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Assessment of Physicochemical and Thermal Characteristics of Selected Agricultural Wastes for Briquettes Production

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Abstract: The increasing demand for sustainable energy solutions and the need for effective agricultural waste management underscore the importance of biomass briquettes as an alternative energy source. This study evaluates the physicochemical and thermal characteristics of three selected agricultural wastes. Sesame stalk, melon shell, and cassava peel using standard ASTM procedure for their suitability in briquette production. Proximate analysis revealed that cassava peel exhibited the highest fixed carbon (66.67% raw, 71.50% carbonized) and the lowest ash content in its raw state (5.83%), indicating superior energy density and clean combustion potential. Conversely, melon shell showed the lowest moisture content (5.50% carbonized) and the highest volatile matter (34.50% carbonized), making it ideal for quick ignition. Sesame stalk provided balanced characteristics, with moderate fixed carbon (55.50% carbonized) and ash content (18.5% carbonized), making it suitable for blending. Ultimate analysis confirmed cassava peel's dominance in carbon content (75.45%) and hydrogen content (4.48%), enhancing its energy yield. Thermal analysis (TGA/DTA) further highlighted cassava peel's stable thermal degradation and significant heat release, while melon shell exhibited rapid degradation due to high volatile matter. Sesame stalk displayed gradual degradation, indicating steady energy output. The findings suggest cassava peel as the most promising raw material for energy-dense briquettes and sesame stalk can complement its properties in blended briquettes, while melon shell can be utilized for quick ignition fuels. The study highlights the potential of utilizing the selected agricultural residues for briquette production, offering sustainable energy alternatives and contributing to waste management in Nigeria.

Keywords: *Biomass Briquettes; Physiochemical Properties; Agricultural Waste Utilization; Thermal Decomposition.*

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I. INTRODUCTION

The increasing global demand for sustainable and renewable energy sources has highlighted the urgent need to explore alternatives to fossil fuels. This is particularly critical in Nigeria, where overreliance on firewood, charcoal, and kerosene has contributed to widespread deforestation, environmental degradation, and health challenges due to indoor air pollution [1]. Biomass energy, derived from agricultural residues, has emerged as a viable alternative, offering a sustainable solution for energy generation while addressing waste management issues. Among the various forms of biomass energy utilization, briquetting stands out as an efficient method of converting loose agricultural residues into compact, energy-dense, and environmentally friendly solid fuels [2]. Nigeria’s biomass potential is vast and remains largely untapped. The country has ample agricultural, forestry and municipal resources that can be converted into sustainable energy such as biogas, biodiesel, briquettes and electricity [3].

Nigeria is among the largest producer of Cassava, Sesame seed and Melon seed in the world, producing over 60million metric tons of cassava annually in recent years. Cassava peels make up about 10-12% of the total weight of harvested cassava tubers giving an estimated peel of 6-12million tons annually [4]. Sesame seed production is placed at between 450,000 to 500,000metic tons. The stalk to seed

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ratio is typically about 2:1 giving an estimated Sesame stalk to 1million metric tons annually [5]. Melon seed production is less standardized but estimates suggest Nigeria produces between 200,000 to 300,000 metric tons annually. The shell typically represents about 20-30% leading to an estimate of 40,000 to 50,000 metric tons annually [6].

The physicochemical properties of biomass, including moisture content, ash content, volatile matter, and fixed carbon, are critical indicators of its suitability for briquette production. These properties influence the combustion efficiency, energy density, and overall performance of the briquettes [7]. Thermal properties, such as calorific value, thermal stability, and combustion behavior, are equally important in assessing the energy potential of agricultural residues [8]. Understanding these parameters is essential for optimizing the quality and efficiency of biomass briquettes.

This study investigates the physicochemical and thermal characteristics of sesame stalk, melon shell, and cassava peel, three selected agricultural residues in Nigeria, with a view to evaluate their energy potential and combustion efficiency, providing a foundation for their effective utilization as renewable energy sources.

II. MATERIALS AND METHOD

- *Sample Collection and Preparation*

Samples of Sesame stalk, Melon shell and Cassava peel were collected from Nasarawa LGA, Nasarawa State, Nigeria, located at $8^0$32' N $7^0$42'E. Sesame stalk was collected randomly from a farmland, while Melon shell and Cassava peels were collected from processing sites Both samples were separately washed thoroughly with water to remove any contaminant (sand), sun dried for one week and packaged for use [9]

- *Carbonization of the Samples*

Carbonization or partial pyrolysis is a controlled process that drives off volatile compounds and moisture from biomass leaving fuel with a higher proportion of carbon residue (char).

The procedure of Evuti [9] was adopted for the carbonization of the samples. The. samples were carbonized using a muffle furnace at a temperature of 270^0C for 20 minutes

- *Proximate Analysis*

Moisture Content: The percentage moisture content of the samples was determined in accordance with ASTM D3173 (1990) [10] as reported by Ige[11] based on the sample weight measurement before and after oven drying. The amount of weight lost is the moisture content expressed in percentage and calculated using equation (1):

$$\% \text{ Moisture Content } (MC) = \frac{\text{Wi}-\text{Wf}}{\text{Wi}-\text{Wc}} \ X\ 100 \ldots\ldots\ldots\ldots\ldots (1)$$

Where, W_i, W_f and W_c are the initial weight of the sample plus crucible, weight of the sample plus crucible after oven dry and weight of empty crucible respectively.

Volatile Matter**:** The percentage volatile matter of the sample was determined with Lenton furnace in accordance with ASTM D3175(1990) [10] as adopted by Elinge [12]. The percentage volatile matter was computed using equation (2):

$$\% \text{ Volatile Matter } (VM) = \frac{\text{Wrd}-\text{Wds}}{\text{Wst}} \ X\ 100 \ldots\ldots\ldots\ldots\ldots (2)$$

Where, W_{rd} , W_{ds} and W_{st} are the weight of the residual dry sample, weight of dry sample after heating and weight of sample taken respectively.

Ash Content: The ash content of the sample was determined by ASTM D3174 (1990) [10] method using furnace residue. The percentage ash content was calculated using equation (3):

$$\% \text{ Ash Content } (AC) = \frac{\text{Wca}-\text{Wc}}{\text{Wod}} \ X\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, W_c , W_{ca} and W_{od} are the weight of crucible, weight of crucible and ash and oven dry weight of sample respectively.

Fixed Carbon: Percentage fixed carbon which is the measure of the amount of the non-volatile carbon remaining in the sample was determined by difference from 100%, using data obtained in the proximate analysis as reported by Alfa [13] shown in equation (4);

% Fixed Carbon (FC) = 100% **-** (%MC + % VM + %A... (4)

MC= Moisture Content, VM= Volatile Matte rand AC= Ash Content

- *Ultimate Analysis*

Elemental analysis was conducted to analyze the percentages of Carbon (C), Hydrogen (H),

Nitrogen (N), and Oxygen (O) from the samples. The analysis was carried out using ASTM D5373-16 (2016) [14] standard procedure in a Perkin Elmer 2400analyzer. 2mg of sample was used to measure the percentage weight of each element present.

- *Thermogravimetric Analysis (TGA/DTA)*

The thermal decomposition behavior of the raw biomass sample was conducted using TA-60WS thermogravimetric analyzer (TGA) [15]. The weight loss of the samples was recorded and the resulting TG/DTA data was subsequently analyzed using the Proteus 6.1 software.

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III. RESULTS

Table 1a Proximate Analysis of Raw Samples (%)

Sample	**Moisture Content**	**Ash Content**	**Volatile Matter**	**Fixed Carbon**
Sesame stalk	$12.00^{a}\pm0.50$	$7.67^{b}\pm0.29$	$15.63^{a}\pm0.32$	$65.17^{b}\pm0.21$
Melon shell	$10.00^{b}\pm0.50$	$8.17^{a}\pm0.76$	$15.60^{a}\pm0.10$	$56.23^{c}\pm0.95$
Cassava peel	$12.33^{b}\pm0.57$	$5.83^{c}\pm0.76$	$15.63^{a}\pm0.21$	$66.67^{a}\pm0.31$

Table 1b Proximate Analysis of Carbonized Samples (%)

Sample	**Moisture Content**	**Ash Content**	**Volatile Matter**	**Fixed Carbon**
Sesame stalk	$10.00^{a}\pm0.50$	$18.5^{b}\pm0.50$	$9.80^{c}\pm0.20$	$55.50^{b}\pm0.10$
Melon shell	$5.50^{c}\pm0.50$	$6.33^{c}\pm0.29$	$34.50^{a}\pm0.50$	$54.67^{b}\pm0.58$
Cassava peel	$7.00^{b}\pm0.00$	$37.5^{a}\pm0.50$	$18.17^{b}\pm0.76$	$71.50^{a}\pm0.20$

Table 2 a; Ultimate Analysis of Raw Samples (%)

Sample Carbon	**Hydrogen**	**Oxygen**	**Nitrogen**	
Sesame stalk	$67.67^{b}\pm0.03$	$3.26^{f}\pm0.02$	$27.17^{e}\pm0.01$	$0.51^{h}\pm0.001$
Melon shell	$62.94^{c}\pm0.92$	$3.04^{g}\pm0.02$	$27.12^{d}\pm0.04$	$0.58^{h}\pm0.02$
Cassava peel	$72.74^{a}\pm0.02$	$4.48^{e}\pm0.04$	$22.67^{c}\pm0.12$	$0.50^{h}\pm0.001$

Table 2b; Ultimate Analysis of Carbonized Samples (%)

Sample Carbon	**Hydrogen**	**Oxygen**	**Nitrogen**	
Sesame stalk	$59.15^{b}\pm0.74$	$2.64^{h}\pm0.0$	$24.46^{e}\pm0.04$	$0.39^{i}\pm0.002$
Melon shell	$52.03^{c}\pm0.17$	$2.28^{h}\pm0.01$	$21.40^{f}\pm0.03$	$0.68^{i}\pm0.009$
Cassava peel	$75.45^{a}\pm0.15$	$3.38^{g}\pm0.02$	$20.16^{d}\pm0.02$	$0.37^{i}\pm0.021$

Results are means of three determinations ± SD. Means that do not share a letter are significantly different.

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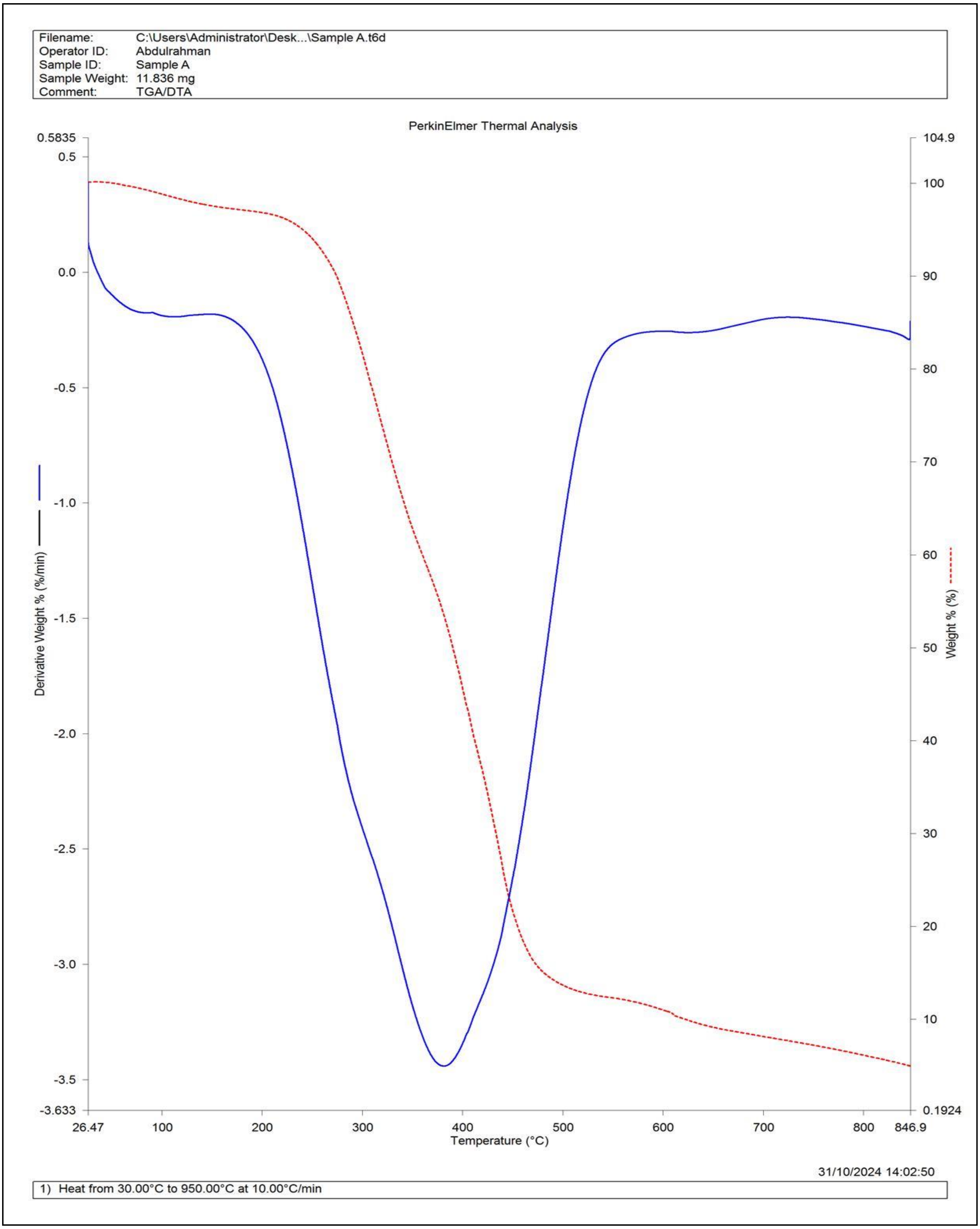

Fig1 TGA/DTA of Sesame Stalk

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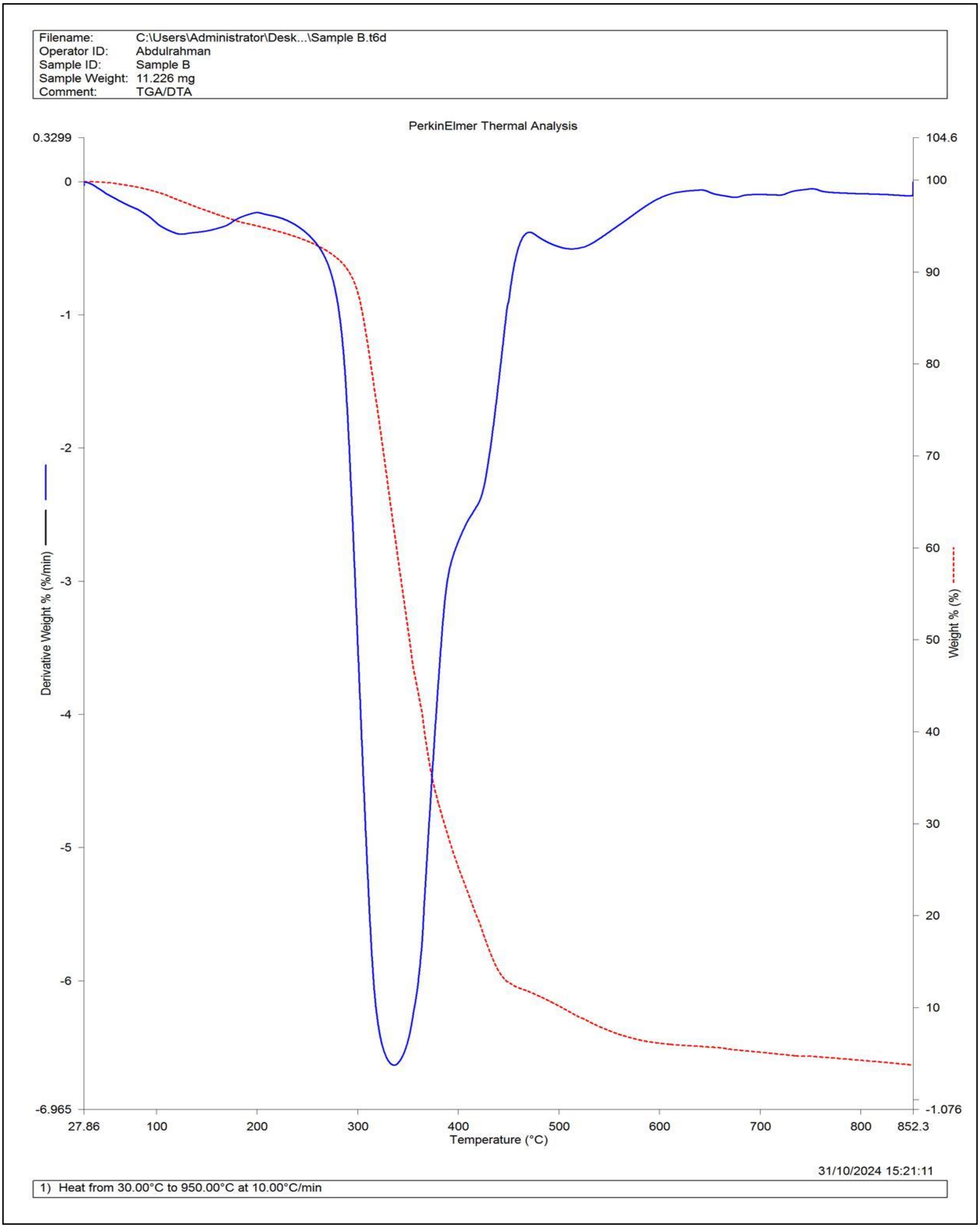

Fig 2 TGA/DTA of Melon Shell

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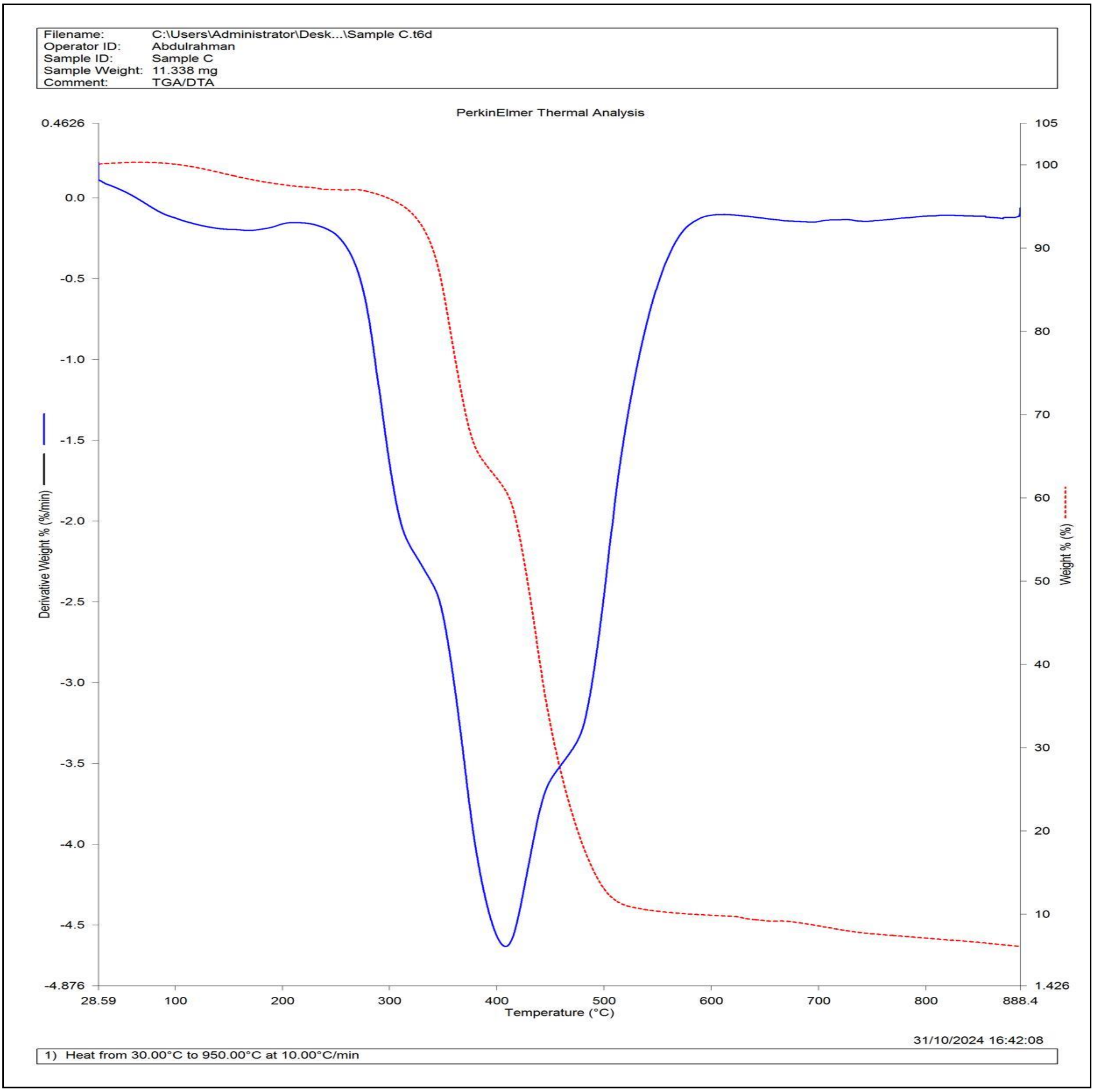

Fig 3 TGA/DTA of Cassava Peel

IV. DISCUSSION

The study investigates the physicochemical and thermal characteristics of sesame stalk, melon shell, and cassava peel to assess their potential for briquette production. Statistically significant differences were observed in moisture content (MC), ash content (AC), volatile matter (VM), and fixed carbon (FC) among the three samples at a 95% confidence level.

➢ *Moisture Content (MC):*

After carbonization, melon shell exhibited the lowest MC (5.50%), enhancing its combustibility [1]. All samples recorded MC below 12%, aligning with recommended standards for effective briquetting [16].

➢ *Ash Content (AC):*

Raw cassava peel had the lowest AC (5.83%), favorable for clean combustion. However, its AC increased significantly to 37.5% post-carbonization, possibly leading to slagging issues [17]. Conversely, melon shell showed a decrease in AC after carbonization (6.33%), making it more suitable for clean-burning applications.

➢ *Volatile Matter (VM):*

All raw samples showed similar VM (~15.6%), suitable for ignition [2]. After carbonization, melon shell had a

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significantly higher VM (34.50%), suggesting its suitability for quick ignition fuel applications [2].

➢ *Fixed Carbon (FC):*

Cassava peel exhibited the highest FC values (66.67% raw; 71.50% carbonized), indicating superior energy density and prolonged combustion [16]. This establishes it as the most promising material for energy-dense briquettes.

The Ultimate Analysis (table 2) showed Cassava peel also recording the highest carbon (75.45%) and hydrogen content, contributing to high-energy output and efficient combustion [18]. Nitrogen content across all samples remained below 1%, reducing the risk of NOx emissions [17].

➢ *Thermal Analysis (TGA/DTA):*

As shown in Figure 3, Cassava peel displayed stable thermal degradation and significant exothermic energy release, supporting its potential as a high-energy briquette feedstock [2]. Melon shell showed rapid weight loss as indicated in figure 2, due to its high VM, making it ideal for fast-burning use [19]. Sesame stalk as shown in figure 1, exhibited moderate, sustained thermal behavior, making it a useful blend material [20].

Cassava peel is best suited for energy-dense briquette production, although its high ash content may require blending. Melon shell is ideal for ignition due to high VM and low MC, while sesame stalk serves as a versatile intermediate. These residues offer a sustainable path for renewable energy development and agricultural waste utilization in Nigeria.

V. CONCLUSION

The physicochemical and thermal characteristics of sesame stalk, melon shell, and cassava peel demonstrate varying potentials for briquette production, with each material offering distinct advantages and challenges. However, the observed significant differences among the samples emphasize the need for careful selection or blending strategies to optimize briquette quality. This study underscores the potential of agricultural wastes as valuable resources for renewable energy production, contributing to waste management and energy sustainability goals.

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