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Contextual Learning of Bioethanol: Effect of NPK and Urea Application on Production from Pineapple Waste

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Abstract: *The global energy crisis drives the search for environmentally friendly renewable energy sources, one of which is bioethanol. This research aims to determine the effect of NPK and urea on bioethanol production. The method used research is experimental method, The production process includes the hydrolysis stage using 5% HCl, fermentation for 7 days with Saccharomyces cerevisiae, purification through distillation, measure alcohol content using an alcohol meter. Variations of materials such as pineapple peels, pineapple leaves, and a combination of both, as well as the influence of nutrient addition during the fermentation process, by adding nutrients in the form of NPK, Urea, and a combination of both. The research results show that pineapple peels treated with urea produced the highest alcohol content at 17%. Pineapple leaves showed the highest yield at 5%. in the treatment, the combination of pineapple skin and leaves showed the highest content of 8% in the single NPK treatment. The use of pineapple peels is more effective than pineapple leaves. application of nutrients, especially NPK, has been proven to enhance fermentation efficiency, particularly on more complex substrates. This research shows that NPK and urea have an influence on the production of bioethanol from pineapple peels and leaves.*

Keywords: *bioethanol; pineapple leaves; pineapple peels; NPK; urea*

INTRODUCTION

Currently, the energy problem has reached a scarcity level, and the energy crisis has become one of the biggest challenges facing the world today. In the past few decades, energy demand has surged due to global population growth, industrial development, and rising living standards. However, in this competition, aspects are often overlooked. The limitations of energy resources and the unsustainable exploitation of natural resources have brought us to a critical point (Logayah et al., 2023). The use of renewable energy sources is becoming increasingly important in the current era. One of the promising alternative energy sources is biomass (Sulasminingsih et al., 2023). Biomass is an organic material derived from the metabolic residues of plants, animals, or produced waste. According to several researchers, biomass consists of several components that can be utilized, namely cellulose, hemicellulose, and lignin. As a country with high fertility, it has great potential in utilizing biomass as an energy source (Suhartoyo and Kristiawan, 2020). One of the alternative energy sources from biomass that has the potential to replace fossil energy is bioethanol. Basically, bioethanol is ethanol or an alcohol compound produced through the fermentation process of biomass with the help of microorganisms (Wandono et al., 2020).

The issue of the energy crisis is not only an environmental and economic concern but also a highly relevant topic to study in the context of education, particularly in chemistry education. The topic of bioethanol as an alternative energy source from biomass can be used as a project-based learning model that discusses chemical concepts such as hydrolysis reactions, fermentation, organic compounds, and environmentally friendly technology. Through this learning, one can understand the application of chemistry in real life, as well as instill awareness of the importance of utilizing agricultural waste for more beneficial purposes.

One of the agricultural wastes that can be utilized as bioethanol is pineapple fruit waste. In Bengkulu, pineapple peel waste has not yet been optimally utilized despite its great potential. One of the local specialties is Kue Bay Tat, which is widely produced by home industries in Bengkulu. This food has become a favorite souvenir for tourists visiting the area. Bay Tat cake is made from wheat flour and coconut milk, with a topping of pineapple jam. However, in the process of making it, only the flesh and core of the pineapple are used, while the other parts, such as the skin, eyes, stem, and crown, are discarded. This pineapple waste is very unfortunate if not utilized properly (Fitriani et al., 2021).. Therefore, in this study, pineapple peels and leaves will be used as bioethanol.

In the research previously conducted by (Lazuardi et al., 2024),titled Utilization of Yellow Kepok Banana Peel (Musa acuminata balbisiana) as a Raw Material for Bioethanol in an Eco-Friendly Technology Context, five variations were carried out, namely: a) composition A is 100% yeast (without the addition of urea and NPK fertilizers); b) composition B is 100% urea; c) composition C is 100% NPK; d) composition D is 50% urea and 50% NPK; e) composition E is 75% urea and 25% NPK. In this study, only one main ingredient was used, which is the skin of yellow kepok bananas.

This study offers a new approach to the application of contextual chemistry by integrating the use of two types of agricultural waste pineapple peel and pineapple leaves as substrates for bioethanol production. Unlike previous studies that often rely on a single type of biomass, this study highlights the potential of combining lignocellulosic and sugar-rich materials to optimize ethanol yield.

LITERATURE REVIEW

Chemistry Education in the Context of Energy Crisis and Environmental Friendliness

Education is a learning process that plays an important role in human life to shape quality individuals. One way to improve the quality of human resources is through the learning process, both in school environments and independently. The main goal of education is to help individuals develop their potential, acquire skills, and cultivate a sense of responsibility. Thus, education is expected to support the future development of students so that they can face and solve various life problems they encounter (Az-zahra & Darmana, 2024).

Education plays an important role in shaping public awareness and behavior towards environmental preservation, especially amidst the global energy crisis that has had an increasingly impactful impact in the last decade. The global energy crisis and increasing environmental degradation encourage the need to integrate these issues into the world of education, especially chemistry education. Contextual chemistry education that focuses on the development of renewable energy such as bioethanol makes an important contribution to building student awareness of the importance of science-based solutions to real problems. Direct experience in the learning process is essential to improve and discover new ideas and also encourage students to be active in discovering and developing concepts, principles and theories (Mabsutsah & Yushardi, 2022).

Eco-friendly technology

Chemistry is one of the branches of Natural Sciences (IPA) that studies various abstract concepts, some of which aim to explain chemical events that occur in daily life. The main goal of chemistry education is to introduce students to various phenomena they encounter daily and help them understand the processes that occur in nature (Hasniyah & Muchtar, 2021). Eco-friendly technology (EFTs) encompasses various innovations designed to enhance quality of life while preserving environmental sustainability. This technology generally encompasses aspects such as the use of recyclable or naturally biodegradable materials, the utilization of plant-based materials, pollution reduction, minimization of greenhouse gas emissions, the use of renewable energy, energy efficiency improvements, multifunctionality, and manufacturing processes with low environmental impact. This technology encompasses various innovations, ranging from renewable energy to waste management, to utilize and optimize the potential of renewable energy sources available in various regions of Indonesia, one of which is bioethanol (Riyana et al., 2022). One of the chemistry lessons is green chemistry, which applies the principles of chemistry in designing, using, and producing chemicals with the aim of minimizing the negative impact on the environment and human health due to the use of hazardous substances (Parawansa et al.,2024).

The Process of Formation Bioethanol

Bioethanol is an environmentally friendly fuel derived from plant sources and has a higheroctane rating compared to fossil fuels such as premium gasoline (Purba & Saragi, 2021). Bioethanol as an alternative energy source can be utilized as an environmentally friendly and economical energy source based on its production process. Generally, bioethanol is produced through fermentation with microorganisms. One of the renewable energy sources with potential for bioethanol production is pineapple peel and leaf waste, which still exists to this day (Rosanti et al., 2023). Bioethanol can be formed through several processes, namely hydrolysis, fermentation, and distillation. Most of the raw materials used are plants that contain starch, lignocellulose, and sugar. In its development, the most widely used methods for bioethanol production are fermentation and distillation. Fermentation is the process of breaking down carbohydrates into CO_2 and ethanol, which is produced by the activity of a type of microbe (yeast) in an anaerobic state (Chamidy et al., 2023).

Chemistry is one of the subjects in the natural sciences within education. Chemistry itself has a nature, which consists of two aspects: chemistry as a product and chemistry as a process. Chemistry as a product is knowledge that consists of facts, concepts, and principles of chemistry. Chemistry as a process involves the skills and attitudes possessed by scientists to acquire and develop chemical knowledge kimia (Suyanti & Ramadhani, 2022). In chemistry education, important concepts such as fermentation, hydrolysis, and distillation processes are closely related to organic chemistry and environmental chemistry materials. Research on the utilization of pineapple peel and leaf waste for bioethanol production can serve as a contextual source in education, thereby directly disseminating scientific methods such as designing experiments, data analysis, and result interpretation.

In the stages of bioethanol production, the distillation stage is also involved. Distillation is the process of evaporation and condensation, intended to separate a mixture of two or more liquids into its fractions based on differences in boiling points (Subagyo & Saga, 2019). Bioethanol is a compound with the molecular formula C_2H_5OH and the structural formula CH_3-CH_2-OH, which can also be written as EtOH. Biomass containing sugar, cellulose, and starch can be converted into bioethanol (Wandono et al., 2020).

Biomass Sources for Ethanol Production

Biomass that can be used as a source of bioethanol feedstock includes agricultural waste such as fruit peels, leaves, plant stems, straw, and other organic materials rich in carbohydrates, cellulose, and hemicellulose, making them renewable. In principle, bioethanol can be made from raw materials rich in sugar or starch or other materials containing hemicellulose and cellulose. The selected raw materials are then broken down into lignocellulose through heating, chemical treatment, or mechanical processes (Mulyati et al., 2023).

Pineapple is a fruit that is often used by the Indonesian community as a food ingredient. With the large production of pineapples, the amount of waste generated is also significant, especially the pineapple peel waste. The sugar content, which is quite high according to research, is known to be 15.6%, so it can be utilized to produce bioethanol through the fermentation process followed by distillation (Khuzaima & E, 2021).

Bioethanol can be produced through the fermentation process of carbohydrate and sugar-producing plants. One of the raw materials that can be used for the production of bioethanol is pineapple peel. Pineapple peels contain 81.72% water, 20.87% crude fiber, 17.53% carbohydrates, 4.41% protein, and 13.65% reducing sugars. Considering the relatively high carbohydrate and sugar content, pineapple peels can be utilized as a raw material for bioethanol (Rifdah et al., 2022).

Meanwhile, pineapple leaves are the main waste from pineapple farming, accounting for about 90% of the total harvest. Pineapple leaves contain 4.4-4.7% lignin and 69.5-71.5% cellulose. Currently, the utilization of pineapple leaves is still limited, generally returned to the land as fertilizer, and has not yet been further developed into higher economic value products (Amraini et al., 2020). The innovation being developed is the production of bioethanol based on pineapple peels and supplemented with pineapple leaves.

Nutrition

This research was conducted experimentally to observe the effect of NPK and urea concentration. The growth and development process of Saccharomyces cerevisiae requires the addition of nitrogen elements. The addition of NPK and urea is one way to meet the growth needs of Saccharomyces cerevisiae during the fermentation process. NPK and urea function as nutrients for microbes during the fermentation process. The addition of urea can also increase the protein content because urea contains 42%-45% nitrogen (Qomariyah & Sindhuwati, 2023).

METHODS

The method used in this research is the experimental method. This research was conducted from October 2024 to January 2025 at the Ruyani Biological Sciences Learning Resource Center (SBIH), Bengkulu City. The experimental method applied in this research is very suitable for inclusion in chemistry laboratory learning at both schools and universities. Through the bioethanol experiment from pineapple waste, it can teach scientific work skills and conduct critical analysis of the obtained results. This hands-on experience will enhance the understanding of chemical concepts while also building scientific character and environmental awareness. This research was conducted to observe the alcohol content in bioethanol from pineapple peel and leaf waste that was fermented for 7 days with different material variations.

Tools and materials

The tools used in the bioethanol production process are: blender, scale, measuring flask, measuring cup, a set of distillation equipment, vial bottles, and alcoholmeter. The materials used are: pineapple peel waste (*Ananas comosus*), pineapple leaf waste (*Ananas comosus*), water, 5% HCl, NPK, and urea.

Research procedure

The process of making bioethanol is carried out in several stages, including preparation of materials, hydrolysis, fermentation, and distillation. Hydrolysis is a chemical reaction between water and a substance that produces a new substance and the decomposition of a solution using water. Hydrolysis can be performed using an HCl solution. Fermentation is a process of converting sugar into organic acids or alcohol. The microorganism used in the fermentation process is Saccharomyces cerevisiae (Kurniati et al., 2021), and the fermentation period is 7 days. The distillation process is a condensation or evaporation process to separate ethanol from the fermentation solution (Khairiah & Ridwan, 2021).

1. Preparation of Ingredients
   Wash the pineapple skin and leaves thoroughly, then cut them into small pieces and blend them with 200 mL of aquades. The function of chopping the material and adding aquades during the bioethanol production process is to facilitate the grinding process and increase the surface area of the material, thereby accelerating the conversion of carbohydrates into fermentable sugars (Arifiyanti et al., 2020).when grinding each variation of the sample mass used, namely:
   a. Pineapple peel (200 gr) (4 samples)
   b. Pineapple leaves (200 gr) (4 samples)
   c. Pineapple peel (100 gr) & pineapple leaves (100 gr) (4 samples)
2. Hydrolysis
   The hydrolysis process is carried out to convert cellulose into glucose. Glucose is converted by fermentation microorganisms into ethanol and carbon dioxide (Nuraini & Ratni, 2021). Each sample that has been ground is first filtered, then each one is heated for 60 minutes at a temperature of 90-95°C and 5 mL of 5% HCl solution is added. After that, it is cooled first and then placed into bottles and nutrients are added before fermentation.

Tabel 1. Sample variation.

Nutrient	Material Variation
Control	pineapple skin (200g)
	pineapple leaves (200g)
	pineapple skin (100g) + pineapple leaves (100g)
NPK (5g)	pineapple skin (200g)
	pineapple leaves (200g)
	pineapple skin (100g) + pineapple leaves (100g)
Urea (5g)	pineapple skin (200g)
	pineapple leaves (200g)
	pineapple skin (100g) + pineapple leaves (100g)
NPK (2,5g) + Urea (2,5g)	pineapple skin (200g)
	pineapple leaves (200g)
	pineapple skin (100g) + pineapple leaves (100g)

3. Fermentation
   after the hydrolysis stage, the sample is fermented for 7 days. The process of sugar transformation carried out by Saccharomyces cerevisiae involves the release of chemical bonds from the carbon chain of glucose, fructose, and sucrose. The release occurs one by one, then becomes ethanol, carbon dioxide gas, and generates heat. Saccharomyces cerevisiae requires anaerobic conditions to produce ethanol. In the ethanol fermentation process, glucose will be broken down into

ethanol and carbon dioxide (Qomariyah & Sindhuwati, 2023).

4. Bioethanol Distillation

The distillation equipment is assembled and prepared correctly, then the fermentation sample is placed into the flask and set on the distillation apparatus. Distillation is carried out for 60 minutes, the resulting distillate is placed into sealed vials, and then the alcohol content is measured and analyzed using an alcoholmeter.

5. Alcohol Test

In this study, an Alcohol Content test was conducted. An alcoholmeter is a vital tool in the bioethanol production process. This tool helps determine the alcohol content in bioethanol accurately and easily. The way it works is quite simple. Based on its principle, the alcoholmeter floats on top of the bioethanol solution. The higher the alcohol content, the lower the density of the solution, and the higher the alcoholmeter floats.

RESULT AND DISCUSSION

The process of making bioethanol is a complex series of transformations involving three main stages: hydrolysis, fermentation, and distillation. Starting with the hydrolysis stage, which is an important process in bioethanol production because it transforms complex materials into simple sugars that can be fermented into alcohol.

Fermentation is a biochemical process where changes or chemical reactions involving microorganisms convert organic materials into ethanol. In the research conducted during the fermentation process, CO_2 gas was formed as a byproduct of microbial activity. This CO_2 gas is indirectly detected using litmus paper.

Acids and bases are fundamental materials that serve as the foundation for studying more complex chemistry concepts (Ginting & Dibyantini, 2024). When the gas is released and dissolves in the air, it forms carbonic acid, causing the blue litmus paper to turn red, indicating an increase in temperature due to the presence of CO_2 gas.

The distillation process is the purification process of ethanol. The distillation process is carried out to separate ethanol from the fermentation solution by heating the solution (Puspitasari et al., 2018).

The results of this research can be used as open contextual material that integrates chemistry concepts with environmental and energy issues. analyzing the experimental results, finding the relationship between the chemical structure of the materials (cellulose, lignin, carbohydrates) and the products produced (bioethanol). Additionally, we can also discuss how the addition of nutrients such as NPK and urea affects the performance of Saccharomyces cerevisiae in fermentation, which is relevant to the concepts of inorganic chemistry (nitrogen, phosphorus, potassium elements) and biochemistry (enzymes, microorganism metabolism).

According to (Marlina & Hainun, 2020), the boiling point of pure ethanol is 78°C while that of water is 100°C (standard conditions). At a temperature of 78°C, ethanol evaporates before water. Ethanol vapor is channeled through a pipe submerged in water, causing it to condense and revert to liquid ethanol. This is consistent with the research conducted at a temperature range of 80°-85°C, where ethanol has evaporated, but the resulting ethanol is not pure because it has been mixed with water.

Based on the research conducted on pineapple peels and leaves over 7 days, along with the addition of nutrients such as urea, NPK, and a mixture of urea and NPK, the following results were obtained:

Table 2. The ethanol content of pineapple peel and pineapple leaves with several variations of nutrient addition

Variation	without nutrients	Urea	NPK	Urea + NPK

pineapple skin	13%	17%	16%	15%
pineapple leaves	2%	4%	5%	4%
pineapple skin + pineapple leaves	4%	6%	8%	5%

In table 2, it can be seen that, with variations of pineapple peel and the addition of nutrients used, namely urea, NPK, and a mixture (Urea+NPK), the results show that the pineapple peel with added urea yielded the highest result of 17%. This is because pineapple peel has the potential to be used as a raw material for bioethanol due to its high content of carbohydrates or natural sugars, which is 10.54-17.53% carbohydrates, 0.69-4.41% protein, 0.02% fat, 0.48% ash, and 13.65% reducing glucose (Siskayanti et al., 2023). Therefore, when urea is added, it yields the highest result because urea is an artificial fertilizer resulting from the reaction of NH4 with CO_2, with a total N content in urea fertilizer ranging from 45-46%, and it is easily absorbed by microorganisms (Gafiera et al., 2019).

In fermentation, nitrogen is required as a basic material for the formation of enzymes and proteins by the microorganism Saccharomyces cerevisiae, which directly plays a role in converting glucose into ethanol. Therefore, the addition of urea increases the growth rate and accelerates the fermentation process. In general, the addition of nitrogen is necessary for the growth of microorganisms and can increase the ethanol content produced (Gafiera et al., 2019). Based on what has been done, pineapple peel as a raw material is very promising for producing high ethanol content.

This is consistent with the research conducted by (Nuraini & Ratni, 2021), which shows that the addition of urea fertilizer produces more ethanol than NPK fertilizer during a 7-day fermentation because the NPK fertilizer ($NH_4H_2PO_4$) used contains 16% N, 16% P_2O_5, and 16% K_2O. because the nitrogen content in urea fertilizer is higher compared to NPK fertilizer, so cell growth will be greater with the addition of urea compared to the addition of NPK fertilizer, making urea more efficient for fermentation. Additionally, supplementary elements such as potassium and phosphorus in certain amounts can disrupt pH stability and negatively affect microorganism activity.

The combination of urea and NPK does not yield better results compared to urea alone. One of the factors that can influence the fermentation process is nutrition. Saccharomyces cerevisiae requires nutrients for the growth process during fermentation (Susmanto et al., 2020).This is most likely caused by an imbalance in nutrient composition or interactions between elements that lead to a decrease in yeast metabolism efficiency. Under certain conditions, excess minerals or ion interactions in the fermentation solution can cause osmotic pressure or pH disturbances that inhibit enzyme activity.

Unlike pineapple peels, which yield the highest ethanol content when supplemented with urea, the table above shows that the highest ethanol content in pineapple leaves is achieved when they are supplemented with NPK, resulting in 5%. Pineapple leaves contain 4.4-4.7% lignin and 69.5-71.5% cellulose (Amraini et al., 2020). Cellulose and lignin are more difficult to hydrolyze compared to simple carbohydrates in pineapple skin. Making it more difficult to break down into fermentable simple sugars. In these conditions, microorganisms require more energy to hydrolyze and ferment the substrate.

NPK contains phosphorus, which is important for ATP synthesis, the energy source for microbial cells. It is this phosphorus that helps increase metabolic activity when facing complex substrates due to the lignocellulosic structure that is difficult to manage in pineapple leaves (Saini et al., 2022). Additionally, potassium in NPK helps regulate cell osmotic pressure and maintain fermentation environment stability. The combination of these elements supports microbial conditions to remain active even when the substrate is difficult to decompose.

On the other hand, urea only supplies nitrogen without the support of other elements needed in complex metabolism. As a result, microorganisms that ferment pineapple leaf substrate experience energy limitations and suboptimal enzyme activity. The results of the combination of urea and NPK, which did not exceed the application of single NPK, also indicate the possibility of competition or nutrient imbalance between the two types of nutrients used simultaneously.

This is in accordance with the research conducted by (Lazuardi et al., 2024) The addition of urea has a more significant effect on increasing bioethanol levels compared to the addition of NPK (Composition B 100% urea and Composition C 100% NPK). The bioethanol levels are influenced by the higher nitrogen content in urea fertilizer compared to NPK fertilizer, so the cell growth with urea fertilizer addition will be greater than with NPK fertilizer addition.

In the mixture of pineapple peel and leaf materials, the highest ethanol content was obtained from the treatment with 100% NPK (5g), which was 8%. This shows that the combination of complete nutrients in NPK greatly aids the performance of microorganisms in fermenting substrates with different characteristics, namely glucose-rich peels and fiber-rich leaves. Pineapple leaves contain 69.5-71.5% cellulose and 4.4-4.7% lignin (Natalia et al., 2019). NPK supports energy production (ATP) and maintains the stability of the microbial cell environment, thereby optimizing the conversion process of sugar into ethanol.

The 100% urea treatment produced an alcohol content of 6%, higher than without nutrients (4%), but still lower than NPK. This confirms that urea alone is not strong enough to support the fermentation of a fairly complex mixture.

Interestingly, the combination of urea + NPK (2.5g + 2.5g) actually resulted in a lower alcohol content (5%) compared to the use of NPK alone. This is likely caused by: The concentration of each nutrient becoming too low to work optimally, and the interaction between elements disrupting the pH and ion balance in the fermentation medium.

Thus, the use of single NPK has proven to be the most effective choice for fermenting a mixture of pineapple peel and leaves, while the nutrient mixture does not provide the expected synergistic effect.

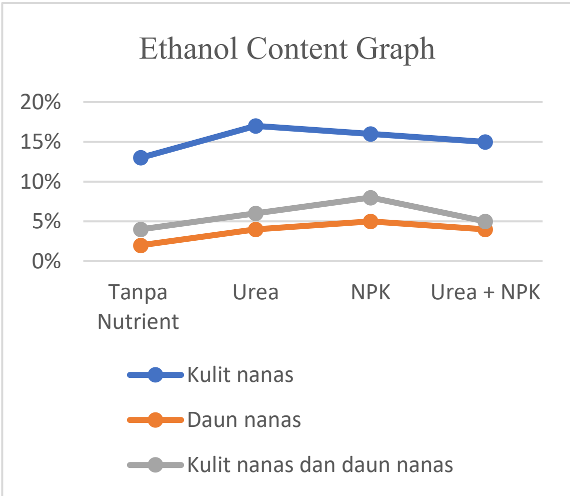

Figure 1. The effect of nutrient addition on the ethanol concentration produced

This also shows the influence of providing various types of nutrients (without nutrients, urea, NPK, and a combination of urea + NPK) on three variations of organic materials, namely pineapple peel, pineapple leaves, and a combination of pineapple peel and leaves. Based on the data, it is evident that the difference in the types of nutrients used has an impact on the bioethanol content produced (Susmanto et al., 2020).

In the treatment without nutrient addition, it was observed that pineapple peels produced the highest ethanol content, which was around 13%. This shows that the skin is one of the raw materials that can be used to produce bioethanol. Ethanol from pineapple peels can be produced by Saccharomyces Cerevisiae through fermentation. Pineapple peels contain 17.53% carbohydrates, 13.65% sugars, 20.87% crude fiber, and 4.41% protein. By utilizing these contents through the fermentation process, pineapple peels can be used as a raw material for bioethanol (Ihtifazhuddin et al., 2024). On the other hand, pineapple leaves only produce an alcohol content of about 2%, and a combination of pineapple skin and leaves yields about 4%. The low yield in pineapple leaves indicates that the sugar or fermentative nutrient content in them is much lower compared to the skin. Pineapple leaves contain cellulose fibers of 69.5-71.5% (Setiawan et al., 2017). The combination of skin and leaves produces a slightly higher alcohol content than the leaves alone, but still lower than the single pineapple skin, possibly because the mixing of materials with different fermentative qualities causes the dilution of the fermentation substrate.

The addition of urea significantly increased the ethanol content of all materials. Pineapple peel increased from 13% to 17%, pineapple leaves increased from 2% to 4%, and the combination of pineapple peel and leaves increased to 6%. This increase indicates that although the basic materials like pineapple leaves are less supportive, the addition of urea can still optimize the fermentation process, albeit not as much as the results from pineapple peels. This shows that microbial growth is greatly influenced by the availability of energy sources. According to (Suryani et al., 2017), urea is a highly effective nitrogen source in supporting microbial growth and fermentation. According to (Fitria & Lindasari, 2021), urea is a nutrient needed by microbes in producing bioethanol levels; urea is used as a nitrogen source that can help increase bioethanol levels. In the fermentation process, urea is needed as a nitrogen source for growth and to increase the ethanol content produced.

In the treatment with NPK, pineapple peel produced 16% ethanol, slightly lower than the yield with urea, but still considered high. Pineapple leaves produced 5%, the highest among all leaf treatments, indicating that NPK is more effective than urea in enhancing fermentation because pineapple leaves contain a lot of fiber, with 69.5-71.5% cellulose in pineapple leaf fiber (Setiawan et al., 2017), making it more difficult to break down into fermentable simple sugars. Thus, NPK contains phosphorus, which is important for ATP synthesis, the energy source for microbial cells. This phosphorus helps increase metabolic activity when facing substrates and enhances the fermentation process. The combination of pineapple skin and leaves reached an alcohol content of 8%, the highest compared to other treatments in the material combination. This shows that the macro nutrients in NPK (nitrogen, phosphorus, and potassium) can enhance fermentation activity, especially when used in mixed materials.

The combination of urea and NPK actually does not yield the best results. Pineapple peel produces 15%, lower than the use of urea or NPK alone. Pineapple leaves remain at 4%, the same as the yield from urea alone, and the combination of skin and leaves only produces 5% alcohol. This shows that the combination of the two nutrients is not always synergistic and can actually disrupt fermentation. The possibility of nutrient composition imbalance, pH changes, or interactions between elements causes suboptimal microbial activity.

CONCLUSION

The addition of nutrients significantly affects the alcohol content produced. Urea yields the highest results (17%) on pineapple peels because its high nitrogen content supports the activity of fermentation microorganisms. The findings of this study have several practical implications. In the renewable energy sector, this study shows that pineapple peel and leaf waste can be effectively used as feedstock for bioethanol production, contributing to sustainable energy solutions while reducing agricultural waste. The results also inform fermentation optimization strategies by showing that nutrient selection should be tailored to substrate characteristics—urea is more effective for sugar-rich substrates such as pineapple peel, while NPK favors more complex fibrous materials such as leaves. In an educational context, this study provides a valuable model for project-based learning in chemistry, linking theoretical concepts to real-world environmental issues. This research can inspire students to apply scientific methods to solve energy and sustainability-related problems, and support STEM-based teaching that aligns with national curriculum goals.

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