Bananaroot Waste Valorization as Alternative Fuel

S. Raji, D. D. Sarode

***Abstract:** Around the world, one of the significant difficulties confronting numerous countries is the energy crisis and proper disposal of waste. 'Jalgaon' a city in the state of Maharashtra (India) is referred to as 'Banana City' as it produces half of the state's Banana production. In Jalgaon, banana cultivation is carried out in about 45,000 hectares of land. Here, the accumulation of waste roots post-harvest, about 67000 MT, is huge, creating environmental issues. The open dumping of waste roots occupies a huge problem limiting the valuable space in the field. The purpose of this study was to explore an appropriate method to dispose of the banana root waste efficiently. No study has been reported yet to effectively use banana root waste as fuel pellet. In this work, pellets were made out of the banana root waste, without additional binder, and the combustion properties such as proximate analysis, ultimate analysis, high heating value, and thermal decomposition behaviour were studied. The high heating value of the pellets was observed as 16.29 MJ/kg. The results of ash elemental analysis by Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscopy (EDX) detector showed that ash can be used as adsorbent and fertiliser. The work attempts to convert the banana root into a fuel of good commercial value thereby addressing the waste disposal issue after harvest.*

***Keywords** – Biomass, Banana root; Waste; Fuel; Pellet; Waste conversion.*

I. INTRODUCTION

World's second-largest fruit produce, Banana, with an expected gross production surpassing 139 million tonnes (Food and Agriculture Organization of the United Nations - FAO, 2017). The world's prominent banana and plantain growers are India, China, Uganda, Ecuador, Philippines, and Nigeria. India ranks first in banana production, contributing about 23 % in the world pool of banana production. Maharashtra, Tamil Nadu, Gujarat, Madhya Pradesh, Andhra Pradesh, Karnataka, and Assam are the main Banana producing states in India. In Maharashtra, banana is primarily grown in Jalgaon in Western Maharashtra (Sarode and Agriculture, 2009). The scientific name of Banana is Musa acuminata and Musa balbisiana (Padam et al., 2014). Bananas are mainly cultivated for their fruits; thus, banana farms generate several tons of underused by-products and wastes post-harvest. Moreover, the adoption of tissue culture has reduced the use of sucker plants for replanting, thereby increasing the waste generated post-harvest. Therefore, due to improper agricultural waste management practice, a huge amount of valuable untapped commodity is lost, also causing serious ecological damages (Padam, Tin, Chye, Abdullah, et al., 2014). Several studies have been reported to improve the usage of banana by-products to meet the escalating demand for raw materials supply in various industries (Emaga et al., 2011). Although we have found various studies for use of banana stem, peels, leaves, and other parts, no study has been reported to effectively utilize banana root (Padam, Tin, Chye and Abdullah, 2014). Also, investigation on the banana root in pursuit of energy recovery has not been attempted yet.

The study intends to find an alternate means to dispose of banana root waste utilizing energy recovery. The goal of this study is to study the energy content of banana root pellets, delivering a high-quality fuel pellet.

II. MATERIALS AND METHODS

2.1 Collection and Preparation of Banana root waste

About 600 kg of banana root waste were collected post-harvest, from Khiroda, a village located in the Satpuda Hills 7 km north of Savda in Jalgaon district. The samples were cleaned and sundried for 21 days to reduce the moisture level of the samples. The moisture content of banana root samples after sun drying was 10.58 % against the as-received moisture composition of 18.60 %. The samples were then shredded and chipped to a size of 4-6 mm and stored for further characterization.

Fig 1. Banana root waste

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2.2 Characterization of sample

Proximate Analysis was done to determine the moisture content, volatile matter, fixed carbon, and ash content present in the sample. ASTM E790 was followed to determine the moisture content of the sample while ASTM E897 and ASTM E830 were used to determine the volatile and ash content of the sample. The fixed carbon content was determined by the difference between the total weight of the sample and the sum of moisture, volatile, and ash content of the sample. The analysis was done in triplicate to have a consistent result. The elemental analysis was conducted using a CHN Thermo Finnigan Flash EA 1112 analyser. (ASTM E777-08) was used to determine carbon, hydrogen, and nitrogen present in the sample while ASTM E775-87 was used to estimate the elemental sulphur present in the sample. The oxygen was calculated by the difference between the total weight of the sample and the sum of carbon, hydrogen, nitrogen, and Sulphur contained in the sample. The gross calorific value (HHV) of the sample was determined using an oxygen bomb calorimeter (Model: IKA C 200). ASTM E 711 was the standard reference used for the analysis.

2.3 Pelleting process

Banana root feedstock was pelletized using flat die type, 8mm diameter, 5 HP Motor, a pelleting machine with an output capacity of 25- 75 kg/hr. The pellets produced were allowed to cool at room temperature and packed in sealed plastic bags for further analysis.

2.4 Pellet quality parameters

The pellet quality was assessed by measuring moisture content of the pellet by digital moisture meter, dimensions of the produced pellets such as length and diameter were measured using a digital Vernier calliper, particle density was found out by ratio of mass to volume. Tumbling resistance measurement is conducted to test the durability of the pellets. Pellet sample of 250 grams was taken in a container and was covered with a lid. The container was rotated at 50 r.p.m for 15 min. Then, the weight loss of pellet was noted. Durability was calculated by the ratio of weight of the pellet before tumbling to that of pellet after tumbling.

2.5 Pellet performance parameters

The output capacity (kg h^{-1}) of pellet machine is measured by the amount of pellet produced per hour without choking and was found out by weighing the pellets produced at an interval of 15 minutes. The pellet residue or fines was determined by finding the ratio of weight of fines generated to weight of pellet taken and run for 15 minutes. The readings taken two times each run and average is taken.

2.6 Analysis of results

The statistical software tool Minitab version 18.0, was used for analysing the data by ANOVA. Multiple linear regression was used to study the influence of feedstock moisture (mc_f), milling size (m_s) and diameter of die hole (D_{dh}) on pellet quality parameters. Regression model equation with more than one independent variable and interaction terms are quadratic terms and the equation is

$$Z=\beta_0+\beta_1\times X_1+\beta_2\times X_2+\beta_3\times X_3+\beta_4\times X_1^2+\beta_5 X_2^2+\beta_6\times X_3^2+\beta_7\times X_1\times X_2+\beta_8\times X_1\times X_3+\beta_9\times X_2\times X_3+\beta_{10}\times X_1\times X_2\times X_3 \quad (1)$$

Where, X_1, X_2 and X_3 are variables

X_1	Feedstock moisture content (mc_f)
X_2	Milling size (m_s)
X_3	Die hole diameter (D_d)
Z	Pellet quality parameter (response variable)

The models were developed for all pellet quality parameters, its linear, quadratic and interaction terms which were not statistically significant were removed from the models. Factorial approach was used for design of experiment with 16 runs. Details of experiment run, predictor and responses are shown in Table 2.

2.7 Ash constituent analysis

Ash analysis was performed on the pellets to determine the composition of inorganics present in the pellets. Ash elements were determined using a JEOL JSM-7600F Field Emission scanning electron microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscopy (EDX) detector.

III. RESULTS AND DISCUSSION

3.1 Characterisation of Banana root waste feedstock

The results obtained from the characterization of the banana root feedstock and fuel pellets were presented in Table I. The volatile content of the banana root feedstock sample was 64.89 % which influences the thermal degradation behaviour of the sample fuel pellet (Molina-Moreno et al., 2016). The values obtained for volatile matter and fixed carbon of banana root is comparable to switchgrass and corn stove (Tumuluru et al., 2012). The carbon content and the HHV were 47.5 ± 1.7 % and 15.27 ± 0.6 MJ kg $^{-1}$, which is comparable to that of any agricultural or herbaceous biomass (Gravalos et al., 2016). This low heating value could be due to its high ash content (13.66 %). Higher ash content contributes to the lower heating value of the pellets and a greater risk of sintering. Further, high ash content affects the milling process (Garcia-Maraver et al., 2015). Compared with other fuels (such as coal or peat), biomass contains relatively high amounts of oxygen and hydrogen. This high oxygen content makes biomass a good fuel although oxygen itself does not contribute toward the energy value of the fuel. The higher oxygen content results in reduced air (oxygen) requirements during the combustion reaction (Caillat and Vakkilainen, 2013). The presence of less percentage of nitrogen content indicates that all these samples will not release significant NOx emission when combusted. It is interesting to note that the sulphur content was not detected in banana root samples. This indicates that banana root as fuel will not emit sulphur oxides when combusted thereby not polluting the environment. Generally, samples with low nitrogen and sulphur content release less emission (De Oliveira Maia et al., 2014; War et al., 2016).

3.2 Characterisation of Banana root waste fuel pellet

The moisture content of the pellet was measured using a digital moisture meter after 2 to 3 hours after the pellets were produced. The moisture content of pellets was also measured by the oven drying method, 105°C for 24 hours. The average moisture content of the pellet was 8.67 %. Pellet diameter and length were measured by digital Vernier calliper and an average of ten random samples were taken.The average length of the estimated pellet samples varied from 46 mm to 65 mm. The average diameter of the pellets was 8 mm. The average weight of individual pellets varied from 4.80 g to 5.46 g was estimated for the sample. Bulk density of the banana root waste increased to 816 kg m^{-3} after pelletizing. Higher bulk density pellets improve high energy per unit volume of material (Densification et al., 2007). Also, indicates that a longer burning time and a large quantity of heat will be produced during combustion (Obernberger and Thek, 2004). From the above results obtained, the moisture content of pellets made of banana root waste was 8.97 %. The pellets had a shiny surface and no cracks seen on the surface. The volatile combustible matter content in the fuel pellet was observed to be 65.33± 0.2 % which represents low value, leads to incomplete combustion results significant amount of smoke (Obernberger and Thek, 2004). The percentage of fixed carbon for biomass pellet samples was 11.88 ± 0.6 and this value is favourable, as it aids in slow-burning of fuel, resulting in prolonged heat release (Akowuah et al., 2012). The highest ash content was observed at 14.12 ± 0.2 %. Higher ash content in a fuel indicates higher dust emissions, affects the combustion volume and efficiency. Also, high ash content of the fuel pellet will lower its calorific value (Puig-Arnavat et al., 2016). In the present investigation, the high heating value of the banana root waste fuel pellet was found to be 15.27 ± 0.2 MJ kg $^{-1}$. In comparison with various international standards (CEN/TS 14588, ISO 17225-6) for most agricultural residues, the HHV is about 14.98–16.98 MJ kg $^{-1}$(Sheng and Azevedo, 2005; US-EPA et al., 2012). The fuel pellet samples tested have reasonably good heating values, indicates that banana root waste can serve as a good fuel that could be used for both commercial and industrial heating applications.

Table 1: Characterisation of banana root waste feedstock and fuel pellet

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Characteristics	Analysis (Reference)	Banana root waste	Banana root pellet
Moisture content (%dry basis)	ASTM E790	9.36 ± 1.7	8.67 ± 0.7
Volatile matter	ASTM E897	64.89 ± 1.4	65.33 ± 0.2
Fixed carbon	By difference	12.09 ± 1.7	11.88 ± 0.6
Ash content	ASTM E830	13.66 ± 2.7	14.12 ± 0.2
Elemental analysis (% dry basis)			
Carbon	ASTM E777	47.5 ± 1.7	48.5 ± 0.6
Hydrogen	ASTM E777	5.13 ± 0.9	4.97 ± 0.1
Nitrogen	ASTM E778	0.13 ± 0.05	0.10 ± 0.04
Sulphur	ASTM E775	Beyond detectable	Beyond detectable
Oxygen	By difference	47.23 ± 0.3	48.5 ± 0.6
High heating value (MJ kg^{-1})	ASTM E711	15.36±**0.2**	16.29±**0.2**

To investigate the effect of pelleting parameters on pelleting quality, 16 experimental runs were performed and evaluated statistically using the model. Regression models for different pellet quality parameters are shown in Table 2.

Table 2: Pellet quality parameters and pellet process parameter

Experiment run	Pellet quality parameters							Pelleting process parameters		
	M C%	Diameter (d) mm mm	Length (L) mm	Particle density kg/m³	Durability %	Output Capacity kg/hour	Fines (%)	mc (%)	Milling size(m) (mm) in mm	Die hole diameter (D) (mm)
1.	4.8	5.9	46	1268	98.0	38.4	3.6	6	6.35	6
2.	4.1	7.9	47	1198	96.6	36.4	3.8	6	6.35	8
3.	4.3	5.8	44	1202	97.2	38.2	3.2	6	3.20	6
4.	4.8	7.9	42	1226	96.5	43.2	2.1	6	3.20	8
5.	3.8	5.9	48	1302	95.3	32.2	4.8	10	6.35	6
6.	4.1	6.0	52	1263	96.5	34.6	3.6	10	6.35	6
7.	4.7	8.0	48	868	95.1	44.6	3.2	10	3.20	8
8.	7.7	5.9	42	1152	94.2	43.2	3.8	10	3.20	6
9.	9.1	8.2	38	878	89.2	42.2	2.8	14	6.35	8
10	5.2	5.8	46	928	90.3	44.2	5.4	14	6.35	6
11	6.8	8.1	41	956	88.4	44.6	5.2	14	3.20	8
12	6.1	8.1	42	996	87.9	42.2	3.1	14	3.20	8
13	7.8	6.1	34	934	86.0	46.8	6.8	18	6.35	6
14	9.4	6.1	37	928	84.5	50.6	5.4	18	6.35	6
15	10.2	8.2	34	894	86.2	48.6	4.2	18	3.20	8
16	10.9	8.4	33	826	84.6	47.2	6.8	18	3.20	8

Table 3: Regression models for pellet quality parameters

Model	Model Equations	R^2
1.	Moisture Content = − 6.55 + 1.1231 MCF	0.95
2.	Diameter = 6.528 − 0.42 MCF − 3.5 D − 0.59MCF × D	0.96
3.	Length = 83.46 − 3.523 MCF + 0.41 D	0.67
4.	Particle density = 1977 − 38.10 MCF + 67.0 D −142 MCF×D	0.92
5.	Durability = 123.47 + 2.506 MCF − 0.2 S − 0.1 D − 2.2 MCF × MCF − 1.44 MCF × D	0.95
6.	Output capacity = −5.2 + 8.79 MCF + 14.26 D	0.68
7.	Fines generated = − 25.19 + 27.7 S +20.7D − 12.1D x S	0.86

Effect of moisture content on pellet quality

The pellet moisture content affects the heating value, burning of the fuel pellet and burning efficiency (Obernberger and Thek, 2004). From the model equation, it is known that the pellet moisture was affected by the feedstock moisture content (Model 1. Table 3). The pellets produced with high feed moisture had ruptured surface, could be due to the lack of bonding between particles. The moisture content of the fuel pellet was observed to be 4 to 6 % less after pelletisation.

IV. EFFECT OF PELLET DIMENSIONS

The average diameter of the pellet made was 5.9 and 8.1 mm for the die size of 6 and 8 mm respectively. It was observed that when the feedstock moisture increased the diameter of the pellet slightly varied (Ungureanu et al., 2018).The pellet diameter was similar to die size (Table 2).Model 2. (Table 3), also showed highest coefficient of determination (R^2). R^2 value indicates the accuracy of the regression model. It was observed that when the feed moisture content increased length of the pellet reduced and is evident in the Model 3 (Table 3). It denotes that high moisture content affect the compaction and prevents the agglomeration of particles thereby reducing the length.(Garcia-Maraver et al., 2015).

Effect of particle density, durability, output capacity and fines produced

From the regression model, it is observed that milling size (S) did not have any influence on particle density (Model 4, Table 3). Model showed that when feedstock moisture is low and at smaller size of die. This could be due to the reduced pelleting pressure with die size and moisture content of the feed stock. Durability of the pellet enhances the transport and handling properties. Model 5,(Table 5) indicates that feed stock moisture had effect on durability. Durability of the pellet decreased with increase in feedstock moisture content according to the developed Model 5, Table 5. The accuracy of the predicted model for durability had an R^2 value of 0.95. The average durability reduced from 97.07 to 85.3 % as mill size increased from 6mm 8 mm. The average output capacity observed were 39.0, 38.6, 43.3 and 48.3 for the MCF of 6, 10,14 and 18 % respectively. Regression model had positively correlated with output capacity (Model 6, Table 3). R^2 value is low with a value of 0.68, indicates output capacity depends on factors other than die hole diameter, feedstock moisture and milling size. Fines generated in the range of 2.1 – 6.8 %. It is observed that size of the particle was less, the number of fines generated was observed less.

V. ASH ELEMENT ANALYSIS

The ash elemental composition of selected biomass pellet samples was analysed using a Scanning Electron Microscope (SEM) equipped with an Energy Dispersive X-ray Spectroscopy (EDX) detector. The surface morphology of banana root ash was observed using SEM and is shown in Figure 2. The image shows long fibrous lignocellulosic and irregular structure which signifies the process has not been enough for the complete coalescence of the ash into spherical particles. Some of the particles were long, fibre-like agglomerates similar to the original wood fibre structure.

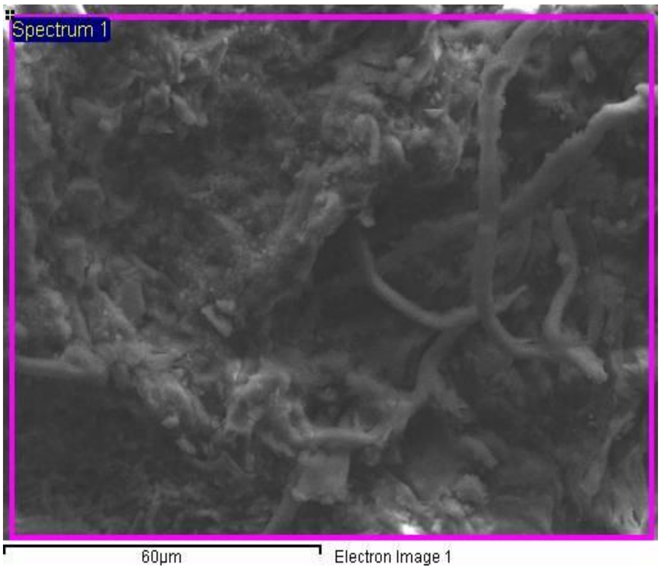

Figure 2. SEM image of banana root ash

Ash constituents were obtained from the SEM EDAX spectrum and displayed in Table 3. From the table, it can be noted that that the banana root ash consists of various proportions of minerals such as silica, aluminium, iron, calcium, magnesium, sodium, potassium, titanium, and manganese, etc. The major elements (>1%) present in the ash sample were C, O, Si, K, and Cl and lesser amounts (0.01-1 %) of Ca, Na, Mg, S, Fe, and Al. Due to high silica content, the ash could be used as building material in concrete as filler. EDX analysis showed high carbon content on the unburnt ash surface, was found to be 36.37 %. Due to high carbon content and pores in the structure, this could be used as low-cost adsorbent.(Yao et al., 2017). In general, the presence of Na and K in fuel speeds up the thermochemical conversion processes such as combustion, pyrolysis, and gasification. The presence of Na and K in the sample indicates that it could undergo thermal degradation at a relatively higher rate.

The presence of Ca in the fuel is beneficial as it can act as a sorbent adsorbing CO_2. The chlorine and potassium in the fuel significantly increase the deposit formation and corrosion potential in combustion devices.

VI. CONCLUSION

The significant findings of this study have shown that pellets produced using banana root waste along with other agricultural waste can be used as an alternative feedstock for fuel pellets thereby waste disposal problems can be addressed.

1. The physicochemical characteristics of the banana root pellet showed that moisture content of the banana root after pelletisation was 8.67 %, the durability of the pellet was 98.2 %, which meets the European and International standards. (CEN/TS 14588, ISO 17225-6)
2. The pellets produced shown high durability with a moisture content of 8.67 %
3. The high heating value of the pellets was observed as 16.27 MJ/kg, which is slightly low, compared to standards, and could be due to the high ash content of the feedstock.
4. TG analysis revealed that decomposition of banana root waste undergone in three stages, deterioration of hemicellulose-cellulose happened somewhere in the range of 200 and 360^{0}C, where an extensive change in the pattern of the TG curve was observed, and a significant drop in weight of 38.74 % was noted.
5. The residual weight is noted to be 30.91 % at 820°C and it mainly comprises char and ash content.
6. EDX analysis revealed that the ash can be used to develop as a low-cost adsorbent product due to its high carbon content present in ash.
7. The results from the ultimate analysis show that banana root pellets could be eco-friendly and pollution-free since the nitrogen content is very low and sulphur content could not even be detected.
8. Since the pellets were produced without adding any binder, this technology can be adopted in areas where the banana plantation is done and also with limited space of about 10 m^2.
9. The use of banana root for fuel pellets helps the farmer to get additional income during crop distress, it also provides employment after harvest season.
10. To increase the characteristics, banana root waste can be blended with other locally available wastes such as sawdust, coconut leaves, wood shavings, etc. to achieve high calorific value and alter the properties of the fuel pellets.
11. In banana plantations tissue culture is adopted now a days, therefore waste roots are left behind in the farm post-harvest, causes environmental issues due to open dumping and burning of waste.

Based on the observed results it can be concluded that the banana root waste pellets could be readily applied as a fuel.

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