Research Article

Journal of Environmental Nanotechnology

Energy Potential and Properties of Agro Biomass Briquettes with Nano Kaolin Binder for Sustainable Environment

D. Ambika[1*], N. Atthikumaran[2], R. Boopathi[3] and E. K. Mohanraj[4]

[1]Department of Agricultural Engineering, Nandha Engineering College, Perundurai, TN, India
[2]Department of Civil Engineering, Nandha College of Technology, Perundurai, TN, India
[3]Department of Mechanical Engineering, Sri Shanmugha College of Engineering and Technology, Sankari, Salem, TN, India
[4]Department of Civil Engineering, Nandha Engineering College, Perundurai, TN, India
Received: 29.07.2024 Accepted: 07.09.2024 Published: 30.09.2024
*ambikaceg@gmail.com

ABSTRACT

The utilization of Tanner's Cassia waste (T) and African Wonder tree waste (A) in the biomass production chain presents an opportunity for generating value-added products and enhancing productivity. Incinerating these wastes can pose environmental challenges; however, transforming them into briquettes offers a sustainable approach to produce high-energy fuel. This study investigated various mixtures of Tanner's Cassia and African Wonder Tree waste, denoted as TA1 (0:100), TA2 (25:75), TA3 (50:50), TA4 (75:25), and TA5 (100:0), with the addition of 20% nano kaolin as a binder. The resulting briquettes underwent thorough analysis including physical, SEM and elemental analysis. The density of the TA briquettes ranged from 836.38 to 1105. 57 kg/m^3. Key metrics evaluated include ash content, moisture content, volatile content, and fixed carbon content. The results for TA1 (0:100) are 11.22% ash, 5.73% moisture, 69.39% volatile, and 13.66% fixed carbon, while for TA5 (100:0), they are 14.17% ash, 9.87% moisture, 58.07% volatile, and 17.89% fixed carbon, showing a trend of increasing ash and fixed carbon content and decreasing moisture and volatile content across the samples. The SEM analysis of the briquettes reveals distinct characteristics for each mix ratio. Energy Dispersive X-ray analysis indicated carbon and oxygen as the major elements, with 54.48 wt.% and 37.92 wt.%, respectively. These findings highlight the potential of TA briquettes with a 20% nano kaolin binder as a viable alternative energy source due to their low moisture and ash content, coupled with a high calorific value.

Keywords: Nano kaolin binder; Tanner's cassia; African wonder tree; Biomass briquette.

1. INTRODUCTION

With the rise of industrialization, there is a growing demand for energy to support various development initiatives. Currently, this demand is primarily met through the use of fossil fuels, but their limited availability and escalating prices are becoming significant concerns (Dinesha *et al.* 2019). Moreover, burning fossil fuels releases harmful gases like sulphur, nitrogen oxides, and unburnt carbon, leading to severe air pollution and associated health issues such as bronchitis, skin cancer, lung cancer, and eye irritation (Chin and Siddiqui, 2000). To address these challenges, alternative energy sources are needed. Renewable energy sources offer a viable solution, with biomass emerging as a sustainable option due to its ability to generate both electrical and thermal energy effectively (Bot *et al.* 2022). Biomass fuels can be derived from sources like crops, offering a renewable energy option. The sustainable generation of green energy can be achieved through the consistent supply of municipal waste, construction waste, and residues from development activities (Stolarski *et al.* 2013). Agricultural waste residues, including rice husks, banana leaves, bark, wood waste, and various plant leaves, serve as readily available and eco-friendly biomass fuels, aiding in the efficient management of agricultural byproducts (Eswaramoorthi *et al*. 2024). However, using agricultural residues as fuel presents challenges such as higher moisture content and lower bulk density compared to fossil fuels (Velusamy *et al.* 2023). These agricultural wastes can be compacted into biomass briquettes, which have a smaller volume, making them easier to handle and transport, thereby reducing costs and storage space (Han *et al.* 2019). Additionally, the compressed form of agro wastes ensures durability during handling, storage, and transportation, minimizing the risk of damage.

Setting up a plant for reliable and profitable briquette production is highly attractive, particularly in regions with unpredictable economic conditions (Nagarajan and Prakash, 2021). The briquette manufacturing process includes stages such as drying, carbonization, crushing, mixing with binders, pressing, and final drying. Briquette fuel has many advantages over raw materials. It is a renewable resource with a higher calorific value than many solid fuels, has a low ash content (2-10% compared to 20-40% in coal), and burns more efficiently (Chaloupková *et al.* 2018). The quality and durability of the briquettes hinge on their physical and chemical properties, necessitating careful control of variables such as compression pressure, pressing time, and binder usage during the densification process. Chen et al. (2009) have extensively investigated the influence of these process variables on briquette formation.

The current study focuses on utilizing wastes from Tanner's cassia and African wonder tree to manufacture biomass briquettes, using nano kaoline as a binder. These agricultural residues are abundantly available and have shown efficacy in briquette production. The waste materials were sourced from Dharapuram taluk in the Tiruppur district and are typically disposed of through landfilling or open incineration, leading to environmental pollution (de-Oliveira *et al*. 2022). The study addresses these environmental concerns by converting these waste materials into fuel briquettes. This approach also benefits local farmers by providing a solution for agricultural waste disposal and contributes to fuel substitution in nearby industries. The study examines the ignition and burning characteristics of the briquettes relative to their density to optimize their production. The study also characterized the properties of biomass briquettes derived from Tanner's cassia and African wonder tree remnants. Nano kaoline was chosen as a binder for its availability and non-edible nature in the study region. It was utilized as a thickening agent to enhance the physical characteristics and overall quality of the briquettes, especially those with higher densities.

2. MATERIALS AND METHODS

2.1 Material Preparations

The biomass materials utilized in this study comprise Tanner's cassia waste and African wonder tree waste (Fig. 1). These materials were sourced from Dharapuram Taluk, Tiruppur District, Tamil Nadu, India, at coordinates latitude 10.7954°N and longitude 77.7081°E. The agricultural residue was finely ground, dried and sieved to achieve a particle size below 5 mm (Falemara *et al.* 2018) to facilitate compact briquette formation. Various ratios of Tanner's cassia and African wonder tree wastes (0:100, 25:75, 50:50, 75:25, and 100:0) were used to produce briquettes, with 20% nano kaoline added as a binder to all samples.

2.2 Preparation of Nano Kaoline Binder

The preparation of a nano kaoline binder for biomass briquettes involves several key steps to ensure a homogeneous and effective binding solution. A specific amount of nano kaoline powder was measured and gradually distilled water was added while continuously stirring to form a smooth slurry free of lumps (Deshannavar et al. 2018). The slurry was allowed to rest for a few hours to ensure complete hydration and dispersion of the nano kaoline particles. Next, the hydrated nano kaoline binder was combined with the chosen biomass material, such as sawdust or agricultural waste, ensuring thorough mixing to achieve uniform distribution. The resulting mixture was then compressed into briquette molds using a briquetting machine (Fig. 2) applying sufficient pressure to form well-compacted briquettes as described by Ali *et al.* (2024). These briquettes were carefully removed from the molds and dried either in an oven at a controlled temperature or air-dried in a well-ventilated area until they reached a stable moisture content (Veeresh and Narayana, 2013).

Fig. 1: Images of (a) Tanner's cassia and (b) African wonder tree

2.3 Briquette Production

The process of producing briquettes involved the use of a cylindrical pelleting mold with an inner diameter of 74 mm, a thickness of 6 mm, and a height of 125 mm. To achieve consistent briquette size, a hydraulic press method was employed, utilizing a compaction piston measuring 70 mm in diameter, 160 mm in height, and weighing 12 kg. The study employed a Model TUF-C-100 SERVO controlled universal testing machine, which has a maximum capacity of 1000 kN. Each briquette made from waste biomass was subjected to a dwelling time of 75 seconds. Briquettes were produced in various ratios (Fig. 3) of Tanner's cassia waste and African wonder tree waste blending, denoted as 0:100 (TA 1), 25:75 (TA 2), 50:50 (TA 3), 75:25 (TA 4), and 100:0 (TA 5), with nano kaoline binder added at a concentration of 20% of the briquette sample's weight.

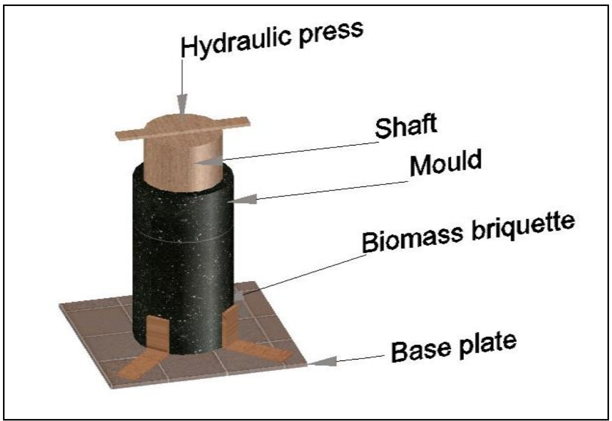

Fig. 2: 3D Diagram of mould used for preparation of briquette

Fig. 3: Produced sample biomass briquette

2.4 Assessment of Briquette Properties

2.4.1 Physical Attributes of Biomass Briquettes

a) Width of TA Briquettes

The width of TA briquettes is an important dimension that contributes to their overall stability and handling properties (Ibitoye *et al.* 2021). After production, the briquettes were measured to ensure they meet the specified width requirements for consistency and quality control. Accurate width measurements were taken using precise instruments to guarantee uniformity across batches, as variations can impact the performance and efficiency of briquettes. Maintaining consistent width of TA briquettes helps ensure their effectiveness as a reliable biofuel source.

b) Volume of TA Briquettes

The volume of TA briquettes is a crucial parameter that affects their density, energy content, and burning efficiency. After production, the volume of briquettes was carefully measured to ensure they meet the specified standards for consistency and performance. Precise volumetric measurements are essential for maintaining uniformity across batches, as variations can influence the overall effectiveness of briquettes as a biofuel (Palanisamy *et al*. 2023). Consistent volume ensures the reliability and efficiency of briquettes in energy production. With the radius known, the height, and the volume can be calculated using the formula $\pi r^2 h$.

c) Density of TA Briquettes

The density of the briquettes was assessed to ensure their suitability for thermochemical applications. It is a key factor influencing their combustion characteristics and energy output efficiency. This parameter is measured post-production to ensure consistency and quality control. By accurately determining the density using standard methods, such as mass and volume measurements, manufacturers can optimize the briquetting process to achieve desired fuel performance. Maintaining uniform density across batches is critical for ensuring reliable and efficient burning, making density an essential metric in the production of high-quality TA briquettes for biofuel applications. This assessment employed a stereometric method using a weigh balance for weight measurement and a vernier caliper for dimension acquisition. The briquette density was calculated using the following formula:

$$D_b = B_m / B_v \qquad \text{.... (1)}$$

where,
D_b = Density of the briquette in kg/m^3
B_m = Briquette mass in kg
B_v = Briquette volume in m^3

d) Relaxed Mass of TA Briquettes

The relaxed mass of TA briquettes refers to the stable mass of the briquettes after they have been allowed to cool and settle post-production, ensuring consistency and quality for practical use. Following initial compaction, the briquettes were formed using specified mix ratios of biomass and binder. They were allowed to cool and settle in a controlled environment to stabilize their mass. The mass of each briquette was measured with a precise scale after reaching room temperature and evaporation of any excess moisture. This relaxed mass was compared across different batches to ensure uniformity and quality control, with variations potentially indicating differences in compaction pressure, binder distribution or moisture content.

2.4.2 Proximate Analysis of TA Briquettes

Proximate analysis refers to a set of laboratory tests used to determine the approximate composition of a material. It typically includes tests for moisture content, volatile matter, fixed carbon, and ash content. These tests are commonly used in various industries, including agriculture, food processing, and energy production, to assess the quality and characteristics of materials such as coal, biomass, and agricultural products.

a) Volatile Matter of TA Briquettes

In order to determine the volatile matter content of the African wonder tree and Tanner’s cassia waste briquettes, a crucible was filled with a 2 g ground sample, and the sample’s initial weight was noted. The sample was kept in a furnace with a steady temperature of 550℃ for about ten minutes. The sample was taken out and allowed to cool in a desiccator after heating. Using the following formula, the percentage of volatile matter was determined.

Volatile Matter (%) =

(Weight of Volatile Matter/Weight of Sample) × 100 … (2)

b) Remaining Residue After Combustion of TA Briquettes

A crucible was filled with a 2-gram sample of pulverized briquettes, and the sample's initial weight was noted (Ravichandran *et al.* 2022). After that, the sample was heated to 550℃ in the furnace for about four hours. Following cooling in a desiccator, the sample's final weight was determined. The following formula was utilized to ascertain the percentage of ash content:

Ash content (%) =

(weight of ash/weight of sample) ×100 … (3)

c) Moisture content of TA Briquettes

By weighing a 2-gram sample of briquettes in a crucible until a stable mass was reached, the moisture content was determined. The weight of the sample was recorded when the sample was put in an oven set at 105℃ for 60 minutes. The following formula was used to determine the moisture content:

Moisture content (%) =

(weight of moisture/weight of wet sample) × 100 … (4)

d) Carbon content of TA Briquettes

By deducting the proportion of volatile substances and the amount of ash, the fixed carbon content in the African wonder tree and Tanner’s cassia waste briquette sample was computed, using the following formula:

Fixed carbon (%) =

(weight of fixed carbon/weight of sample) × 100 … (5)

2.4.3 Elemental Analysis of the TA Briquettes

Elemental analysis was used to determine the elemental composition of biomass, which included carbon, oxygen, potassium, calcium, chloride, silicon, aluminum, magnesium, cobalt, and iron. This analysis was conducted using an EDAX system equipped with a GEMINI column and a SIGMA lens model. The FESEM (Field Emission Scanning Electron Microscope) lens for the system has two lens detectors: the SE2 detector and the BSD detector. It is made by Carl Zeiss in the USA and has a resolution of 1.5 mm. The device is a German-made BRUKER model that makes use of the Nano Xflash detector. The ASTM standards were followed in the analysis of these properties.

2.4.4 SEM analysis of TA briquettes

Scanning Electron Microscope (SEM) was used to examine the surface morphology, elemental composition, and structural features of briquette biomass.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of the TA Briquettes

The physical properties of briquettes made from Tanner's cassia waste and African wonder tree waste were analyzed based on ASTM standards. The results are summarized in Table 1. Notably, all briquettes had a uniform diameter of 70 mm and thickness ranged from 47 to 52 mm. The volumes for TA1, TA2, TA3, TA4, and TA5 briquettes were 193.66 m^3, 189.51 m^3, 191.42 m^3, 192.90 m^3, and 190.54 m^3, respectively. Briquette density ranged from 836.38 to 1105. 57 kg/m^3. These higher densities indicate lower porosity, which is in line with Velusamy *et al*. (2023) findings. The relaxed state mass was highest for TA2 at 199.88 g and lowest for T1 at 197.89 g. A higher comfortable density suggested increased durability. Density and relaxation ratios were consistent across proportions, with shattered index values exceeding 95%, meeting accepted standards according to Palanisamy *et al*. (2023).

Table 1. Physical properties of waste biomass briquettes

S. No.	Mix Ratio of TA briquettes	Width of TA briquettes	Nano Kaoline Binder	Thickness of TA briquettes (mm)	Density of TA briquettes (kg/m^3)	Volume of TA briquettes (m^3)	Relaxed mass of TA briquettes (g)
1	0:100 (TA1)			48	836.38	193.66	197.89
2	25:75 (TA2)			47	938.54	189.51	199.88
3	50:50 (TA3)	70 mm	20 %	51	1003.89	191.42	196.67
4	75:25 (TA4)			50	858.67	192.90	199.53
5	100:0 (TA5)			52	1105. 57	190.54	198.90

Table 2. Proximate analysis of waste biomass briquettes

S. No.	Mix Ratio	Ash content of TA briquettes (%)	Moisture content of TA briquettes (%)	Volatile content of TA briquettes (%)	Fixed carbon content of TA briquettes (%)
1	TA1 (0:100)	11.22	5.73	69.39	13.66
2	TA2 (25:75)	13.51	6.97	64.05	15.47
3	TA3 (50:50)	12.32	8.23	64.56	14.89
4	TA4 (75:25)	11.98	7.86	64.28	15.88
5	TA5 (100:0)	14.17	9.87	58.07	17.89

3.2 Results of Proximate Analysis for TA Briquettes

The proximate analysis was conducted following ASTM standards. Table 2 compares the characteristics of TA briquettes at different mix ratios, labeled TA1 to TA5, with proportions of components indicated in parentheses. Key metrics evaluated include ash content, moisture content, volatile content, and fixed carbon content. The sample TA5 (100:0) presents the highest ash content and fixed carbon content (14.17% and 17.89%, respectively) and lowest volatile content at 58.07%. Ash content in TA briquettes ranged from 11.22% to 14.17%. These findings align with the study of Veeresh and Narayana (2013) who reported 10% to 15% ash content for similar briquettes. Moisture content showed a range of 5.73% to 9.87% and volatile content decreased from 69.39% to 58.07%. This observation was similar to the work done by Falemara *et al.* (2018), who found moisture content ranging from 5% to 10% and volatile content from 60% to 70%, consistent with higher volatile content in lower mix ratios. The fixed carbon content in the current study increased from 13.66% to 17.89%. Chaloupková *et al*. (2018) reported fixed carbon content from 12% to 18%, supporting the observed increase as a proportional rise in one component.

3.3 SEM Analysis of the TA Briquettes

The SEM analysis provided distinct characteristics of microstructural differences among the TA briquettes at various mix ratios. Understanding these microstructural characteristics is essential for optimizing the performance and application of TA briquettes in various settings. The sample TA1 (0:100) exhibited a smooth surface with minimal cracks and pores, indicating a dense structure attributed to lower ash and moisture content. In contrast, TA2 (25:75) displayed moderate pores and cracks, suggesting a less dense structure with increased ash and moisture content. The sample TA3 (50:50) showed a pronounced porous structure with visible cracks and voids, contributing to higher moisture and ash content. Similarly, TA4 (75:25) and TA5 (100:0) exhibited increasingly porous and cracked surfaces, with TA5 being the most porous, correlating with its highest ash and moisture content. Microstructural analysis reveals similar trends: TA1 featured compact particles, TA2 showed a mix of dense and dispersed areas, TA3 was heterogeneous with balanced properties, TA4 indicated increased density, and TA5 exhibited a highly heterogeneous structure with large voids. Comparative SEM analysis showed that higher proportions of the second component increase porosity and decrease density, affecting mechanical strength and combustion efficiency. Irregular particle distribution further impacts structural integrity as mix ratios vary (Fig. 4). These observations complement the compositional analysis, highlighting the relationship between microstructure, porosity, and the physical properties of the briquettes.

3.4 EDAX Analysis of TA Briquettes

The EDAX analysis examined the elemental composition of the briquettes across different mix ratios.

Fig. 5 provides image of an X-ray fluorescence (XRF) spectrum and a corresponding elemental composition.

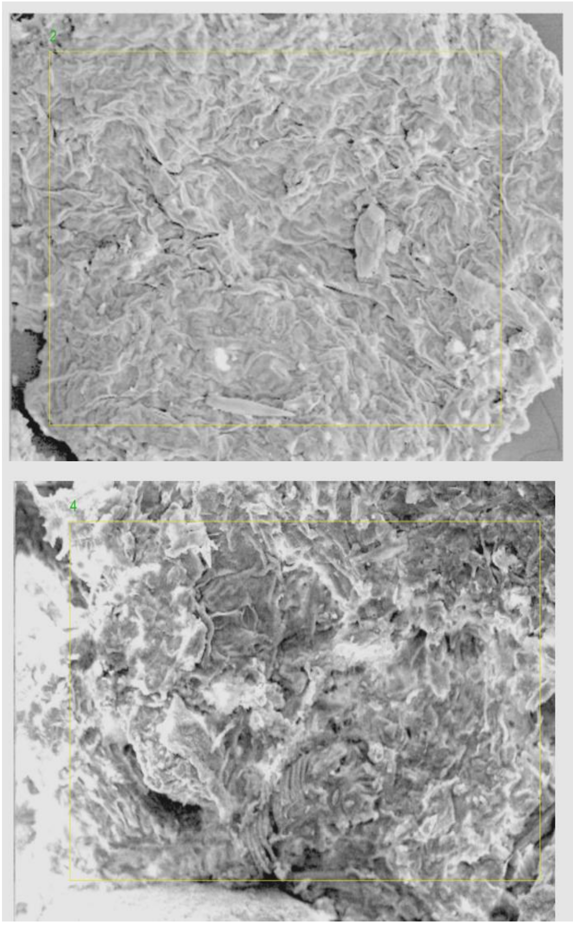

Fig. 4: SEM images of TA briquettes

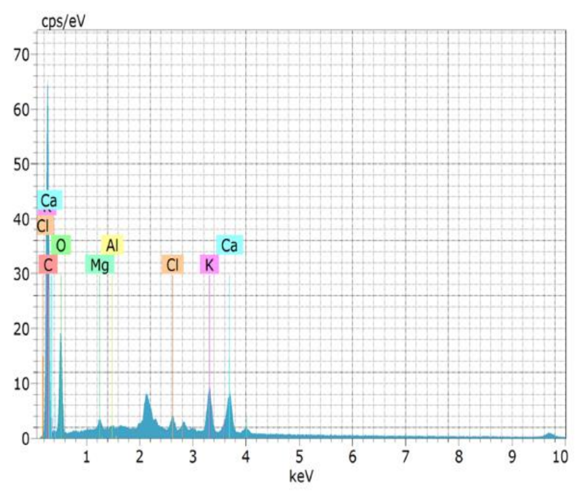

Fig. 5: EDAX Analysis of TA Briquettes

The XRF spectrum shows the intensity (cps/eV) versus energy (keV) peaks for various elements present in the sample, identified as Ca, Cl, O, C, Mg, Al, and K. The accompanying Fig. 5 lists these elements along with their corresponding series (K-series), their unnormalized and normalized concentrations (wt.%) and atomic percentages (at.%), as well as their respective errors (3 Sigma). The data indicate that the sample contains significant amounts of carbon (54.48 wt.%), oxygen (37.92 wt.%), and smaller quantities of magnesium, chlorine, potassium, calcium, and aluminum. The total concentration of the sample sums to 100%, ensuring a comprehensive analysis with elemental composition.

4. CONCLUSIONS

The physical properties, proximate analysis, and surface morphology of briquettes made from Tanner's cassia waste and African wonder tree waste were evaluated based on ASTM standards. The briquettes, all with a uniform diameter of 70 mm, displayed thickness ranging from 46 to 52 mm. Density and volume were consistent across different mix ratios, indicating durability and mechanical strength. The proximate analysis highlighted variations in ash content, moisture, volatile matter, and fixed carbon content, correlating with the briquette mix ratios. The SEM analysis illustrated that higher proportions of the second component increased porosity and decreased density, impacting mechanical strength and combustion efficiency. The elemental results align with the SEM and proximate analysis, providing a detailed understanding of the elemental and structural properties of briquettes, essential for optimizing their performance and applications. The EDAX analysis of the TA briquettes revealed a comprehensive elemental composition, with significant amounts of carbon (54.48 wt.%), oxygen (37.92 wt.%), and minor quantities of magnesium, chlorine, potassium, calcium, and aluminum.

FUNDING

This research did not receive any specific grant from public, commercial or non- profit funding agencies.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

REFERENCES

Ali, A., Kumari, M., Manisha, Tiwari, S., Kumar, M., Chhabra, D. and Sahdev, R. K., Insight into the Biomass-Based Briquette Generation from Agro-Residues: Challenges, Perspectives, and Innovations, *Bioenergy Res.*, 17, 1-41 (2024). https://doi.org/10.1007/s12155-023-10712-5

Bot, B. V., Axaopoulos, P. J., Sakellariou, E. I., Sosso, O. T. and Tamba, J. G., Energetic and economic analysis of biomass briquettes production from agricultural residues, *Appl. Energy*, 321, 119430 (2022). https://doi.org/10.1016/j.apenergy.2022.119430

Chaloupková, V., Ivanova, T., Ekrt, O., Kabutey, A. and Herák, D., Determination of particle size and distribution through image-based macroscopic analysis of the structure of biomass briquettes, *Energies*, 11(2), 331 (2018). https://doi.org/10.3390/en11020331

Chen, L., Xing, L. and Han, L., Renewable energy from agro-residues in China: Solid biofuels and biomass briquetting technology, *Renewable Sustainable Energy Rev.*, 13(9), 2689-2695 (2009). https://doi.org/10.1016/j.rser.2009.06.025

Chin, O. C. and Siddiqui, K. M., Characteristics of some biomass briquettes prepared under modest die pressures, *Biomass Bioenergy*, 18(3), 223-228 (2000). https://doi.org/10.1016/S0961-9534(99)00084-7

de-Oliveira, P. R. S., Trugilho, P. F. and de0Oliveira, T. J. P., Briquettes of acai seeds: characterization of the biomass and influence of the parameters of production temperature and pressure in the physical-mechanical and energy quality, *Environ. Sci. Pollut. Res.*, 29, 8549–8558 (2022). https://doi.org/10.1007/s11356-021-15847-6

Deshannavar, U. B., Hegde, P. G., Dhalayat, Z., Patil, V. and Gavas, S., Production and characterization of agro-based briquettes and estimation of calorific value by regression analysis: An energy application, *Mater. Sci. Energy Technol.*, 1(2), 175-181 (2018). https://doi.org/10.1016/j.mset.2018.07.003

Dinesha, P., Shiva, K. and Marc, A. R., Biomass briquettes as an alternative fuel: A comprehensive review, Energy Technol., 7(5), 1801011 (2019). https://doi.org/10.1002/ente.201801011

Eswaramoorthi, P., Suthaviji, S., Manoj, S., Jothi, L. N. and Sampathkumar, V., Combustion Analysis of Solid Biomass Derived from Turmeric and Onion, using Nanoclay as a Binding Material, for a Sustainable Environment, *J. Environ. Nanotechnol.*, 13(1), 26-31 (2024). https://doi.org/10.13074/jent.2024.03.241496

Falemara, B. C., Joshua, V. I., Aina, O. O. and Nuhu, R. D., Performance evaluation of the physical and combustion properties of briquettes produced from agro-wastes and wood residues, *Recycl.*, 3(3), 37 (2018). https://doi.org/10.3390/recycling3030037

Han, K., Gao, J. and Qi, J., The study of sulphur retention characteristics of biomass briquettes during combustion, *Energy*, 186, 115788 (2019). https://doi.org/10.1016/j.energy.2019.07.118

Ibitoye, S. E., Jen, T. C., Mahamood, R. M. and Akinlabi, E. T., Densification of agro-residues for sustainable energy generation: an overview, *Bioresour. Bioprocess.*, *8*(1), 75 (2021). https://doi.org/10.1186/s40643-021-00427-w

Nagarajan, J. and Prakash, L., Preparation and characterization of biomass briquettes using sugarcane bagasse, corncob and rice husk, *Mater. Today Proc.*, 47, 4194-4198 (2021). https://doi.org/10.1016/j.matpr.2021.04.457

Palanisamy, E., Velusamy, S., Al-Zaqri, N. and Boshaala, A., Characterization and energy evaluation analysis of agro biomass briquettes produced from Gloriosa superba wastes and turmeric leave wastes using cassava starch as binder, *Biomass Convers. Biorefin.*, 13(12), 11321-11337 (2023). https://doi.org/10.1007/s13399-023-04543-9

Ravichandran, S. R., Venkatachalam, C. D., Sengottian, M., Sekar, S., Kandasamy, S., Subramanian, K. P. R., Purushothaman, K., Chandrasekaran, A. L. and Narayanan, M., A review on hydrothermal liquefaction of algal biomass on process parameters, purification and applications, *Fuel*, 313, 122679 (2022). https://doi.org/10.1016/j.fuel.2021.122679

Stolarski, M. J., Szczukowski, S., Tworkowski, J., Krzyżaniak, M., Gulczyński, P. and Mleczek, M., Comparison of quality and production cost of briquettes made from agricultural and forest origin biomass, *Renewable energy*, 57, 20-26 (2023). https://doi.org/10.1016/j.renene.2013.01.005

Veeresh, S. J. and Narayana, J., Sustainable utilization of agro-waste for high calorific energy briquettes, *Energy Sources Part A*, 35(14), 1375-1384 (2013). https://doi.org/10.1080/15567036.2010.525594

Velusamy, S., Subbaiyan, A., Shanmugamoorthy, M. and Thirumoorthy, P., Characterization of solid biomass briquette biofuel from the wastes of Senna auriculata and Ricinus communis using Tapioca starch for sustainable environment, *Environmental Science and Pollution Research*, 30(4), 10110-10127 (2023). https://doi.org/10.1007/s11356-022-22823-1