, from https://www.iea.org/

OCDE. (2013). Education at a Glance 2013. In *Education at a Giance*. http://www.oecd-ilibrary.org/docserver/download/4213201e.pdf?expires=1395222439&id=id&accname=gue st&checksum=F9C6674E09CE56B8C66B5B09314145B0

Pakistan Environmental Protection Agency. (n.d.). Retrieved September 18, 2023, from https://environment.gov.pk/index

Pheakdey, D. V., Quan, N. Van, Khanh, T. D., & Xuan, T. D. (2022). Challenges and Priorities of Municipal Solid Waste Management in Cambodia. *International Journal of Environmental Research and Public Health 2022, Vol. 19, Page 8458*, *19*(14), 8458. https://doi.org/10.3390/IJERPH19148458

World Health Organization (WHO). (n.d.). Retrieved September 18, 2023, from https://www.who.int/