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Numerical Modelling and Optimization of Bioethanol Concentration Produced from Local Sawdust following Response Surface Methodology

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Abstract

This work studies the modelling and optimization of bioethanol production from locally sourced saw dust waste. The saw dust samples are obtained from common wood species in the Nigerian tropical rain forest. Nigeria is one of the producers of wooden products in the world. Many species of wood can be found in Nigeria's tropical rain forest. Some of the most common wood species include; *Astonia boonei* (duku), *Bombax bounopozense* (West African bombax), *Brachystegia eurycoma* (Okwen), *Terminalia superba* (White afara). Sawdust samples were obtained from a local saw mill in Edo State, Nigeria. The samples were pre-treated, hydrolyzed, fermented and the bioethanol distilled out. Optimization of bioethanol was performed by using Central Composite design of response surface methodology. Four variables such as acid concentration, hydrolyzing time, hydrolysis temperature and fermentation time were considered as influencing factors on the yield of bioethanol. The optimization of ethanol was investigated in this study under the following conditions: acid concentration (0.5-2.5 %w/w), hydrolysis temperature (100-130 °C), hydrolysis time (10-50 minutes) and fermentation time (2-6 days). It was observed from the statistical analysis that the maximum ethanol yield of 24.85 % (g/L) was obtained at optimum acid hydrolysis of acid concentration 2.0 %w/w, Hydrolysis time 40 minutes, Hydrolysis temperature 122.50 °C, and Fermentation time 5 days.

Keywords: Bioethanol; Hydrolysis; Sawdust; Modelling; Fermentation; Optimization

1. Introduction

Bioethanol is the most widely used biofuel worldwide, partially able to replace fossil fuels, reducing the environmental impact of greenhouse gas emissions [1, 2].

Sawdust is a waste by-product of the timber industry that is either used as cooking fuel or a packing material. Some investigations have shown that wood waste has the potential to be used as a raw material for the production of bioethanol [3]. Saw dust is a fine particle of wood obtained during wood sawing. The accumulation of sawdust poses certain dangers, such as the risk of fire, air pollution, and proliferation of vermin. This waste also has the ideal size for processing in the initial stage of bioethanol production. Thus, operations with high energy requirements and costs can be avoided [4]. Lignocellulosic materials such as sawdust are, basically, made up of cellulose, lignin, hemicelluloses, water and some salts

The steps involved in the production of bioethanol include; pre-treatment, hydrolysis, fermentation and finally distillation process. Each of this process is specific that is, it has its own functionality and rationale.

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Nigeria is one of the producers of wooden products in the world. Many species of wood can be found in Nigeria's tropical rain forest. Thus, a variety of species of sawdust from wood are produced when processing the wood. There is at present an inadequacy of study on the use of locally sourced sawdust species and its potential capacity to produce ethanol.

Although some significant amount of work has been done in the area of producing bioethanol from various wood wastes in different parts of the world especially in Europe, America and Asia, not much indigenous research has been done on the use of saw dust wastes from the unique wood species abundantly available in the Nigerian tropical rain forests for bioethanol production. Some of these unique wood species found in Nigeria's tropical rain forest from which the saw dust waste being investigated are obtained are as follows; *Astonia boonei* (duku), *Bombax bounopozense* (West African bombax), *Brachystegia eurycoma* (Okwen), *Terminalia superba* (White afara).

A model is simply a representation usually in terms of mathematical equations of a process so as to predict the behaviour and interactions of the process variables under varying conditions. Modelling involves generating a representation defined by a set of mathematical equations that conforms closely in reality to what actually takes place [5, 6, 7].
As an important subject in the statistical design of experiments, the Response Surface Methodology (RSM) is a collection of mathematical and statistical techniques useful for the modeling and analysis of problems in which a response of interest is influenced by several variables and the objective is to optimize this response [8].

In this work, bioethanol is produced from locally sourced saw dust wastes from wood species in Nigeria's tropical rain forest and the Response Surface Methodology feature of the Design Expert Software is used to perform statistical modelling and optimization of the process parameters viz; temperature, pH and acid concentration for the hydrolysis step of the process. This work will serve to contribute to the knowledge on production of bioethanol from Lignocellulosic biomass in general and locally sourced sawdust from Nigerian wood species in particular.

2. Material and methods

2.1. Materials

The sawdust and fungi; *Saccharomyces cerevisiae (baker's yeast)* were the two major feedstock used for this experiment. Other materials used were reagents such as sulfuric acid for acid pretreatment and hydrolysis, Sodium hydroxide for pH adjustment and fermentation, Mineral salts to prepare fermentation medium, Potassium dichromate and Acetate buffer during analysis. Equipment / Apparatus used also included PH meter, conical flask, stirring rod, Electronic balance, Oven, Sieve, Fermenter, measuring cylinder, 1000mL beakers, Buchner funnel. The distillation unit consisted of three components: a reboiler, condenser pipe, and a distillate or receiving flask. Characterization equipment includes UV-Vis Spectrophotometer Model 752, Scanning Electron Microscope (Phillips XL-30 ESEM, USA), Fourier Transform Infrared Spectrophotometer, (Spectrum 65 FT-IR, Perkin Elmer, and USA)

2.2. Experimental Procedure

2.2.1. Feedstock Preparation & Pre-treatment

Sawdust was obtained from a saw mill in Oluku, Benin City, Edo State. The sawdust was then sieved to obtain 1mm particles and the materials were divided into 10 kg each in containers at room temperature until use. Dilute acid pre-treatment was carried out by treating the samples with a dilute solution of sulphuric acid (0.5 % H_2SO_4 of 250 ml) and the mixtures were placed in an oven at a temperature of 100 °C for 50 mins.

2.2.2. Hydrolysis Step

Acid hydrolysis was carried out by treating the samples with solutions of sulfuric acid of different concentrations (0.5-2.5 % H_2SO_4 of 250 ml) and the mixtures were placed in an oven while varying the temperatures (100-130 °C) for different amounts of time (10-50 mins). At the end of the hydrolysis reaction, the solid residue was separated by using a filter paper. The clear solution was collected in bottles as.

2.2.3. Fermentation

The pH of the hydrolysate resulting from the pretreatment was adjusted to 5.5 using 0.5 M H_2SO_4 as desired**.** The fermentation medium had the following composition (per 100ml of hydro lysate): 0.8 g $MgSO_4$, 0.08 g $CaCl_2$, 0.6 g $FeCl_3$, 4.0 g KH_2PO_4, 4.0 g K_2HPO_4, 4.0 g KNO_3. The fermentations for evaluating all treatments were performed in one-liter bioreactor equipped with a tap. The flasks containing the medium were inoculated with 10ml of activated Baker's yeast

(*Saccharomyces cerevisiae)* and fermentation was allowed to occur for duration of 3-5 days. 100 ml of NaOH with phenolphthalein indicator was fixed to the tap of bioreactor and the tap was opened.

2.2.4. Distillation

After the fermentation process is completed, liquid samples are taken from the fermentation broth. The samples were distilled using a simple distillation set and with a hot plate as heat source. Cooling water was circulated through the condenser for cooling and thereby condenses the alcohol vapor. Distilled products were stored in bottles and cocked firmly to prevent evaporation.

2.3. Analysis of Bioethanol

Using an aliquot of standard stock solution containing 1.0 mg/mL, 5 mL of potassium dichromate solution, 5 mL of acetate buffer pH 5.5 and 25 mL of 1N sulfuric acid was added in 50 mL of volumetric flask. The mixture was shaken gently for 1 minute and allowed to stand for 120 minutes as incubation period at room temperature resulted in the formation of green colored reaction product. After the incubation period the absorbance at 600 nm was read on UV-Vis spectrophotometer Model 752. This procedure was followed for each of the three samples prepared in triplicates. Software supplied with the instrument was used to plot concentration curve for standard and concentration of sample was calculated.

$$\text{Percentage of ethanol in sample (\%)} = (Cs/Cu)\ (Au/As) \times 100$$

Where Cs = Concentration of standard, Cu = Concentration of sample as per Labeled Claim, Au = Absorbance of standard, As = Absorbance of sample. [9]

2.4. Experimental Design

Table 1 Experimental range and levels of independent variables

Independent Variable	**Symbols**	**Coded and Actual Levels**				
		-2	**-1**	**0**	**+1**	**+2**
Acid concentration (%w/w)	X_1	0.5	1.0	1.5	2.0	2.5
Hydrolysis temperature (°C)	X_2	100	107.5	115	122.5	130
Hydrolysis reaction time (minutes)	X_3	10	20	30	40	50
Fermentation time (days)	X_4	2	3	4	5	6
Independent Variable	**Symbols**	**Coded and Actual Levels**				
		-2	**-1**	**0**	**+1**	**+2**
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Hydrolysis temperature (°C)	X_2	100	107.5	115	122.5	130
Hydrolysis reaction time (minutes)	X_3	10	20	30	40	50
Fermentation time (days)	X_4	2	3	4	5	6

A four-variable central composite design (CCD) for response surface methodology was used to develop a statistical model for the hydrolysis and fermentation process. The range of the variables that were optimized is shown in Table 1. The CCD is a design that combines the vertices of the hypercube whose coordinates are given by a 2n factorial design with star points. The star points provide the estimation of curvature of the nonlinear response surface. The experimental design made up of 30 runs was developed using Design Expert® 7.0.0 (Stat-ease, Inc. Minneapolis, USA). The coded and actual values of the independent variables were calculated as follows.

$$x_i = \frac{Xi - Xo}{\Delta X}$$

Where xi and Xi are the coded and actual values of the independent variable respectively. Xo is the actual value of the independent variable at the centre point and ΔXi is the step change in the actual value of the independent variable. The following generalised second order polynomial equation was used to estimate the response of the dependent variable.

$Y_i = b_o + \sum b_i X_i + \sum b_{ij} X_i X_j + \sum b_{ii} X_i^2 + e_i$

Where Yi is the dependent variable or predicted response, Xi and Xj are the independent variables, b_o is offset term, b_i and b_{ij} are the single and interaction effect coefficients and e_i is the error term.

3. Results and discussion

3.1. Statistical Modelling

Analysis of the experimental data using the Design Expert software revealed that the quadratic model was significant for ethanol production. This was further confirmed by ANOVA results which showed that the p-value of the model was less than 0.05 indicating statistical significance (Table 3).

$$Y = 349.77597 - 12.16250X\_1 + 5.84778X\_2 + 1.16438X\_3 + 14.19500X\_4 + 0.025333X\_1\ X\_2 + 0.050500X\_1\ X\_3 + 0.10750X\_1\ X\_4 - 8.53333E\text{^}(-0.03)\ X\_2\ X\_3 + 0.035500X\_2\ X\_4 - 0.030875X\_3\ X\_4 + 5.06250X\_1\text{^}2 + 0.027189X\_2\text{^}2 + 2.28125E\text{^}(-0.03)\ X\_3\text{^}2 + 1.42813X\_4\text{^}2 \quad (1)$$

Where X1 is acid concentration, X2 is hydrolysis temperature, X3 is hydrolysis time and X4 is fermentation time and these are independent variables.

Table 2 Central Composite Design Matrix for the Optimization of Variables and the Response Values of ethanol Produced

Run No	Factors								Response	
	Coded levels				Actual values				Ethanol concentration	
	X_1	X_2	X_3	X_4	X_1	X_2	X_3	X_4	Observed	Predicted
1	0	0	0	0	1.50	115.00	30.00	4.00	14.57	14.79
2	-1	-1	1	-1	1.00	107.50	40.00	3.00	18.53	19.40
3	-1	-1	-1	1	1.00	107.50	20.00	5.00	12.97	13.64
4	1	-1	-1	1	2.00	107.50	20.00	5.00	16.76	15.49
5	-1	1	1	-1	1.00	122.50	40.00	3.00	22.64	21.59
6	0	0	0	0	1.50	115.00	30.00	4.00	14.86	14.79
7	0	0	2	0	1.50	115.00	50.00	4.00	19.74	21.14
8	1	1	1	1	2.00	122.50	40.00	5.00	26.21	24.97
9	-2	0	0	0	0.50	115.00	30.00	4.00	17.26	17.79
10	0	-2	0	0	1.50	100.00	30.00	4.00	16.02	17.10
11	1	1	-1	1	2.00	122.50	20.00	5.00	21.59	20.92
12	0	0	0	0	1.50	115.00	30.00	4.00	16.32	14.79
13	-1	1	-1	-1	1.00	122.50	20.00	3.00	17.43	17.31
14	-1	1	-1	1	1.00	122.50	20.00	5.00	20.17	19..45
15	0	0	0	2	1.50	115.00	30.00	6.00	20.32	21.60
16	1	1	1	-1	2.00	122.50	40.00	3.00	24.32	23.85

17	1	-1	-1	-1	2.00	107.50	20.00	3.00	14.32	14.20
18	0	0	-2	0	1.50	115.00	10.00	4.00	9.54	10.26
19	1	1	-1	-1	2.00	122.50	20.00	3.00	18.81	18.56
20	-1	-1	1	1	1.00	107.50	40.00	5.00	21.32	19.24
21	0	0	0	0	1.50	115.00	30.00	4.00	14.76	14.79
22	0	0	0	0	1.50	115.00	30.00	4.00	14.11	14.79
23	1	-1	1	-1	2.00	107.50	40.00	3.00	23.65	22.05
24	0	0	0	-2	1.50	115.00	30.00	2.00	18.56	19.41
25	0	2	0	0	1.50	130.00	30.00	4.00	23.67	24.71
26	-1	-1	-1	-1	1.00	107.50	20.00	3.00	13.65	12.57
27	1	-1	1	1	2.00	107.50	40.00	5.00	21.78	22.10
28	2	0	0	0	2.50	115.00	30.00	4.00	20.32	21.91
29	0	0	0	0	1.50	115.00	30.00	4.00	14.11	14.79
30	-1	1	1	1	1.00	122.50	40.00	5.00	22.17	22.49

Table 3 Analysis of Variance (ANOVA) for Quadratic Model for Ethanol Concentration

Source	**Sum of Squares**	**df**	**Mean Square**	**Fvalue**	**P-value[Prob>F]**
Model	437.28	14	31.23	16.60	<0.0001
X_1-Acid Concentration	25.38	1	25.38	13.49	0.0023
X_2-Hydrolysis Temperature	86.87	1	86.87	46.16	<0.0001
X_3-Hydrolysis Time	177.78	1	177.78	94.48	<0.0001
X_4-Fermentation Time	7.19	1	7.19	3.82	0.0694
X_1X_2	0.14	1	0.14	0.077	0.7855
X_1X_3	1.02	1	1.02	0.54	0.4729
X_1X_4	0.046	1	0.046	0.025	0.8775
X_2X_3	6.55	1	6.55	3.48	0.0817
X_2X_4	1.13	1	1.13	0.60	0.4496
X_3X_4	1.53	1	1.53	0.81	0.3822
X_1^2	43.94	1	43.94	23.35	0.0002
X_2^2	64.16	1	64.16	34.09	<0.0001
X_3^2	1.43	1	1.43	0.76	0.3975
X_4^2	55.94	1	55.94	29.73	<0.0001
Residual	28.23	15	1.88		
Lack of Fit	24.91	10	2.49	3.75	0.0787
Pure Error	3.32	5	0.66		
Cor Total	465.50	29			

The predicted response levels of ethanol concentration using Equation (1) are also presented in Table 2. The fit of the statistical model for the ethanol concentration was assessed by carrying out analysis of variance (ANOVA) and the results are presented in Tables 3 and 4.

The model Fisher F-test value of 16.60 and very low probability value ($p<0.0001$) showed that the model was significant. The "Lack of Fit" P value of 0.0787 implies that there was insignificant relative to pure error. A non-significant lack of fit is desirable as it implies that the model could be used for theoretical prediction of the production of ethanol.

The coefficient of variation (CV) obtained was 7.48 % (Table 4). This value indicates the degree of precision with which the treatments were compared [10]. The relatively low value of CV obtained showed that the treatments were carried out with high precision and reliability [11]. An adequate precision value of 15.166 was obtained. Cao et al [12], reported that the Adeq. Precision gives an indication of the signal to noise ratio and suggested that a value greater than 4 is generally desired [12]. The value of 15.166 obtained indicates an adequate signal and the model can be used to navigate the design space. The coefficient of determination (R^2) was obtained as 0.939. This indicates that 94 % of the variability in the response could be explained by the statistical model while 6% could not be accounted for by the independent variables [13]. The R^2 value indicates the degree to which the model was able to predict the response. The closer the R^2 value is unity, the better the model can predict the response [10].

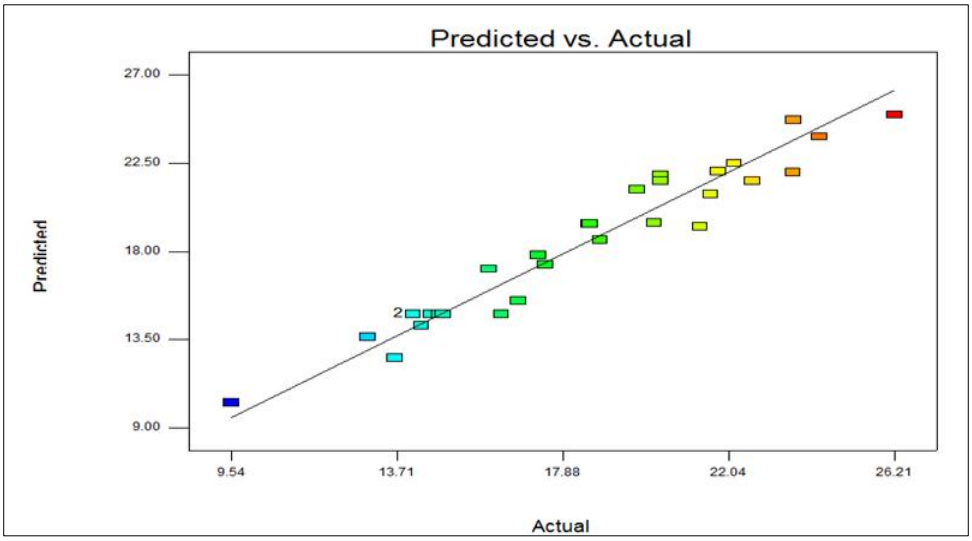

Figure 1 Graph of Predicted Yield against Experimental Yield

Table 4 Statistical Information for ANOVA

Parameter	Response
R-Squared	0.939
Adjusted R-Squared	0.883
Standard Deviation	1.37
CV %	7.48
Adeq. Precision	15.166

3.2. Optimization of Ethanol Concentration of Sawdust

To determine the optimal levels of the variables that influence the ethanol concentration of sawdust, response surface plots were generated according to Equation (1). The three-dimensional (3D) plots were generated by keeping two variables constant at the centre point and varying the others within the experimental range. The resulting response surfaces showed the effect of acid concentration, hydrolysis temperature, hydrolysis time and fermentation time on the total ethanol concentration.

Figure 2 shows the effect of acid concentration and hydrolysis temperature on the ethanol concentration. It was observed that at low temperatures, there was a rapid and progressive increase in the total ethanol concentration when the acid concentration was increase from 1.0 to 2.0 %w/w. The same trend was observed at high temperatures as the ethanol concentration also increased with increase in acid concentration. The trend observed may be as a result of the catalytic activity of the acid. Increasing the acid concentration during hydrolysis leads to a corresponding increase in the concentration of hydrogen ions which in turn increases the rate of the hydrolysis reaction and consequently the rate at which the glycosidic bonds are broken will increase resulting in a high conversion of hemicellulose fraction into fermentable sugars [14, 15]. Hu et al. [16] investigated the acid hydrolysis of sugar maple wood extract at atmospheric pressure using dilute sulphuric acid. They observed that increasing the concentration of acid resulted in an increase in the concentration of fermentable sugars. This led them to conclude that the acid acted as a catalyst in the cleavage of the β (1–4) glycosidic linkages in the xylooligomers to yield xylose monomers. Lenihan et al. [17] also reported that increasing the concentration of acid at mild temperatures resulted in an increase in the rate of the hydrolysis reaction.

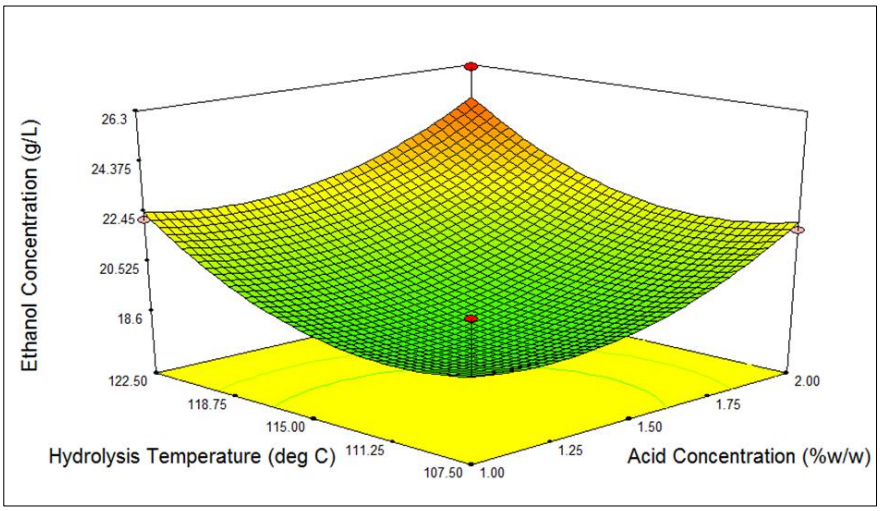

Figure 2 Response Surface Plot Showing the Effect of Acid Concentration and Hydrolysis Temperature on Total Ethanol Concentration

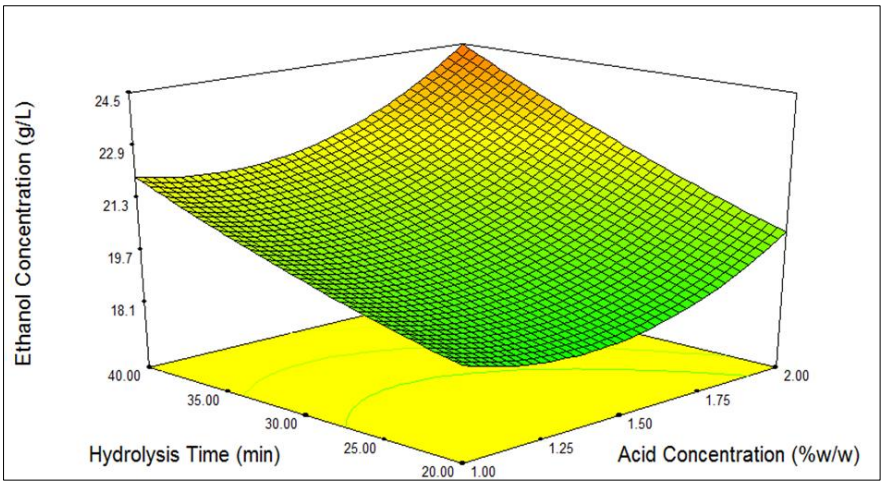

Figure 3 Response Surface Plot Showing the Effect of Hydrolysis Time and Acid Concentration on Total Ethanol Concentration

Figure 3 shows the effect of the interaction between hydrolysis time and acid concentration on the total ethanol concentration produced at a hydrolysis temperature of 122.5 °C and a Fermentation Time of 5 days.

For the entire range of acid concentration investigated, the concentration of ethanol produced generally increased with increase in hydrolysis time. This suggests that the hemicellulose fraction of the lignocellulosic biomass was being broken down to produce fermentable sugars.

The maximum sugar concentration was obtained at a hydrolysis time of 25 minutes and an acid concentration of 0.59 %w/w. Lu et al. [18] investigated the dilute acid hydrolysis of corn stover making use of sulphuric acid concentrations of 2, 4 and 6 % w/w and temperatures of 80, 100 and 120 °C. They reported optimum hydrolysis conditions of 2 %w/w acid concentration, 43 minutes' hydrolysis time and hydrolysis temperature of 120 °C.

Biniyam et al. [19] reported the optimum processing conditions drawn from RSM were an acid concentration of 2 % (v/v), temperature of 128.01 °C, and time of 55 minutes. Under these conditions, the maximum concentration of total reducing sugar obtained was 184.72 mg/g.

Figure 4 presents the effect of the interaction between fermentation time and acid concentration. The ethanol concentration produced during hydrolysis increased with an increase in acid concentration and an increase in fermentation time. At low fermentation time, there was a rapid and progressive increase in the ethanol yield when the acid concentration was increased from 1.0 to 2.0 %w/w. The same observation was recorded at high temperatures.

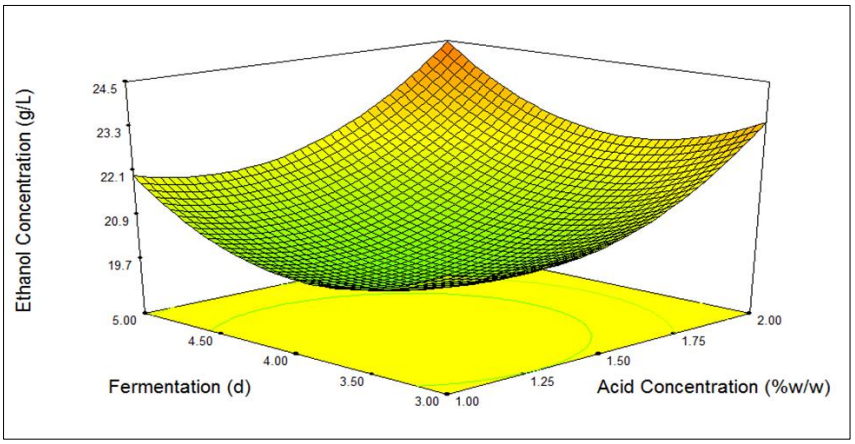

Figure 4 Response Surface Plot Showing the Effect of Fermentation Time and Acid concentration on total Ethanol concentration

The effect of temperature and time on the hydrolysis yield is shown in Figure 5. At high reaction times, the hydrolysis yield increased slowly with an increase in temperature from 107.50 to 122.5 °C. This observation might be attributed to the increase in the rate of collision of the molecules of the reacting species during the reaction. Hence the higher the temperature, the more frequent the molecules will collide with each other resulting in reaction. The maximum ethanol yield of about 85.4 % was obtained at a temperature of about 122.5 °C and a time of about 38 minutes. Lu et.al. [18] Reported the optimum yield of dilute acid hydrolyzed corn stover as 85.4 % using a sulphuric acid concentration of 2.0 %, at a temperature of 120 °C and a reaction time of 43 minutes. Amenaghawon et.al. [13] Also reported the optimum hydrolysis conditions at a temperature of 122.5 °C, acid concentration of 2%w/w, reaction time of 20.5 minutes and a liquid to solid ratio of 25 mL/g the maximum sugar yield obtained at these optimized conditions was 81.63 %.

The conversion of some lignocellulosic biomass wastes into bioethanol with concentrated H_2SO_4 and enzymatic hydrolysis produced the highest ethanol yield from all the samples on the 7th and 10th day of the fermentation periods [20].

Hydrolysis temperature has a positive effect on ethanol production as shown in Figure 6. This is seen in the increase in the amount of ethanol produced when the level of temperature was increased within the range studied.

Adenomon et al. [21] concluded that for hydrolysis process yield is optimum at 110 °C and 30 mins, while for fermentation process yield is optimum at 35 °C and at 6 days and 7 days respectively.

The fermentation periods had effect on ethanol production. Fermentation time increases with increase in percentage of ethanol contents. This agrees with the findings of Keun. et al. [22] who reported that fermentation time had significant effect on ethanol production where the ethanol yield continues to increase from day one (1) to day four (4). They further

reported that a longer fermentation time beyond four days produces no further increase of ethanol production. It is also in conformity with the findings of Shubhra et al. [23] who also observed the increase in ethanol concentration during the fermentation time produced from different carbohydrate sources, from day one (1) to day five (5).

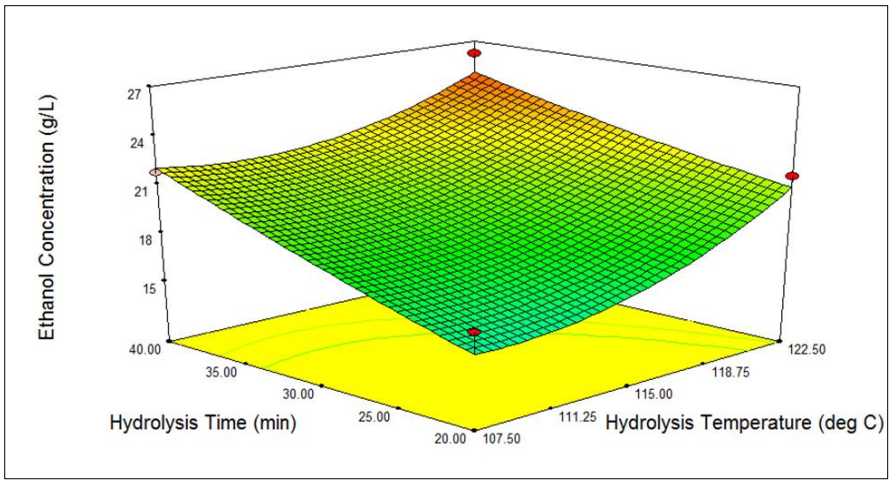

Figure 5 Response Surface Plot Showing the Effect of Hydrolysis Time and Hydrolysis Temperature on Ethanol Concentration

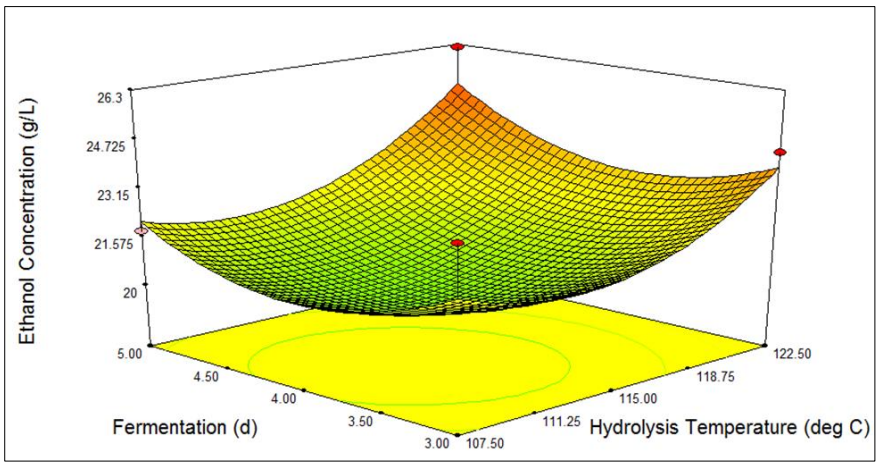

Figure 6 Response Surface Plot Showing the Effect of Fermentation Time and Hydrolysis Temperature on Ethanol Concentration

Figure 7 shows the effect of fermentation time and hydrolysis time on the ethanol concentration. It was observed that at low fermentation time, there was a rapid and progressive increase in the total ethanol concentration when the hydrolysis time was increase from 20.0 to 40.0 minutes. The same trend was observed at high fermentation time as the ethanol concentration also increased with increase in time.

Ueda et al. [24] observed a similar trend. In their study on production of ethanol from raw cassava starch by a nonconventional fermentation method they reported that the rate of fermentation or carbon dioxide evolution ceased after 5 days of fermentation at 30°C. The duration of fermentation however depends on the method used for starch liquefaction, saccharification and fermentation, yeast type and concentration and also the conditions of fermentation [25].

Ocloo et al. [26] reported that Fermentation was completed over the period of 48, 72 and 120 hours for 20, 15 and 5 % yeast concentrations respectively. The results obtained supported the fact that the speed of fermentation depends on the yeast concentration, the higher the concentration, the shorter the fermentation period required to achieve maximum alcohol yield [27].

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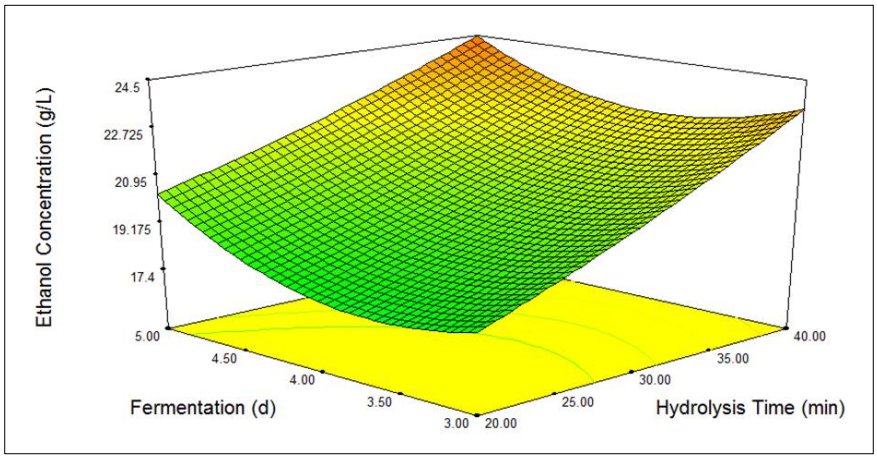

Figure 7 Response Surface Plot Showing the Effect of Fermentation Time and Hydrolysis Temperature on Ethanol Concentration

3.3. Numerical Optimization

Results obtained from numerical optimization carried out using the Design Expert software revealed that the optimal ethanol concentration was 24.93 g/L. This was obtained with an acid concentration of 2 %(w/w), hydrolysis temperature of 122.5 °C, and hydrolysis time of 39.99 minutes and fermentation time 5 days.

Furthermore, ethanol yield from wood sawdust was estimated to be 30.9 g/L with 28.43 g/L purity from 10 kg of Sawdust [28] which is close our ethanol yield of 24.93 g/L.

3.4. Validation of the Model

The suitability of the model equation for predicting the optimum response values was tested using the optimum conditions mentioned above. The results obtained from three replications demonstrated that the maximum ethanol concentration 26.21 g/L obtained was close to the predicted value 24.93 g/L. This result indicates that there is excellent correlation between experimental and predicted values and in turn proves the validity of the model.

4. Conclusion

The optimization result of locally sourced sawdust clearly demonstrates that it is a promising raw material for production of ethanol. The optimum processing conditions drawn from RSM were an acid concentration of 2 %(w/w), hydrolysis temperature of 122.5 °C, and hydrolysis time of 40 minutes and fermentation time 5 days. Under these conditions, the maximum concentration of ethanol obtained was 24.93 g/L. RSM with central composite design has proved to be a useful tool in identifying the important factors that influence the dilute acid hydrolysis of sawdust as well as their optimized levels.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study.

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