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Production and Characterization of Pellets from Agricultural Residue: Cotton, Tur, and Soybean

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Abstract: Substituting biomass for conventional sources of fuel can help to provide cleaner energy. Woody biomass pellets are gaining popularity in the primary energy industry. Agricultural biomass is either burned on the farm or used as fodder for animals recently, which releases toxic chemicals in environment. Locally cultivated crop waste has potential to be more environmentally benign than imported biomass. As a result, residues of locally grown Cotton, Tur, and Soybean crops were used for pelleting in this study. The collected residues were sundried and shredded to particle sizes ranging between 2.36 mm to 4.75mm. The pellets were prepared without binder by using pelleting machine. The proximate and ultimate analysis of crop residue and pellet samples was carried out to check characteristics and applicability of pellets as bioenergy source. The thermogravimetric analysis was conducted to check thermal behaviour and SEM-EDS analysis was carried out to detect the inorganics present in ash sample. The obtained calorific values of cotton, tur, and soybean pellets are 3696.57, 3487.83, and 3281.65 Kcal/Kg respectively and moisture content is below 10% for all three types of pellets. The findings showed that crop residue pellets as an alternative to conventional fuel sources provide superior economic and environmental outcomes.

Keywords: Crop Residue, Pelleting, Thermochemical Characterization, Thermogravimetric Analysis, SEM-EDS Analysis.

Graphical Abstract:

I. INTRODUCTION

The worldwide consumption of coal, natural gas, and crude oil is rising rapidly creating a major imbalance between supply and demand for energy [1]. Also, the fast depletion of conventional fossil fuels has increased the demand for bioenergy as a replacement. Worldwide commerce has grown in conjunction with increased demand, particularly for biodiesel and wood-based pellets. Global net commerce in bioenergy products increased from 200 PJ in 2004 to 610 PJ in 2015[2].

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Carbon dioxide emissions will rise by 70% with an 80% increase in fossil fuel consumption. While the energy and fuels derived from biomass are thought to be almost carbon neutral [3]. Forest biomass is scarce, and obtaining it is difficult. As a result, agricultural sources are more likely to provide the feedstock for bioenergy. Due to its wide availability and low cost, using agricultural biomass in combustion systems offers a huge potential to enhance the use of bioenergy[3.A][4]. Agricultural crop residues like wheat straw, maize, rice, sugarcane, cotton, tur, and soybean have become more popular as lignocellulosic feedstock as a result of the growing use of bioenergy as a substitute for fossil fuels [5]. However, due to their poor energy productivity and weak thermochemical characteristics, agricultural wastes are not suitable fuel sources [6]. The 141 million hectares of fertile land in India are used to create 800 Mt of agricultural and horticultural products each year. Between 90 and 140 Mt of the excess leftovers are burned on fields each year [7][8]. Agricultural wastes can be transformed into solid biomass briquettes or pellets to provide a sustainable fuel supply. According to research conducted by various researchers, a significant portion of rural Indian families still relies on traditional cooking methods that involve the use of firewood or agricultural and animal waste.

64% of these families still use firewood as their primary cooking fuel [9]. This has resulted in an alarming rate of deforestation and environmental degradation in these areas. However, there is hope for a more sustainable future. Modern biomass energy systems are becoming increasingly available for decentralized use in rural regions, providing a cleaner and more efficient alternative to traditional fuels[10][11][12]. By adopting these new technologies, India's rural communities can help to mitigate the negative impact of cooking practices on the environment and thus improve the quality of life. Cotton cultivation in India accounts for around 37% of total cotton cultivation worldwide[1]. Similarly, India is one of the world's top cotton producers according to the cotton advisory board, accounting for around 23% of worldwide cotton production and 25% of global cotton consumption, making it one of the world's largest cotton consumers. Furthermore, according to Food and Agricultural Organization (FAO) Statistics 2018, India leads the world in both pigeon pea (Tur) crop area (64%) and production (57%). While the soybean crop continues to be significant as the world's most important seed legume, India ranks fourth in terms of soybean production. Biomass generated from these crop residues is majorly burned in the field or utilized as fodder causing various health and environmental hazards[13][14]. Therefore, in this study residue of cotton, tur, and soybean crop were considered as feedstock for pelletization. Prior research comparing agricultural pellets to wood pellets concluded that agricultural pellets are going to surpass wood pellets economically, sustaining the wood pellet market[15]. The global search for new raw materials is intensifying. Previously, several researchers used a variety of agricultural, forest, and garden leftovers for pelleting. Z. Kazimierz pelleted soybean waste, as well as chamomile trash, birch sawdust, and pea waste[16] H. Xiao researched rice straw pellets, whereas Liu X. investigated rice husk and wood pellets utilising proximate analysis and heating value [17], [18]. Liu Zhijia studied bulk density and calorific value of bamboo biomass pellets[19] and W. Xinwen studies the banana leaf fibre-based biomass pellets[20]. V. Civitarese and A. Acampora pelleted poplar wood chips and hazelnut and olive tree pruning to detect several features such as diameter, length, moisture content, ash melting point, lower heating value, and nitrogen, sulphur, and heavy metals[20.A], [21]. However, there is a lack of literature on cotton, tur (pigeon pea), and soybean crop residue pelleting and thermochemical analysis. Therefore, crop residue pellets were characterized in this study using a variety of physical, mechanical, and chemical examinations.

II. MATERIALS AND METHODOLOGY

2.1 Collection and Preparation of Crop Residue

Cotton, tur, and soybean residues were collected from farmers in Maharashtra's Yavatmal district. 50 kg of each cotton, tur, and soybean crop residue was collected and sundried for 15 days to remove unnecessary moisture. Dust and other impurities were removed before further physical and chemical evaluation. Crop residue was subsequently shredded to particle sizes ranging from 3 mm to 4.75 mm using a hammer mill equipped with a cyclone separator, as shown in Figure 1, and stored for future use.

Figure 1: Hammer Mill and Shredded Biomass

2.2 Palletisation of Crop Residue

The primary examination and manufacturing of the pellet were carried out by considering the unique characteristics and composition of each crop residue. In primary examination moisture content, particle size, and structure of crop residue were observed. To produce the pellets, collected and sun-dried cotton, tur, and soybean crop residue were transported to the pelleting mill. Crop residue was pelleted using a semi-automatic flat die pellet mill with two pressure rollers, a 3 hp motor power, 1440 rpm motor, an 8 mm die hole diameter, a 320 mm die ring diameter, and an output capacity of 80 to 100 kg per hour.

Before generating the pellet, a small amount of water was sprayed on the crop residue with a hand spray to ensure proper binding. Crop residue was fed into the pellet mill through the feed hopper and allowed to pass through the upper box with the pressure roller and die assembly illustrated in Figure 2, and pellets were collected from the discharge hopper. Then, proximal and ultimate analysis was used to examine these pellets.

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2.3 Characterisation of Crop Residue and Its Pellets

To determine whether crop residue is suitable for pelletizing, its characteristics must be examined physically and chemically, which also influence how it performs as a fuel. Bulk density, volatile content, fixed carbon, ash concentration, moisture content, and thermal behaviour are all intriguing physical properties of crop residue and pellets. The particle size employed for pelleting was determined through sieve analysis of loose crop biomass. Proximate analysis was used to evaluate these characteristics. Similarly, heating value analyses and ultimate analyses were carried out to determine the elemental composition and thermal attributes of a fuel.

Figure 2: Pelleting Mill and Pellet Samples

2.3.1 Proximate Analysis

The proximate analysis includes the calculation of the moisture content, volatile content, ash concentration, and fixed carbon content. A Muffle furnace was used to carry out the proximate analysis. The moisture content of the crop residue was calculated using code ASTM D3173-11, volatile and ash content of the crop residue was determined using code ASTM D3175 and ASTM D3174 respectively, by knowing these two values total fixed carbon was calculated by using following Equation 1.

Equation 1

$$\begin{aligned} &\mathit{Total\ Fixed\ carbon} \\ &= \mathit{Total\ Sample\ Weight} \\ &- \mathit{Moisture\ Content} \\ &+ \mathit{Volatile\ Content} + \mathit{Ash\ Content} \end{aligned}$$

2.3.2 Ultimate Analysis and Biomass Heating Value Determination

Crop residue samples were analysed for carbon, hydrogen, nitrogen, sulphur, and oxygen by carrying out the ultimate analysis. CHN Thermo Finnigan flash EA 1112 analyser determined carbon, hydrogen, and nitrogen. Code ASTM E775-87 was used to determine the sulphur content. While oxygen content was determined by subtracting the weight of carbon, hydrogen, Nitrogen, and sulphur from the total weight of the biomass sample. The heating value of the crop residue pellet was calculated using a bomb calorimeter as shown in Figure 3 by following the procedure given in the code ASTM D5865-13.

Figure 3: Assembly of Bomb Calorimeter

2.3.3 Thermogravimetric Analysis (TGA)

In TGA, biomass was studied for its thermal degradation and disintegration. A thermogravimetric analysis (TGA) machine from Hitachi, the STA7300, was used in this study to investigate biomass fuels. It comprises heating a small sample of feedstock under controlled conditions and measuring the mass change as a function of temperature or time. The biomass sample was first dried at a specific temperature to remove any moisture. The sample was reduced to a fine powder to ensure even heating during the TGA examination and placed on a sample pan to be examined. The sample pan was then placed in the TGA instrument, which warms the sample at a rate of 10 degrees Celsius per min. The mass loss curve (TGA vs temperature) and its derivative (DTG vs temperature) were demonstrated. In addition to the TG and Differential Thermo Gravimetry (DTG) curves of crop residue pyrolysis, which represents the degradation of biomass, Differential Scanning Calorimetry (DSC) curves were used to identify the energy consumption trade in pyrolysis.

2.3.4 Analysis of Physical Properties

Physical properties play a crucial role in the usage of pellets as a fuel source in terms of storage, transportation, and handling. The physical attributes like length and diameter of the pellet were calculated using a Vernier Caliper having an accuracy of 0.1 mm and the mass of the pellet was measured using a digital weighing balance having a measuring accuracy of 0.01g. After measuring the diameter (d), length (l), and mass (m) of pellets, bulk density (σ_w) was calculated using Equation 2.

Equation 2

$$\sigma_w = \frac{4 \times m}{\pi \times d^2 \times l}$$

2.3.4.1 Shattering Resistance

Shattering resistance is an important aspect of biomass pellets as it is associated with the transportation and handling of biomass pellets. The shattering resistance of the pellets was measured by dropping each pellet from a height of 1.85m on a metal plate. A similar procedure was repeated 6 times and an average was taken to get more precise results. Shattering resistance was measured using Equation 3 and Equation 4:

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Equation 3

$$\text{weight Loss}\ (\%) = \frac{(M_1 - M_2)}{M_2} \times 100$$

Equation 4

$$\text{Shattering Resistance}\ (\%) = 100 - \text{Weight Loss}\ (\%)$$

Where M_1 and M_2 are the initial weight of the pellet before dropping (g) and the final weight of the pellet after dropping (g) respectively.

2.3.4.2 Durability of Pellet (Tumbling Resistance)

Pellet durability is critical for pellet storage and long-term use. In this test, a known-weight pellet was taken and stored in a box with a cover. The box was shaken vigorously for 10 minutes at a speed of 50 rpm. The pellets were then allowed to pass through a sieve size 0.8 times the diameter of the pellet (4.75 to 6.3 mm)[22], and the weight loss was recorded and durability was calculated by using Equation 5.

Equation 5

$$\text{Tumbling Resistance}(\%) = \frac{D_2}{D_1} \times 100$$

Where, D_1 and D_2 refer to the weight of pellet before tumbling (g) and weight of pellet after tumbling (g) respectively.

2.3.5 Analysis of Ash Constituents

Ash analysis of biomass pellets was carried out to determine the composition of the inorganics present in the pellets after burning as it can cause the rusting of metals in a processing unit. Ash constituents of the fuel pellets were determined using energy dispersive spectroscopy in conjunction with JEOL JSM-7600F field emission scanning electron microscope.

III. RESULTS AND DISCUSSION

The investigations conducted in this study used cylindrical pellets of cotton, tur, and soybean crop residue to examine the physical, chemical, and thermal qualities affecting the transportation, storage, and handling of pellets. Crop residue has been researched for its viability and efficiency as a fuel source.

3.1 Characterisation of Crop Residue Feedstock

The results obtained from the proximate analysis and bulk density of crop residue samples are given in Table. 1. Moisture content is present in biomass impacts its combustion characteristics therefore it is necessary to have moisture content well within the permitted limit for fuel use. The moisture content obtained from cotton, tur, and soybean crop residue was 6.89±1.0%, 6.48±1.4%, and 6.71±0.9% respectively, which is below 10% and therefore acceptable according to standards given by the Government of India, Ministry of Power. Similar to this, volatile matter content in biomass affects its calorific or heating value. Higher volatile content in biomass results in better combustion because it has a higher heating value and lower combustion temperature. Good combustion was indicated by the volatile matter levels detected in the cotton, tur, and soybean residues, which were 73.46±1.5%, 73±2.3%, and 76.66±1.7%, respectively. The fixed carbon content of biomass indicates the presence of non-volatile materials. A high level of fixed carbon indicates a slower rate of burning. Cotton, tur, and soybean crop residues each had fixed carbon contents of 11.91±0.2%, 11.63±1.0%, and 10.96±0.5%, respectively. The ash created by the combustion process creates additional waste in the reactors or boilers. To limit trash generation, biomass feedstock with a low ash concentration is required. The ash content of cotton, tur, and soybean crop obtained from the study was 7.74±1.2%, 8.89±0.6, and 5.67±1.6 respectively, which is very less and acceptable. The bulk density of crop residues was calculated, to get the difference in densities before and after palettization to find out whether storage and handling problems are being resolved. The bulk density of cotton, tur, and soybean crops calculated was 170.33, 236, and 184.33 Kg/m3 respectively. Then the particle size distribution of biomass feedstock was studied by using IS sieves. The result of the sieve analysis shown in Figure 4 indicates that more than 75% of particles of each cotton, tur, and soybean crop residue are passing through the 2.36 mm sieve. As a result, according to the guidelines of the Government of India's Ministry of Power, it is acceptable to use this biomass for pelleting.

Table 1:Proximate analysis and bulk density of crop residue

Sr. No.	Crop Residue Sample	Composition (Wt. %)				Bulk Density (Kg/m^3)
		Moisture Content	Volatile Content	Fixed Carbon	Ash Content	
1.	Cotton Residue	6.89±1.0	73.46±1.5	11.91±0.2	7.74±1.2	170.33
2.	Tur Residue	6.48±1.4	73±2.3	11.63±1.0	8.89±0.6	236
3.	Soybean Residue	6.71±0.9	76.66±1.7	10.96±0.5	5.67±1.6	184.33

Table 2:Sieve analysis of crop residue

Sieve Size	% Retained		
	Cotton	Tur	Soybean
>4.75mm	0	0	0
4.75mm> x >2.36mm	20.77	1.75	8.16
2.36mm> x >1.18mm	33.88	34.4	46.70
1.18mm> x >600µm	25.74	25.20	28.12
600µm> x >300µm	13.17	27.15	12.36
300µm> x >150µm	4.67	10.92	2.42
150µm> x >90µm	0.25	0.36	0.42
>90µm	0.45	0.16	0.59
Pan	1.05	0.04	1.15

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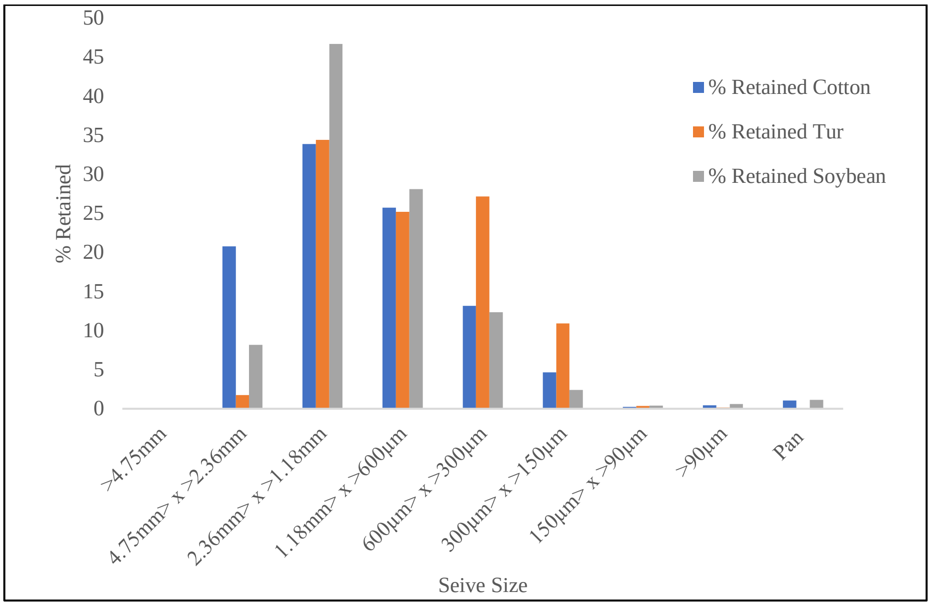

Figure 4: Particle size distribution of biomass

3.2 Characterisation of Crop Residue Pellet

The dimensional analysis of crop residue pellets was performed in accordance with the ISO 17829:2015 standard. Pellets made from cotton, tur, and soybean crop residue have diameters of 8±0.1mm and lengths of 32±3mm. As the die hole diameter was 8mm, a little change in diameter may have occurred due to physical swelling and moisture liberation during die press release, and a difference in length may have occurred due to temperature changes in the processing unit and outlet hopper [23], [24]. The moisture content of cotton, tur, and soybean crop residue pellets was measured using the oven drying method by keeping the sample in a hot air oven for 24 hr at 100±5°C and found to be 8.51±0.9%, 7.24±0.7%, and 6.43±1.3%, respectively. Volatile matter calculated for cotton, tur, and soybean crop residue pellets were 68.35±1.9%, 72.55±1.1%, and 71.78±1.2% respectively. The volatile matter present in tur and soybean pellets suggests good combustion and lower smoke release, whereas the lower value of cotton pellets implies higher smoke release and incomplete combustion[25]. The amount of fixed carbon obtained for cotton, tur, and soybean crop residue pellets was 13.14±2.1%, 9.75±1.6%, and 11.61±0.8% respectively. These fixed carbon values are acceptable because they represent a longer duration of heat release and slow combustion[26]. Similarly, ash content obtained from experiments for cotton, tur, and soybean pellets was 10.00±0.6%, 10.46±1.0%, and 10.18±0.3 % respectively. Higher values of ash content indicate higher dust content and also higher deposition of waste in reactors[27] while the obtained values are acceptable according to guidelines given by the Government of India, Ministry of Power. The bulk density of cotton, tur, and soybean pellets was 821.47, 820.62, and 808.57 Kg/m3 which was a significant increase of nearly 4 times that of loose biomass shown in Table 3. This rise in bulk density value will alleviate the problem of biomass handling, storage, and transportation while also making its use more cost-effective. The values of shattering resistance and tumbling resistance for cotton, tur, and soybean pellets are given in Table 4. The shattering resistance values indicate that crop residue pellets have retained their fibrous structure instead of disintegrating. While the tumbling resistance value indicated the higher durability of the pellets and durability values above 90% are acceptable [28]. The shattering resistance and durability of pellets are the important characteristics influencing the storage, handling, and transportation of pellets [29].

Table 3:Proximate analysis and bulk density of crop residue pellets

Sr. No.	Crop Residue pellet Sample	Composition (Wt. %)				d (mm)	l (mm)	Bulk Density (Kg/m^3)
		Moisture Content	Volatile Content	Fixed Carbon	Ash Content			
1.	Cotton Residue	8.51±0.9	68.35±1.9	13.14±2.1	10.00±0.6	8±0.1	32±2	821.47
2.	Tur Residue	7.24±0.7	72.55±1.1	9.75±1.6	10.46±1.0	8±0.1	32±1	820.62
3.	Soybean Residue	6.43±1.3	71.78±1.2	11.61±0.8	10.18±1.3	8±0.1	33±2	808.57

Table 4: Mechanical properties of crop residue pellets

Sr. No.	Crop Residue Pellet Sample	Shattering Resistance (%)	Tumbling Resistance (%)
1.	Cotton Residue	93.43±2.0	95.41±1.1
2.	Tur Residue	96.83±2.4	96.30±0.8
3.	Soybean Residue	97.28±1.4	98.50±0.7

3.2.1 Thermogravimetric Analysis

The TG, DTG, and DSC curves for crop residue pellet samples were studied to determine the combustion parameters thermal stability, breakdown rates, and composition of the biomass as shown in Table 5 and Table 6. TGA vs temperature and DTG vs temperature were plotted to show the mass loss curve and its derivative respectively. Furthermore, DSC curves illustrating the energy consumption pattern in Crop residue pyrolysis were obtained along with TG and DTG curves, which represented crop residue degradation. The moisture content, volatile matter, residual matter, burnout temperature, and ignition temperature have been interpreted from the graph formulated shown in Figure 6, Figure 5, and Figure 7 below. Burnout and ignition temperatures have been found using the Intersection Method. The ignition temperature for cotton, tur, and soybean pellets is 240°C, 240°C, and 260°C respectively and the burnout temperature is 450°C,500°C, and 390°C respectively. By delaying the initiation of fire, the ignition temperature values indicate the safety against fire during storage. The burnout temperature indicates the highest temperature needed to ensure complete biomass pellet combustion in the reactor or processing unit. The slight difference in the values of moisture content, volatile matter, and residual matter obtained from TGA and obtained from the experimental procedure is due to environmental factors and human errors. But values obtained from TGA are also within permissible limits given by the Government of India, Ministry of Power, and are more favourable. Cotton, tur, and soybean residue pellet TG-DTG curves show three stages of degradation. The first stage of the cotton residue pellet TG-DTG curve Figure 4 shows 7.29% deduction in weight due to moisture loss, which observed between 36°C and 180°C. From 180-198°C little to no weight loss was observed. The second stage, that has a larger peak, illustrates an 80.50% weight loss between 198°C and 450°C as a result of hemicellulose and cellulose degradation and the emission of volatile materials. Due to lignin degradation, 4.22% percent weight loss was detected in the third stage from 450°C to 798°C. Following that, the weight of the residue remained steady at 7.99%, indicating residual matter in the sample that does not combust further. Similarly, three stage degradation data of tur and soybean residue pellet is shown in Table 6.

Table 5:Thermogravimetric analysis data

Crop residue pellet sample	Composition (Wt. %)			Ignition Temperature (°C)	Burnout Temperature (°C)
	Moisture Content	Volatile Matter	Residual Matter		
Cotton Residue	7.29	84.72	7.99	240	450
Tur Residue	8	84	8	240	500
Soybean Residue	6.17	68.32	25.48	260	390

Table 6:Inference from TG-DTG curves

Parameters	Cotton Residue	Tur Residue	Soybean Residue
Temperature Range of Moisture Loss (°C)	36-180	36-153	35-128
Temperature Range of Hemicellulose-Cellulose Degradation (°C)	198-450	188-514	186-392
Temperature Range of Lignin Degradation (°C)	450-802	514-805	392-800
Composition of Hemicellulose-Cellulose Degradation (%)	80.50	79.92	54.39
Composition of Lignin Degradation (%)	4.22	4.27	13.06

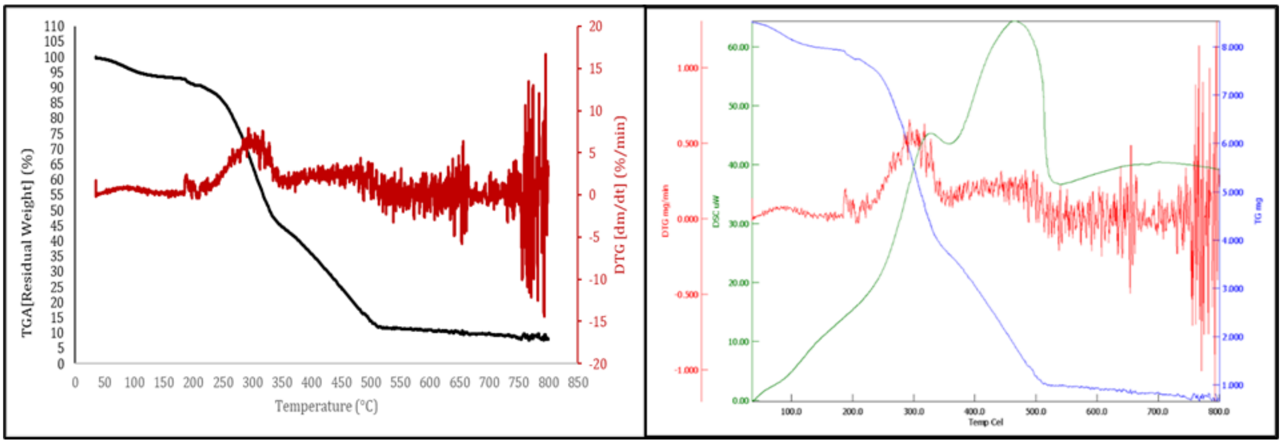

Figure 5: Representation of TGA-DTG-DSC data for tur crop residue pellet.

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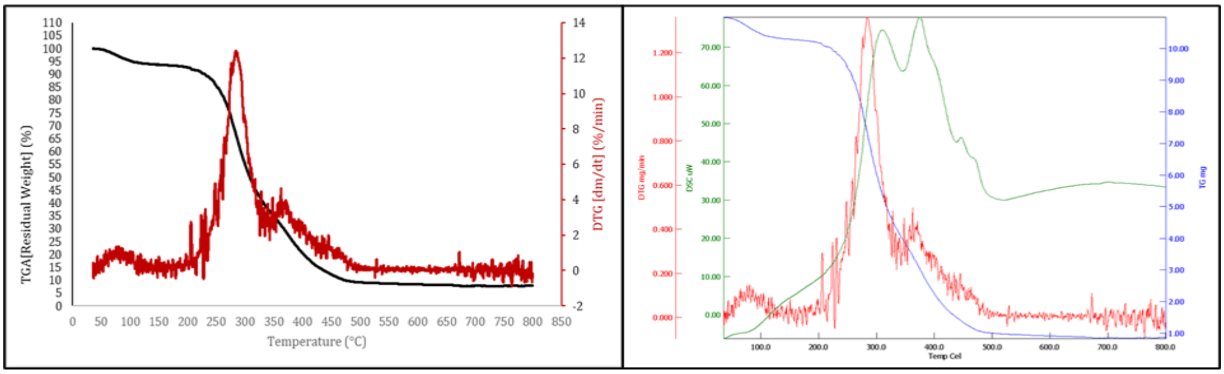

Figure 6: Representation of TGA-DTG-DSC data for cotton crop residue pellet

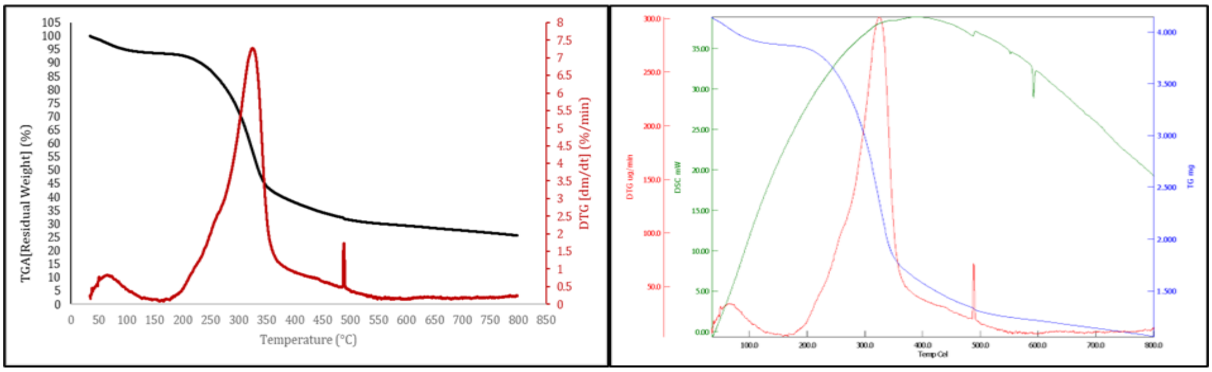

Figure 7: Representation of TGA-DTG-DSC data for Soybean crop residue pellet

3.2.2 Ultimate Analysis and Higher Heating Value of Crop Residue Pellets

The results of ultimate analysis and higher heating value are given in Table 7. It is a chemical analysis that identifies the carbon, hydrogen, sulphur, nitrogen, and oxygen content of crop residue pellets[30]. Generally, biomass contains a higher amount of carbon and oxygen which makes it suitable as fuel. Higher values of oxygen 53.18%, 54%, and 53.16% in cotton, tur, and soybean pellets respectively signify less need for air during combustion. while the lower values of nitrogen and sulphur given in Table 7 indicate a lesser amount of nitrogen oxides and sulphur oxides emissions, making it a viable fuel source. The obtained higher heating or calorific values of cotton, tur, and soybean pellets are 3696.57, 3487.83, and 3281.65 Kcal/Kg. These values are quite close to the calorific value of low-quality coal, as a result, crop residue pellets can be used as a fuel source in conjunction with coal.

Table 7:Ultimate analysis data and calorific value of crop residue pellets

Crop residue pellet sample	Composition (Wt. %)					HCV of pellet sample (Kcal/Kg)	NCV of Pellet Sample* (Kcal/Kg)
	Carbon	Hydrogen	Nitrogen	Sulphur	Oxygen		
Cotton Residue	40.70	5.58	0.54	0	53.18	3696.57	3401.78
Tur Residue	39.72	5.68	0.60	0	54	3487.83	3181.31
Soybean Residue	40.38	5.80	0.66	0	53.16	3281.65	2981.68
HCV-Higher Calorific Value, NCV- Net Calorific Value (*Calculated by Dulong's formula)							

3.2.3 Analysis of Ash Constituents

SEM photographs of the ash created by burning pellets of cotton, tur, and soybean crop residue were used to examine the surface morphology of the ash. Shown in Figure 8. It displays erratic lignocellulosic structures, which suggests that the ash did not condense sufficiently into spheres and further combustion is possible. Ash constituents were obtained from the EDS spectrum shown in Table 8. According to the table, cotton, tur, and soybean pellet ash are made up of several minerals, including sodium, magnesium, aluminium, silica, potassium, calcium, titanium, iron, manganese, nickel, copper, etc. Fuel thermochemical reactions including combustion, pyrolysis, and gasification are typically increased when Na and K are present.[30] However, the potassium in the area can cause metals in the processing unit to corrode. Pre-treatment with water washing and the addition of potassium sorbent to prevent potassium contamination can help to decrease harm[31][32]. Because the ash contains silica, it can be used in a variety of construction projects.

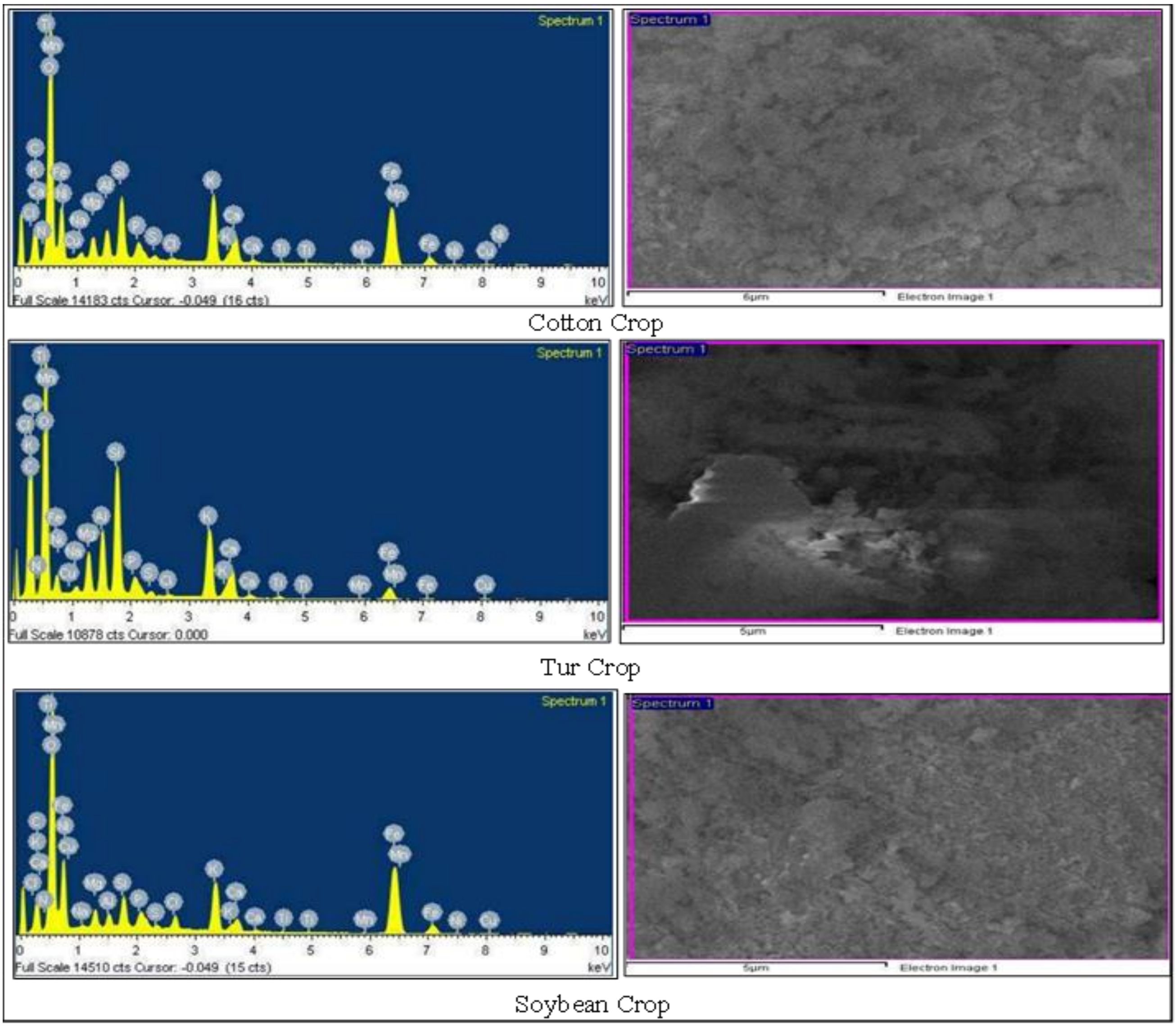

Figure 8:SEM-EDS images of crop residue pellet ash

Table 8: Ash constituents obtained from SEM-EDS

Element	Weight%		
	Cotton	Tur	Soybean
C	5.51	23.25	5.99
N	0.00	0.00	0.00
O	42.22	42.69	39.25
Na	0.67	0.43	0.35
Mg	1.76	2.17	1.63
Al	1.94	2.52	0.98
Si	4.48	6.17	2.47
P	0.77	0.80	0.68
S	0.43	0.37	0.40
Cl	0.28	0.23	1.50
K	8.14	8.38	6.66
Ca	3.99	4.67	1.77
Ti	0.07	0.31	0.06
Mn	0.12	0.12	0.09
Fe	29.76	7.75	37.91
Ni	0.07	0.04	0.06
Cu	0.15	0.10	0.20
Total	100		

IV. CONCLUSION

This research proved that cotton, tur, and soybean crop residue pellets can be used as an alternative feedstock for fuel pellets, hence reducing waste disposal challenges. The physical and chemical properties of cotton, tur, and soybean crop residue pellets revealed that the moisture content is less than 10%, shattering resistance is greater than 90%, and pellet durability is greater than 90%, all of which meet the standards set by various international and national organizations. According to the criteria of the Government of India's Ministry of Power, the calorific values determined for cotton and tur residue pellets,3696.57Kcal/Kg and 3487.83Kcal/Kg respectively, are within permissible limits. The calorific value of the soybean residue pellet is 3281.65 Kcal/Kg, which is a little lower than expected due to higher residual matter. According to the TG analysis, hemicellulose and cellulose have thermal breakdown zones in the 220-315°C and 315-400°C temperature ranges, respectively, with the highest mass losses occurring from 268°C to 355 °C in all three cases.TG study also found that the biomass pellets produced posed no fire risk due to their higher ignition temperature. Because the nitrogen concentration of the pellet is extremely low and the Sulphur content is undetectable, the pellet does not generate any hazardous pollutants such as nitrogen oxide and Sulphur oxide during combustion.

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SEM-EDS analysis of ash revealed that ash does not contain any harmful inorganic compounds and can be used as a construction material due to the presence of a high amount of silica. Overall, it can be inferred from this study that pellets generated from cotton, tur, and soybean crop residue can be used as a fuel source and provide economic benefits in rural regions. It is advisable from the study to combine these three crop residues in the future to produce a pellet with a higher calorific value.

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NOMENCLATURE

Mt: Million tonnes
PJ: Peta Joules
FAO: Food and Agricultural Organization
TGA: Thermogravimetric Analysis
DTG: Differential Thermo Gravimetry
DSC: Differential Scanning Calorimetry
EDS: Energy Dispersive Spectroscopy
SEM: Scanning Electron Microscope
HCV: Higher Calorific Value
NCV: Net Calorific Value

DECLARATION

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