International Scientific Organization
http://iscientific.org/
Chemistry International
www.bosaljournals.com/chemint/

Assessing the economic feasibility of commercializing cellulosic ethanol fuel production in Nigeria

Idongesit Effiong Ekpo*, Regina Ogali and Ozioma Achugasim

Department of Pure and Industrial Chemistry, University of Port Harcourt, Nigeria
*Corresponding author's E. mail: idongesit.ekpo@uniport.edu.ng

ARTICLE INFO

Article type:
Research article
Article history:
Received January 2024
Accepted May 2024
July 2024 Issue
Keywords:
Cellulosic ethanol
Hexose and pentose sugars
Inhibitors
Economic feasibility
Saccharification
Fermentation

ABSTRACT

This study aims to assess the economic feasibility of commercializing cellulosic ethanol fuel in Nigeria, it proceeds beyond evaluating theoretical yield from the process of hydrolysis to investigation of yields based on total amounts of biomass or substrate used, cellulosic materials pretreated as well as enzymes used in the process of production. The cellulosic material in this study was *Pernnisetum purpureum* S, with three pretreatment methods including; dilute acid, sulphite pretreatment to overcome the recalcitrance effects of lignocellulose (SPORL) and alkaline wet oxidation methods used, followed by enzymatic hydrolysis then fermentation with zymase. It was observed that the smallest biomass particle size of 200 µm gave the highest ethanol yield and the actual ethanol yield obtained were 3.61, 6.90 and 7.71 % for dilute acid, alkaline wet oxidation and SPORL pretreatment methods respectively; this may not be economically feasible compared to the theoretical yield of 0.51 g ethanol/g glucose that is envisioned.

Capsule Summary: A study on cellulosic ethanol production in Nigeria evaluated various pretreatment methods on *Pernnisetum purpureum* S biomass, finding ethanol yields of 3.61%, 6.90%, and 7.71% for dilute acid, alkaline wet oxidation, and SPORL methods respectively, suggesting economic feasibility challenges compared to theoretical yields.

Cite This Article As: I. E. Ekpo, R. Ogali and O. Achugasim. Assessing the economic feasibility of commercializing cellulosic ethanol fuel production in Nigeria. Chemistry International 10(3) (2024) 80-80.
https://doi.org/10.5281/zenodo.11105487

INTRODUCTION

Ethanol is the second compound of the monoalkanols and has a molecular formula of CH_3CH_2OH. According to the law of definite proportion in chemistry, pure forms of all compounds remain the same in composition as well as physical and chemical properties; ethanol could be produced from petroleum or synthetically by reacting some substances and the elemental compositions in its one molecule will remain the same as that produced from fermentation of biomass (Gregersen, 2024). This work will focus on assessing the economic feasibility of commercializing cellulosic ethanol production. Plant biomass is ubiquitous and grasses are highly productive. So, researchers have utilized this advantage for research to investigate the possible route to derive optimum bioethanol from grasses. The carbohydrate source in grasses is cellulose, this makes the bioethanol produced from grasses to be specified as cellulosic ethanol (Ekpo et al., 2016a). It is pertinent that proximate analyses of the composition of grass biomass should be carried out to investigate the presence of active components (carbohydrates) before pretreatment, hydrolysis and fermentation processes are carried out to convert the biomass to cellulosic ethanol, this will possibly reduce the

cost of carrying out trials that are not economically feasible (Ekpo et al., 2016a).

The morphological composition of elephant grass across different parts of the plant and seasonal monitoring were carried out to detect the best part and season to obtain useful components for bioethanol production. It was detected that the leaf contained a higher amount and quality of biomass and in the wet season, it was detected that the amount of lignin in the stem was twice the amount in the leaves and the stems had 20 % less lignin in the wet season. More hemicellulose than cellulose was detected in the stem and the regrowth from the wet season recorded more hemicellulose, less cellulose and less lignin, than that from the dry season. However, the wet season regrowth should be preferred over that from the dry season. The chemical composition of elephant grass was majorly affected by age (Rueda et al., 2000).

The works of Ekpo et al. (2016a), on the comparison of three grass biomass was carried out quantitatively using spectrophotometric and gravimetric methods of analyses. The grass biomass was *Eleusine indica, Pernnisetum purpureum* and *Panicum maximum*. The composition of acid detergent fiber present in these grasses were 45.55, 36.92 and 34.61% respectively; the composition of lignin was 4.14, 5.62 and 3.09 respectively; the composition of hemicellulose was 32.51, 39.31 and 42.57 % respectively; the composition of cellulose was 26.10, 34.04 and 32.71 % respectively. It was deduced that *Pernnisetum purpureum* might produce the best ethanol because of its highest composition of cellulose as cellulose is the most utilized component of cellulosic materials for fermentation reaction in the production of cellulosic ethanol.

Elephant grass (*Pennisetum purpureum Schum.*) was used as biomass for cellulosic ethanol production using steam for pretreatment and enzymatic hydrolysis followed by *Saccharomyces cerevisiae* (lyophilised culture) for fermentation processes. The maximum yield of ethanol obtained was 1.8 g/l from 0.19-liter hydrolysate of 0.7g glucose available for fermentation. This gave a maximum ethanol theoretical yield of 94.44% (Soares et al., 2011).

The work to differentiate between synthetic ethanol in a mixture of gasoline using low-level liquid scintillation counting (LSC) was carried out, this was to encourage the use of bioethanol and restrict synthetic ethanol as a fuel enhancer with sub-octane gasoline as transportation fuel. In this study, the authors deduced that the difference in the composition of bioethanol and synthetic (petroleum) ethanol is in the composition of the carbon isotopes. From their investigations among the three isotopes of carbon; ^{12}C, ^{13}C and ^{14}C the radioactive isotope ^{14}C is dominant in plants and could not be stable through the geochemical stages of the formation of fossil fuels. So, LSC was used to detect ^{14}C from bioethanol which was absent in synthetic ethanol. In the other hand, the American standard testing method (ASTM) is developed to distinguish between bioethanol and petroleum-based (synthetic) ethanol, this is the ASTM 6866; it uses two developed procedures; radiometric and accelerator mass spectrometry for this analysis and its major consideration is to detect the presence of ^{14}C in the substance to be tested. This has been used to award tax credit to investors who utilize bioethanol for gasoline fuel enhancer (Tamers, 2006; Kim et al., 2009).

An investigation for the potential of producing cellulosic ethanol from selected 11 grass types was carried out. This started with alkaline peroxide pretreatment method, then enzymatic hydrolyasis was applied followed by yeasts, *Saccharomyces cerevisiae* and *Pichia stipitis* for cofermentation. The pretreatment process gave lignocellulosic components of 31.85–38.51 %, 31.13–42.61 % and 3.10–5.64 % for cellulose, hemicellulose, and lignin respectively. The reducing sugar obtained during hydrolysis was 500–600 mg/g grasses; specifically using cellulase and xylanase. The yeasts, *Saccharomyces cerevisiae* and *Pichia stipitis,* were applied for cofermentation, the highest yield of ethanol obtained was 1.14 g/L or 0.14 g/g equivalent to 0.98 g/L or 0.12 g/g substrate; from Sri Lanka ecotype vetiver grass (Wongwatanaipaiboon et al., 2012).

Napier grass (*Pennisetum purpureum* Schumach) was used for the production of cellulosic ethanol. Three pretreatments medium; alkali, dilute acid, and their combinations were used followed by enzymatic hydrolysis using commercial cellulose. The experimental techniques involved separate hydrolysis and fermentation (SHF) as well as simultaneous saccharification and fermentation (SSF). The enzymes for fermentation *Saccharomyces cerevisiae* and *Scheffersomyces shehatae* were targeted to ferment hexose and pentose sugars present in the hydrolysate respectively. The optimum production obtained in this work was 187.4 g/kg (44.7 g/L) ethanol concentration (Kongkeitkajorn et al., 2020*)*.

On investigating the formation of enzymatic inhibitors in the cause of producing cellulosic ethanol with *Pernnisetum purpureum*. The major focus was to investigate the inhibitive effects of some substances that reduce the production yield of bioethanol during production from lignocellulosic materials. Three pretreatment methods; dilute acid, sulphite pretreatment to overcome the recalcitrance effects of lignocellulose (SPORL) and alkaline wet oxidation were used on three varied biomass particle sizes. Cellulase was used for saccharification reaction at 10 and 15FPUcellulase/gcellulose loading and the fermentation reaction was carried out with *Saccharomyces cerevisiae* from yeast. Lignin as a component of the biomass was observed to generate most of the inhibitive substances, the pretreatment method that was more effective in delignification was the alkaline oxidation method while the dilute acid pretreatment gave the least result. The three organic enzymatic inhibitors investigated in the cause of this work were acetic acid, 5-hydroxymethyl furfural (HMF) and total extractible phenolics. HMF was observed to be deteriorating with time as the reactions proceeded while the others were generating. The difference between the theoretical ethanol yield from the total amount of glucose converted (EY2) and the theoretical ethanol yield from the initial amount of glucose before fermentation (EY1)

was 23.88% and 8.80% for enzyme loading of 10FPU/g and 15FPU/g respectively; the low yields were suggested to be due to the formation of the potential recalcitrance to enzymatic activities. This was further confirmed by the low values of enzymatic convertibility of cellulose and enzymatic convertibility of glucose; 28.92% and 25.92% respectively (Ekpo et al., 2016b).

The work on cassava starch extracted from its tuber using enzymatic hydrolysis and fermentation gave an actual ethanol yield of 44 % at 30% w/v biomass loading. The used of cassava peels using acid hydrolysis process gave an actual ethanol yield of 8.5 % at 10 % w/v biomass loading. While another work that used a non-food crop (*Icacina trichanta*), gave an actual ethanol yield of 28% at 10 % w/v biomass loading (Hauwa et al., 2019; Adewumi et al., 2021; Wangpor et al., 2017). This study aims to assess the economic feasibility of commercializing cellulosic ethanol fuel in Nigeria. It goes beyond evaluating theoretical yield from the hydrolysis process to investigating yields based on the total amounts of biomass or substrate used, as well as the cellulosic materials pretreated and the enzymes used in the production process. The cellulosic material examined in this study was *Pernnisetum purpureum* S. Three pretreatment methods were employed: dilute acid, sulphite pretreatment to overcome the recalcitrance effects of lignocellulose (SPORL), and alkaline wet oxidation methods. These pretreatments were followed by enzymatic hydrolysis and fermentation with zymase.

MATERIAL AND METHODS

Chemicals and reagents

The chemical reagents used for this study were of analytical grades and obtained from Sigma-Aldrich, Germany and Megazyme, Ireland. These substances include; cellulase enzyme from *Trichoderma reesei* (Atcc 26921), vizcozyme (cellulolytic enzyme mixture), zymase from *Saccharomyces cerevisiae* (Type II), neutral detergent solution, sodium tetraborate decahydrate, sodium dodecyl sulphate with purity of ≥98.5%, di-sodium hydrogen phosphate, ethylenediaminetetraacetic acid disodium salt dihydrate with purity of ≥99.0%, 2-Ethoxy ethanol, Alpha amylase from *aspergilus oryzae*, sodium sulphite with purity of 98.0-100%, mixture of cis and trans decahydronaphthalene, acid detergent solution, hexadecyltrimethyl ammonium bromide (±)-2-octanol, saturated potassium permanganate, silver nitrate, lignin buffer solution, iron(III)nitrate nonahydrate, acetic acid with purity of ≥ 99.9%, potassium acetate, methylpropan-2-ol, demineralising solution, oxalic acid dihydrate, absolute ethanol solution with purity of ≥99.8%, ethanol standard solution with purity of ≥ 99.8–100%, ethanol test kits (a product of megazyme), tannin, Folin-denis' reagent, sodium tungstate dihydrate with purity of ≥99.0%, phosphomolybdic acid, orthophosphoric acid, methanol with purity of ≥98.8%, sodium carbonate with purity of ≥99.8%, perchloric acid, nitric acid with purity of 35.0%, sulfuric acid with purity of ≥38.0%, sodium sulphite, hydrochloric acid with purity of 35.5%, peptone, glucose solid, glucose standard solution, dinitrosalicylic acid solution, 3,5-dinitrosalicylic acid, sodium hydroxide with purity of 98.0–100%, sodium potassium tartarate, phenol, sodium metabisulfiteD-(+) xylose standard solution with purity of ≥99.9%, phloroglucinol, benzioc acid, ammonium sulphate with purity of ≥99.0%, magnesium sulphate with purity of ≥97.0%, potassium hydroxide of purity ≥85.0% and ammonium hydroxide were used.

Plant material and enzymes

The lignocellulose used as substrate in this work was *Pernnisetum purpureum* S., its common name is elephant grass, genus (Pennisetum), family (Poaceae), order (Cyperales), Class (Liliopsida) and specie (P. purpureum). The enzymes used were Cellulase enzyme from *Trichoderma reesei* (Atcc 26921) for hydrolysis and vizcozyme (cellulolytic enzyme mixture) for reducing the accumulation of cellulose, as well as zymase from *Saccharomyces cerevisiae* (Type II) for fermentation.

Sample collection and preparation

The sample *Pernnisetum purpureum* is a predominant biomass in the South-South Zone of Nigeria; it was collected within the University of Port Harcourt environment. Samples were thoroughly washed with deionized water, cut into (1-2 cm) sizes and air dried for 6 days. The dried biomass was ground and sieved to 200 - 450 μm particle size using a DH-300T test sieve machine. The dried and sieved biomass was preserved in cool and dry chamber at an average temperature of 12 ^{0}C.

Determination of biomass composition

The biomass composition; neutral detergent fiber (NDF), acid detergent fiber (ADF), permanganate lignin (PML), hemicellulose (HEMCEL), cellulose (CEL), lignin (LIG) and total extractable polyphenolics (TEPs) were first analyzed before carrying out the production of ethanol after the pretreatment process. This was done to ensure that carbohydrate components that are necessary for the process are present in significant amounts and also to determine the amount of these components available for the saccharification stage of production. The methods used for these analyses are as stated in the reported study (Ekpo et al., 2016a).

Determination of hexose and pentose sugars

The pretreatment and hydrolysis stages of production released reducing sugars and these were detected as hexose (glucose) sugar as well as pentose (xylose) sugar, the methods of analyses for these substances are as described elsewhere (Ekpo et al., 2016b).

Table 1: The Concentration (g/L) of reducing sugars in pretreatment liquor

Dilute Acid		SPORL		Alkaline wet oxidation	
Glucose	Xylose	Glucose	Xylose	Glucose	Xylose
10.32	0.14	1.65	0.18	1.61	0.23

Table 2: Concentration (g/L) of glucose and xylose during hydrolysis with 15 FPU cellulase/g cellulose loading rate for SPORL pretreated biomass

End of 4 hours		End of 8 hours		End of 12 hours	
Glucose	Xylose	Glucose	Xylose	Glucose	Xylose
14.78	0.19	18.79	0.22	25.43	0.3

Table 3: Concentration (g/l) of Recalcitrance Generated during Hydrolysis with 15 FPU cellulase/g cellulose loading rate.

End of 4 hours			End of 8 hours			End of 12 hours		
HMF	AA	TEPs	HMF	AA	TEPs	HMF	AA	TEPs
0.013	0.023	0.404	0.011	0.027	0.729	0.009	0.054	1.066

Table 4: Concentration (g/L) of unconverted glucose and ethanol during fermentation with 15 FPU cellulase/g cellulose loading rate on hydrolysis with alkaline oxide pretreated biomass

End of 24 hours		End of 48 hours		End of 72 hours	
Glucose	Ethanol	Glucose	Ethanol	Glucose	Ethanol
16.63	4.38	7.51	5.28	3.51	9.25

Cellulosic ethanol production and determination

The hydrolysate was fermented to ethanol and its quantitative analysis was determined by the complete oxidation of ethanol to acetic acid using nicotinamide-adenine dinucleotide (NAD+) as an oxidizing agent as well as alcohol dehydrogenase (ADH) and aldehyde dehydrogenase (Al-DH) as a catalyst. The quantitative evaluation was carried out at 340 nm wavelength with 1801UV/Vis model spectrophotometer. The methods adopted here as well as detailed procedures (Kim et al., 2009; Megazyme, 2014; Ekpo et al., 2016b).

Analyses of organic inhibitors to enzymatic activities

The amount of three organic substances that pose potential recalcitrance to the reaction processes where analyzed; 5-hydroxymethyl furfural (HMF) and total extractable polyphenolics (TEPs) were analyzed using spectrophotometric method of analysis, while acetic acid (AA) was analyzed using volumetric titration (White, 1994; Zappal et al., 2004; Rocha et al., 2004; Kmecl and Skerl, 2004; Zhang et al., 2013 and Ekpo, 2016b).

RESULTS AND DISCUSSION

The data in Table 1 show that a high amount of reducing sugars was found in the pretreatment liquor and these are the components of interest during the fermentation stage. Ekpo et al. (2016b) reported the presence of enzymatic recalcitrance in the pretreatment liquor which implies that fermentation of this component to bioethanol may not be economically feasible. Moreover, the dilute acid pretreatment liquor with the highest amounts of recalcitrance as discussed in the previously mentioned study contains the highest amounts of glucose.

The concentration of reducing sugar produced within the 12 hours of hydrolysis monitored during the production process with SPORL pretreated Biomass as shown in Table 2, indicated a 4 g/l increase in glucose concentration in the first four hours of hydrolysis and a 7 g/l increase in the next four hours. While the production of xylose did not show a

significant increase in concentration. This could imply that subjecting the reaction to a longer period of hydrolysis may yield higher amounts of glucose required for hydrolysis. However, pentose sugar may be converted to inhibitory substances, which by combination with other inhibitors may reduce the yield of the desired product of fermentation. Table 3 shows that HMF is used up while acetic acid (AA) and total extractive phenolics (TEPs) were formed as the hydrolysis reaction proceeded.

From stoichiometry of the fermentation reaction, about 26 % of ethanol is produced at 100 % efficiency. The amounts of glucose introduced for fermentation from the fermentation medium and hydrolysate was 36.24 g/l (Ekpo et al., 2016b) and this gave ethanol concentrations of 4.38, 5.28 and 9.25 g/l within the 1st, 2nd and 3rd days of fermentation respectively (Table 4). This shows that the reaction process was increased within the three (3) days that it was monitored; without the use of a catalyst, it might have taken longer than three days to obtain complete fermentation. Another important deduction here is that the factors that slowed the rate of reaction did not show any significant effect of reducing the amounts of glucose for the formation of side products.

Economics evaluation from data generated

The quantitative expressions evaluated for assessing the economic feasibility of commercializing cellulosic ethanol fuel in the study are shown in the following equations.

$$PGP = \frac{\text{Amount of ethanol after fermentation}}{\text{Amount of CEL \& HEM after pretreatment}} \times 100$$

$$EY_1 = \frac{\text{Amount of experimental ethanol (g/L)}}{\text{Theoretical ethanol amount before fermentation (g/L)}} \times 100$$

$$ECC = \frac{(\text{Conc.of final ethanol} - \text{Conc.of initial ethanol})\ g/L}{(\text{Amount of cellulose after pretreatment X 0.57})\ g/L} \times 100$$

$$ECG = \frac{(\text{Conc.of final ethanol} - \text{Conc.of initial ethanol})\ g/L}{(\text{Amount of glucose after hydrolysis X 0.511})\ g/L} \times 100$$

$$EY_2 = \frac{\text{Amount of experimental ethanol (g/L)}}{\text{Amount of Biomass (g/L)}} \times 100$$

Potential glucose in Pretreated Sample, EY_1-Ethanol Yield from the initial amount of Glucose (hydrolyzed) used for the Process of Fermentation, EY_2-Actual Ethanol Yield, ECG-Enzymatic Convertibility of Glucose during the process of Fermentation, ECC - Enzymatic Convertibility of Cellulose during the process of Hydrolysis (Manzanares et al., 2003; Stroeve et al., 2009; Gouveia, Soares and Wanderley, 2014).

Table 4, shows that the yield curve for alkaline-treated biomass will show a normal curve as the concentration of bioethanol increases with time taken for the fermentation reaction. A similar variation would be observed for acid and SPORL-treated biomass. For this discussion, we will look beyond variation with time and consider variation of yield with particle sizes of biomass.

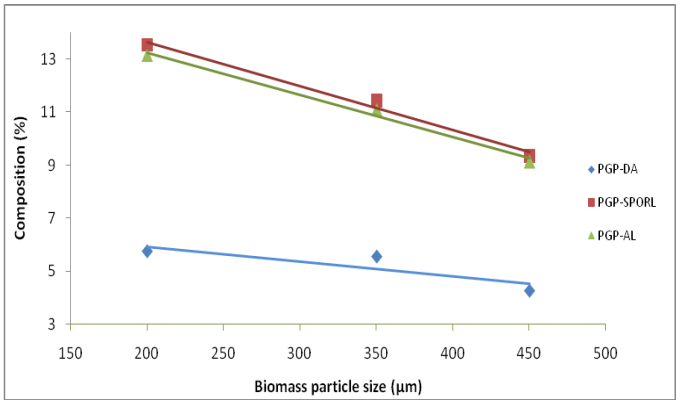

Fig. 1: variation of amounts (%) of potential glucose in different pretreatment methods with particle sizes, µm (200 µm ↔ ≤ 200 µm; 350 µm ↔ > 200µm ≤ 350 µm; 450 µm ↔ > 350 µm ≤ 450 µm).

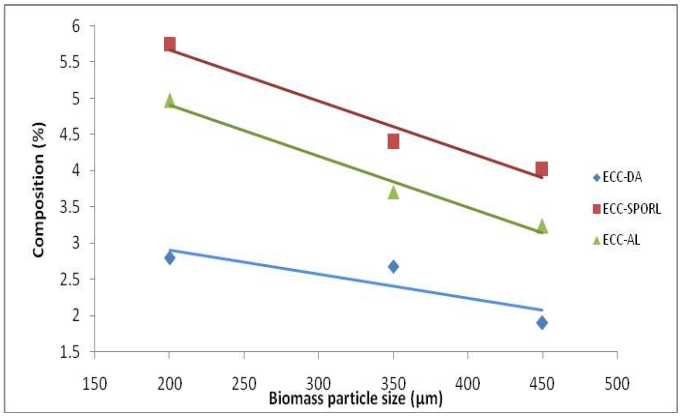

Fig. 2: Variation of the amounts (%) of enzymatic convertibility of cellulose (ECC) from *P. purpureum* with particle sizes, µm (200 µm ↔ ≤ 200 µm; 350 µm ↔ > 200 µm ≤ 350 µm; 450 µm ↔ > 350 µm ≤ 450 µm).

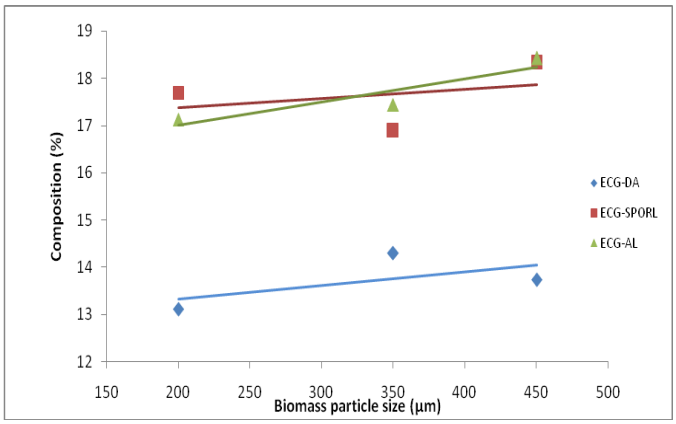

Fig. 3: Variation of enzymatic convertibility of glucose (%) from *P. purpureum* with different particle sizes and pretreatment methods at the end of fermentation (200 µm ↔ ≤ 200 µm; 350 µm ↔ > 200 µm ≤ 350 µm; 450 µm ↔ > 350 µm ≤ 450 µm).

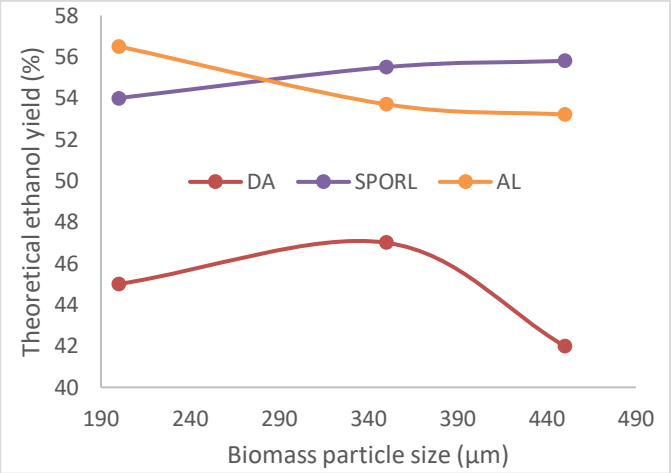

Fig. 4: Variation of the amounts (%) of theoretical yield (EY1) from *P. purpureum* with particle sizes (µm) and pretreatment methods (200 ↔ ≤ 200 µm; 350 µm ↔ > 200 µm ≤ 350 µm; 450↔ > 350 µm ≤ 450 µm).

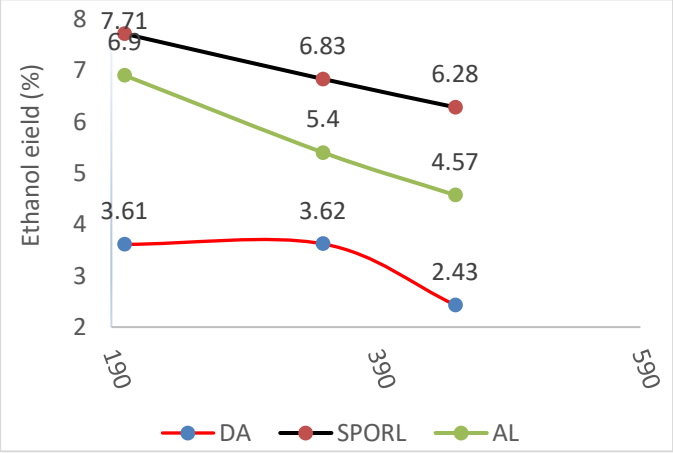

Fig. 5: Variation of amounts (%) of actual ethanol yield (EY2) with different pretreatment methods and particle sizes, µm (Biomass particle size: 200 ↔ ≤ 200 µm; 350 ↔ > 200 µm ≤ 350 µm; 450 ↔ > 350 µm ≤ 450 µm).

Potential Glucose in Pretreated Sample (PGP) variation with particle size shows an inversion as particle size increases with a decrease in PGP. This could be interpreted as the effect of surface area in contact favors a decrease in particle size for scarification reaction. Also, a narrow spread is observed for SPORL and alkaline-pretreated biomass and a widespread for acid-pretreated biomass compared to the other two methods (Fig. 1).

Enzymatic convertibility of cellulose generally showed inversion with an increase in particle size for all pretreatment methods (Fig. 2), although the declined spread between SPORL and alkaline pretreatment methods was higher than that for the previous evaluations. Variation of the spread between dilute acid and the other two pretreatment methods were geometrically higher. The amount of enzymatic convertibility of cellulose was between 1.90– 5.75 % for all three pretreatment methods, which was significantly low for an economically feasible process.

Enzymatic convertibility of glucose (ECG) showed a general increase in concentration as biomass particle sizes increased; this was observed for all pretreatment methods. Nevertheless, a narrow spread was observed between SPORL and alkaline pretreatment methods and a wider spread was observed between these two methods and the dilute acid method of pretreatment (Fig. 3). Similarly, 13.11 to 18. 43 % as the range observed for the ECG of these processes was not significant for an economically feasible process.

Figure 4 shows that the three pretreatment methods have different variations of theoretical ethanol yield with biomass particle sizes. The dilute acid pretreated curve shows a proportional yield at the beginning and ends with an inversion; this shows that lower yields are produced with increasing particle sizes. SPORL pretreated samples showed proportional variation with a nearly flat yield towards the end. While alkaline oxidation pretreated biomass showed an obvious inversion curve. The spread for SPORL and alkaline pretreated biomass is narrow and both are wide compared to that of dilute acid pretreated biomass; this makes alkaline oxidation and SPORL pretreatment methods to be more prominent than dilute acid pretreatment. During the fermentation process, some amounts of glucose were introduced via solutions of inoculums and fermentation medium; these would have also increased the theoretical ethanol yield to the obtained range of 41.10 – 56.73 % across all pretreatment methods.
The actual ethanol yield (EY2) showed obvious inversions with particle sizes of biomass for all pretreatment methods (Figure 5). The spread of values for dilute acid pretreatment with the other two methods remains as wide as the observations for previous economic calculations. The range of the actual bioethanol yield of 2.43–7.71 % across the three pretreatment methods may show that the process is not economically feasible.

CONCLUSIONS

Global efforts toward substituting fossil fuels for sustainable and green sources of energy are the major considerations of research on biofuels with evolving biofuel technologies. The process of converting cellulose to bioethanol employs the use of different catalysts, with their availability foreign to the Nigerian economy. Moreover, the presence of plant recalcitrance in the grass biomass reduces the convertibility of this catalyst in the process. The 7.71% maximum actual ethanol yield obtained in this work was attributed to the constraints during production, which has severe consequences especially as it concerns the effects of catalysts inhibitions from recalcitrant generated during the process of production. An alternative route to this production with the use of energy food crops is not sustainable in the region

because of the detrimental effects on the food supply. Therefore, the region's quest for renewable and sustainable sources of energy should embrace the concept of an energy mix rather than an energy swap which may be achieved in the future when some level of development is attained. Some Experts in two renowned energy conferences in 2023 in Nigeria; The 2023 Nigerian International Energy Summit (NIES) in Abuja and the 2023 Renewable and Alternative Energy Society of Nigeria (RAESON) Conference in Awka proposed that the journey to energy transition in Nigeria should focus on raw materials with comparative advantage in her locality thereby attaining energy sustainability; major emphasis was placed on natural gas which has been globally declared to be a green source of energy. As at 1st January 2023, Nigerian's natural gas reserve was 208.62 trillion cubic feet (NIES, 2023).

This study buttresses the recommendations from other experts stating that Nigeria could overcome her energy challenges by strategically following the following points in the stated progression: Exploring new investment options tailored to the energy transition, focusing on human capital development, exploring technology and innovation, being conscious of verifiable data collection via research, collaborates with required stakeholders and engage in policy implementation.

DECLARATION OF COMPETING INTEREST

The authors declare no competing financial interest.

ACKNOWLEDGEMENTS

The authors express their gratitude to the Department of Pure and Industrial Chemistry of the University of Port Harcourt for providing the laboratory space and some instrument for this work to be carried out. We are also not forgetful of the immense guide of Late Dr. Samuel Ofordile at the commencement of this work.

REFERENCES

Aden, A., Foust, T., 2009. Techno-economic analysis of the dilute sulfuric acid and enzymatic hydrolysis process for the conversion of corn stover to ethanol. Cellulose 16, 535–545.

Adewumi, C.N., Ekpo, I.E., Achugasim. O., Ogali, R.E., Akaranta, O., 2022. Substrate concentration: A more serious consideration than the amount of 5-hydroxymethylfurfural in acid-catalyzed hydrolysis during bioethanol production from starch biomass. Heliyon 8, e12047.

Adewumi, C.N., Achugasim. O., Ogali, R.E., Akaranta, O., 2021. Bioethanol Production from *Icacina trichanta Oliv* as non food crop. A Doctorate of Philosophy Thesis of the Emarit Center, World Bank Sponsored, University of Port Harcourt, Nigeria.

Beutler, H.O., 1988. Ethanol. In Methods of Enzymatic Analysis (Bergmeyer, H. U., ed.), Publishers (UK) Ltd., Cambridge, UK, 3rd ed., 6: 598-606.

Fadel, M., Keera, A. K., Mouafi, F. E. and Kahil, K., 2013. High level ethanol from sugar cane molasses by a new thermotolerant *Saccharomyces cerevisiae* Strain in Industrial Scale. Biotechnology Research International 1-7.

Ekpo, I., Ogali, R., Ofodile, S., Achugasim, O., 2016a. Comparison of biomass content for the evaluation of cellulosic ethanol fuel production from predominant perennial grasses in South-South, Nigeria. International Journal of Applied Science and Technology 6(2), 38-46.

Ekpo, I., Ogali1, R., Ofodile, S., Achugasim, O., Osakuade, F., 2016b. Formation of enzymatic recalcitrance during bioethanol production from *Pernnisetum purpureum* with three pretreatment methods. Journal of Energy Technology and Policy 6(11), 10-22.

Gregersen, E, 2024. Law of definite proportions. Encyclopedia Britannica.https://www.britannica.com/science/homogeneous-reaction

Hauwa, M. M., Dahiru, S., Abdulrahman, B., Abdullahi, I., 2019. bio-ethanol production from cassava (*Manihot esculenta*) waste peels using acid hydrolysis and fermentation process. Science World Journal 14, 45-50.

Kim, M., Suh, H., Cho, E. J., Buratowski, S., 2009. Phosphorylation of the yeast Rpb1 C- terminal domain at serines 2, 5, and 7. Biological Chemistry 284(39), 26421-6.

Kim, S., Kim, J. Shin, S., Agblevor, F.A., 2009. Distinction between bioethanol and synthetic ethanol in a mixture of gasoline using low level liquid scintillation counting. Chemistry Letters (38), 850-851.

Kmecl, V., Škerl, M. I., 2014. A comparison of two methods for determination of HMF in honey and bee food: HPLC method versus spectrophotometric Winkler method. A Scientific Paper, Ribarstvo, lovstvo i pčelarstvo 471-475.

Kongkeitkajorn, M. B., Sae-Kuay, C., Reungsang, A., 2020. Evaluation of napier grass for bioethanol production through a fermentation process. Processes 8(567), 2-19.

Manzanares, P., Rojas, V., Gil, J.V., Pinaga F., 2003. Acetate ester formation in wine by mixed cultures in laboratory fermentations. International Journal of Food Microbiology 86(2), 181-188.

Megazyme 2014. Ethanol Assay Procedure. Megazyme International Ireland, www.mergazyme.com [Accessed: 16-03-2015].

N.I.E.S., 2023. Nigeria International Energy Submit Post Event Summary. https://nigeriaenergysummit.com/nies-2023-post-event-summary/[Accessed:12-12-2023].

University of Nebraska, ''Manual of Laboratory Techniques": 2009. Ruminant Nutrition Laboratory. http://feedlot.unl.edu/rnlab/ManualWebsite.htm. [Accessed 13-11-2012].

Rocha, S. M., Coimbra, M. A., Delgadillo, I., 2004. Occurrence of furfuraldehydes during the processing of Quercus suber L. cork. Simultaneous determination of Furfural, 5-

Hydroxymethyl furfural and 5-Methyl furfural and their relation with cork polysaccharides. Carbohydrate Polymers 56, 287–293.

Rueda, J.A., Guerrero-Rodríguez, J.D., Sergio Ramírez-Ordoñes, Aguilar-Martínez, C.U., Hernández-Montiel, W., Ortega-Jiménez, E., 2000. Morphological composition and fiber partitioning along regrowth in elephant grass CT115 intended for ethanol production. Scientific Report 10, 1-9

Wangpor, J., Prayoonyong, P., Sakdaronnarong C., Sungpet A., Jonglertjuny, W., 2017. Bioethanol production from cassava starch by enzymatic hydrolysis, fermentation and ex-situ nanofiltration. Energy Procedia 138, 883-888.

White, J.W., 1994. The role of HMF and diastase assay in honey quality evaluation. Bee World 75(3), 104-117.

Wongwatanaipaiboon J., Kangvansachol K., Burapatana V., Inochanon R., Winayanuwattikun P., Yongvanich T., Chulalaksananukul W., 2012. The Potential of Cellulosic Ethanol Production from Grasses in Thailand. Journal of Biomedicine and Biotechnology 10, 1-9.

Stroeve, P., Kumar, P., Barrett, D.M., Delwiche, M.J., 2009. Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. Industrial and Engineering Chemistry Research 48, 3713–3729.

Soares, I. B., Marques, O. M., Benachour, M., de Abreu, C. A. M., 2011. Ethanol production by enzymatic hydrolysis of elephant grass. Journal of Life Sciences 5, 157-161.

Tamers, M., 2006. Distinguishing between bio-ethanol and petroleum ethanol. Beta Analytic Article from Ethanol Producer Magazine, Published June 1, 2006.

Van Soest, P.J., 1963. Use of Detergents in the Analysis of Fibrous Feeds. II. A Rapid Method for the Determination of Fibre and Lignin. The Association of Official Analytical Chemists 46, 830.

Van Soest, P.J. and Wine. R.H., 1968. Permanganate lignin. The Association of Official Analytical Chemists 51, 780.

Wanderley, M.C.D.A., Soares, S., Gouveia, E.R., 2014. Selection of inoculum size and *Saccharomyces cerevisiae* strain for ethanol production in simultaneous saccharification and fermentation (SSF) of sugar cane bagasse. African Journal of Biotechnology 13(27), 2762-2765.

Zappal, M., Fallico, B., Arena, E., Verzera, A., 2004., Methods for the determination of HMF in honey: a comparison. Food Control 16, 273- 277.

Zhang, J., Li, J., Tang, Y., Xue, G., 2013. Rapid Method for the Determination of 5-Hydroxymethylfurfural and Levulinic Acid Using a Double-Wavelength UV Spectroscopy. Scientific World 12, 1-7