International Journal of Advances in Scientific Research and Engineering (ijasre)

E-ISSN : 2454-8006

DOI: 10.31695/IJASRE.2022.8.11.6

Volume 8, Issue 11
November - 2022

Study of Energy Value Estimated from Mixture Design Matrix of Some Agricultural Waste Blends pulverized nut shells

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ABSTRACT

Energy sources that are sustainable and renewable include biomass resources. Efficient use of these biomass resources to provide a worldwide energy supply that is sustainable. The techniques that enhance this biomass's energy potential require a thorough grasp of its physicochemical characteristics. The energy content of biomass resources (HHV or NHV) is a crucial factor to consider when determining their suitability for energy production. In this work, proximate assessments of biomass materials (agricultural residues) and their blends were developed based on some published empirical model equations to investigate the impact on their net and high heating value. EFB, corncob, and groundnut shell blends' computed net heating value (NHV) and high heating value (HHV) were found to be between 16.157 and 18.483 MJ/kg. According to the findings, agricultural residues are excellent substrates for the generation of solid fuel. The energy values of biomass samples might also be calculated using the empirical formulae based on their nearby characteristics.

Keywords: Agricultural residue, Proximate analysis, High heating value (HHV), Net heating value (NHV).

1. INTRODUCTION

The main ingredient in the generation of benign energy, a readily available renewable energy source, is biomass. Because it is inexpensive, clean, and renewable, biomass combustion technology for energy generation is typically and economically effective and practical for home application, especially among rural residents in Nigeria [1]. However, burning biomass as fuel provides several benefits for the environment and the economy. [2]. Fuel qualities including calorific value, volatile matter, and ash fusion temperature are taken into account while designing the equipment and burners used in biomass handling for power plant boilers. Significant effects on the efficiency and safety of a power plant can result from notable changes in the qualities of biomass fed into boilers [3].

The chemical composition of biomass materials, which is often described in terms of proximate analysis and ultimate analysis, is a crucial characteristic. Only the mass percentages of the four components of the proximate analysis are shown: volatile matter (VM), fixed carbon (FC), moisture (M), and ash (ASH) [4]. In-depth information on the biomass substrate's C, H, O, N, and S elemental makeup is also provided by the final analysis [5].

On the other hand, proximate analysis is significantly simpler to do and simply needs standard equipment. As a result, it may be used to assess the quality of biomass. Databases for power plants usually contain proximate analysis information as well as information on total sulfide content and higher heating value (HHV) [6]. Unfortunately, there is a dearth of information on the final analysis because the experimental measurement requires complex equipment and highly qualified analyzers. However, the elemental makeup of biomass aids in determining the stoichiometric air requirement, composition, and flow rate of the flue gas, all of which are vital for preserving the right ratio of air and coal in the combustion chamber, preventing heat loss due to an excess air supply, and minimizing the power used to move air and flue gas throughout the furnace. Real-time elemental biomass composition monitoring is becoming more important in power plant operations [5].

The continual demands of modern life are the cause of the current growth in the global energy problem [3]. According to predictions, fossil fuels account for around 90% of worldwide energy use, which contributes to global warming and greenhouse gas emissions. However, these energy supplies are finite and will ultimately run out [7]. Countries have vigorously encouraged the use of alternate fuel sources, including agricultural waste for solid fuel, to combat this hard situation [8]. Given that they are renewable resources and can provide low-cost auxiliary fuel, employing this fuel for small-scale combustion or thermochemical conversion has several advantages [9].

The most crucial characteristic of a fuel is its calorific value, which establishes the amount of energy that can be utilized to build the system's control for converting biomass into fuel [10]. Similar to this, biomass's calorific value reveals how much combustion energy it has. So, this may be assessed by experimentation or approximated through its final or preliminary analysis [11]. Compared to proximate analysis, which is very simple to do using standard laboratory equipment, experimental determination of calorific value and ultimate analysis needed costly technology [12]. Over a period of time, researchers concentrated on empirical connections between the high heating value of biomass fuels and its proximal and ultimate data, with a focus on agricultural wastes in particular.

Nigerians, especially those who live in rural areas, are forced to cut down trees for home energy needs due to the high cost of fossil fuels in the country. Serious environmental difficulties were created by them. Based on known empirical correlation equations and their proximate and final analytical data, three agricultural biomass waste mixture blends were created for this study in order to examine the impact of mixing blends on high heating value. Additionally, the mixes' potential for conversion to solid fuels was examined in terms of their energy content.

2. MATERIALS AND METHODS

2.1. Biomass Sample Collection

The biomass samples utilized in this study were pulverized nut shells from Kebbi state, Nigeria, and empty fruit bunch fiber from palm oil that was derived from maize cobs in Benue state in Nigeria as well. To maintain consistent size, the materials were crushed and sieved through 60 meshes.

2.2 Proximate Analysis

According to the experimental design matrix presented in Table 2.1 using the ASTM D4442-16 technique, approximate analyses (which comprise moisture, ash, volatile matter, and fixed carbon content) were calculated for blends of the biomass. Following ASTM E1755-01 and ASTM E872-82, the amounts of volatile matter and ash were measured. Equation 1 was used to compute the difference and determine the fixed carbon content in the biomass samples. Equation 2 was used to calculate total organic matter (OM) by deducting the ash content (on a dry basis) from 100.

$$FC = 100 - (\%MC + \%Ash + \%VM) ---------- \quad 1$$

Where FC = Fixed carbon content, % MC = Percentage moisture content, %Ash = Percentage Ash Content, % VM = Percentage Volatile Matter.

$$OM = 100 - \%Ash ----------------2$$

DOI: 10.31695/IJASRE.2022.8.11.6

Table 2.1: Mixture Design Matrix of the Component

	FACTORS			RESPONSE								
Run Order	EFB (g)	CORN COB (g)	G. SHELL (g)	MC (%)	ASH (%)	VM (%)	FC (%)	C (%)	H (%)	O (%)	HHV (MJ/g)	NHV (MJ/g)
1	6	0	0									
2	4	1	1									
3	6	0	0									
4	2	2	2									
5	0	6	0									
6	0	6	0									
7	1	4	1									
8	0	6	0									
9	0	0	6									
10	1	4	1									
11	0	0	6									
12	4	1	1									
13	1	4	1									
14	6	0	0									
15	1	1	4									
16	2	2	2									
17	4	1	1									
18	2	2	2									
19	1	1	4									
20	1	1	4									
21	0	0	6									

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2.3 Determination of Ultimate Analysis

The ultimate analyses of the sample blends were estimated from the proximate analysis using Parikh's[11] equations 1, 2, and 3.

C = 0.637FC + 0.455VM……………………………………………………………(1)

H = 0.052FC + 0.062VM……………………………………………………………(2)

O = 0.304FC + 0.476VM…………………………………………………………….(3)

2.4 Determination of Net Heating Value and High Heating Value

Using equations 4 and 5 developed by Erol *et al.*[12] and Yin [13], the net heating value (NHV) and high heating value (HHV) were determined from the proximate analysis performed on the biomass sample mixes (2011).

NHV = -116 – 1.33[Ash] – 0.005[VM] + 1.92[VM + Ash] – 0.0227[VM x Ash] – 0.0122$[VM]^2$ + 0.0299$[Ash]^2$ + 6133$[OM]^{-1}$ – 0.82$[Ash]^{-1}$---(4)

$$HHV = 0.1905VM + 0.2521FC \quad (5)$$

3. RESULTS AND DISCUSSION

3.1 Proximate Analysis

These agricultural blends' proximate analysis results, which are shown in Table 3.1, reveal that their moisture content (MC) ranges from 1.260 to 7.67%, and that a high MC suggests a considerable poor combustibility substrate [14]. The findings show that the mixes had ash concentrations between 3.330 to 12.35 percent, which is in line with Pogaku *et al*. [10] The EFB has the largest proportion of ash content, whilst the groundnut shell has the least ash level of the substrates. High levels of alkali metals, which are known to have negative impacts by clogging reactors and causing secondary catalytic cracking, are indicated by the substrate's high ash concentration [1].

The volatile matter results shown in Table 3.1 are in the range of 79.89 to 85.03%, with the mixture of EFB, groundnut shell, and corncob in the ratio of (4:1:1) having the highest volatile matter content and the blend of EFB, groundnut shell, and corncob in the ratio of (0:6:0) having the lowest volatile matter content. As a result, this showed that the blends' volatile matter percentages varied significantly, which was obvious given that nearly all of the substrates had the same amount. Given that a larger portion of the volatile matter components are non-combustible fractions, understanding the relationship between the volatile matter of biomass and its heating value is quite difficult [2].

The percentage of fixed carbon (FC) result shown in Table 3.1 ranged from 2.050 to 9.45%, with the lowest value coming from the mixture of EFB, ground nut shells, and corncobs (1:1:4) and the greatest value coming from the EFB, ground nut shell, and corncob ratio (1:1:4). (0:0:6). When a biomass is burned and the volatile substances are released, a solid combustible residue known as fixed carbon (FC) is left behind, indicating a prolonged combustion duration of the biomass sample and an increase in the sample's heat-harming potential (HHV) [15]. Given that it has a favorable impact on the energy potential of biomass, the fixed carbon content of biomass may be simply linked with the calorific value [16].

The percentage of organic matter (OM) result shown in Table 3.2 also ranged from 87.650 to 96.670%, with the maximum value coming from the mix of EFB, ground nut shell, and corncob (6:0:0), while the lowest value came from the ratio of EFB, ground nut shell, and corncob (0:0:6). This makes it very evident that whereas 100% groundnut shell has the greatest OM level, 100% EFB has a low OM concentration. Because the blends have low incombustible proximal characteristics, they might serve as ideal substrates for direct solid fuels for sustainable energy (moisture and ash content). The nature of the biomass, variances in the soil, and environmental factors that have an impact on the ash content and characteristics of the biomass may be to blame for the disparities in content between the feedstock [17].

DOI: 10.31695/IJASRE.2022.8.11.6

Table 3.1: **Proximate Analysis of Mixture Design Matrix**

Run Order	EFB (g)	CORN COB (g)	G. SHELL (g)	Moisture Content (%)	Ash (%)	Volatile Matter (%)	Fixed Carbon (%)	Organic Matter (%)
1	6	0	0	1.26	12.35	81.63	4.76	87.65
2	4	1	1	3.5	8.75	82.24	5.51	91.25
3	6	0	0	1.19	12.15	81.23	5.43	87.85
4	2	2	2	5.6	6.63	82.03	5.74	93.37
5	0	6	0	8	6.24	79.89	5.87	93.76
6	0	6	0	6.93	6.75	81.09	5.23	93.25
7	1	4	1	6.36	7.51	80.02	6.11	92.49
8	0	6	0	7.67	8.98	80.32	3.03	91.02
9	0	0	6	4.67	4.9	82.34	8.09	95.1
10	1	4	1	6.27	5.173	80.53	8.027	94.827
11	0	0	6	5.03	3.71	81.81	9.45	96.29
12	4	1	1	3.63	9.07	82.05	5.25	90.93
13	1	4	1	6.43	5.12	80.01	8.44	94.88
14	6	0	0	2.57	11.82	80.23	5.38	88.18
15	1	1	4	5.93	9.92	82.1	2.05	90.08
16	2	2	2	5.13	6.54	82.86	5.47	93.46
17	4	1	1	3.8	8.9	85.03	2.27	91.1
18	2	2	2	5.2	7.25	82.88	4.67	92.75
19	1	1	4	4.4	9.27	83.62	2.71	90.73
20	1	1	4	3.67	9.74	84.16	2.43	90.26
21	0	0	6	2.79	3.33	84.17	9.71	96.67

3.2 Ultimate Analysis, Net Heating Value (NHV) and Heating Value (HHV) Analysis

The final examination of the blends shown in Table 3.2 revealed increased carbon content (44.483-38.476%), according to the results. Thus, the ratio of (0:0:6) yielded the highest carbon content, whereas (0:6:0) yielded the lowest. The proportion of hydrogen varied from 5.138 to 5.724%, which is consistent with the results. Additionally, it was determined that the mixes' oxygen concentration ranged from 39.154 to 43.017%. As a result, this was lower than the Perales *et al.*[18] report but still within the range described by Sulaiman and Abdullah [19]. Therefore, the final analysis, which is a typical method of assessing the quality of biomass substrate, finds that these blends of agricultural residue include a sizable amount of Carbon and Hydrogen [20].

The values for the high heating value (HHV) and net heating value (NHV) shown in Table 3.2 were computed from proximal utilizing Erol *et al.*'s [12] empirical correlations equation, which was represented in MJ/kg. The HHV and NHV estimates differed amongst mixes because the biomasses had variable burning characteristics. The computed result for HHV varied from 16.065 to 18.483MJ/kg, with the ratio of EFB, groundnut shell, and corncob ratio (0:0:6) bent recording the greatest value. Analogous to this, Table 3.2 results for the net heating value (NHV) of blends range from 17.268 to 18.217%, with the mix of EFB, groundnut shells, and corncob ratio recording the highest NHV value at 18.217 (6:0:0) the little variation in heating values may be explained by the different ash content %, and the results were in excellent accord with those of other biomasses described in the literature [21]. A feedstock's HHV or NHV is its energy density, which is also known as its calorific value. It is described as the amount of heat generated by burning a particular amount of biomass [22].

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Table 3.2: **NHV and HHV estimated from Proximate Analysis**

Run Order	EFB (g)	CORN COB (g)	G. SHELL (g)	Carbon (%)	Hydrogen (%)	Oxygen (%)	NHV (MJ/g)	HHV (MJ/g)
1	6	0	0	40.174	5.309	40.303	17.895	16.751
2	4	1	1	40.93	5.386	40.822	17.210	17.056
3	6	0	0	40.419	5.319	40.317	17.980	16.844
4	2	2	2	40.981	5.385	40.792	17.437	17.074
5	0	6	0	40.09	5.259	39.813	17.934	16.699
6	0	6	0	40.228	5.300	40.189	17.633	16.767
7	1	4	1	40.302	5.279	39.947	17.796	16.785
8	0	6	0	38.476	5.138	39.154	17.733	16.065
9	0	0	6	42.619	5.526	41.654	17.740	17.726
10	1	4	1	41.755	5.411	40.773	18.010	17.365
11	0	0	6	43.244	5.564	41.815	18.196	17.968
12	4	1	1	40.677	5.361	40.652	17.268	16.955
13	1	4	1	41.781	5.400	40.651	18.105	17.37
14	6	0	0	39.932	5.255	39.825	18.217	16.641
15	1	1	4	38.662	5.197	39.703	17.298	16.157
16	2	2	2	41.186	5.422	41.105	17.247	17.164
17	4	1	1	40.135	5.390	41.165	16.296	16.771
18	2	2	2	40.686	5.382	40.871	17.133	16.966
19	1	1	4	39.774	5.326	40.627	16.777	16.613
20	1	1	4	39.841	5.345	40.799	16.595	16.646
21	0	0	6	44.483	5.724	43.017	17.884	18.483

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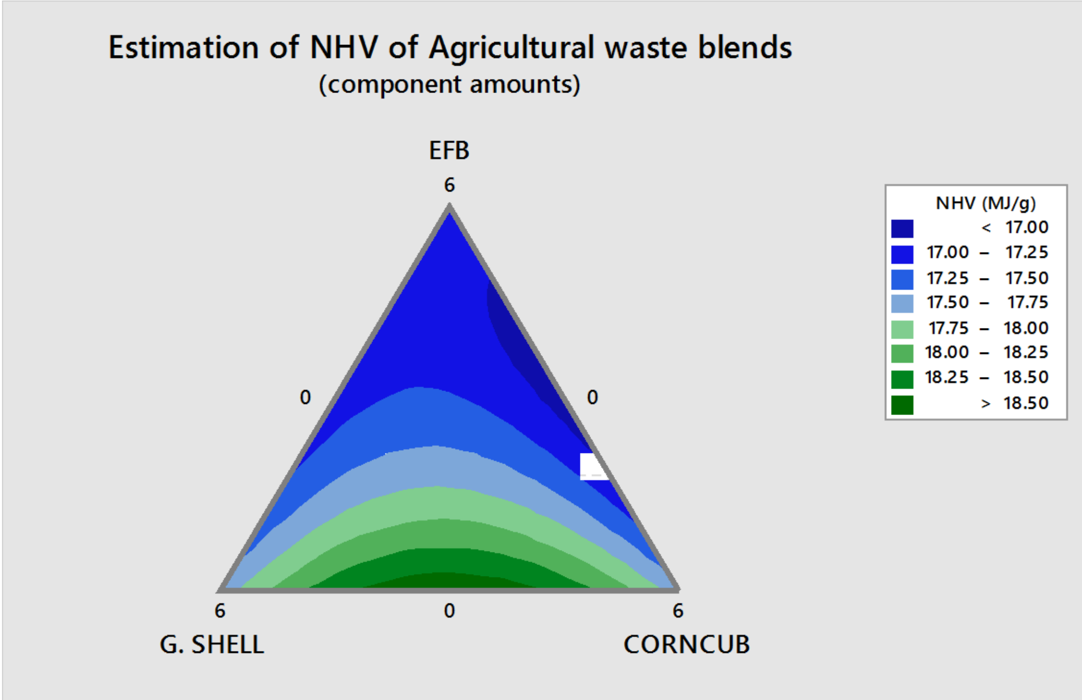

Figure 3.1: Contour Plot of NHV from Proximate analysis

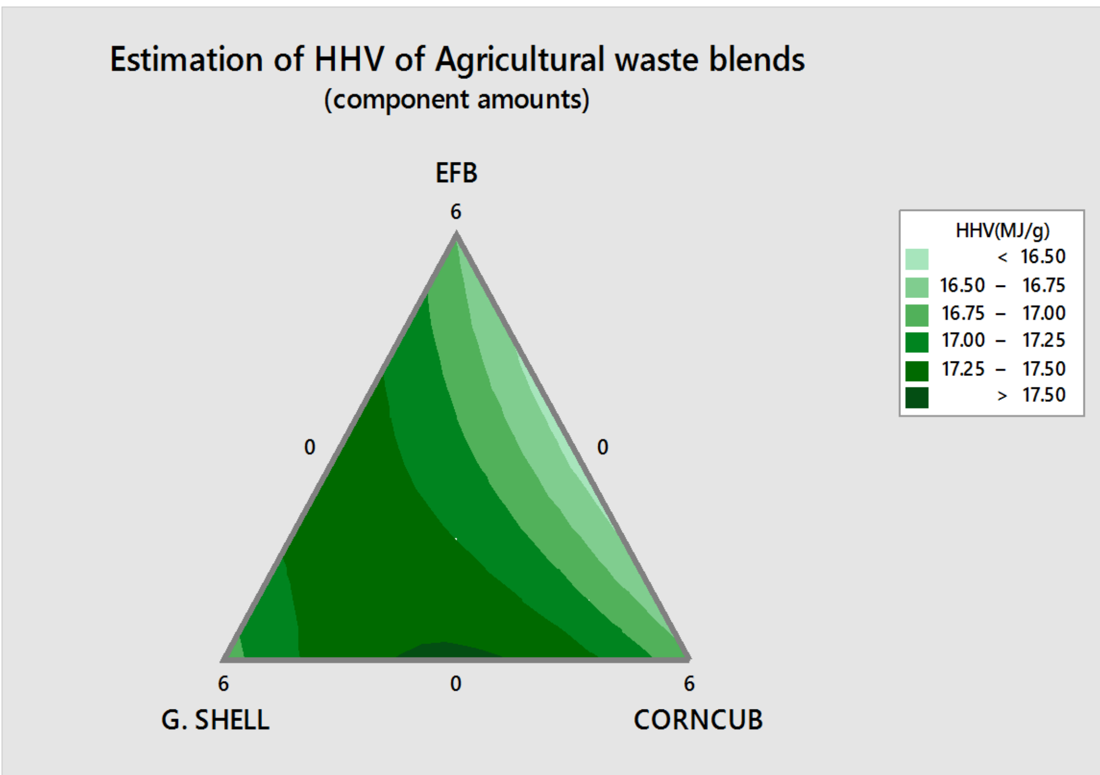

Figure 3.2: Contour Plot for HHV of blends from proximate analysis

The contour plot of the regression analysis performed using the blends for both NHV and HHV is shown in Figures 1 and 2, respectively. The contour plot is used to determine the area with the best heating value. When these three samples were combined, a noticeable synergy in the energy content of the substrate was seen. This may be seen to be more pronounced between mixes of

DOI: 10.31695/IJASRE.2022.8.11.6

groundnut shell and corncob near the plot's base. Nevertheless, was significantly decreased when groundnut and EFB fiber were combined. When EFB fiber, corncob, or groundnut were combined, the mixes' energy content fell between 16 and 17 MJ/K. Despite the low energy level of the EFB fiber mixes, a high energy content (18–19MJ/K) was attained when a 100% EFB fibre sample was employed. This demonstrates the existence of the synergy between the samples, which results in high groundnut and corncob yields but poor yields when combined with EFB.

The regression analysis of the mixture design matrix presented in Tables 3.3 and 3.4 portrayed that the design is good because it has regression coefficient values is about 83.42% and 74.50% for adjusted and predicted respectively. Also, it was observed the P-value of the model is 0.00 which indicated that their factors are significantly different from each other.

Table 3.3: Model Summary

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	7	5.246	0.74938	9.35	0.000
Sample Ratio	7	5.246	0.74938	9.35	0.000
Error	13	1.042	0.08019		
Total	20	6.288			

Table 3.4: Regression Analysis Summary

Parameter	Value
S	0.283171
R-squire	83.42%
R-squire (adjusted)	74.50%
R-squire (predicted)	*

4. CONCLUSION

Results obtained from this study revealed that the EFB fibre, corncob and groundnut shell blends have a good energy content that can be used directly as solid fuels. It was also established that these three biomass samples when mixed in different proportions have a significant influence on their energy contents.

ACKNOWLEDGEMENTS

The authors are grateful to the Tertiary Education Trust Fund (TETFUND) for funding this research through IBR 2022 intervention.

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