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RESEARCH ARTICLE

Sustainable Growth through Garden Waste Pelletization

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Abstract

Objectives: In metropolitan regions, management of solid wastes continues to be the main challenge. One of them is garden waste management. Garden waste generated in cities is either recycled into fertilizers or dumped on landfills, polluting the land. This study intends to discover sustainable waste management options for garden waste and to achieve a shift in energy from petroleum to renewable sources such as biomass, which can minimize emission of contaminants in the atmosphere. **Methods:** The pelletization method of managing garden waste was examined in this study. The garden waste including Palm, Jackfruit, and Ashoka leaves was collected separately from the college yard. Pelletization of these leaves was carried out after pretreatment and pulverization. The mechanical, physiochemical, and thermal characteristics of pellets were studied using several analytical techniques such as Thermogravimetric Analysis (TGA), proximate analysis, Energy dispersive spectroscopy (EDS) and scanning electron microscopy (SEM). **Findings:** The calorific value for pellets made from palm, Jackfruit, and Ashoka leaves was 3414.46 kcal/kg, 3304.02 kcal/kg, and 3833.88 kcal/kg, respectively. These values are reminiscent to those for sub-bituminous coal, lignite, and peat. Additionally, the very low levels of nitrogen and sulphur indicate a lower threat of contaminants in the air. Pellets have an over 90 percent impact resistance and durability , thus signifies resistance to damage and are simple to handle, store, and transport. The results of analyses indicate that pellets made from palm, jackfruit, and Ashoka leaves can be bonded strongly and display the appropriate thermochemical behavior to be used as biofuels. **Novelty and applications:** The pelleting of specifically Palm, Jackfruit, and Ashoka leaves has not been explored for biofuel use. The pellets generated can be used in boilers, reactors, and other combustion units along with coal to generate revenue and reduce air pollution to some extent.

Keywords: Garden Waste; Sustainable Development; Physiochemical Analysis; Thermogravimetric Analysis; Pellets

1 Introduction

Solid biomass has gained popularity in recent decades due to its ability to serve as a renewable source of energy and as an intermediate product for biomass refineries, which produce a wide range of high-value goods in established manufacturing networks. Power plants are enhancing simultaneous combustion and dedicated burning of biomass fuel to boost fuel versatility and lower greenhouse gas pollution[(1)],[(2)]. With the need to phase out the use of fossil fuels, biomass has been identified as a potential alternative[(3)]. On the other hand, the disposal of solid waste in urban region is a growing concern worldwide. In 2021, garbage was produced at a rate of 1.6 MT per day on average in India; ninety-five percent of this waste was picked up and delivered to landfills creating the problems like soil pollution, leaching and odour[(4)]. This municipal waste includes household waste, industrial waste, and municipal service garbage. Wastes from various gardens, recreational facilities, and street cleaning are among them, and it comprises dried leaves, tree trimmings, plastics, papers and other items. Dry leaves have already been commonly used in various regions for the production of garden compost, but its abundance poses a storage problem that leads to insect breeding and stink. This less economical approach to garden waste management, along with its availability, creates a gap for the valorization of dry leaves as biofuel feedstock. Dry leaves from various trees are readily accessible and can be used as a feedstock for biofuels rather than being discarded or burned openly. There are a few recent studies depicting the pelletization of different biomasses given in Table 1.

Table 1. Recent studies on pelletization of biomass

Sr. No.	Feedstock Source	Characteristics
1.	Garden Biomass (GB), Municipal Solid Waste (MSW), Cow Dung (CD), Aerobic Sludge (AS), Anaerobic Sludge (ANS), Glycerol (GL)[(5)]	Moisture content:7 to 18% Calorific value: 2750 to 5750 Kcal/Kg Volatile Matter:23.64 to 36.42% Ash Content: 23.63 to 36.41%
2.	willow, poplar, willow leaf sunflower and giant miscanthus[(6)]	Moisture Content : 6.85% Ash Content: 9.92% Calorific Value:4158.7 Kcal/Kg Lignin: 29.0%
3.	Spent coffee grounds (SCGs) and tea leaf[(7)]	4.5 wt.% of N and 0.2 wt.% of S on average Moisture Content :3.25 to 4.38% Calorific value:4842.25 to 5712.23Kcal/Kg Ash content:1.21 to 4.20%
4.	Post-harvest barley straw and pomace from apple fruit, carrot root and red beet root juice production[(8)]	Moisture content:17 to 22% Ash content:2.77 to 6.56% Calorific value:4072.6 to 4196.94 Kcal/Kg Lignin:5.1 to 15%
5.	Mixed garden waste collected from two different municipal waste disposal sites[(9)]	Ash: 12.2 to 56.4% Calorific Value:2318.36 to 4134.79 Kcal/Kg
6.	Jujube tree branches Additives: coco coir (CC) and bone meal (BM)[(10)]	Moisture Content:2.45 to 5.24% Ash: 1.84 to 15.21% Calorific Value: Nearly 4390.54 Kcal/Kg
7.	Wood, wheat straw, and maize stalk[(11)]	Moisture Content: 4.8 to 7.6% Ash:1 to 12.5% Bulk Density:460 to 667.3 Kg/m^3 Calorific Value:3441 to 4216 Kcal/Kg
8.	Spruce sawdust, beech sawdust, pine bark, spruce bark, beech bark, and pine cones[(12)]	carbon content :6.25 to 47.26%, hydrogen content:6.26 to 6.36%, and nitrogen content: 0.24 to 0.32%. Ash: 0.42 to 6.28% Moisture content:4.6 to 7.98%
9.	Fibrous hemp, maize, and faba bean[(13)]	Bulk Density: 1195.8 kg/m^3 Moisture content: 3.9 to 8.8% Ash: 4.5 to 6.8% Calorific value: 4015 to 4086 Kcal/Kg
10.	Miscanthus, sida, and cup plant[(14)]	Moisture content: 8.7% to 9.6% Bulk density: sida-1072.3 $\pm$ 43.4 Kg/m^3 Ash :6.07 to 9.96%
11.	Pruning residues from hazelnut and olive groves[(15)]	Bulk density: 581.30 to 562.38 Kg/m^3 Durability: 98% Moisture content: 11 to 11.45% Ash :2.5 to 3.1 %

The demand for different biomass sources for biofuel generation has been increasing rapidly. Therefore, this study looked into the potential of garden waste in the college yard as a bioenergy source. The college campus selected for study was the Institute of Chemical Technology, Mumbai. The palm, jackfruit, babul, and Ashoka trees dominate the campus yard. These trees produce a massive amount of biomass waste, which is typically used as fertilizer for other plants or discarded as trash as discussed above. Although palm oil-based bioenergy is widely known[(16)], bioenergy derived from palm tree waste has received little attention. Palm tree waste is commonly utilized as a building material[(17)]and adsorbent[(18)], but it also has the potential to generate bioenergy[(19)]. Empty palm bunches along with rubber and agro waste were used to produce the pellets previously[(20)].

Similarly, Ashoka and jackfruit tree leaves have lignocellulosic properties which can be used to generate biofuel. The wood of the jackfruit tree was historically used to manufacture furniture and musical instruments. Several activated carbons, dyes, and adsorbents were also made from jackfruit peel and waste to avoid environmental issues. Additionally, jackfruit waste was formerly used for the production of biogas, briquettes, and biochar [(21)]. But, very few literatures are available on utilization of jackfruit tree leaves, palm leaves and Ashoka leaves for biofuel generation. The commercial value of these trees can be increased through proper waste utilization, which can also lower the cost of solid waste management in urban area. Thus, in this research study, biomass waste derived from the leaves of Ashoka, Jackfruit, and palm trees has been pelleted in an effort to both create bioenergy and address the issue of trash disposal.

2 Material and Methods

The leaves of Palm, Jackfruit, and Ashoka trees were collected from the college yard with the help of gardeners for this investigation. These materials are typically stockpiled in the yard to be utilized as fertilizers and the remaining is discarded as waste. Garbage storage generates issues such as leaching, breeding flies, worms, insects, and odor. As a result, proper waste management of Palm, Jackfruit, and Ashoka tree leaves was required.

2.1 Material Pre-treatment and Processing

Palm tree leaves were vigorously shaken to remove dust, while Jackfruit and Ashoka tree leaves were sieved through a wide mesh of size 4.36 mm to separate dust and tiny stones. Hand segregation was used to remove plastic, wrappers, paper chips, and other contaminants. These leaves were then exposed to the sun for 10 days to minimize moisture levels in leaves before being shredded using a hammer mill to an average particle size of 2 to 3 mm as specified in ISO 17829. The pellets were made from five kilograms of Palm, Jackfruit, and Ashoka leaves. To make the pellets, Eco Pellet Maker EPM-100 mill with a power requirement of 7.5 KW / 10 HP, 440 Volts, 50Hz, 3 Phase, dimension 1000 x 560 x 1400 mm, weight 280 kg and an output capacity of 90-120 kg/hr. present at college ICT, Mumbai college campus were used. This manual pelleting machine is equipped with two press rollers having diameter 100mm and rotations 85 rpm and a die with an 8mm die hole diameter and 200mm die inner diameter. The pellets were then sundried for 20 minutes and stored for subsequent physiochemical and thermal analysis as shown in (Figure 1).

Fig 1. Pellets produced from Palm, Jackfruit, and Ashoka leaves

2.2 Analytical Methods

The physicochemical and thermal characteristics of the three types of pellets and biomass were determined by using different analytical methods. The volatile matter, moisture level, quantity of ash, and fixed carbon of shredded leaves and pellets were determined using the standard approach stated in Table 2. The moisture content of samples was estimated by drying the samples at 105±5°C for 24 hours. The weight loss was recorded, and the moisture percentage was computed. Following that, 1 gram of each oven-dried sample was placed in a muffle furnace for 6 minutes at 940±10°C to measure the volatile content of the pellets and biomass samples. Ash content was found by keeping the samples of biomass and pellets in a muffle furnace at 700±20°C for 3 hours. In both cases, weight loss was observed and values of volatile content and ash content were calculated respectively.

Fixed carbon content was calculated by subtracting the value of volatile content, ash content, and moisture content from 100. The mechanical qualities of the pellet, such as impact resistance and durability, were also calculated using ISO 17831-1 standard procedure. Vernier caliper was used to measure physical parameters such as diameter and length. Bulk density was calculated by weighing the pellet sample and dividing it by the volume of the pellet; this process was repeated three times to ensure reliable findings. The Carbon, Hydrogen, Nitrogen, Sulphur, and Oxygen compositions of three types of feedstock and pellets were calculated using the CHNS-O analysis.

Table 2. Details of Analysis

Analysis	Instrument Used and Source	Standard Used
Moisture content	Muffle Furnace Source: Four tech ltd. Mumbai	ASTM D3173-11
Volatile Matter		ASTM D3175
Ash Content		ASTM D3174
CHNS	Thermo Fisher Scientific, Mumbai Model: Flash smart V CHNS/O Specification: Estimation of CHN/CHNS/O in percentage level to high concentration level.	Carbon: ASTM E777-08 Hydrogen: ASTM E777-08 Nitrogen: ASTM E778-08 Sulphur: ASTM E775-87
Heating value	Digital Bomb calorimeter Source: ARICO, New Delhi, India.	ISO 18125:2017
Thermogravimetric Analysis	Thermogravimetry/ Differential Thermal Analyzer HITACHI (STA7300) Source: ICT, Mumbai	ASTM E 1131-03
Ash constituents: SEM-EDS	JEOL JSM-7600F FEG-SEM Analyzer, Mumbai	ASTM E1755-01 (2015)

An oxygen bomb calorimeter calibrated by combustion of benzoic acid was used to calculate the higher and lower calorific values of the three pellet samples. The crucible was filled with known quantities of oven-dried pellet samples of Ashoka, Jackfruit, and palm leaves. In an enclosed bomb, samples were first burned with oxygen using fuse wire and cotton thread. The calorific value of the fuel sample was then determined by measuring the heat of resulting reaction from the rise in temperature of the adjacent water bath by using Equation 1. Later lower calorific value was calculated using Dulong's formula given in Equation 2.

$$\text{Higher Calorific Value (HCV)} = \frac{\text{Water Equivalent Factor}}{\text{Sample Weight}} \times \Delta t \tag{1}$$

$$\text{Lower calorific value (LCV)} = \text{ Higher calorific value } - \frac{9H}{100} \times 587 \tag{2}$$

Where, $\Delta t = t_2 - t_1$, t_1 is initial temperature of water in °C and t_2 is final temperature of water in °C. Water equivalent factor is calculated by multiplying the benzoic acid's HCV by the sample weight, deducting the HCV of cotton thread and nichrome wire from the equation, and then dividing the result by the increase in temperature. H is percentage of hydrogen present in sample.

Thermogravimetric analysis (STA7300/Hitachi) ranging from 35°C to 900°C, under nitrogen gas was used to measure the disintegration and thermal breakdown of the three different types of pellets at a rate of 10°C/min. The thermal disintegration of fuel pellets was depicted by the graph of residual weight % vs. temperature and its derivative, which was produced using TG analysis. Factors including moisture content, residual matter, volatile content, flash point, and burnout point were identified using these graphs. Energy dispersive spectroscopy (EDS) and scanning electron microscopy (SEM) were used to identify the inorganic components contained in the pellet ash samples.

3 Results and Discussion

The results of the physiochemical analysis of shredded leaves and pellets are given in Table 3. The shredded Palm, Jackfruit, and Ashok leaves were sieved using IS sieves, and it was discovered that more than 70% of the biomass passed through the 2.36mm sieve size. The moisture content of Palm, Jackfruit, and Ashoka leaves when collected was found to be 5.88, 12.90, and 7.48 % respectively before pelletization. Moisture content is a crucial parameter affecting the combustion, compressibility, hardness, and durability of pellets[13],[14]. The moisture level in Palm and Ashoka tree leaves was low and within acceptable limits according to ISO 18134-1,2 requirements, but it was higher in Jackfruit tree leaves, thus it was sundried for a longer period. Because this garden leftovers were pelleted without the use of a binding agent only a small quantity of water was added to shredded biomass. Therefore, the moisture content of Palm, Jackfruit, and Ashoka leaves pellets, 6.75, 9.05, and 8.09% respectively was slightly higher but within the permitted range (<10%) according to ISO 18134. Pellet moisture content is typically less than 15%[22,23]. Higher heating values and easier combustion were noted in diverse literature at reduced moisture content[21]. The pellets made from these materials are therefore capable of being used as biofuels and can generate high combustion efficiency.

Volatile matter in Palm, Jackfruit, and Ashoka leaves before pelletization and after pelletization is fairly equal. Volatile matter in the pellets varies from 68 to 75%. While the ash content was increased after pelletization this may occur due to the addition of dust present in pelleting machine or incomplete combustion. Palm leaf pellets have a significantly higher ash percentage of 14.86%, which can induce deposits in the reactor, hence combining Palm leaves with other biomass while pelleting is recommended. The bulk density of Palm (217.67kg/m^3), Jackfruit (217.67 kg/m^3), and Ashoka (208.33 kg/m^3) tree leaves have significantly increased to 1321.35, 1268.32, and 1244.53 kg/m^3 respectively after densification which is more than various materials mentioned in literature given in Table 1 and satisfies the criteria of ≥600 Kg/m^3 given in ISO 17828. This can solve the space, handling, and shipping problems associated with loose biomass. The average length of Palm, Jackfruit, and Ashoka tree leaves pellets was 30, 34, and 32 mm, respectively, with an average diameter of 8mm for all pellets. Palm, Jackfruit, and Ashoka tree leaves had higher calorific values of 3414.46, 3304.02, and 3833.88 kcal/kg, respectively. The calorific value of Ashoka leaves pellets was very significant. The calorific value obtained from the densification of forest leaves was in the range of 2900 Kcal/Kg to 3600 Kcal/kg[24] and calorific value of biomass feedstock containing 80% of garden biomass was observed to be 2754 kcal/kg[5]. As a result, it is reasonable to conclude that palm, jackfruit, and Ashoka leaf pellets taken in study are effective biofuel sources. The results of CHNS-O analysis give the % composition of Carbon, Nitrogen, Hydrogen, Oxygen, and Sulphur. Because the oxygen content of the pellets was high based on the CHNS-O study, no extra oxygen will be required for burning. The Sulphur composition is exceptionally low and nitrogen content is also low, indicating a lower risk of greenhouse gas emissions[25,26]. Sulphur content is undetectable satisfying the criteria for industrial use according to ISO 16994. While the nitrogen content in pellets is also within permissible limit i.e. ≤1% according to ISO 16948. It could be possible to improve the quality parameters that remain unsatisfactory by mixing these materials with different types of wood.

Table 3. Physiochemical and mechanical characteristics of biomass

Parameters	Palm	Jackfruit	Ashoka
Biomass Characteristics			
Moisture content (%)	5.88±0.45	12.90±0.65	7.48±1.54
Volatile matter (%)	68.92±0.29	69.78±2.59	71.55±1.91
Ash content (%)	11.83±0.48	10.06±0.69	7.55±0.55
Fixed carbon content (%)	13.37±1.07	7.26±1.94	13.42±2.0
Bulk density (kg/m^3)	217.67±3.3	217.67±5.78	208.33±3.8
Carbon (%)	39.682±1.08	37.41±1.14	46.186±1.03
Hydrogen (%)	5.743±0.45	4.748±0.56	6.210±0.52
Nitrogen (%)	1.076±0.23	0.612±0.25	1.501±0.31
Oxygen (%)	53.498	57.230	46.104
Pellet Characteristics			
Diameter (mm)	8±0.2	8±0.2	8±0.2
Average Length (mm)	30±2.71	34±1.41	32±0.82
Moisture content (%)	6.75±0.19	9.05±0.33	8.09±0.27
Volatile matter (%)	64.29±4.74	69.71±5.89	69.49±2.22
Ash content (%)	14.86±0.36	11.99±0.99	8.85±0.45
Fixed carbon content (%)	14.10±2.94	9.25±4.77	13.57±3.93
Bulk density (kg/m^3)	1321.35±17.55	1268.32±13.61	1244.53±24.81
Higher calorific value (kcal/kg.)	3414.46±9.65	3304.02±7.63	3833.88±8.32
Lower calorific value (kcal/kg.)	3125.95±9.65	3029.99±7.63	3519.49±8.32
Carbon (%)	38.788±1.13	38.783±2.05	43.168±0.67
Hydrogen (%)	5.461±0.48	5.187±0.07	5.951±0.12
Nitrogen (%)	0.683±0.12	0.673±0.18	0.879±0.05
Oxygen (%)	55.068	55.357	50.003
Flashpoint (°C)	245±2	240±2	240±2
Burnout point (°C)	410±5	410±5	420±5
Impact Resistance (%)	98.24±0.15	98.87±0.23	99.06±0.18
Durability (%)	90.82±1.25	92.14±0.62	97.68±0.21

3.1 Thermogravimetric Analysis

The thermal disintegration of Palm, Jackfruit, and Ashok tree leaves pellets and raw leaves were analyzed by using thermogravimetric analysis (TGA). The results of TGA are given in Table 4. The thermal disintegration in terms of percent weight loss vs temperature and its derivative showing the thermal behavior for Palm, Jackfruit, and Ashoka tree leaves pellets are depicted in Figures 2, 3 and 4 respectively. The flash point and burnout point for palm leaves pellets were 245°C and 410°C , respectively, indicating that the pellet started disintegration at 245°C and was entirely burned at 410°C. Similarly, the flash point for Jackfruit and Ashoka leaves pellets was found to be 240°C, with burnout values of 410 and 420°C. This states that a temperature of not more than 420°C is required to thoroughly burn the pellets.

According to the literature [27,28], thermal decomposition occurs in three zones: zone 1 includes moisture removal and occurs between 35-200°C, zone 2 includes hemicellulose and cellulose decomposition and occurs between 200-400°C, and zone 3 includes lignin decomposition and removal of inorganic matters and occurs between 400-900°C [29,30]. In this investigation, zone 1 moisture removal for palm, jackfruit, and Ashoka leaves was reported between 35-170°C, 35-245°C, and 36-205°C, respectively, while percentage weight loss was observed around 7.5%, 9%, and 7.8%, respectively in this zone. The second zone of hemicellulose and cellulose degradation was observed between 170-380°C, 245-425°C, and 205-440°C for palm, jackfruit, and Ashoka leaves, with percentage weight loss of 58%, 55.5%, and 54.5%, respectively. Zone 3 of lignin degradation and inorganic matter removal for palm, jackfruit, and Ashoka leaves was observed between 380-790°C, 425-760°C, and 440-750°C, with percent weight loss of 20%, 23.5%, and 27.7%, respectively. The weight percent of residual matters in palm, jackfruit, and Ashoka leaves pellets left after 900°C were 14.5%, 12%, and 10%, respectively.

Table 4. Percentage weight loss in thermogravimetric analysis

Samples	Moisture (% wt.)	Hemicellulose and cellulose decomposition (% wt.)	Lignin decomposition (% wt.)	Residual Matter (% wt.)
Palm Leaves pellet	7.5	58	20	14.5
Jackfruit leaves pellet	9	55.5	23.5	12
Ashoka leaves pellet	7.8	54.5	27.7	10
Palm Leaves Raw	6.3	60	23.2	10.5
Jackfruit Leaves Raw	8.6	56	25.5	9.9
Ashoka Leaves Raw	6.8	55.3	28.8	9.1

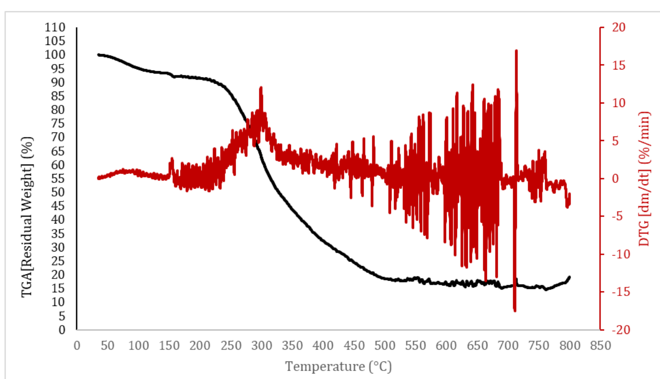

Fig 2. TGA-DTG curve (%) for Palm Leaves Pellets

Similarly, thermal disintegration of feedstock i.e. palms, jackfruit and Ashoka leaves were also studied using TG analysis in conjunction with DTG (Differential thermogravimetry) shown in Figures 5, 6 and 7, respectively. A moisture loss of 6.3%, 8.6%, and 6.8% was observed between 35-170°C, 36-215°C, and 33-225°C for raw palm, jackfruit, and Ashoka leaves biomass, respectively. Cellulose and hemicellulose decomposition of 60%, 56%, and 55.3% was observed between 170-450°C, 215-475°C and 225-480°C, respectively. While the lignin decomposition of 23.2%, 25.5%, and 28.8% was observed between 450-725°C, 475-610°C, and 480-780°C, respectively and residual matter observed in the palm, jackfruit, and Ashoka leaves was 10.5%, 9.9%, and 9.1%, respectively. The above analysis gives the approximate amount of cellulose, hemicellulose, and lignin content in the biomass sample. The lignin content of pellet samples ranged between 23 and 29%. When lignin melts at high temperatures,

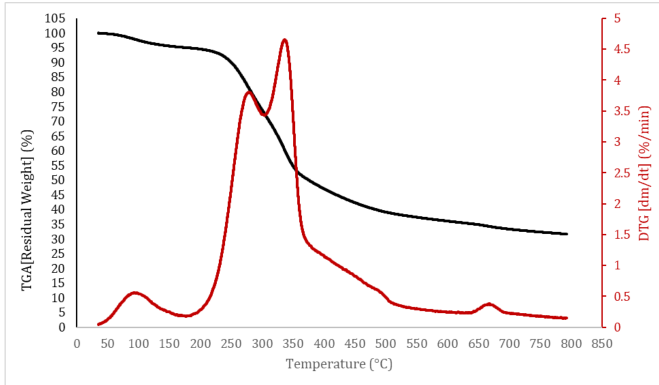

Fig 3. TGA-DTG curve (%) for Jackfruit Leaves pellet

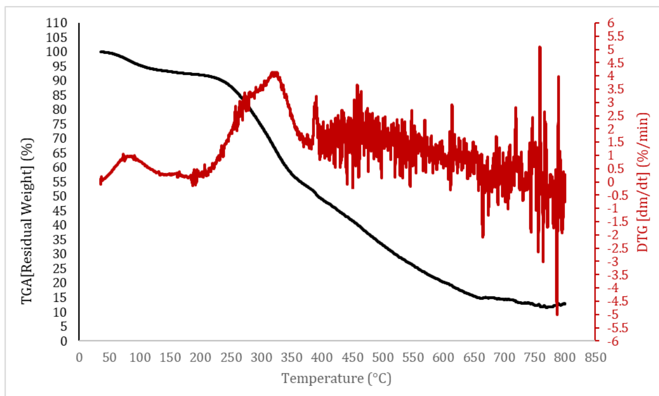

Fig 4. TGA-DTG curve (%) for Ashoka Leaves Pellet

it seeps into the outermost layer of pellets, causing them to adhere together and create a smooth coating that makes shattering difficult and offers toughness[8]. Therefore, the pellets obtained from Ashoka leaves are more resistant to impact and shattering than palm and jackfruit leaves.

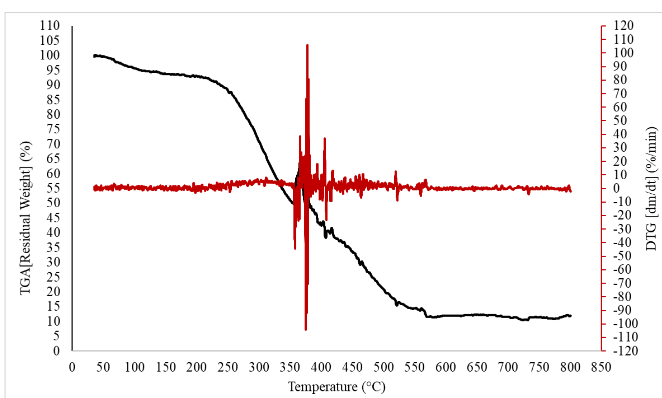

Fig 5. TGA-DTG curve (%) for Palm Leaves Raw

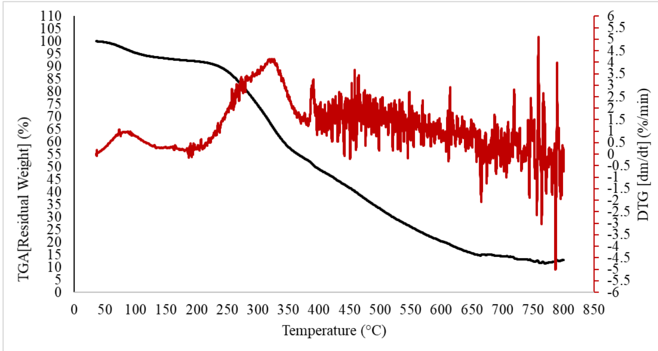

Fig 6. TGA-DTG curve (%) for Jackfruit Leaves Raw

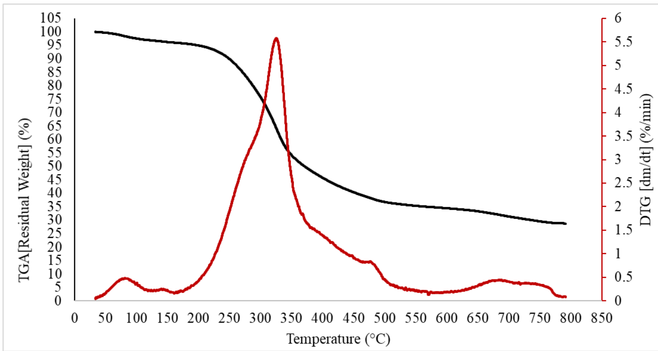

Fig 7. TGA-DTG curve (%) for Ashoka Leaves Raw

3.2 SEM-EDS Analysis

After pellet combustion, SEM-EDS analysis of Palm, Jackfruit, and Ashoka leaves reveals the metallic and inorganic elements present in the ash. SEM image (Figure 8) of Palm leaves pellet shows the granules and strand-like structure. It demonstrates that some strands remain in the ash even after combustion. The SEM images of Jackfruit and Ashoka leaves i.e., (Figure 9) and (Figure 10) respectively show the granular structure depicting complete burning.

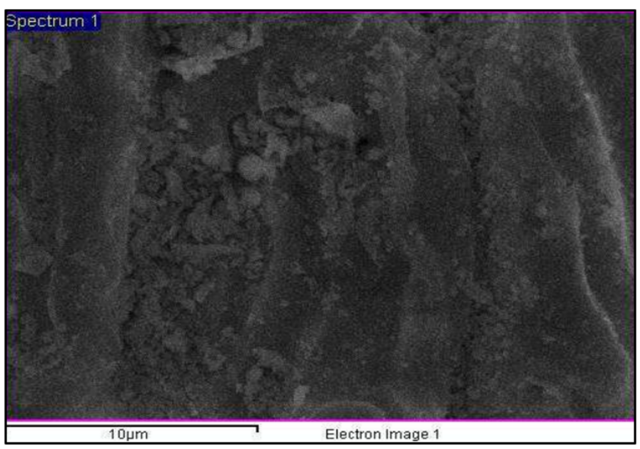

Fig 8. SEM-EDS Image of Palm Leaves Pellet Ash

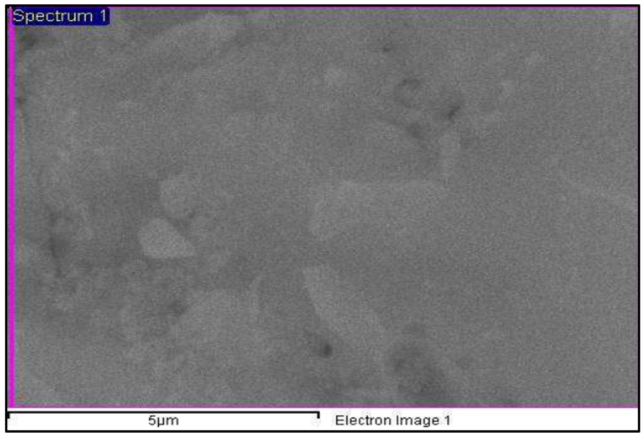

Fig 9. SEM-EDS Image of Jackfruit Leaves Pellet

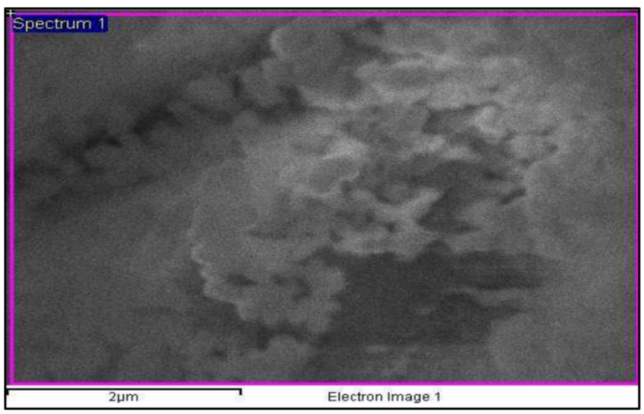

Fig 10. SEM-EDS Image of Ahsoka Leaves Pellets

Elemental characteristics of ash are given in Table 5. The ash from palm and Ashoka leaves pellets has a high silica concentration, allowing it to be used as an additional component to construct a wide range of structures but also depicts the danger of sintering in the reactor. A low potassium and chlorine concentration indicate that there won't be much corrosion in the reactors[31]. However, the oxygen concentration of 55.64, 43.71, and 51.04% in pellet ash indicate that the concentration of unburned char is minimum.

Table 5. Pellet Ash Elemental Characteristics

Element	Weight (%)		
	Palm	Jackfruit	Ahsoka
Carbon	11.21	36.31	16.96
Nitrogen	0.00	0.00	0.00
Oxygen	55.64	43.71	51.04
Sodium	0.91	0.61	0.16
Magnesium	1.21	0.75	0.13
Aluminum	0.78	0.00	0.00
Silicon	21.11	11.16	26.92
Phosphorous	0.41	0.25	0.00
Sulphur	0.32	0.17	0.15
Chlorine	0.62	0.21	0.40

Continued on next page

Table 5 continued

Potassium	3.30	2.53	3.79
Calcium	2.99	3.95	0.28
Titanium	0.00	0.00	0.00
Manganese	0.05	0.00	0.02
Iron	1.14	0.17	0.00
Nickel	0.20	0.03	0.07
Copper	0.13	0.16	0.09

4 Conclusion

Pollution of the air and land has increased recently. Risks to human health and the environment may result from burning dry leaves openly and negligently. As a result, this investigation involved the pelletization of commonly available palm, jackfruit, and Ashoka leaves. It has been identified as a promising solution in the pursuit of sustainable development and effective waste management. According to the physiochemical analysis and thermogravimetric analysis of the pellets made from these three types of biomasses, it offers a renewable energy source that can be effectively used for heating or power generation, making it an environmentally friendly substitute for fossil fuels. This novel approach resolves the issues with conventional tree leaves waste disposal techniques like burning or landfilling, both of which pollute the air and occupy the valuable land. The calorific value of Palm and Jackfruit pellets is 3414.4 and 3304.02 kcal/kg respectively is moderately good and can be improved by adding the Ashoka leaves waste having a higher calorific value of 3833.88 kcal/kg. Palm, Jackfruit, and Ashoka leaves pellets have excellent impact resistance values of 98.24, 98.87, and 99.06 % respectively. Also, the durability of pellets is above 90% which suggests the practicability of these pellets during storage and transportation. In broader terms, pellets made from Ashoka, Jackfruit, and palm leaves can be used as a source of biofuel. Thus, this initiative contributes to global efforts to reduce greenhouse gases and combat climate change as well as advancing a variety of sustainable development goals, including energy security, waste reduction, and resource utilization, all of which are crucial to achieve a more sustainable future. It is suggested that these leaves should be combined with a higher proportion of Ashoka leaves to produce a feedstock for fuel pellets with the optimum calorific value and high combustion efficiency for commercial use.

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