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Development of Biomass Briquettes from Ashok (*saraco asoca*) Leaves and Coconut (*coco nucifera*) Shells for Domestic Use

Ephraim Yakubu Dabwor[1]*; Gyang Yakubu Pam[1]; Ahmed Abdul Ibrahim[2]

[1,2]Mechanical Engineering Department, Faculty of Engineering, Ahmadu Bello University. Zaria Nigeria.

Corresponding Author: Ephraim Yakubu Dabwor*

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Abstract: This research investigated the development and optimisation of domestic biomass briquettes formulated from ashok leaves and coconut shells. Using a Taguchi design of experiments, the production parameters evaluated included particle sizes ($50\mu m$, $60\mu m$, and $70\mu m$); mixing ratios ($70/30$, $80/20$, $90/10$ wt. %), and compaction pressures (4, 5, and $6MPa$) applied via a hydraulic press. Cassava starch served as the binder at a fixed concentration of 20 wt. %. Physicochemical and mechanical characteristics were determined through proximate analysis and mechanical testing, while parametric optimisation was executed using Minitab 19 through signal–to-noise (S/N) ratio and Grey Relational Analysis (GRA). Proximate results across the formulations (B1 to B9). Energetic and mechanical assessments yielded calorific values between 16.71 and 18.85 MJ/kg, compressive strengths of 0.31 – 3.51 MPa. The optimal production configuration identified through GRA was 50 µm particle size, a 90/10 mixing ratio, and a 6 MPa compaction pressure. ANOVA for the grey relational grade indicated that the mixing ratio exerted the most pronounced effect (p = 0.063). The optimised parameters yielded a predicted grey relational grade of 0.7880 (a 39.20 % improvement over the initial design), which was validated experimentally at 0.8347 (an 47.45% improvement). Thermal performance tests in a charcoal stove revealed superior burning rates (1.39 – 2.09 g/min) and faster water boiling time (8 – 12 min) compared to conventional charcoal (1.09 g/min and 14 min).

Keywords: *Development, Optimisation, Briquettes, Compressive Strength, Calorific Value.*

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I. INTRODUCTION

The depletion of traditional energy, coupled with the effects of desertification, has created a global desire for research into alternative renewable energy sources [1], which are essential for meeting energy needs. Prominent among the renewable sources are wind, solar, and biomass in the form of forest and agricultural residues [2]. In terms of combustible energy sources, biomass has wide acceptance as an alternative source due to its availability, ease of handling, affordability, and compatibility [3]. For domestic and industrial applications, briquettes produced from biomass have proven to be a suitable replacement for fuelwood [4]. Biomass may be used directly as solid fuel for cooking or converted via a variety of technologies such as pyrolysis, gasification, combustion, and biofuel utilisation [3]. The use of briquettes as a solid fuel has necessitated the utilisation of agricultural residues and the organic fractions of municipal solid waste [5]. Where potential reduction in environmental pollutions, with modern heating and cooking fuels for domestic, institutional, and industrial use, are not readily available [6].

Key drivers of success in briquette development and marketing include ensuring a consistent supply of raw materials with good energy qualities, appropriate technologies, and consistency in the quality and supply of the briquettes [6]. Hence, biomass such as ashok leaves waste and coconut shells may turn out to be briquette feedstock for alternative energy to the existing conventional fuel. Due to a lack of penetration of technology and awareness of its environmental concerns, it is allowed to be burned or dumped as solid waste [7].

➢ *Energy Resources Can be Classified into Two Forms:*

Non-renewable and renewable energy sources. Non-renewable resources such as coal, nuclear, petroleum, and natural gas are in limited supply when used and are not replenished. Renewable energy sources such as solar, wind,

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hydro, geothermal, and biomass, on the other hand, can be replenished naturally and quickly [8].

Nigeria is endowed with a significant proportion of its energy consumption by non-renewable sources such as crude oil, natural gas, lignite, and coal. Unfortunately, these sources are virtually unavailable in most rural parts of the country [9]. Dependence on non-renewable sources of energy will not be able to lift the rural people out of traditional subsistence living, especially with the free market forces under which nobody seems to be able to control prices [9]. The share of renewables has increased significantly in the electricity, heating, cooling, and transport sectors (RENS21). China and India led in global investment in renewable power and fuels [10]. Nigeria possesses vast untapped potential in renewable energy, which remains largely unexplored [11]. Historically, reliant on fossil fuels like crude oil for energy, the country has become a significant contributor to global greenhouse gas emissions, accounting for approximately 1.01% of the total [11]. However, there is a growing recognition of the need to shift towards sustainable energy sources due to concerns about environmental impact and the diminishing significance of crude oil in the future energy landscape [12]. Findings from [24]show that coconut shell biomass has a high density of $412kg/m^3$, a calorific value of $19.4MJ/kg$, carbon of 40.1%, moisture of 5.6%, and ash of 1.8%. [25] in their work on pellets achieved Calorific values of palm fruit = 3414.46kcal/kg, jack fruit= 3304.02kcal/kg and ashoka leafs= 3833.8kcal/kg. [13] used taguchi to optimised calorific values of briquettes from rice husk and sawdust and achieved optimal value of 22826J/g. from the study it is essential to fill the gap in utilising optimization approach to recover ashok leaves and coconut shells waste as composite briquettes to reduce litters on the environment which increased health risk.

II. METHODS

➢ *Materials and Briquetting Procedure*

The feedstock, ashok leaves and coconut shells were obtained from Kogi State, cleaned and dried for $7days$. $1.5kg$ of coconut shells was carbonised, using a tube furnace at a temperature of 800°C for $2hrs$ under inert conditions. Both feedstocks were pulverised into three particle sizes with a maximum of $50\mu m$, $60\mu m$, and $70\mu m$ using a milling machine and mortar. The methods of briquette development involve transforming agricultural waste (ashok leaves and coconut shells) into high-density and higher energy material that are easier to handle, store, and burn than raw biomass. The methods are in Fig 1

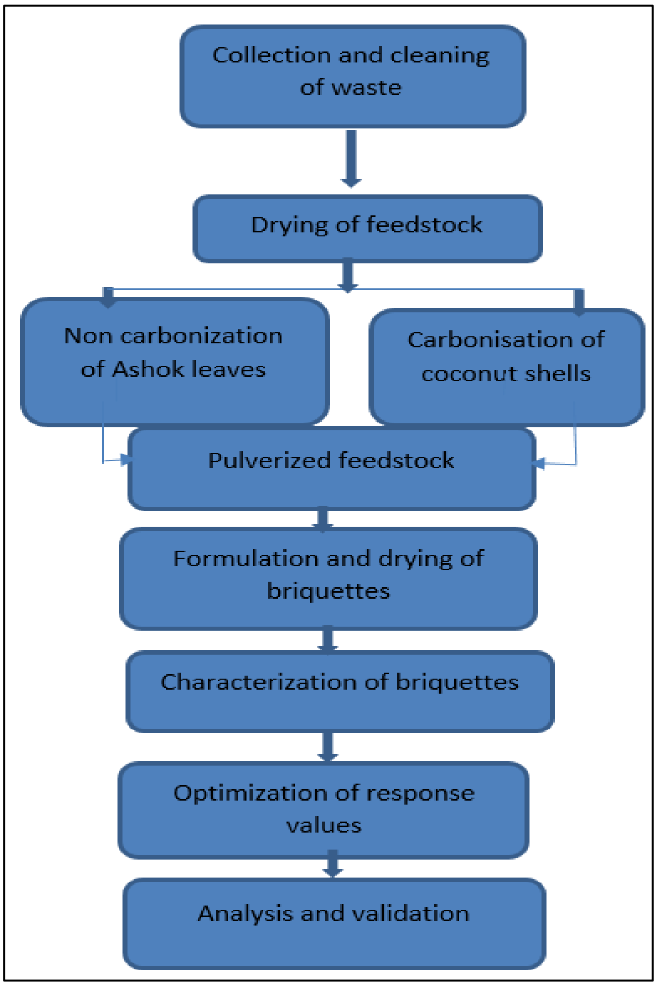

Fig 1 Flowchart of the Production of Briquettes.

➢ *Briquettes Development Procedures*

In this work, the factor parameters for the production of blended ashok leaves and coconut shells with cassava starch as binders were combined for individual performance characteristics using the Taguchi technique [13]. Factors are the particle sizes considered, which were $50\mu m$, $60\mu m$, and $70\mu m$, while the mixing ratios employed were $70/30$, $80/20$, and $90/10$ wt. % ashok leaves to coconut shells carbon, and the compaction pressures were $4MPa$, $5MPa$, and $6MPa$, respectively, considering low, medium, and high levels. The pulverised feedstock, used for the production of the briquettes consisting of 1083gramme of Ashok leaves and 243.71gramme of coconut shell carbon. The different particle sizes of the Ashok leave and coconut shells carbon were mixed in ratios of 70:30, 80:20, and 90:10 using a measuring cylinder and a digital weighing balance. Low, medium, and high proportions were considered, with cassava starch serving as the binder. The binder was prepared in paste form with water at 20% wt. The mixtures were then densified using a TQ DL1 hydraulic press equipped with a mould of 40 mm diameter by 100 mm height, at compaction pressures of 4 MPa, 5 MPa, and 6 MPa. This process was carried out to enhance the compressibility and durability of the briquettes [14]. The produced briquettes were subsequently dried at room temperature for seven (7) days before characterisation. Sample images of the produced briquettes is presented in Plate 1.

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Plate 1 Sample Image of the Briquettes

➢ *Characterisation of Briquettes*

The properties of the briquettes analysed are: compressive strength and calorific values.

- *Determination of Calorific Value (ASTM D5865)*

The higher calorific value of the sample was determined using a bomb calorimeter (Parr 6100) at the Department of Chemical Engineering, Ahmadu Bello University, Zaria. One (1) gramme of each briquette sample was weighed using an electronic balance, prepared, and carefully placed in the metal cup of the bomb calorimeter, which was then suspended in the cradle. The bomb vessel was subsequently mounted on the calorimeter, after which the sample was charged with oxygen and combusted within the oxygen bomb. The resulting energy value was displayed on the monitor [15].

- *Determination of Compressive Strength (ASTM D2166-85)*

Compressive strength tests were carried out at the Department of Metallurgy and Materials Engineering, Ahmadu Bello University (ABU), Zaria. A Universal Testing Machine (TQDL1, Model PL142-350) was used to apply a perpendicular load to the sample until failure occurred. The magnitude of the applied force was displayed on the machine's digital monitor [16].

- *Determination of Burning Rate (ASTM D635)*

Burning rate is the ratio of the mass of the fuel (in grammes) to the total time taken to burn it (in minutes) [17]. The burning rate was determined on a charcoal stove. 50g of each briquette was used.

$$Burning\ rate = \frac{mass\ of\ fuel\ consume(g)}{total\ time\ taken(min)} \tag{1}$$

The sample image of the burning rate is in plate 2

Plate 2 Sample Images of the Burning Rate of Briquettes

- *Water Boiling Test (ASTM D3173)*

A water boiling test was carried out to compare the cooking efficiency of the optimised briquette sample with that of *Anogeissus leiocarpus* charcoal. The test measures the time required for each briquette and charcoal sample to boil an equal volume of water under similar conditions. Fifty grammes (50 g) of each briquette and charcoal sample were used to boil 50 mL of water in a small stainless-steel pot placed on a domestic charcoal stove [17].

➢ *Data Analysis*

- *The Response Values were analysed Using Minitab 19 Software*

Minitab 19 is a statistical software used for the analysis of experiments. The software received as input the experimental data and provided as output the quality characteristics and the deviation values. The software uses a statistical measure of performance known as signal- to- noise (S/N) ratio. The quality characteristics with "larger- the-better" were used for all performance characteristics (compressive strength, calorific value, and impact strength). The S/N ratio, a logarithmic function, was computed by assessing the proportion of signal (mean) to noise (standard deviation). In order to diminish noise and the effects of uncontrollable factors, higher values of S/N ratios are preferred. A high S/N ratio indicates improved quality of the product [18].

The larger the better signal-to-noise ratio was determined using

$$\left(\frac{S}{N}\right) = -10 * log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_I{}^2}\right) \tag{2}$$

Where n is the number of experiments, y_i represents the response value of the ith experiment in the orthogonal array.

- *Multi-Response Optimisation Using Grey-Relational Analysis (GRA)*

Taguchi experimental methods are adequate for determining the optimal settings of process parameters for a single response characteristic. However, in cases involving two or more responses with different quality characteristics, multi-response optimisation using Grey Relational Analysis (GRA) is preferred. In this approach, multiple objective optimisation problems are transformed into a single-objective optimisation problem using Grey Relational Analysis, applying the "higher-the-better" loss function approach. The mean values are first normalised and then converted into Grey Relational Coefficients according to the steps involved in Grey Relational Analysis [18].

- *Grey-Relational Generation*

In GRA, data pre- processing was performed to normalise the original reference sequences to a comparable sequence within the range of zero to one (0-1).

The higher- the- better characteristics, the sequence was normalised using [18].

$$X_i(\mathrm{K}) = \frac{Yi(K) - \min yi\ (K)}{\max yi\ (K) - \min yi\ (K)} \tag{3}$$

Where:

$X_i\ (k)$ *is the value after the grey relationageneration*

$min\ y_{i\ (K)}$ *is the smallest value of* $y_{i\ (k)}$ *for the kth response*

$Max\ y_{i\ (k)}$ *is the largest value of* $y_{i\ (k)}$ *for the kth response*

- *Deviation Sequence*

Once the sequence was normalised, the next step was the calculation of the deviation sequence of the reference sequence [18].

Deviation sequence:

$$\Delta_{0i\ (K)} = X_0\ (K) - X_{i\ (K)}\ | \tag{4}$$

Where $\Delta_{0i\ (K)}$, $X_{0\ (K)}$, and $X_{I\ (K)}$ refer to the deviation reference and comparability sequences, respectively.

- *Grey Relational Coefficient*

The grey relational coefficient was determined using [18].

$$\mathcal{E}_i(k) = \frac{\Delta min + \zeta \Delta max}{\Delta 0i + \zeta \Delta max} \tag{5}$$

Where $\mathcal{E}_i\ (k)$ signifies the grey relational coefficient of individual response variables as a function of **Δ**min and **Δ**max, the minimum and maximum deviations of the responses. The identification coefficient **ζ** is generally set at 0.5 to allocate equal weights to every parameter.

- *Grey Relational Grade*

The grey relational grade (GRG) was computed by averaging the grey relational coefficient of each response variable using (Sylajakurami *etal*,2018).

$$\gamma_{i=} \frac{1}{n} \sum_{i=1}^{n} \mathcal{E}i\ (k) \tag{6}$$

Where γ_i represents the value of grey relational grade (GRG) for the ith experiment, n being the aggregate of performance characteristics.

- *Prediction and Verification*

The optimal level of factors was determined using grey relational grade (GRG). The final step is prediction and verifying the quality characteristics using [18]

$$\gamma_{prediction} = \gamma_{m+} \sum_{i=1}^{q} \gamma o - \gamma_m \tag{7}$$

Where γ_o denotes the maximum of the average grey relational grade (GRG) at the optimal level of factors, and γ_m represents the mean grey relational grade. While q signifies the number of factors affecting the response values.

- *Analysis of Variance (ANOVA)*

The analysis of variance was used to investigate whether the design parameters have a significant effect on the response values using Minitab 19.

III. RESULTS AND DISCUSSIONS

> *Multi-Response Values (Compressive Strength and Calorific Value*

Table 1 Multi-Response Parameter of Briquettes

Variable	CS (MPa)	CV (MJ/kg)
1	0.4	16.71
2	1.46	17.05
3	3.51	18.30
4	1.13	16.90
5	1.09	17.25
6	0.71	18.35
7	0.51	17.10
8	0.31	17.56
9	0.32	18.85

From Table 1, the compressive strength ranges between 0.31 MPa and 3.51 MPa, with briquette B8 having the lowest value and briquette B3 having the highest compressive strength. The calorific value ranges between 16.71 MJ/kg and 18.85 MJ/kg, with briquette B1 having the lowest calorific value and briquette B9 having the highest value. All values are within the standard range [19].

> *Effect of Control Factors on Compressive Strength*

The experimental data for the compressive strength response values in Table 1 were converted into signal-to-noise (S/N) ratios using Minitab 19 statistical software. The dominant control factors were identified from the response table of the S/N ratio. This was computed based on the difference between the lowest and highest average values of each factor. The factor with the highest delta value was

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ranked first, indicating the most influential factor, as shown in Table 2. The results reveal that particle size, with a delta value of 10.7176, is the most significant contributing factor. This is followed by compaction pressure with a delta value of 8.9708 and mixing ratio with a delta value of 3.5934.

Table 2 Response Table for Signal to Noise Ratios of Compressive Strength. The Larger is Better

Level	Particle size(μm)	Mixing ratio (%)	Compaction pressure (MPa)
1	2.0781	-4.2486	-7.0355
2	-0.3882	-2.0457	-1.8495
3	-8.6395	-0.6552	1.9354
Delta	10.7176	3.5934	8.9708
Rank	1	3	2

From the responses in Table 2, the main effects plot for S/N ratios was generated as shown in Fig. 2. The plot indicates that compressive strength is greatly influenced by changes in particle size. The steep decrease in S/N ratio for compressive strength from 50 µm to 70 µm in Fig. 2 shows that the quality of the response decreases as particle size increases.

The relationship between mixing ratio and S/N ratio shows an increasing trend as the mixing ratio changes from 70/30 to 90/10. Similarly, the plot for compaction pressure shows an increase in S/N ratio from 4 MPa to 6 MPa. From the main effects plot for S/N ratios in Table 2 and Fig. 2, it is suggested that to obtain a high S/N ratio for compressive strength, the optimal factor levels are PS1, MR3, and CP3.

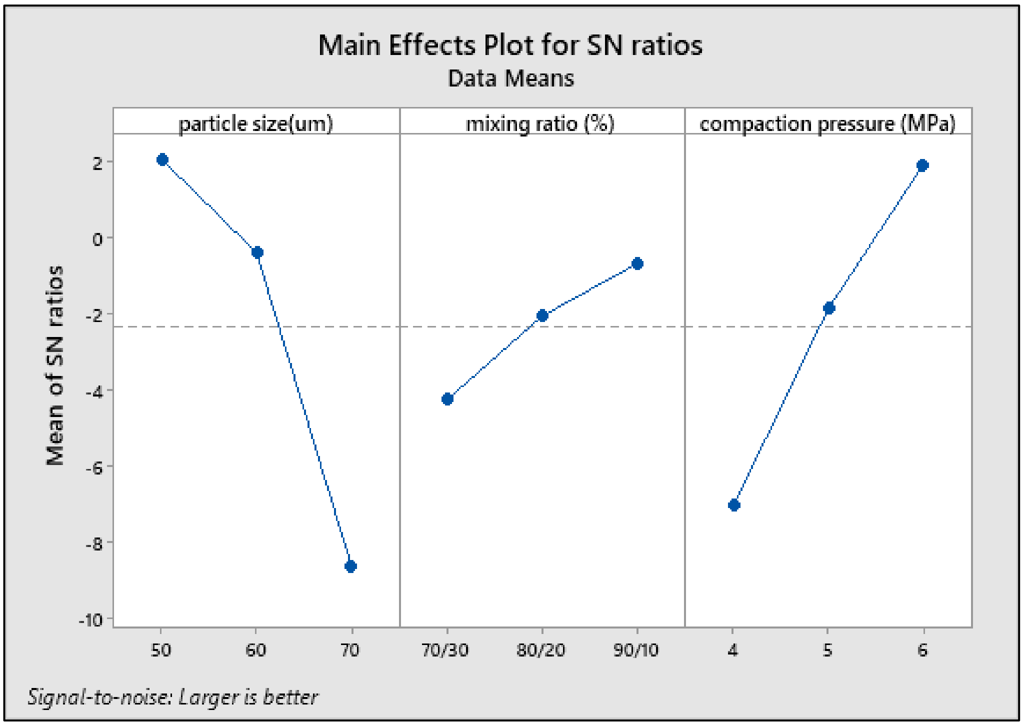

Fig 2 Main Effects Plot for Signal- to- Noise Ratio of Compressive Strength (CS).

To determine the factor levels, analysis of variance(ANOVA) was performed to obtain the percentage contribution of each factor effect on the compressive strength (CS) shown in Table 3. It was observed that particle size has the highest percentage contribution of 48.35%, followed by compaction pressure of 31.13% and mixing ratio of 5.04%. A 95% confidence level, with p-values higher than 0.05, they are considered insignificant.

Table 3 ANOVA of Compressive Strength

Factors	DF	Seq SS	Adj MS	%Con	F	P
Particle size	2	189.03	94.516	48.36	3.12	0.243
Mixing ratio	2	19.70	9.849	31.13	0.33	0.755
Compaction pressure	2	121.70	60.848	5.04	2.01	0.332
Residual Er	2	60.55	30.274	15.47		
Total	8	390.97		100		

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- *Effect of Control Factors on Calorific Value(CV)*

In order to determine the effect of control factors on calorific value, the S/N ratio of the experimental data of calorific value was tabulated as shown in Table 4. The result shows that the mixing ratio with a delta value of 0.78 has the highest effect on the calorific value, followed by particle size and compaction pressure, with delta values of 0.24 and 0.02, respectively.

Table 4 Response Table for Signal to Noise Ratios of calorific values

Level	Particle size(um)	Mixing ratio (%)	Compaction pressure (MPa)
1	24.78	24.56	24.88
2	24.86	24.75	24.90
3	25.02	25.34	24.88
Delta	0.24	0.78	0.02
Rank	2	1	3

The plot of the main effect for calorific value, as exhibited in Figure 3, shows that the calorific value is greatly influenced by variation in mixing ratio. The steep increase in the S/N ratio for calorific value from 70/30 to 90/10 indicates that the quality of the response value increases with an increase in mixing ratio. Likewise, the calorific value increases with an increase in particle size and varies marginally with compaction pressure.

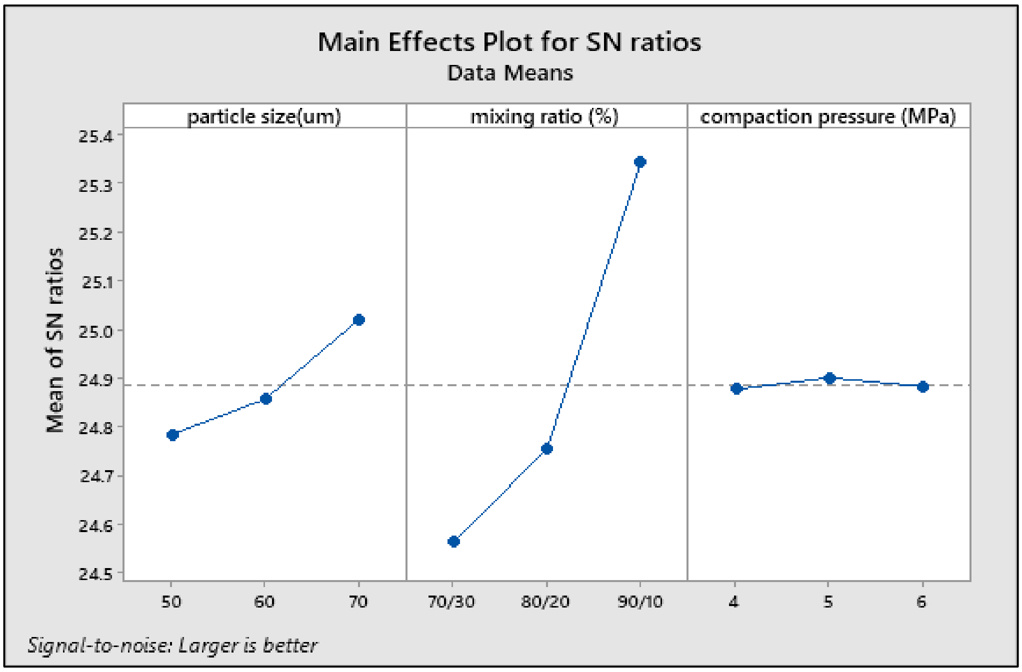

Fig 3 Main Effects Plot for S/N of Calorific Value

Furthermore, to determine the significant factors and percentage contribution of each factor on the calorific value, an ANOVA was performed, as presented in Table 3.5. A 95% confidence level, the mixing ratio has the highest percentage contribution of 91.48%, followed by particle size at 8.06% and 0.083 for compaction pressure. The p-value of the mixing ratio and particle size is less than 0.05, indicating significant factors. The high values of R values signify goodness of fit and affirm the validity of the model.

Table 5 Analysis of Variance for S/N ratios of calorific values

Source	DF	Seq SS	% contr	Adj MS	F	P
particle size(μm)	2	0.08776	8.06	0.043881	21.63	0.044
mixing ratio (%)	2	0.99548	91.48	0.497741	245.40	0.004
compaction pressure (MPa)	2	0.00090	0.083	0.000452	0.22	0.818
Residual Error	2	0.00406	0.377	0.002028		
Total	8	1.08820	100			

$$S = 0.0450\ R - Sq = 99.63\%$$

$$R - Sq(adj) = 98.51\%$$

The signal- to- noise ratio approach above generates three sets of optimal parameters for the three responses. It is essential in real world application to determine a single optimal parameter combination for multiple responses [20].

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➢ *Multi-Response Optimisation Using Grey Relational Analysis*

Grey relational analysis (GRA) was employed to solve problems having a limited set of data. It approximates the behaviour of a system with no black or white solutions and is widely used to optimise multiple- factor problems. Data pre-processing was performed on the experimental data of the responses by grey relational generation in Table 3.6, namely Compressive strength(CS), and Calorific value(CV). The reference of the responses is between 0 and 1.

- *Grey Relational Coefficient, Grade and Rank*

Table 6 Grey Relational Coefficient, Grade and Rank

Run	CS	CV	GRG	Rank
1	0.3679	0.3333	0.3506	9
2	0.5904	0.3741	0.4823	4
3	1.0000	0.6694	0.834	1
4	0.5273	0.3545	0.4409	6
5	0.5195	0.4035	0.4615	5
6	0.4417	0.6905	0.5661	3
7	0.3959	0.3810	0.3885	8
8	0.3333	0.4583	0.3958	7
9	0.3455	1.0000	0.6728	2

From Table 6, the grey relational coefficient was obtained by quantifying the reference sequence and the comparison sequence. The briquettes with higher coefficient values mean that their sequence are more correlated. For CS, the briquette B3 shows a higher value of 1.0000, signifying the most correlated, and B8 shows the lowest value of 0.3333, which indicated least correlation. while for calorific value B9 with a higher coefficient of 1.0000 and B1with lowest value of 0.3333. The grey relational grade value is the mean average of the response values of the individual briquette. The briquette with the highest grade was considered first in the ranking, implying that the briquette B3 parameter is the optimal combination for the development of the briquette.

Table 7 Response Table for Means of GRG

Level	**Particle size**	**Mixing ratio**	**Compaction pressure**
1	0.5559	0.3933	0.4375
2	0.4895	0.4465	0.5320
3	0.4857	0.6912	0.5616
Delta	0.0701	0.2979	0.1241
Rank	3	1	2

The mean GRG = 0.5104

From Table 7, the response value of GRG signifies that the mixing ratio is the most contributory factor with a delta value of 0.2979, followed by compaction pressure with a delta value of 0.1241, and particle size is the least dominant factor with a delta value of 0.0701.

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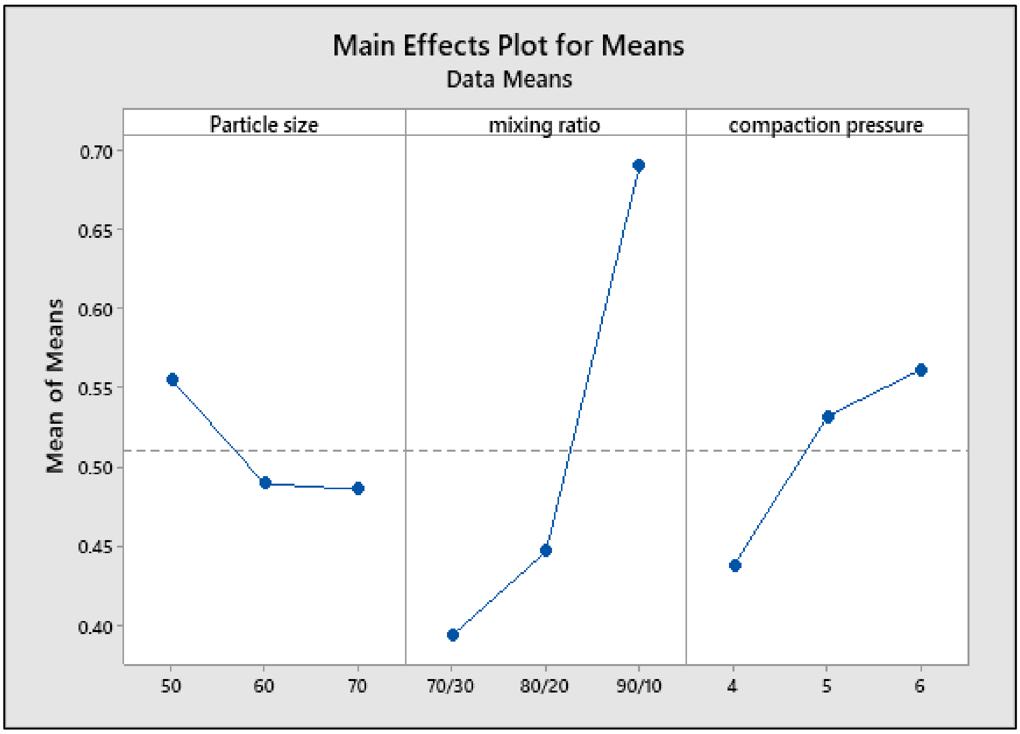

Fig 4 Main Effects Plot for GRG Data Means

From Figure 4 the response values serve as a correlation between the comparable sequence and reference sequence of the grey relational analysis, the optimal parameters that maximise the overall response grey relational grade exist at PS1, MR3, and CP3. Hence, the optimal settings for the development of the briquettes are the particle size at $50\mu m$, mixing ratio at $90/10$, and compaction pressure at $6MPa$.

Table 8 Analysis of Variance for Means of GRG

Source	DF	SS	contr	MS	F	P
Particle size	2	0.009	4.76	0.0046	0.91	0.52
mixing ratio	2	0.151	77.18	0.0757	14.8	0.06
compaction pressure	2	0.025	12.84	0.0125	2.46	0.28
Residual Error	2	0.010	5.215	0.0051		
Total	8	0.196	100			

S= 0.0715, R-Sq=94.78 RSq(adj) = 79.14%

To determine the percentage contribution and significance of each factor on the multi-response characteristics of the briquettes, analysis of variance was performed at 95% confidence level. Table 3.13 shows that the mixing ratio has the highest effect at 77.185%, followed by compaction pressure, with 12.84%, and particle size, with a minimal effect of 4.76%. The p-values are slightly above 0.05. shows that it insignificantly influences the development of the briquette. The R values signify goodness of fit of the design model [21].

The dominance of mixing ratio in the present study is consistent with multi-response optimisation of composite materials. [22] reported that drill materials contributed 29.08% and feed rate 24.24% to the GRG for drilling Al/SiC composites, while reinforcement percentage was statistically insignificant. Similarly, [23] found that SiC content contributed 31.93% to the GRG for milling Al7075/SiC composites, exceeding the contribution of cutting speed and feed rate. This indicates that both biomass briquettes and particulate composites, materials composition governs the trade-off between conflicting properties more strongly than processing parameters.

➢ *Confirmation Tests*

The expected mean (μ) at the optimal settings was found to be 0.7880, while the response values by the confirmation experiment trial at the optimal settings are $CS = 3.51MPa$, and $CV = 18.30MJ/kg$, with grey relational grade 0.8347.

➢ *Burning Rate and Water Boiling Test of Briquette and Charcoal*

Results for the time and temperature of burning of 50g of each briquette at 2min interval.

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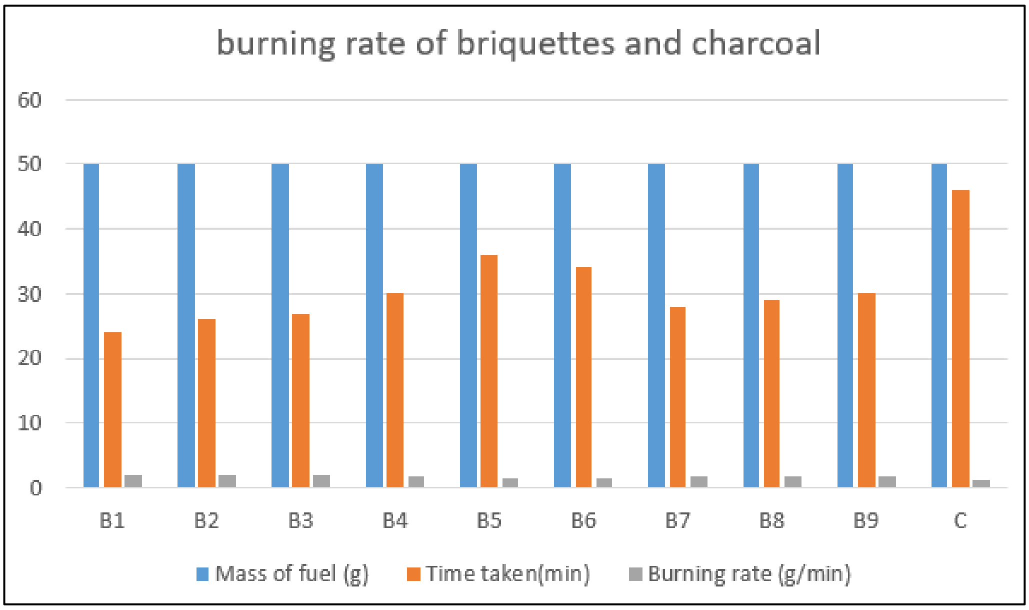

Fig 5 Burning Rate of the Briquettes and Charcoal Chart

The burning rate from figure 5, shows briquette B1 has the highest value of 2.08g/min and B5 display the lowest value of 1.39g/min, while the burning rate of charcoal is 1.09g/min. The result shows that the briquettes burn little faster than the anageissus leoicarpus charcoal. The comparison enables us to determine the effectively of the briquettes to replace charcoal as more sustainable alternatives to wood charcoal which contributed to deforestation.

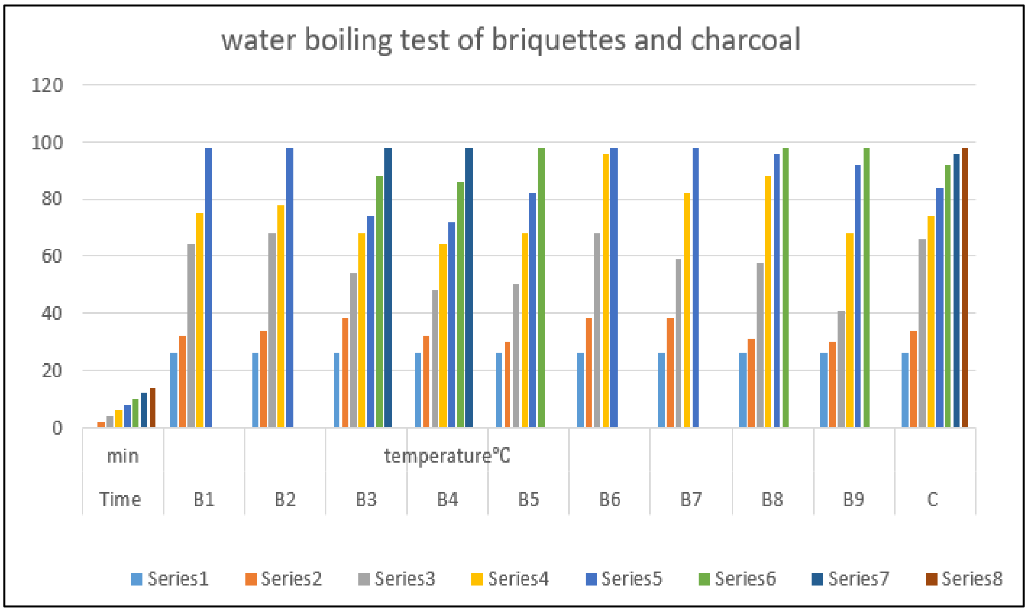

Fig 6 Water Boiling Test Chart

From Figure 6, it was observed that all the briquettes were burned with uniform flame under free convection in a charcoal cooking stove. The samples B1 and B2 raised the temperature of the water to the boiling point(99℃) in 8minutes, and samples B5, B8, and B9 raised the temperature of the water to the boiling point (99℃) in 10minutes, while samples B3and B4 raised the temperature of the same quantity of water in 12minutes. The charcoal sample C raises the temperature in 14minutes. This signified that all the briquettes boil water faster than charcoal, indicating that the higher the burning rate of the briquette, the quicker the boiling point of water.

IV. CONCLUSIONS

In this work, ashok leaves and coconut shells carbon, have been mixed at different proportions with the intention of improving the mechanical and chemical properties of the briquettes for domestic use. The output responses considered are compressive strength and calorific values. Grey relational analysis a multi-response optimisation softwares has been used to identify the optimal mixing level of the feedstock in order to achieved better values for the considered output response. Signal-to-noise ratio and main effect plots obtained from the grey relational grade values have been drawn for the confirmation of the optimal value for the development of the briquettes. The best combination gives particle size of 50µm, mixing ratio 90/10% and, compaction pressure of 6MPa. Performance evaluation of the optimized briquettes was compared with that of *Anogeissus leiocarpus* charcoal., which showed that briquette $(B5)$ has a burning rate of $1.39\ g/min$ close to the Anogeissus leiocarpus charcoal rate $1.09\ g/min$, signifying that the briquettes burn faster than the charcoal with minimal smoke. The water boiling test showed that the briquette boils water faster than charcoal. The maximum time for boiling $50\ ml$ of water by the briquette is $12min$; it took charcoal $14min$ to boil the same quantity of water.

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