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Production of Bioethanol from Date Palm Frond (DPF): Influence of Process Parameters

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ABSTRACT

Bioethanol is biodegradable and the most used biofuel to reduce greenhouse gas emissions. To date, mass production of bioethanol is mainly from sugarcane, cassava, corn, and oil palm frond. Therefore, this paper was aimed at producing bioethanol from date palm frond (DPF) and to study the effect of some critical parameters such as temperature, fermentation period and pH for optimum bioethanol yield. Saccharomyces cerevisiae was used based on its ability to ferment the date palm frond efficiently. Pre-treatment processes of DPF was done followed by hydrolysis process of the cellulose to fermentable sugars and finally the fermentation of sugars to alcohol. The results showed that at lower temperature, the fermentation is very slow. As the temperature increased, the bioethanol yield increased. However, as the temperature increases, particularly, above 35℃, the bioethanol yield decrease because of intercellular changes in the yeast cells, which slow the yield of bioethanol produced. Hence, at a temperature of 35℃ higher yield bioethanol was achieved. Similarly, increase in fermentation period at constant temperature increased the bioethanol yield. At every pH value and at constant optimum fermentation period (72 h), the highest bioethanol yield achieved (6.85g/L). Therefore, the optimum pH that produced the highest yield was 5.5 (6.85 g/L).

1. INTRODUCTION

Date palm *(Phoenix dactylifera L.)* is one of the oldest cultivated plants grown in the desert and semi-desert area (Abdel Moneim *et al.,* 2012). It is a multi-purpose tree highly regarded as a national heritage in many countries (El-Mously *et al.,* 2020). Date palm is believed to have been introduced into Nigeria in the early 8th century by Arab traders from North Africa (Hamza *et al.,* 2010). The tree can be grown extensively and commercially in the arid region of northern Nigeria from latitude 10°N in the Sudan savannah and the Sahel

regions. This includes Kaduna, Katsina, Kano, Sokoto, Kebbi, Zamfara, Jigawa, Yobe, Borno, Gombe and Bauchi State (Sanusi *et al.,* 2018). The Nigerian date palm industry has the potentials of enhancing rapid economic growth and development if adequately exploited. The date palm has been in cultivation for many years in Nigeria and the production level differ in the country (AbdulQadir *et al.,* 2011).

DPF is a lignocellulosic material, a renewable resource that can be processed either chemically or biologically to biofuel such as bioethanol. The major constituents of date palm biomass are cellulose, hemicellulose, and lignin alongside with high volatile solids content and low moisture content (Sait *et al.,* 2012; Abdel Moneim *et al.,* 2012). These make date biomass an excellent waste-to-energy resource in Nigeria. A wide range of thermal and biochemical technologies exists to convert the energy stored in date palm biomass to useful forms of energy. The low moisture content in palm wastes position these resources well-suited to thermochemical conversion technologies like combustion, gasification and pyrolysis which may yield steam, syngas, bio-oil etc. On the other hand, the high volatile solids content in date palm biomass indicates its potential towards biogas production in anaerobic digestion plants, possibly by co-digestion with sewage sludge, animal wastes and food wastes (Al-Juhaimi *et al.,* 2014). The cellulosic content in date palm wastes can be transformed into biofuel (bioethanol) by making fermentation process. Thus, abundance of date palm trees in Jigawa and the Kano can catalyze the development of biomass and biofuels sector in Nigeria compared to other types of feedstocks for bioethanol (Sanusi *et al.,* 2018). The DPF is essentially free, being an agricultural waste, low cost in terms of cropping practice, collection, and storage. In terms of economic and environmental considerations, the conversion of DPF to bioethanol would continue to be a strategic and synergistic move for the date palm industry. Three main components of lignocellulosic DPF (cellulose, hemicellulose and lignin) are in the range of 40-50, 20-35 and 15-35 %, respectively (Ali *et al.,* 2014).

According to Chauhan, (2014) bioethanol is a colorless liquid, biodegradable, low in toxicity and causes little environmental issues. Ethanol derived from waste product biomass has an advantage over fossil fuel (Castillo *et al.,* 2023). In the 1970s, Brazil and the United States of America (USA) began their mass production of bioethanol from sugarcane and corn respectively (Bon *et al.*, 2007, Soccol *et al.,* 2010). However, this is not applicable in long term, as the food chain could be affected due to decreasing food supply. Therefore, it is of government benefit to produce bioethanol from lignocellulosic materials, particularly those from date palm frond. The most common usage of bioethanol is to power automobiles (Hossain *et al.,* 2017). It can be combined with gasoline in any concentration up to pure ethanol (E100). Ethanol fuel blends are now widely available in the United States of America, Brazil, Europe and China. Today, bioethanol contributes around 3% of total road transport fuel globally on an energy basis (IEA, 2010).

The degradation of lignocellulosic biomass involves a pretreatment process followed by hydrolysis process of the cellulose to fermentable sugars and finally the fermentation of sugars to alcohol. Although other studies have been carried on bioethanol production from different varieties of date fruits such as Abd-Alla and El-Enany, (2012) Ahmad *et al.* (2021), Arshad *et al.* (2017), Taghizadeh-Alisaraei *et al.* (2019), and Zeinelabdeen *et al.* (2013), this paper was aimed at producing ecofriendly product (bioethanol) from date palm frond (PDF) and study the effect of different parameters. In this study, a DPF sourced from Dutse, Jigawa State was used. *Saccharomyces cerevisiae* was used based on its ability to ferment the date palm frond efficiently.

2. MATERIALS AND METHODS

2.1. Date Palm Fronds Collection and Preparation

Date palm fronds was collected from a farm in Dutse, Jigawa State, Nigeria. The DPF as then chopped into small pieces and taken to Chemical Analysis Laboratory in Bayero University Kano. The chopped DPF was washed with water and then oven dried overnight at 105°C and ground to powder following a method described by Mardawati *et al.* (2019) and placed in plastic bag at room temperature for pretreatment used. Pretreatment was done to reduce the lignin structure, thus making the enzymatic hydrolysis of cellulose composition easier. The pretreatment of ground solid DPF was done according to Kumneadklang *et al.* (2015) and the sample was pretreated with 2% H_2SO_4 in a 500 ml beaker and then presoaked for 24 hours at room temperature. DPF was then filtered, and the solid fraction was dried and used as the substrate for saccharification.

2.2. Inoculum Preparation

Inoculum preparation involves obtaining the organisms in an optimal state that is compatible with inoculation into cell culture, tissue culture, media, and fermenters. The prime objective is usually to achieve a high level of viable biomass in a suitable physiological state for use as an inoculum (Sood *et al.,* 2011). The organism *Aspergillus niger* used as enzyme was obtained from Department of Microbiology Bayero University Kano and then cultured on Potatoe Dextrose Agar (PDA) slants with distilled water under sterilized conditions and then incubated at 32°C for 7 days until the organism sporulate. The culture is then kept at 4°C until when needed (Puttaswamy *et al.,* 2016).

2.3. Saccharification and Fermentation

Saccharomyces cerevisiae which was used in the fermentation process because of its productivity, cheapness and tolerance was obtained from Ceman chemical lab (Ahmed *et al.,* 2021). *Aspergillus niger* was grown on potato dextrose agar medium in petri-dishes. They were incubated at 35 °C for 48 h. The pretreated sample was loaded in 250 ml Erlenmeyer flask and then diluted by adding sterile distilled water. The pH value of DPF was adjusted using 3 M H_2SO_4 and 3M KOH (Narayanan *et al.,* 2016) prior to autoclaving in order to study the effect of pH (4.5 - 6.0). After dilution, the sample was autoclaved at 121 °C for 15 min at 15 psia, and then pH of the system was adjusted to 4.5 which is the optimum pH for the fungal growth (Boulal *et al.,* 2016; Narayanan *et al.,* 2016). *Saccharomyces cerevisiae* was then added to the sample in the flasks, mixed thoroughly and then incubated at room temperature. The Erlenmeyer flask was then sealed to maintain in anaerobic condition. The Erlenmeyer flask was put into a shaker incubator for 12 hours to start fermentation (Mardawati *et al.,* 2019).

On the other hand, temperature and fermentation period was varied in the range of 25.0 – 40.0 °C and 24 hr – 96 hr under anaerobic condition respectively. The matrix of experiments was designed according to the Table 1 below. Samples were harvested at the end of the fermentation period by distillation for bioethanol production.

Table 1: Matrix of Experiments

S/No	Variables			Measurable response (g/L) (w/v)
	Temperature (°C)	pH	Fermentation period (hr)	
1	25	4	24	Bioethanol concentration
2	25	4	24	Bioethanol yield
3	30	4.5	48	Bioethanol concentration
4	30	4.5	48	Bioethanol yield
5	35	5	72	Bioethanol concentration
6	35	5	72	Bioethanol yield
7	40	5.5	96	Bioethanol concentration
8	40	5.5	96	Bioethanol yield
9	-	6	-	Bioethanol concentration
10	-	6	-	Bioethanol yield

3. RESULTS AND DISCUSSION

3.1. Effect of Temperature and Fermentation Period

Temperature is one of the most important factors that contribute to yeast growth and fermentation performance. Results in Figure 1 (a, b, c, d) showed the effect of temperature over varied fermentation period. It is observed that as the temperature increases at constant fermentation period, the bioethanol concentration, and the yield increases. However, unlike bioethanol concentration, the bioethanol yield decreases at temperature above 35 ℃. This shows that at high temperature, particularly at 40℃ the cells growth and metabolic activities of yeast cells decrease, which resulted in decrease in bioethanol yield at this temperature (Figure 1d). On the other hand, as the fermentation period increases from 24 to 96 hr, bioethanol concentration decreases whereas the yield increases respectively (Figure 1 a to d). For example, at constant fermentation period of 24 hr and at varied temperature (25, 30, 35 and 40 ℃), the bioethanol yield increased from 0.8, 0.9, 1.1, and 1 g/L respectively (see Figure 1 a to d).

As the fermentation period increases from 24 to 96 hr, at constant temperature (e.g., 25℃), the bioethanol concentration decreased from 36.14g/L at 24hr to 25.15 g/L at 96hr, while the bioethanol yield increases from 0.8 g/L at 24 hr to 3.2 g/L at 72 hr. This could be due to the fact that between 24 and 76hr the yeast cell began to consume nutrients in the medium and multiply, at this stage the growth was so fast and exponential, and the bioethanol yield product was higher. The faster the growth of the yeast cell the rapid the production of bioethanol yield. It reached its stationary phase of production due to growth limitation factor. However, it should be noted that the bioethanol yield decreases at 96 hr (2 g/L) because the cells growth and metabolic activities of yeast cells decrease. The fermentation was in a close system so the yeast activities were expected to be low at a short-term (24hr) period because the yeast will go through follicular phase followed by production phase (Huynh *et al.*, 2016). Therefore, as the fermentation period increase, the yield of the product will also increase. However, the decrease of bioethanol yield at 96hr was due to less enzymatic activity after an incubation period of 72 hr.

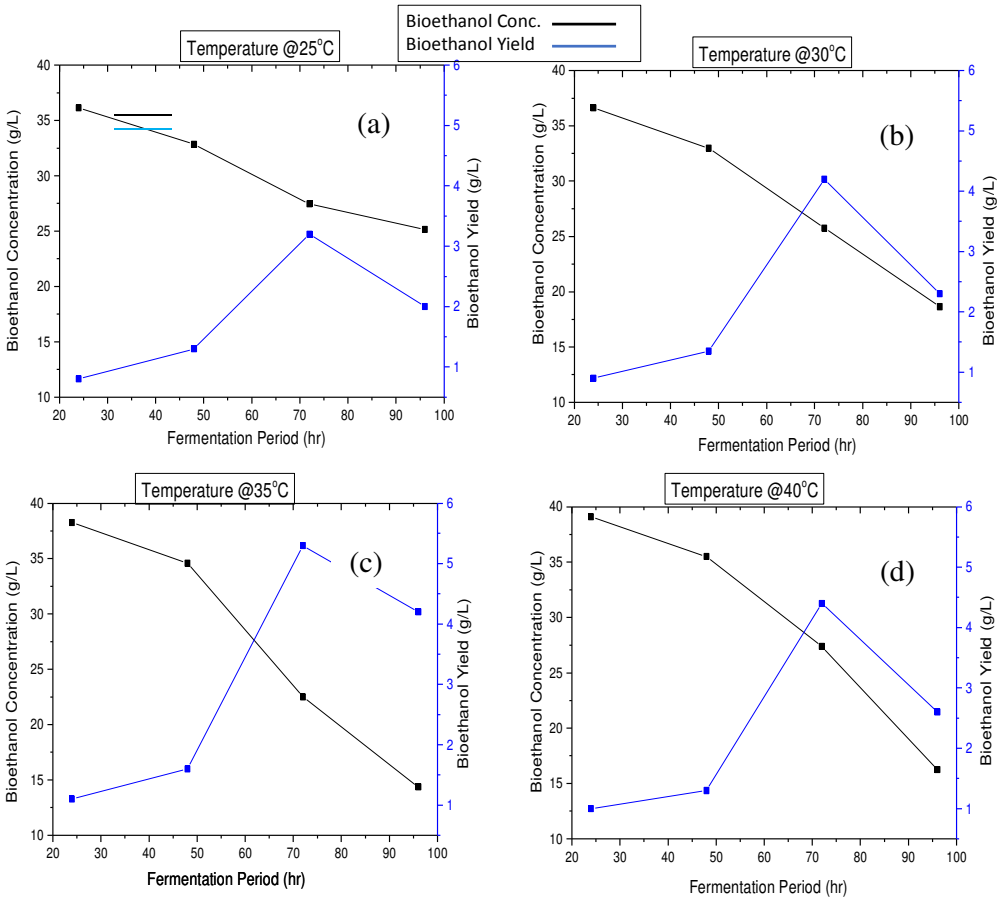

Figure 1: Effect of temperature at (a) 25 ℃ (b) 30 ℃ (c) 35 ℃ (d) 40 ℃ over varied fermentation period on the bioethanol concentration and yield

As shown in the Figure 1, at different fermentation period, the highest bioethanol yield was achieved at 35℃. Therefore, at this temperature, the highest yield across the four series of fermentation period (24, 48, 72, and 96hrs) were 1.1, 1.6, 5.3 and 4.2 g/L respectively. Hence, from the results it can be deduced that at lower temperature the fermentation is very slow and as the temperature increased, the bioethanol yield also increased and increasing the temperature above the highest experimental temperature (35℃) led to decrease in the bioethanol yield because of intercellular changes in the yeast cells and slower the yield of bioethanol produced.

Therefore, yeast growth rate and metabolism increase as the temperature increases until it reaches the optimum value.

3.2. Effect of pH on Bioethanol Production

Generally, the pH of the broth usually affects the bioethanol production as its influence the bacterial contamination, yeast growth, fermentation rate and by-product formation (Edeh 2021). It should be noted that the fermentation solution that are more acidic or alkaline can inhibit the fermentation process, thereby reducing the quantity of bioethanol produced. In this research the pH range studied were between 4.0 and 6.0 with an increment of 0.5. The results in Figure 2 (a, b, c, d, e) shows the effect of pH over varied fermentation period. It was observed that at constant temperature (35℃), and as the pH increases from 4.0 to 6 at constant fermentation period, the bioethanol concentration decreases while the yield increases.

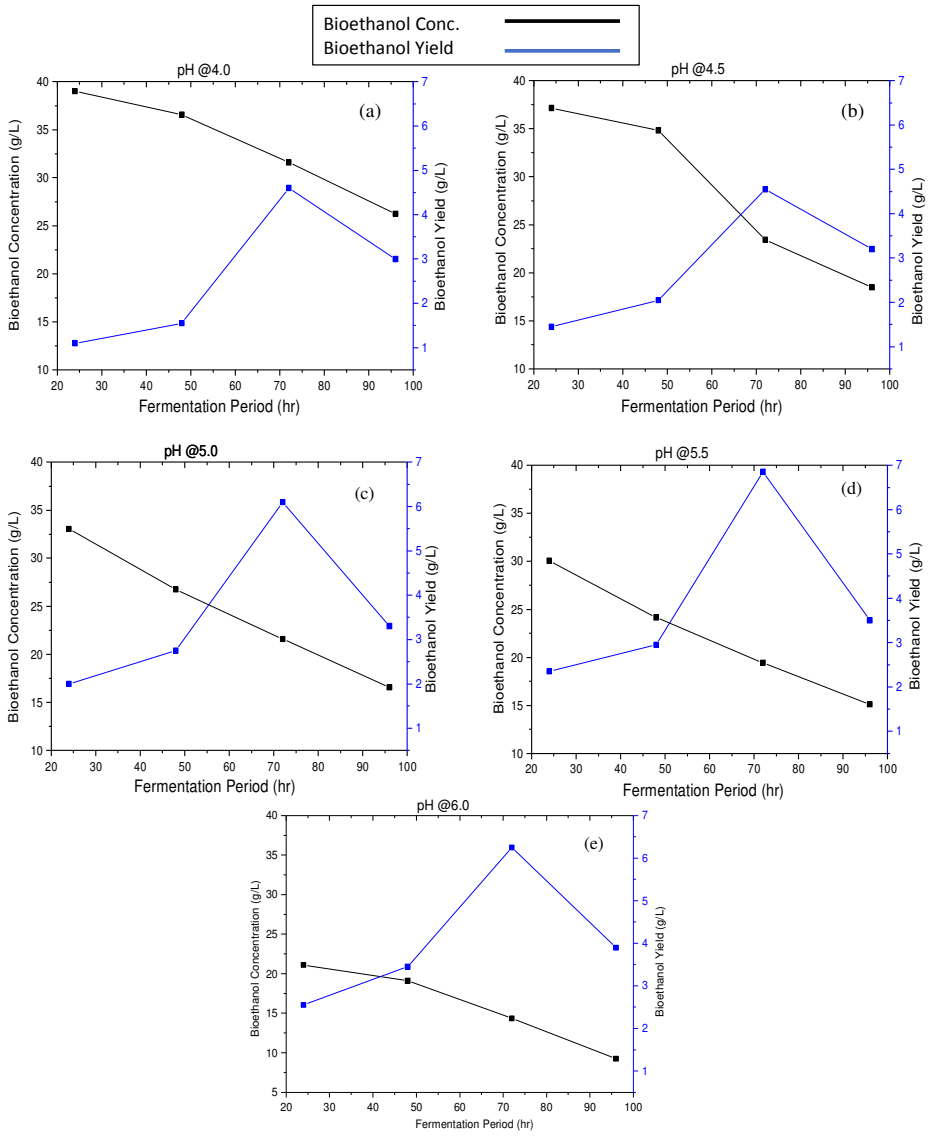

Figure 2: Effect of pH: (a) 4.0 (b) 4.5 (c) 5.0 (d) 5.5 (e) 6.0 over varied fermentation period on bioethanol concentration and yield at constant temperature of 35^{0}C

It was observed that at constant pH of 5.0 under varied fermentation period (24, 48, 72 and 96hr) the bioethanol concentration decreased from 33.05 to 16.55 g/L. Whereas, the bioethanol yield increased from 2.0 to 3.3 g/L (Table 1). As observed from Figure 2 (a to e), pH of 5.5 produced the highest bioethanol yield across varied fermentation period. Hence, an optimum bioethanol yield (6.85 g/L) was observed at 72 hr (Figure 3a).

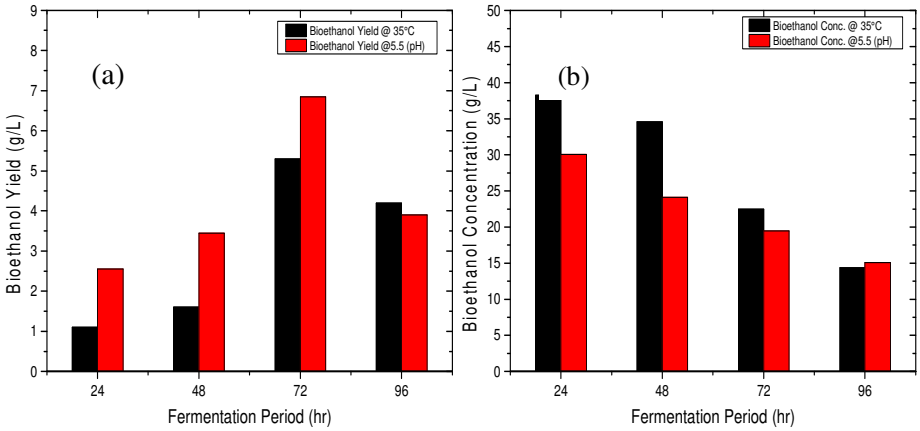

Figure 3: (a) Bioethanol Yield at optimum temperature (35℃) and pH (5.5) at varied fermentation period. (b) Bioethanol Concentration at optimum temperature (35℃) and pH (5.5) at varied fermentation period.

Table 2: Bioethanol yield at different pH value with temperature set at 35 °C

pH value	Bioethanol (g/L)	Fermentation period			
		24 h	48 h	72 h	96 h
4.0	Concentration	39.00	36.55	31.60	26.25
4.0	Yield	1.10	1.55	4.55	3.00
4.5	Concentration	37.13	34.83	23.45	18.48
4.5	Yield	1.45	2.05	4.60	3.20
5.0	Concentration	33.05	26.75	21.60	16.55
5.0	Yield	2.00	2.75	6.10	3.30
5.5	Concentration	30.05	24.15	19.45	15.10
5.5	Yield	2.55	3.45	6.85	3.90
6.0	Concentration	21.10	19.10	14.35	9.25
6.0	Yield	2.50	2.95	6.25	3.40

4. CONCLUSION

This study demonstrated that bioethanol can be produce from DPF as an important economically raw material through a complete fermentation process. The research showed that temperature, fermentation period and pH influenced the production process of bioethanol. The results deduced that at lower temperature the fermentation is very slow and as the temperature increased, the bioethanol yield also increased and increasing the temperature above the highest experimental value (35℃) lead to decrease in the yield because of intercellular changes in the yeast cells, which slow the yield of bioethanol produced. Hence, at 35℃ higher yields bioethanol was achieved. Similarly, increase in fermentation period at constant temperature decreases the bioethanol concentration, whereas bioethanol yield increases. At every pH value and at constant optimum fermentation period (72hr), the highest bioethanol yield achieved (6.85g/L (w/v)). Therefore, the optimum pH that produced the highest yield was 5.5 (6.85 g/L).

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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