THE POTENTIAL OF ELEPHANT GRASS (*PENNISETUM PURPUREUM SCHUM),* A NIGERIAN INDIGENOUS GRASS, IN BIOETHANOL PRODUCTION: A DECARBONIZATION ALTERNATIVE FOR THE MARITIME INDUSTRY

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ABSTRACT

It is true that fossil based energy has contributed immensely to global economic growth. Unfortunately, its usage is accompanied by the emission of carbon dioxide (CO_2), a principal greenhouse gas. Studies using business as usual (BAU) model, has predicted that CO_2 emission into the atmosphere will increase by 50-250% by the year 2050. The transportation industry has remained one of the highest contributors to this global carbonization. About 40% of all CO_2 emissions by 2050 will be caused by shipping and aviation if left unregulated, a study published by the European Parliament revealed. The above scenario has heightened the interest in energy crops development as resources for alternative/renewable energy purpose. Elephant grass (*Pennisetum Perpureum Schum)*, an African indigenous grass, is an abundant, C4 grass, investigated for its potential as a renewable energy source. Elephant grass feedstock (stem & leaves) was subjected to laboratory analysis for its total carbohydrate content (TCC) via proximate composition analysis. For ethanol production experiments, feedstock acidic hydrolysis, using 0.5M of dilute H_2SO_4 was adopted. The pH of the hydrolyzed supernatant was adjusted to 5.0 using 10M NaOH solution. Fermentation medium was prepared using 10g of dextrose, 0.2g yeast extract and 1g urea. The fermentation process using 0.5g of *Saccharomyces cerevisae* at 35^0C for a period of 1 to 5 days was subjected to distillation process at 78.3^0C. Proximate composition analysis showed a 74.2% TCC, a huge content for conversion to bioethanol. The fermentation process showed increase in ethanol yield with increase in feedstock concentration. From the foregoing, elephant grass has the potential to serve as energy crop for biofuel production for automobiles including some auxiliary engines of ships if not major ones.

Keywords: Biomass, biofuel, decarbonization, carbon footprint, crop diversification

1. BACKGROUND

While it is true that fossil based energy (though not renewable) has contributed immensely to global economic growth, it has brought with its usage the emission of carbon dioxide (CO_2), a principal greenhouse gas. Concern over this increasing concentration of carbon dioxide in the atmosphere, has intensified interests in developing biomass crops as resources for alternative/renewable energy purposes. Biomass is any organic matter (biological materials) that can be converted to energy (bioenergy). The energy so produced is needed for public transportation (marine, road, air), consumption uses (cooking, lighting, heating etc), for social needs (education, health services), for industries and agricultural and allied sectors.

Although Africa accounts for a small share of the world's commercial energy consumption (5.5%) it has a large share of the world's biomass energy (ADB, 2004). On a global scale, biomass ranks fourth as an energy resource, providing approximately 14% of the world's energy needs (Hall *et al.*, 1992). In developing countries, biomass accounts for approximately 35% of the energy used, and in the rural areas of these nations, it is often the only accessible and affordable source of energy (Hall *et al.*, 1992). Most of the world's biomass energy consumption is in the sub-Saharan Africa where it accounts for about 86% total energy consumption outside South Africa (ADB, 2004). According to Sanchez (2008), *'When it comes to biomass production for biofuels, the tropics have the edge'*. Nigeria is one of the sub-Saharan African countries which rely mainly on biomass for the supply of energy.

Biofuels (bioethanol and bio-diesel) produced from renewable energy sources are gaining importance in the light of increasing greenhouse effect associated with the use of fossil fuels and its associated damaging environmental impacts. Studies using business as usual (BAU) model, has predicted that emission of CO_2 into the atmosphere will increase by 50 - 250% by the year 2050 with perhaps a commensurate increase in the global carbon footprint (U.S. climate change science program, 2007). The transportation sector one of the highest contribution to CO_2 emissions. In 2010 transport accounted for about 23%of global CO_2 emissions with urban transport accounting for about 40% of end-use energy consumption. CO_2 persists in the atmosphere for over a century, with long-term warming effects (IPCC, 2014). Though Maritime transport is the backbone of world trade and globalization it is estimated that, by the year 2050, Shipping could be responsible for 17% of global CO_2 emissions if left unregulated. Therefore, keeping a continuous check on CO_2 emissions is imperative by the use of alternative and renewable source of energy from biomass.

Suffice to mention here that the past few decades have witnessed bioethanol production from edible crops such as maize, rice, cassava and sugarcane as seen in America, Asia, Africa and Brazil respectively. These crops serve as food for the ever increasing world's human population. These food crops must be preserved otherwise the global food crisis as experienced in recent past will remain unabated. Although much attention has been devoted to the conversion of starch and sugar containing plants (e.g. maize, cassava and sugarcane) to fermentable sugars, little attention has been given to other naturally occurring agricultural menace in our environment (lignocellulosic plants) which are formidable sources of wealth. Therefore, the overall process of using lignocellulosic crops like grasses which hitherto were nuisance to our farmers as they compete for available nutrients, water and air in the farm land is another merit of crop use diversification strategy.

In our vision, an organized approach (via agriculture) which will contribute to the economy in the nearest future would be to provide vast amount of cellulosic biomass for conversion into 'clean' transportation fuel (marine and land transportation industries). Notably, herbaceous energy crops such as switchgrass, elephant grass, etc. are viewed as a strong potential, long term ethanol feedstock to replace food crops such as corn, cassava etc.

The Sustainable Development Goals (SDGs) as extension of Millennium Development Goals (MDGs), seek to build on the MDGs and complete what the latter did not cover or achieved. The agenda and its component entities are indivisible and revolve around the 5 Ps: People, Planet, Peace, Prosperity and Partnerships. The goals are integrated and balance the three platforms of sustainable development namely, economic, social and environmental. While goal 7 seeks to "Ensure access to affordable, reliable, sustainable and modern energy for all", goal 13 is a global clarion call to all and sundry to "Take urgent action to combat climate change and its impacts." In the light of the above, biofuel technology is believed by many, to have the potential to alleviate some of the many problems associated with impacts from dependent on fossil fuels i.e. carbon emission, degradation of natural ecosystems, loss of biodiversity, political instability, conflicts and war.

The U.S. Department of Energy (US-DOE) has selected switchgrass (*Panicum virgatum*), an indigenous grass, as a model species for the development of sustainable herbaceous energy crop production technology from which a renewable source of transportation fuel and/or biomass-generated electricity could be derived (Lynd *et al.*, 1993). Switchgrass was chosen as a result of its demonstrated high productivity across a wide geographical range, suitability for marginal quality land, low water and nutrient requirements and positive environmental benefits (Keshwani & Cheng, 2008).Brazil is a shining example for using ethanol (produced from sugarcane juice) either in pure form or as a blend with petrol (gasohol) for fuelling the automobiles (Eze, 2004). Billions of gallons of bioethanol are being produced in brazil using sugarcane. Ethanol alone accounts for about 90% of total biofuel production (39 billion litres) in 2005 (www.commodityIndia.com) in the world (Reddy *et al*., 2005). The gasohol (blending of ethanol and petrol) is an environment-friendly fuel and its use is encouraged worldwide to reduce air pollution as well as to reduce the fuel-import bills.

In 2010, worldwide biofuel production reached 105 billion litres (28 billion gallons US), up 17% from 2009 and biofuel provided 2.7% of the world's fuels for road transportation. America and Brazil are the world's top producers of biofuel accounting together for about 90% of global production. The world's largest biodiesel producer is the European union, accounting for about 53% of all biodiesel production in 2010. The international Energy Agency (IEA), has a goal for biofuel to meet more than a quarter of world demand for transportation fuels by 2050 in order to combat effects of climate change reduce dependence on fossil fuels.

Elephant grass (*Pennisetum Purpureum Schum*),is an abundant, Nigerian indigenous grass. It is a perennial rhizomatous plant, known to grow and do well on marginal soils, serves to control erosion and retards siltation. It has a fast growth rate and can be harvested up to four times or more in a year (Farrell *et al*., 2002). Its conservation as indigenous, non-threatened species is another factor for its consideration.

Morphologically, it is like the sugarcane plant. Like the highly successful temperate switchgrass, it belongs to the C4 carbon fixation group of plants. These C4 plants are concentrated in the tropics and sub-tropics and possess enhanced capacity for biosequestration of carbon dioxide and represents an important climate change avoidance strategy (Osborne & Beerling, 2006). In the meantime, the grass, which has very little patronage for any known commercial uses, was investigated for its potential as a renewable/alternative energy source in our transportation sector (automobile and shipping).

The objectives of this study therefore include:

1. To determine the total carbohydrate content in the elephant grass feedstock by conducting proximate composition analysis of the feedstock.
2. To evaluate the yield of ethanol from the fermentation of the acidic hydrolysate of the grass feedstock.
3. To examine the effect of feedstock concentration and fermentation time on ethanol yield.

2. METHODOLOGY

2.1 Sample preparation

Processing of lignocellulosic materials to ethanol consists of four major unit operations. The operations include pretreatment, hydrolysis, fermentation, and product separation.

The physical/mechanical preparation steps which form a part of the pretreatment processes include harvesting, cleaning, drying and size reduction by grinding of the biomass feedstock. Pretreatment processes of the feedstock sample are important before the process of hydrolysis commences. The pretreatment process serves to reduce the crystalline nature of cellulose, increase porosity of the biomass and ultimately helps to achieve the desired fractionation (Sun & Cheng, 2002; Mosier *et al*., 2005). Good pretreatment is necessary to improve hydrolysis, minimize carbohydrate losses and to some extent prevent formation of by-products that might inhibit subsequent hydrolysis and fermentation steps.

Plate 1: Harvested Elephant Grass feedstock

2.2 Proximate composition analysis of the feedstock

Proximate composition of food/feedstock is the term applied to the proportion of moisture, fat, carbohydrate, protein and ash present in foods and feedstock. These analyses are carried out through standard procedures (Osborne & Vogt, (1978); Harold *et al.,* (1981)). The composition analysis of the following parameters namely; moisture content, fat or lipid content, ash content, crude protein content and total carbohydrate content were carried out and expressed in percentages (%).

2.3 Hydrolysis, fermentation and distillation processes

Acidic hydrolysis of the feedstock, using 0.5M of dilute H_2SO_4 was adopted for this study. To 100ml of 0.5M dilute H_2SO_4 was added 5g (w/v) of the feedstock. This was heated at 155°C with continuous shaking for 30mins, allowed to cool and centrifuged at 4000 rpm for 30mins. The supernatant was collected into 250ml conical flask and stored in the fridge.

This was repeated 5 times for this feedstock concentration. The above process was repeated for 10g, 15g and 20g feedstock concentration respectively. The pH of the hydrolyzed, stored supernatant was adjusted to 5.0 using 10M NaOH solution dropwise. 100ml fermentation media was prepared using 10g of dextrose sugar, 0.2g yeast extract and 1g serving as nutrients. The fermentation process using 0.5g of *Saccharomyces cerevisae* (baker's yeast) at 35°C for a period of 1 to 5 days and respectively subjected to distillation process at 78.3°C (b.pt. of ethanol).

3. RESULTS AND DISCUSSION

The results of this study are presented in Tables 1 to 4. This covered on one hand the proximate composition of the elephant grass feedstock dry matter (DM) basis (Table 1 and Figures 1 to 2) and on the other hand the yield of ethanol via acidic hydrolysis (represented in Tables 2 to 4, Figures 1-5), fermentation and distillation of the grass feedstock.

3.1. Proximate composition

The result of the proximate composition of elephant grass feedstock dry matter is presented in Table 1 and Figures 1 and 2.

Table 1: Proximate composition of elephant grass feedstock-dry matter (DM)

Parameter (%)	Sample 1	Sample 2	Average
Moisture content	0.25	0.26	0.26
Fat content	3.35	3.27	3.31
Ash content	9.04	9.18	9.11
Crude protein content	13.44	12.81	13.13
Total carbohydrate content	73.92	74.48	74.20
Insoluble carbohydrate content	51.82	51.35	51.60
Soluble carbohydrate content	22.10	23.13	22.62

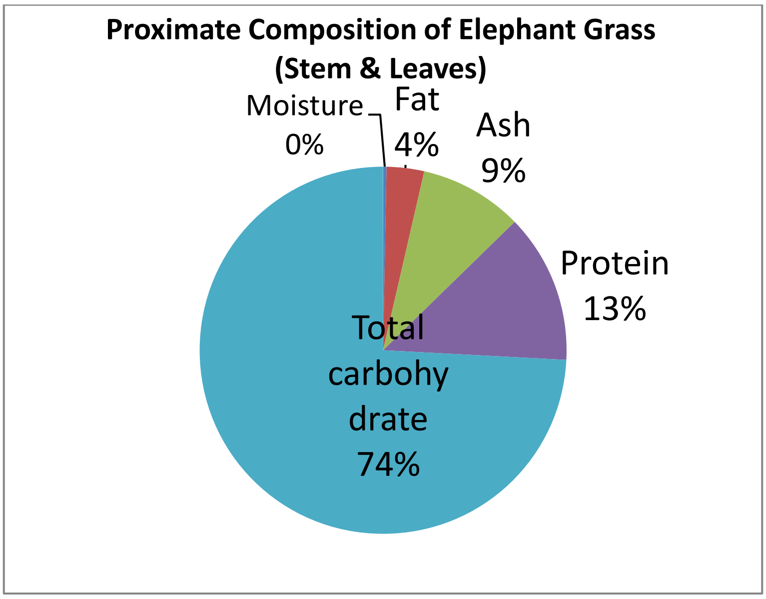


Figure 1: Proximate composition of elephant grass feedstock showing total carbohydrate content

Figures 1 to 2, clearly presented the total carbohydrate content (TCC) constituting 74% as the major fraction, the crude protein (CP) representing 13%, ash content of 9%, fat content of about 4% and moisture content of 0.26%. (Figures 1 & 2 and Table 1).

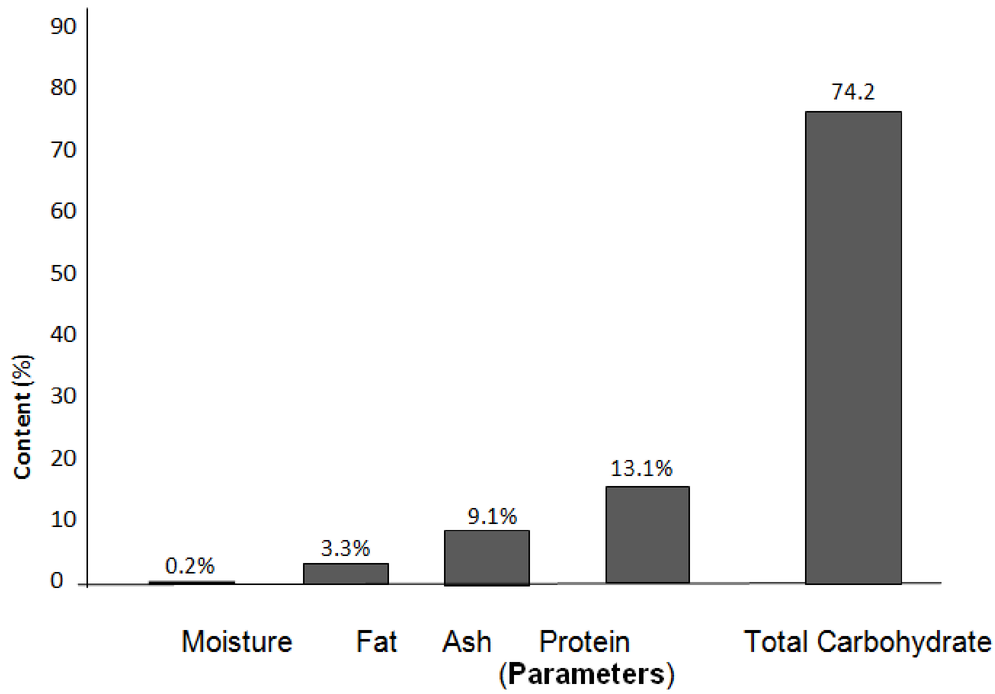


Figure 2: Proximate composition of elephant grass feedstock

3.2 Yield of ethanol

3.2.1 Yield of ethanol with varying feedstock concentrations

The effect of feedstock concentration and fermentation time on ethanol yield at various conditions is shown in Table 2.

Table 2: The effect of feedstock concentrations and fermentation time on ethanol yield

Constant Conditions	Feedstock concentration g/ml	Ethanol yield (ml) Day 1	Ethanol yield (ml) Day 2	Ethanol yield (ml) Day 3	Ethanol yield (ml) Day 4	Ethanol yield (ml) Day 5
pH = 5.0, Temp.= 35^{0}C and Yeast concentration = 0.5g	5	1.20	2.90	5.80	3.80	2.80
	10	4.10	7.40	15.20	11.40	8.80
	15	6.50	9.80	24.60	16.10	10.20
	20	16.50	31.30	54.40	44.20	37.00

The result of ethanol yield with varying feedstock concentrations showed an increasing trend of ethanol production ranging from 1.2ml to 16.5ml of 5g in day one. The same increasing trend was observed for 10g, 15g and 20g samples in days 2 to 5 respectively (Table 2).

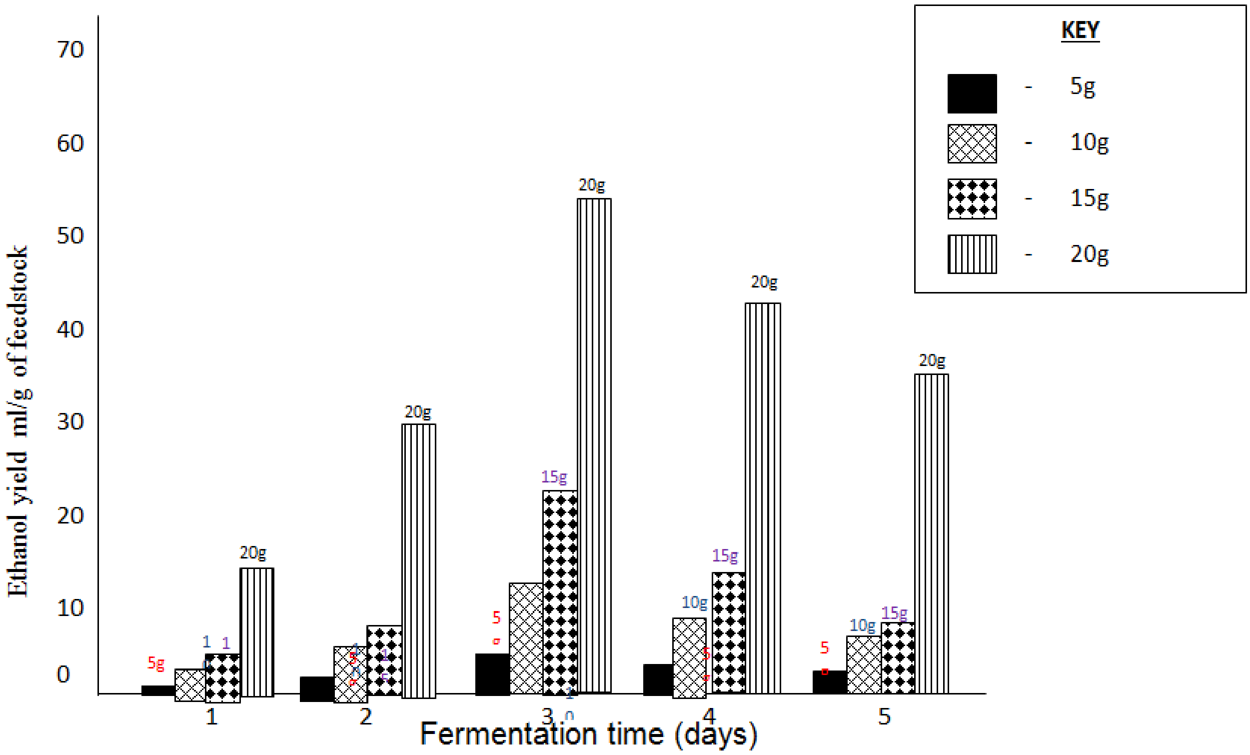
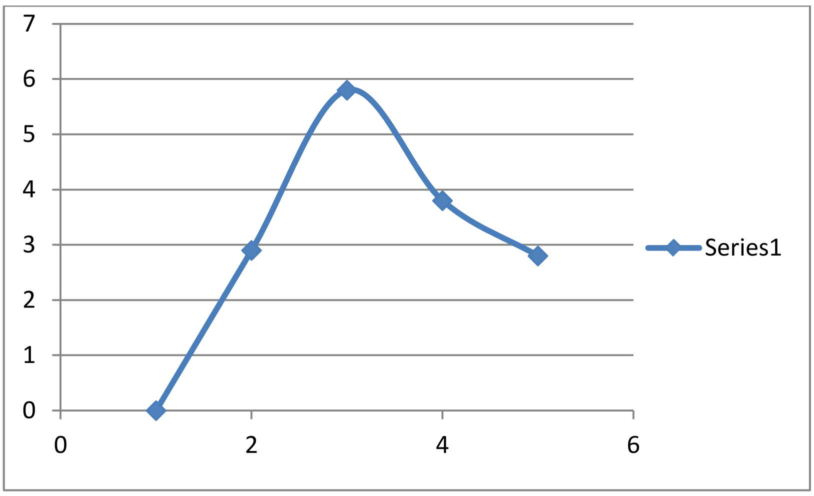


Figure 3: Effect of feedstock concentration and fermentation time on ethanol yield

3.2.2 Yield of ethanol with fermentation time (Days or Hours)

The result showed an increase from 1.2ml (day 1) to a peak of 5.8ml (day 3) and then a decrease to 2.8ml (day 5) for a 5g feedstock concentration (Table 2). The same trend was observed for the various feedstock concentrations of 5g, 10g, 15g and 20g.

There was an increasing trend in the yield of ethanol each day from 5g to 20g (Table 2). Thus, each day depicted an increasing trend in the yield of ethanol from 1.20ml to 16.50ml (day 1); 2.90ml to 31.30ml (day 2); 5.80ml to 54.4ml (day 3) 3.80ml to 44.20ml (day 4) and 2.80ml to 37.00ml (day 5).



Fermentation time (days)

Figure 4: Ethanol yield for 5g feedstock concentration

(The same standard curve was obtained for the other concentrations)

3.3 Standard plot for absolute ethanol at a wavelength of 205nm

3.3.1 Absorbance values for absolute ethanol

The absorbance (nm) of the absolute ethanol plot is shown in table 3.

The absorbance readings of the absolute ethanol showed an increasing trend ranging from 0.087nm to 0.801nm, with an increasing concentration of the absolute ethanol from 10% to 90%.

Table 3: Standard plot for absolute ethanol absorbance at 205nm wavelength

s/no	Amount of ethanol (ml)	Amount of water (ml)	Concentration of ethanol (%)	Absorbance (nm)
1	0 (blank)	25.0	0	0
2	2.5	22.5	10	0.087
3	5.0	20.5	20	0.150
4	7.5	17.5	30	0.204
5	10.0	15.0	40	0.383
6	12.5	12.5	50	0.569
7	15.0	10.0	60	0.658
8	17.5	7.5	70	0.704
9	20.0	5.0	80	0.772
10	22.5	2.5	90	0.801

3.4 Extracted ethanol after distillation process

3.4.1 Absorbance values for extracted ethanol

The absorbance readings for extracted ethanol are shown in Table 4 with the corresponding mean values/day.

3.4.2 The mean value for absorbance of extracted ethanol

The mean values of absorbance of extracted ethanol per day (0.424nm, 0.540nm, 0.655nm and 0.695nm) as read-off from the standard plot gave a corresponding concentration range of 44% to 73%. (Figure 5).

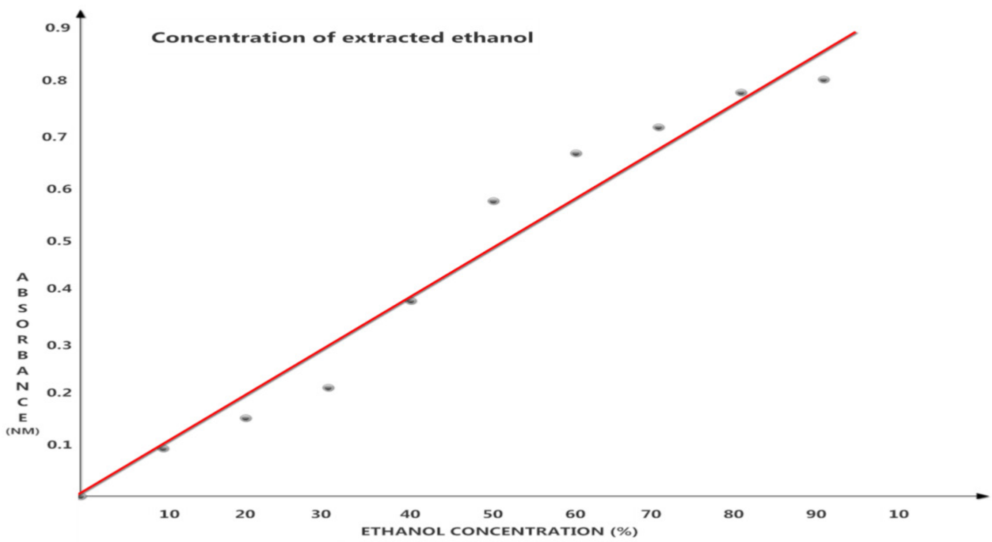


Figure 5: Standard plot for absolute ethanol at 205nm wavelength

Table 4: Mean values of absorbance of extracted ethanol

Feedstock concentration (g)	Ethanol extract Day 1	Ethanol extract Day 2	Ethanol extract Day 3	Ethanol extract Day 4	Ethanol extract Day 5
5	0.396	0.522	0.702	0.691	0.701
10	0.440	0.518	0.697	0.641	0.692
15	0.440	0.578	0.654	0.700	0.677
20	0.430	0.540	0.598	0.688	0.711
Absorbance mean	**0.424**	**0.540**	**0.655**	**0.680**	**0.695**

4. DISCUSSION

Proximates are used in the analysis of biological materials as a composition of food or feedstock into its major constituents. For an industry standard, proximate includes five (5) constituents: moisture, fat, ash, crude protein and carbohydrates (soluble and insoluble).

From the results presented in Table 1, and Figure 1, the total carbohydrate content is 74.2% of the elephant grass feedstock. The feedstock with such carbohydrate content has an impressive substrate available for conversion into bioethanol. Christian *et al*., (2002); Farrel *et al*., (2002) and Soares *et al.,* (2011) in their separate studies reported that the high carbohydrate content of switchgrass and elephant grass respectively accounts for its choice of energy crop for biofuel production. Sluiter *et al*., (2010) collaborates this position in his studies that showed that the importance of accurate and adequate measurement of biomass carbohydrate content is of prime importance because it is directly proportional to ethanol yield (L Mg^{-1}) in biochemical conversion processes. While switchgrass is of American origin, elephant grass is of African origin.

The soluble carbohydrate value of 22.6% from the elephant grass feedstock is higher than that of the highly rated temperate switchgrass (Mick, 2008). This again gives credence to the viability of this feedstock as a desirable bioenergy crop. This insoluble carbohydrate is made available through the various processes of pretreatment and hydrolysis to produce simple sugars and thereafter to ethanol through the process of fermentation (Sun & Cheng, 2002; Mosier *et al*., 2005).

The moisture content of the feedstock with an average of 0.26% is quite negligible as it was analysed on a dry mass basis. Thus, the value of the moisture content, ash content of 9.11% and the average fat content of 3.3% (Table 1 and Figure 1) together constitute less than 13% of the total feedstock content. This can be considered insignificant more so that it has no direct bearing with the processes of biorefinary in line with our study goals.

Table 2, showing the effect of feedstock concentration and fermentation time on ethanol yield at pH (5.0), fermentation temperature (35°C) and yeast concentration (0.5g) showed that ethanol yield increased with increasing substrate or feedstock concentration of 5g to 20g.

The results presented in Figures 2 to 4; showed an increase in ethanol yield from day 1 to day 3 (24hrs – 72hrs) after which there was a decrease in the yield from day 4 to day 5 (96hrs to 120hrs). This means that the activities of the microorganism which results in fermentation of the available simple sugars to ethanol was at its optimum under 72hrs fermentation. The maximum ethanol yield was recorded under the 20g feedstock concentration after 72hrs. This is collaborated by the work of Cheng *et al*., (1997) and Keshwani *et al*., (2001) which depicted that maximum ethanol yield was achieved after 72hrs fermentation time. However, increase in fermentation time after day 3, gave a decrease in ethanol yield (day 4 to day 5). It could be deduced that the ethanol produced after 72hrs as production peak could inhibit the activity of the yeast, hence a drop in yield (Table 2 & Figures 2-4).

The prepared ethanol concentration from absolute ethanol was used to make the standard plot showing a straight line from the origin of absorbance (nm) and ethanol concentration. The extracted ethanol after each distillation process was recorded and the absorbance at 205nm was taken from feedstock concentration and the various fermentation time in days The mean of the absorbance readings for the various days as recorded was in the range of 0.424nm and 0.695nm and when read-off gave ethanol concentration range of 44% - 72.6%.

5. CONCLUSION

From the results of the study obtained, the following conclusions can be reached.

i) The proximate composition analysis result of the elephant grass feedstock – dry mass (dm) basis, depicted a substantial total carbohydrate content of 74.2%. The carbohydrate content is high enough to favourably support the processes that lead to bioethanol production (Sun & Cheng, 2002). Sluiter *et al*., (2010), has reported in his study that process performance leading to ethanol yield from biomass, is directly related to the proportion of total carbohydrate content in the feedstock.

ii) 54.40ml maximum yield of ethanol was achieved under optimum fermentation conditions of 35^0C temperature and 5.0 pH after 72hrs fermentation period.

iii) Ethanol yield increased with increasing feedstock concentrations (5g to 20g) but maximum yield was recorded in each feedstock concentration after day 3 (72 hrs) fermentation period as collaborated by Keshwani *et al.,* (2007).

By the year 2050, Shipping could be responsible for 17% of global CO_2 emissions if left unregulated, Therefore, any agreement at any given Climate Summit must therefore send a clear signal to the International Maritime Organization (IMO) that CO_2 reduction targets and measures for shipping are needed to help keep warming below dangerous levels. In view of the above and coupled with the fact that elephant grass is a fast growing plant and thus, can be harvested about four times in a year, does well on marginal soils etc, as supported by the findings of Farrell *et al*., (2002), Bogdan (1977) and Keshwani & Cheng (2008), positively positions this grass as a desirable energy crop for bioethanol production (to mitigate CO_2 emissions as alternative/renewable energy source) for automobiles including some auxiliary engines of ships if not major ones.

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