Optimization Of Selected Briquette Parameters Using Response Surface Methodology

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Introduction/Background

Valuable products can be obtained from agricultural residues such as briquettes, which have proven to be a substitute of source of energy for domestic use (Ezeokolie *et al*., 2024).

Response Surface Methodology (RSM) aims to identify the optimal conditions for a process or product by analyzing the relationships between variables.

The growing demand for sustainable fuel alternatives shows the need to optimize agricultural waste briquettes, as their current performance in terms of energy output and durability remains limited for consistent daily use.

Optimization of briquette parameters enhance production efficiency and quality.

This study supports the development of alternative fuels for domestic use in developing and underdeveloped countries.

Aims and Objectives

Main Aim

The aim of this study was to optimize selected briquette parameters using Response Surface Methodology (RSM)

Specific objectives

The specific objectives of this study were to:

i. Develop regression model equations for optimizing selected key briquette parameters.

ii. Determine the influence of binder type, binder percentage, biochar type and amount of water on the mechanical and chemical properties of briquettes.

iii. Determine and validate the optimal conditions of briquettes by selecting the desired levels of responses

Materials and Methods

Selected biomass feedstocks were cocopeat, corncob and beans shell and starch and clay were used as a binder. Biomass feedstocks were carbonized in a biochar kiln ranging from 300 °C – 500 °C and residence times of 45 minutes to 2 hours. The biochar obtained were then pulverized using mortar and pestle after which they were sieved separately through a 4 mm sieve.

Equipment used for the experiments are: mechanical screw press, mechanical grinder and sieves, measuring cylinder, weighing balance, mechanical blender, drying oven, biochar kiln, sieve shaker, bomb calorimeter and universal testing machine

Figure 1: A sealed bag of carbonized feedstocks and selected binders (Source: Author's own elaboration)

Figure 2: Produced briquettes (Source: Author's own elaboration)

Experimental design

Central composite design of response surface methodology was used to investigate the effect of independent variables on responses. The selected responses are compressive strength, shatter index, calorific value and ash content. Minitab and Design expert software were used to analyze data.

Table 1 : Continuous Factors for Central Composite Design for briquette production

Continuous Factors	Denotation	Low Level	High level
Amount of water (mL)	A	50	300
Binder (%)	B	10	30

Table 2 : Categorical Factors for Central Composite Design for briquette production

Categorical Factors	Denotation	Number of levels	Level Values		
Binder type	C	2	Clay	Starch	
Biochar type	D	3	BS	CC	CP

Where BS – Beans Shell, CC – Corncob and CP – Cocopeat

Seventy-eight treatments were produced including twenty-four cube points, thirty center points on cube and twenty-four axial points

Responses

Shatter index (%)

The ASTM D440-86 method was used. The briquette was subjected to free fall from a fixed height of 2 m three times, and after each fall it was passed through a 2.5 mm sieve shaker.

$$K = \frac{S_1}{S_2} \times 100 \text{----eqn (1)}$$

Compressive strength (N/mm²)

The property was measured by using a universal testing machine at 1 mm/min cross head speed with a cell capacity load of 100 kN

Calorific value (MJ/kg)

The calorific value of sample was analysed using a bomb calorimeter.

Ash content (%)

The initial sample weight was measured and placed in a furnace operated at 550 °C for 4 h, until the sample would have turned to ash.

$$\%AC = \frac{W_1}{W_2} \times 100 \text{ ---- eqn (2)}$$

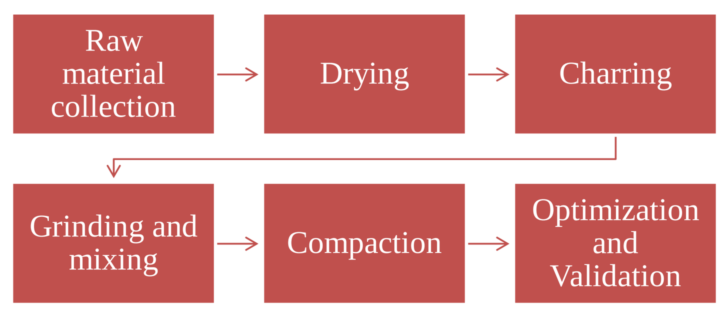


Figure 3 : A flow chart of the optimization process of produced briquettes

Results and Discussion

Development of regression model equation

Calorific value = 18.41– 3.58B + 0.995C – 2.29D_1 + 2.16D_2 + 0.77CD_1 – 0.59CD_2 -------------eq (3)

Compressive strength = 11.93 + 4.03B + 0.86C – 0.72AC + 4.24B^2-------------eq (4)

The correlation coefficients R^2 for compressive strength and calorific value are **92.23 %** and **93.81 %,** respectively. The R^2 closer to unity is an indication of model fitting to actual data

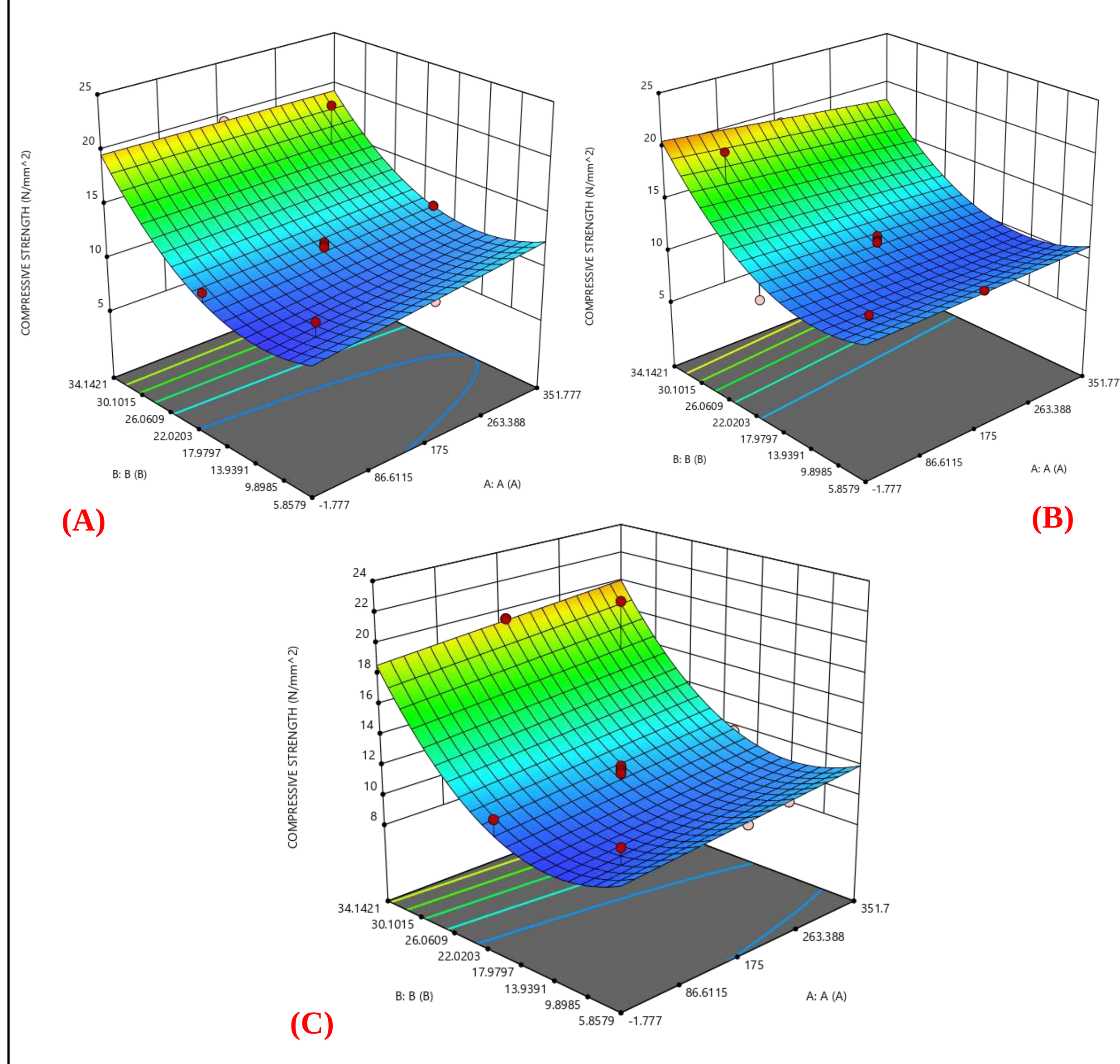
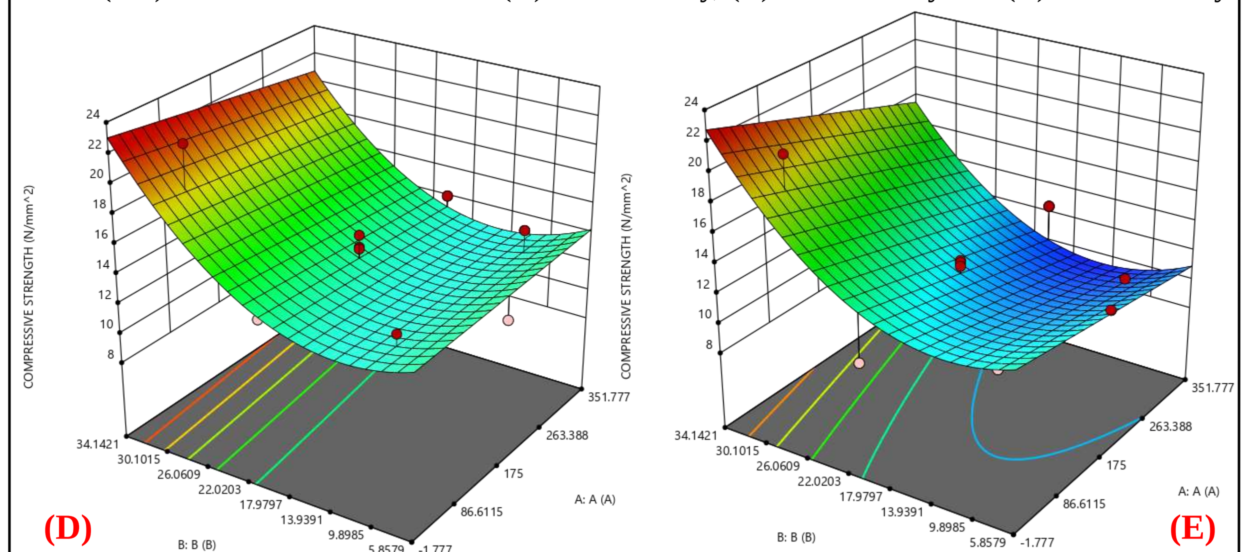


Figure 4: 3D response surface plot for compressive strength versus binder (%) and amount of water (mL) where actual factors are : (A) CP with clay, (B) BS with clay and (C) CC with Clay



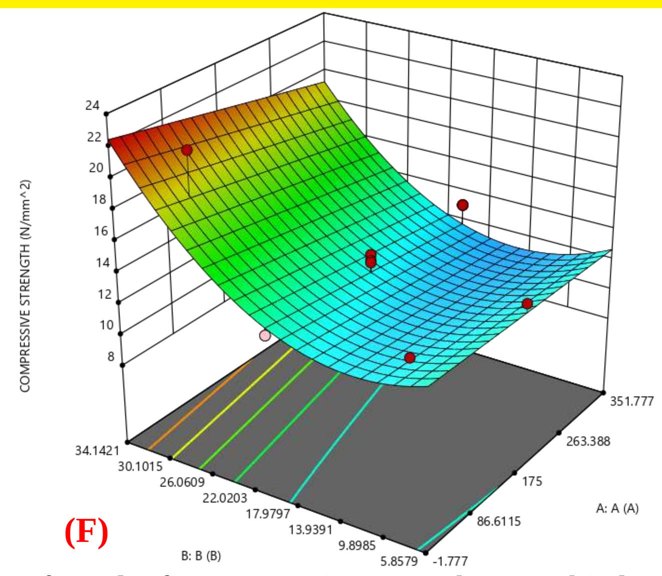


Figure 5: 3D response surface plot for compressive strength versus binder (%) and amount of water (mL) where actual factors are : (D) CP with starch, (E) BS with starch and (F) CC with starch

The binder percentage and binder type had a significant effect on the compressive strength at a quadratic level $p<0.0001$ as shown in Table 3. Another factor which significantly contributed to the compressive strength was B^2. As the binder percentage increases, the compressive strength tend to increase which may be due to its high particle bonding. There was also a significant difference between the binder type affecting the levels of compressive strength as shown in Figure 4 and Figure 5. The findings suggest that binder selection significantly influences the durability of briquettes.

Table 3: ANOVA for response surface quadratic models for compressive strength

Source	Model	A-A	B-B	C-C	D-D	AB	AC	AD	BC	BD	CD	A^2	B^2
p-value	<0.0001	0.3128	<0.0001	<0.0001	0.1689	0.3486	0.0472	0.2409	0.8103	0.9950	0.1888	0.9879	<0.0001

Table 4: Results for optimization and validated results

Optimized parameters	Predicted result	Validation result
Compressive strength	21.61 N/mm²	20.34 N/mm²
Ash content	5.59 %	5.01 %
Shatter index	99.82 %	98.37 %
Calorific value	17.86 MJ/kg	19.78 MJ/kg

Design Expert 13 software was used to develop a desirability function. The compressive strength was maximized, ash content was minimized, shatter index was maximized, and calorific value was maximized. It was predicted that the use of 91.08 mL of water, 34.14 % starch binder, and corn cob biochar will result in compressive strength of 21.61 N/mm², ash content of 5.59 %, shatter index of 99.82 % and a calorific value of 17.86 MJ/kg as shown in Table 4. Validated experiments were carried out to know how fit the models were. The differences between the predicted and validated results in the compressive strength, ash content, shatter index and calorific value were 1.27 %, 0.58 %, 1.45 % and 1.92 %, respectively.

Conclusions and Recommendation

Conclusions

i. The regression model showed a high coefficient of determination R^2 close to unity, indicated a strong fit between the predicted and experimental values.

ii. From the results obtained, the highest compressive strength of 22.31 N/mm² was recorded for briquettes produced from cocopeat char with 50 mL of water mixed with 30 % starch while the lowest compressive strength (9.21 N/mm²) was recorded for briquettes produced from cocopeat char with 175 mL of water mixed with 20 % starch.

iii. The optimized responses and validation results showed excellent agreement which confirmed the model's reliability and accuracy.

Recommendations

i. Further research should explore the use of other biomass materials such as Municipal Solid Waste (MSW), hay and other agro-residues for briquette production.

ii. Future research should also focus on identifying alternative binder types.

iii. Optimization techniques should be applied to other key factors and responses to enhance efficiency and fuel quality; it will contribute significantly to producing sustainable briquettes suitable for energy needs in Ghana.

Reference(s)

Ezeokolie, E. D., Maduoma, T. U., Akpotabor, E. M., Akanni, O., Garbati, A. A., Odeh, A. A., Chukwu, P. M., Achoronye, F. N., and Esonwune, J. N. (2024). Production and optimization of briquette (solid fuels) from waste biomass using industrial starch as binder. *European Journal of Sustainable Development Research*, *8*(4), aem0270. https://doi.org/10.29333/ejosdr/15138