

## **Delonix Regia Seeds and Pods: Characterization and Its Potential as a Feedstock for Thermochemical Conversion**

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**Abstract:** This study investigated the possibility of using *Delonix regia* seeds and pods for solid fuel. From the proximate analysis the seed has 5.26 % moisture, 92.54 % volatile matter, 0.34 % fixed carbon with 1.86 % ash content, while 6.29 %, 91.30 %, 0.63 % and 1.78 % were for the pod. The ultimate analysis recorded 40.67 % carbon, 6.44 % hydrogen and 2.14 % sulphur for the seed, while the pod has 45.00 %, 5.61 %, and 1.69 % respectively. The structural analysis revealed that hemicellulose content was higher than the cellulose. The scanning electron microscope revealed the pod as rods like long piles and the seed as an aggregate of the roundish ball. Energy Dispersed X-ray (EDX) recorded the presence of O, Na, Mg, Si, P, Cl, K, Ca and Br. The thermogravimetric analysis revealed the removal of bond water, degradation of hemicellulose, cellulose, and lignin. The Higher Heating Values using three different formula ranges from 14.19 – 14.49 MJ/Kg. The research indicated that the materials have high volatile matters and higher heating values, with low ash content. Also, the quantity of cellulose, hemicellulose, and lignin is an indication of the plant's suitability for bioenergy production.

**Keywords:** *Delonix Regia*, Bioenergy, Proximate analysis, Ultimate analysis Thermogravimetric, Heating value

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Date of Submission: 26-02-2020

Date of Acceptance: 09-03-2020

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### **I. Introduction**

Environmental implications resulting from continuous utilization of fossil-derived fuels necessitate the search for alternative energy sources that are non-polluting across the globe. In recent years, attention has been shifted to renewable sources which entail solar, wind, hydroelectric as well as biomass as key drivers of cleaner energy. In this discourse, the emphasis is on biomass materials that are widely distributed across the length and breadth of the universe but still remain under-utilized in most developing countries for the benefits of mankind. Indubitably, the socio-economic developments of any developed climes are closely related to energy security (Froggatt et al., 2009). Thus, the proper harnessing of biomass resources offers a great potential in order to achieve sustainable and continuous energy generation which is pivotal to mitigation of global warming posing threat to planetary health (Cassie et al., 2015).

Across the globe, climate change still remains a threat to environmental sustainability as a result of excessive consumption of fossil fuels, coal and natural gas – responsible for the emission of greenhouse gases from combustion (Perera, 2018). However, a great way to checkmate this is by the adoption of biomass resources as a substitute for polluting fuels (Balat and Ayar, 2005). Utilization of lignocellulosic biomass such as forest residues, agro-wastes, energy grasses, aquatic plants and algae for bio-energy production seems promising as they contain low levels of sulfur, nitrogen and ash content with little or no impact on the sustainability of the environment (Margeot et al., 2009; Nigam and Singh, 2011; Srirangan et al., 2012).

*Delonix Regia* is one of the abundantly underutilized biomass materials in Sub-Saharan Africa and even mostly refers to as a waste material (Yuh-Shan and Malarvizhi, 2009). It is a leguminous plant which belongs to the family of Leguminosae ranked as the second largest family among the dicotyledonous plant. It has the following common names; Pride of Barbados, Dwarf Poinciana, Bird of Paradise, flamboyant-de-jardin (Prohp et al., 2004). It is a beautiful, semi-deciduous tree known as flame of forest in Nigeria with a height of about 18cm. It has long pods that dangle from the branches with green and flaccid color when young as well as hard and dark brown as a sign of Pod maturity (Bake et al., 2014; Adje et al., 2008).

For the efficient application of biomass to energy conversion, it is very important to characterize the biomass to determine its suitability. More so, fuel behavior in processes such as combustion, gasification, and pyrolysis can also be determined from characterization (Kazagic and Smajevic, 2007). It has been proposed that

identification and classification of biomass based on its potential value will enhance the higher quality of its integration accompany with the optimized result (Lim and Lam, 2013).

There is under-reporting of the characterization of *Delonix regia* seeds and pods for thermochemical conversion. Those that have worked on it laid emphasis on its utilization as a food supplement and drug development (Bake et al., 2016; Ishaya, 2013; Okoye et al., 2014; Oyedeji et al., 2017). It was also employed in the production of activated carbon with no particular consideration of the plant seeds and pods as a feedstock for bio-oil production (Rajalekshmi et al., 2016; Sugumaran et al., 2012). Few researchers have elucidated on the potentials of *Delonix regia* as a bio-oil feedstock but not comprehensive. Okey and Okey (2013) showed that *Delonix regia* offers a great potential as a bio-oil feedstock. In his report, an optimal biodiesel yield of 87% was obtained from the plant under the following conditions: 6:1 molar ratio, 60 °C temperature, 0.7% catalyst concentration, 600 rpm agitation and 60 min reaction time. Deepu et al (2013) reported that *Delonix regia* oil offer a viable means as a feedstock for green synthesis of biodiesel. Their result showed that a higher yield of biodiesel conversion (92.37%) was obtained using immobilized enzymes as well as oil/methanol molar ratio of 1:4, the temperature of 50°C. Oyedeji et al (2017) worked on Chemical and Nutritional Compositions of Flame of Forest (*Delonix regia*) Seeds and Seed Oil. Their results indicated that oil from the seed can be used as a feedstock for bio-oil production as the characterize oil contains highly oxygenated compounds.

Due to the research gaps in the characterization, kinetic study, ultimate analysis, elemental characterization, compositional properties and thermogravimetric analysis of the plants. This research paper elucidated on the characterization of *Delonix regia* seeds and pods for thermochemical conversion for eco-friendly fuel generation.

## II. Material and Methods

### Sample Collection and Preparation

The matured pods of *Delonix regia* were harvested from a plant grown on the campus of Federal University of Technology Akure, Nigeria. The seeds of *Delonix regia* were obtained by manual opening of the harvested pods with subsequent removal of the seed. The research materials were authenticated at the Department of Crop, Soil, and Pest of the Federal University of Technology Akure, Nigeria. The plant materials were air dried in the laboratory to achieve constant moisture content of about 10% prior to grinding, it was later sieved to obtain a particle size of 425µm and stored in an airtight container. The entire chemicals used in this research are analytical grade from Sigma Aldrich.

### The Chemical Composition of The Sample

To determine the chemical composition of the sample, Moubasher et al (1982) and Oluwasina et al (2014) methods were adopted and modified. Moubasher et al (1982) did not account for dissolved lignin after fiber treatment with 24 % KOH which was accounted for by Oluwasina et al (2014). Thus, in this modification the dissolved lignin was isolated and added to the residue (the lignin) obtained after 72 % H<sub>2</sub>SO<sub>4</sub> treatment of the fraction C. Precisely 2 g of sample was refluxed in with 2: 1 benzene-ethanol for 8 h, washed thoroughly with distilled water and kept in an oven at 40 °C overnight to obtain constant weight sample. The after the refluxed material was subjected to various chemical treatments and different fractions were obtained as follows; the refluxed sample (Fraction A) was treated with 20 % NaOH (w/v) at solid to liquor ratio of 1:30 in a covered container for 4 h at room temperature. After the reaction time, the solution was filtered to obtain the fiber sample and the filtrate. The pH of the filtrate was adjusted to 2 and heated at 80 °C for 2 h to obtain its contained dissolved lignin in solid form (obtained lignin is denoted as Fraction B), this was washed to neutral and dried at 80 °C to constant weight. The obtained fiber sample was denoted as Fraction C. This fraction C was treated with 72 % H<sub>2</sub>SO<sub>4</sub> (v/v) for 3 h for cellulose hydrolysis, the obtained fiber was then refluxed with 5% H<sub>2</sub>SO<sub>4</sub> for 2 hr. This was followed by washing of the sample neutrality using distilled water and then dried to constant weight in an oven at 80 °C. This final residue was denoted fraction D. Chemical composition of the sample was calculated using the following equations;

$$\text{Cellulose} = \text{C-D} \quad (1)$$

$$\text{Hemicellulose} = \text{A-C} \quad (2)$$

$$\text{Lignin} = \text{B+D} \quad (3)$$

### Instrumental Analysis

The moisture content, volatile matter, ash content and fixed carbon determination were done using Perkin Elmer STA 6000. Ultimate analysis for the determination of carbon, hydrogen and sulfur content was determined using Perkin Elmer CHNS/O. Scanning Electron Microscope (SEM) coupled with Energy Dispersed X-ray (EDX) (FEI FIB/SEM Nova 600 Nanolab) was used for the morphological characteristic and elemental composition of the samples. The samples were double-coated with a palladium and gold alloy coating for SEM analysis. TGA (Perkin Elmer STA 6000) in a nitrogen atmosphere, flow rate 20 mL min<sup>-1</sup> at a temperature (30

and 900 °C) and heating rate 10 °C min<sup>-1</sup>, about 10.0 mg sample was used for the thermal stability determination. The Higher Heating Values (HHV) of the samples were calculated using three different methods listed below as described by Dermibas (1996) and Parikh (2005).

$$\text{HHV (MJ/kg)} = 0.312 (FC) + 0.1534 (VM) \dots\dots\dots \text{(i) (Parikh et al., 2005)}$$

$$\text{HHV (MJ/kg)} = 0.3536 (FC) + 0.1559 (VM) - 0.0078 (A) \dots\dots \text{(ii) (Parikh et al., 2005)}$$

$$\text{HHV (MJ/kg)} = 0.196 (FC) + 14.119 \dots\dots\dots \text{(iii) (Dermibas, 1996)}$$

Where *FC* is the Fixed Carbon Content (wt. %); *VM* (wt. %) is the volatile matter and *A* (wt. %) is the ash content

**Kinetics Parameters**

Assuming that the reaction is a First Order reaction, evaluation of kinetic parameters of the Seed and Pod were carried out using the equation derived by Coats and Redfern, (1964).

The overall kinetic reaction is outlined below with clear definition of parameters employed:

$$\frac{dl}{dt} = kf(l) \tag{4}$$

Where *l* is the amount of volatilized component

$$l = \frac{w-wf}{w0-wf} \tag{5}$$

During decomposition, *w<sub>f</sub>* is the biomass final weight (mg); *w<sub>0</sub>* is the initial weight of the biomass (mg) that decomposes to mass *w* (mg) at a time (t). The rate constant, *K* and  $f(l) = (1 - l)^P$  and *P* is the order of the reaction.

Following Arrhenius equation, the rate constant *K* is temperature dependent and it is given as:  $k =$

$$A \exp\left(-\frac{Ea}{RT}\right) \tag{6}$$

From equation 6,

*A* is the frequency factor in (s<sup>-1</sup>)

*Ea* is the activation energy in (kJmol<sup>-1</sup>)

*T* is the temperature in (K)

*R* is the gas constant in (J/K/mol).

Integration of equation 4 with the consideration of equation (5) and (6) for a first-order reaction gives:

$$\ln\left[-\frac{1}{w0-wf} \frac{dw}{dt}\right] = \ln(A) - \left(\frac{Ea}{RT}\right) + P \ln[(w - wf)/(w0 - wf)] \tag{7}$$

The linear form of this equation is:

$$D = J + Hv + Gq \tag{8}$$

$$D = \ln\left[-\frac{1}{w0-wf} \frac{dw}{dt}\right] \tag{9}$$

*v* = 1/*T*

*J* = ln(*A*) is the intercept

*H* = -*Ea*/*T* is the slope

*G* = *P* is the order of the reaction

$$Q = \ln[(w - wf)/(w0 - wf)] \tag{10}$$

Therefore, a plot of  $\ln\left[-\frac{1}{w0-wf} \frac{dw}{dt}\right]$  against  $\frac{1}{T}$  gives a straight line, the slope will give the activation energy which will be multiplied by *R* and the intercept can be calculated from ln *A*

**III. Results And Discussion**

**Proximate Analysis**

Proximate analysis is a key parameter adopted for determining the suitability of biomass materials as a feedstock for bio-oil production (Pradhan and Singh, 2013). It was clearly showed in Table 1 that the moisture content of the *Delonix regia* seed was 5.26 wt. % which is lower than that of the plant pod of 6.29 wt. %. Our result is in tandem with moisture content for biomass fuels reported by other authors Huéscar et al. (2013) with Patel and Gami (2012). The slight difference between the content of moisture of the seeds and the pods may be

attributed to the age of residue, stage of harvest, physical composition, and method of harvesting and storage adopted (Simonyan and Fasina, 2013). These values are within the range recommended for biomass fuels, which must be below 8.00 wt. % (Clarke, 2011). This makes the plants suitable for biofuels as it will aid gasification and combustion (Bridgwater, 2012; Dobele et al., 2007).

Volatile matter recorded 92.54 wt. % for the seed which is fairly more than that of the pod at 91.30 wt. %. The relatively high volatile matter of this matter could be suggestive that the material would be good for biofuel because the high volatile matter is desirable for bio-fuels (García et al., 2012). Sugumaran et al. (2012) reported almost a similar content of volatile matter at 92.03 wt. % for the same plant pod. It was reported by Harun et al.(2013)that a high number of functional groups and low numbers of aromatic structures in organic materials are responsible for high values of volatile matter in biomass. Gaqa et al. (2014) corroborated this claim. Volatile content of the *Delonix regia* seeds and plants are within the range of 64 wt. % to 98 wt. % as reported for all biomass fuels (Fahmi et al., 2008).This feature is an indication that the plant has many prospects for thermochemical conversion (Bordolai et al., 2014).

**Table 1.** Proximate analysis of the *Delonixregia* seed and pod.

Parameters	Seed	Pod
Moisture content (wt. %)	5.26 ± 0.29	6.29 ± 0.14
Volatile matter (wt. %)	92.54 ± 0.15	91.30 ± 0.04
Ash content (wt. %)	1.86 ± 0.06	1.78 ± 0.12
Fixed carbon (wt. %)	0.34 ± 0.083	0.63 ± 0.16
HHV (MJ/Kg) (iv)	14.49 ± 0.01	14.40 ± 0.05
HHV (MJ/Kg) (v)	14.19 ± 0.02	14.24 ± 0.03
HHV (MJ/Kg) (vi)	14.30 ± 0.01	14.20 ± 0.04

Values are means of three replicate ± standard deviation

The leftover carbon after volatiles have been driven off is the fixed carbon content. Noticeably, the fixed carbon of the seed and pod are relatively low at a value of 0.34 wt. % and 0.63 wt. % respectively. Although, the fixed carbon content recommended for biomass is from 7.00 wt. % to 35.00 wt. %, conversely, the result evaluated was extremely below the value. This suggests that lesser time will be required for the gasification. Nasser et al (2016) showed that low fixed carbon content can be linked with a high volatile matter which engenders consumption of the bulk of the residues in the gaseous state during combustion.

As presented in Table 1, there is a close resemblance in the ash content evaluated for *Delonix regia* seed and pod with values of 1.86 wt. % and 1.78 wt. % respectively. It may be possible that the low ash content of the samples was due to late harvest and the sample was also kept free from soil contamination unlike tree trunk, a claim supported by Adler et al. (2006). Lower ash content is desirable in biomass fuels as it leads to higher calorific value as well as influences combustion behavior and thermal decomposition (Bordolai et al., 2014; Gaqa et al., 2014; Van Loo and Koppejan, 2008). According to classification by Lyer et al. (2002) the ash content of biomass fuels should be less than 5.00 wt. % which makes these samples suitable for bio-oil production with no consequent fouling and slagging during gasification.

Based on the data presented in Table 1, *Delonix regia* seed has a heating value of 14.19 MJ/kg to 14.49 MJ/kg which is close to that of the pod at 14.20 MJ/kg to 14.40 MJ/kg. These values are close to those of biomass fuels determined by Adeyinka (2012). A heating value that is close to 15 MJ/kg and above is mostly desired for biomass employed for bio-oil production as the fuel value solely depends on it (Demirbas, 1996; Demirbas, 2004).

### Ultimate Analysis

The data for ultimate analysis of the plants are presented in **Table 2**. For this analysis, the following parameters were evaluated: Carbon, Hydrogen, and Sulphur. Carbon content was 40.67 wt. % for the seed, whereas, 45.00 wt. % was for the pod. The high content of carbon in the pod than seed can be tied to their difference in chemical, physical and biological properties (Knoepp et al., 2005; Lehmann, 2007). The carbon content was below that of coal at 60.00 wt. % Demirbas (2007), but Sugumaran et al.(2012)have suggested that *Delonix regia* pod could be a good source of activated carbon as it yielded 41.09 wt. % of carbon in their experiment; which have varying effects as an adsorbent. The carbon content results obtained in this research are in agreement with those determined by Tumuluru et al. (2011)for biomass fuels at around 40.00 wt. % upward.

**Table 2.** Ultimate Analysis of *Delonixregia* seed and pod.

Parameters (%)	Seed	Pod
Carbon (wt. %)	40.67±0.59	45.00±1.68
Hydrogen (wt. %)	6.44±0.02	5.61±0.31
Sulphur (wt. %)	2.14±0.11	1.69±0.00

H/C Atomic ratio (wt. %)	0.16±0.01	0.13±0.01
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Values are means of three replicate ± standard deviation

The hydrogen content of the seed was 6.44 wt. % which was higher than that of the pod which stood at 5.61 wt. %. This higher hydrogen content in seed could be because it has a higher content of fatty acids compared to the pod, this was corroborated by Adewuyi et al. (2010). Our result agrees with those of biomass fuels evaluated by Yaman (2004) and Fahmi et al. (2008). The result for hydrogen is within those recommended for biomass fuels at 4.82–6.78 wt. % (Jenkins et al., 1998; Tumuluru et al., 2011). This result is an indication that the samples will be a good source of bio-oil. The sulfur content of the seed was 2.14 wt. % fairly more than that of the pod at 1.69 wt. %. This is not desirable for biomass fuels because it has the ability to cause pollution through the release of sulfur oxides during gasification (Easterly and Burnham, 1996). It has been recommended that sulfur content in biomass should be below 0.20 wt. % and in some cases at around 0.50–0.70 wt. % (Demirbas, 2007). Notably, our result falls within the value recommended for coal at 0.50–7.50 wt. %. The sulfur content could be reduced during the gasification by the calcium-based sorbents in-situ capture (Meng et al., 2010).

Hydrogen to carbon ratio allows the measurement of the degree of aromaticity. The seed of the plant has H/C ratio of 0.16 wt. % showing a close resemblance to that of the pod at 0.13 wt. %. A similar result was reported by Edmund et al (2015) for biomass fuels, which falls almost within the range posited for biomass fuels by Krull et al. (2009). This indicated that the sample has a lot of prospects for bio-oil production.

### Structural Analysis

The major component of biomass and lingo-cellulosic materials are cellulose, hemicellulose, and lignin. In this analysis, the seed has cellulose of 34.50 wt. % with close proximity to that of the pod at 34.00 wt. %. This is in agreement with those reported for biomass fuels by Sugumaran et al. (2012). Although, the result falls a little below that recommended for biomass fuels at the range 40.00-80.00 wt. % as posited by Carrier et al. (2011) but it is considered viable for efficiency in pyrolysis and gasification – it can lead to an acceleration of pyrolysis.

**Table 3.** Structural analysis of *Delonix regia* seed and pod.

Parameters (%)	Seed	Pod
Cellulose (wt. %)	34.50±1.50	34.00±0.00
Hemicellulose (wt. %)	39.00±1.00	35.00±1.00
Lignin (wt. %)	16.50±1.50	16.50±0.87
Extractives (wt. %)	8.73±0.75	11.75±0.75

Values are means of three replicate ± standard deviation

The seed hemicellulose was 39.00 wt. %, while 35.00 wt. % was obtained for the pod. The relatively high content of hemicellulose in these plant materials suggests that they may be employed for the production of hemicellulose that could be thickeners and stabilizers in the food, cosmetics, paper, and textile industries pegged the value of biomass fuels at the range 20.00-40.00 wt. % in which our values falls within (Chaires-Martinez et al., 2008; Mikkonen et al., 2007; Sugumaran and Seshadri, 2009).

The lignin content evaluated for these plant materials was at 16.50 wt. %. This result falls within that reported by Carrier et al. (2011) at 10.00-25.00 wt. %. At this value, it is highly suitable for bio-energy production because a higher value than that reported herein may likely interfere with the output. The lignin contents recorded in this research work are in tandem with those reported for bio-renewable fuels by other scientists. To the best of our knowledge, we have not come across any published reports works on the biochemical composition of *Delonix regia* seeds and pods. This research work will provide a platform for other researchers to further delve into the renewable strength of the plant materials for bioenergy production. The extractive recorded for the seed was at 8.73 wt. % a little lower than that recorded for the pod at 11.75 wt. %. This result agrees with that of Fang et al. (2014) for biomass fuels. Extractives have a direct link with the higher heating value, and at the value recorded here is an indication of positive contribution to fuel value.

### Elemental Analysis

The high presence of alkaline metals and alkaline earth metals poses a great threat to gasification as they are responsible for fouling and corrosion problems (Saeed et al., 2015). In this analysis, the following metals, calcium, magnesium, sodium, silicon, potassium, phosphorus and chlorine were obtained. The data presented in **Table 4** showed that oxygen has the highest content for pod and seed 48.11 % and 42.96 % respectively. However, it was recorded that sodium has the lowest value at 0.58 % for pod and 0.92 % for seed. From this research, it can be seen that the ratio of oxygen to carbon was relatively low which an indication of

high energy density owing to more chemical energy in C-C binds and in C-O bonds (Carlos et al., 2014) Chlorine was present in the seed but absent in the pod with the only minimal amount of bromine in the pod.

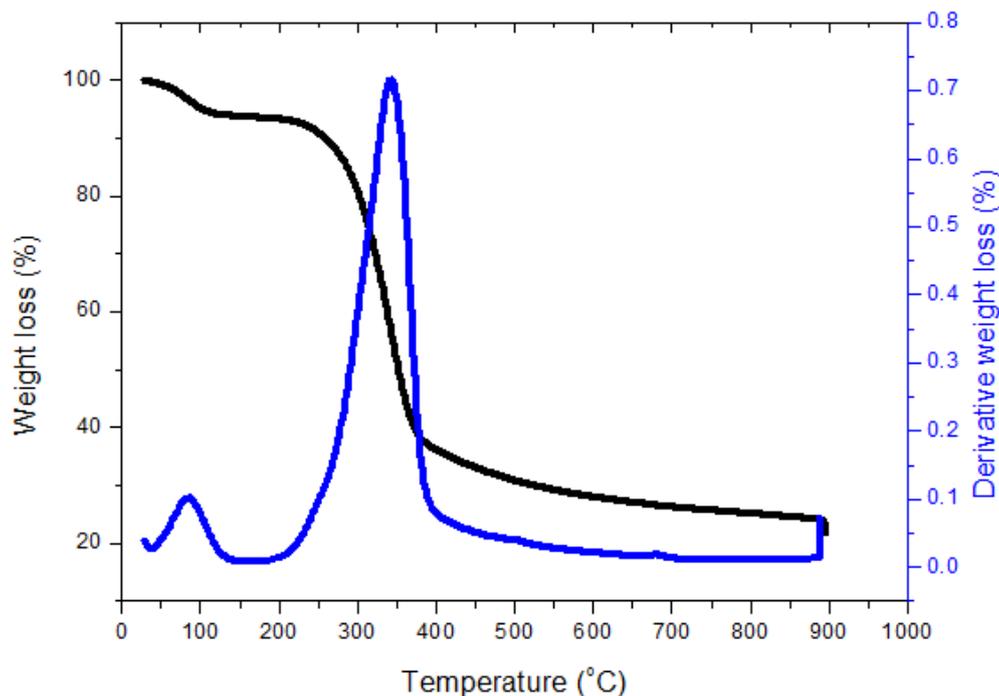
Calcium, magnesium, and potassium were the major mineral constituents in the samples which agree with the claim of Semple and Evans (2000) for biomass fuels. For potassium, 41.23 % was recorded for the pod while 32.44% was for the seed. The high content of potassium was in agreement with Teixeira et al (2012) findings on biomass fuels. Generally, biomass fuels have a varying elemental composition (Maciejewska et al., 2006; Sami et al., 2001) and high amount of potassium can be corrected through washing with water or acid leaching technique (Davidsson et al., 2002). Importantly, this seed can be used as a good source of mineral for bone formation because the Ca/P ratio exceeded one as described by Cockell et al. (2002), thus refuting the claim of Oyedeji et al. (2017) that *Delonix regia* seed cannot be used as a source of minerals for bone formation.

**Table 4.** EDX Analysis of the *Delonix regia* seed and pod.

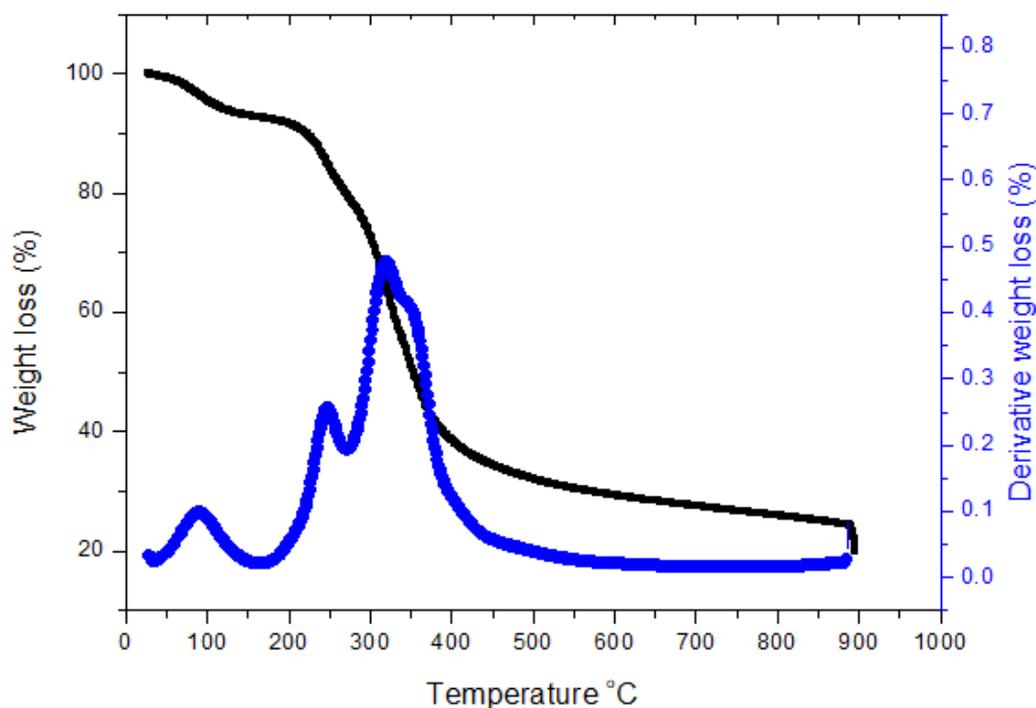
Sample	Element (% Weight)								
	O	Na	Mg	Si	P	Cl	K	Ca	Br
Seed	42.96	0.92	10.77	0.98	3.80	1.74	32.44	6.39	None
Pod	48.11	0.58	1.70	0.78	1.62	None	41.23	5.15	0.82

Thermo-gravimetric analysis (TGA) is employed in determining the thermal behavior of biomass fuels and as a premise for the design of pyrolysis reactor (Okoroigwe et al., 2012). Generally, water evaporation, passive pyrolysis, and active pyrolysis are the three key stages involve in thermal behavior of biomass fuels. As depicted by the graphs, the first stage represents evaporation of moisture contents for the *Delonix regia* pod with a weight loss of 1.75 % which is extremely lower than that estimated for the seed under the same conditions with a weight loss of about 35.35 %. At this point, moisture content is being absorbed from the sample as the heating temperature increases. Our result is in proximity to those reported by Nasser et al (2016) and Kumabe et al. (2007) for biomass fuels employed for the bio-energy production.

Hemicellulose and Cellulose decomposition of the pod was shown by the two distinct peaks in Figure 1. The maximum weight loss at 238.03 °C is 10.81% which can be attributed to hemicellulose decomposition. It can be inferred from Figure 2 that the degradation of cellulose and hemicellulose takes place at 334.41 °C with a weight loss of 35.35 % for the seed. This result falls within that reported by Nasser et al. (2016) for decomposition of hemicellulose and cellulose at the temperature ranges of 260-340 °C and 320-380 °C for biomass fuels. At this stage, active pyrolysis of the sample becomes feasible and may likely be linked to decomposition of volatiles such as CO and CO<sub>2</sub> as well as the destruction of intermolecular associations and weaker chemical bonds (Aldobouni et al., 2015). Zanzi et al. (1989) reported that hemicellulose degradation takes place at a temperature of 180 °C and 270 °C and is always accompanied by an exothermic reaction. A similar result was reported by Kumabe et al for biomass fuels (Kumabe et al., 2007). There was a maximum weight loss of 18.57 % at the degradable temperature of 310.49 °C. At this point, it may be possible that cellulose degradation has taken place with simultaneous lignin decomposition. This stage is marked by the breaking of chemical bonds and destruction of molecular skeletons (Singh and Shadangi, 2011). This corresponds to the result of Nasser et al (2016) in which cellulose degradation of biomass takes place at 275 to 350 °C and lignin at 250 °C and 500 °C. Overall, the differences in thermal degradation behavior of cellulose, hemicellulose, and lignin can be attributed to their chemical nature (Yang et al., 2006). Cellulose is a linear homogeneous polymer and forms the major structural components of plants containing 5000–10,000 glucose units and usually degrades to produce anhydrocellulose and levoglucosan at 240–350 °C. However, hemicellulose is a polysaccharide found in plant cell walls which contains only 150 monomers of repeating saccharides and normally decomposes at 160-300 °C. Hemicellulose also has random amorphous structures with reactive acetyl groups that are easily broken down during acid pyrolysis. The lignin is a complex phenolic heteropolymer that is mostly found in all vascular plants. Its degradation usually takes place from 200°C - 500°C (Kumabe et al., 2007; Mohan et al., 2006).



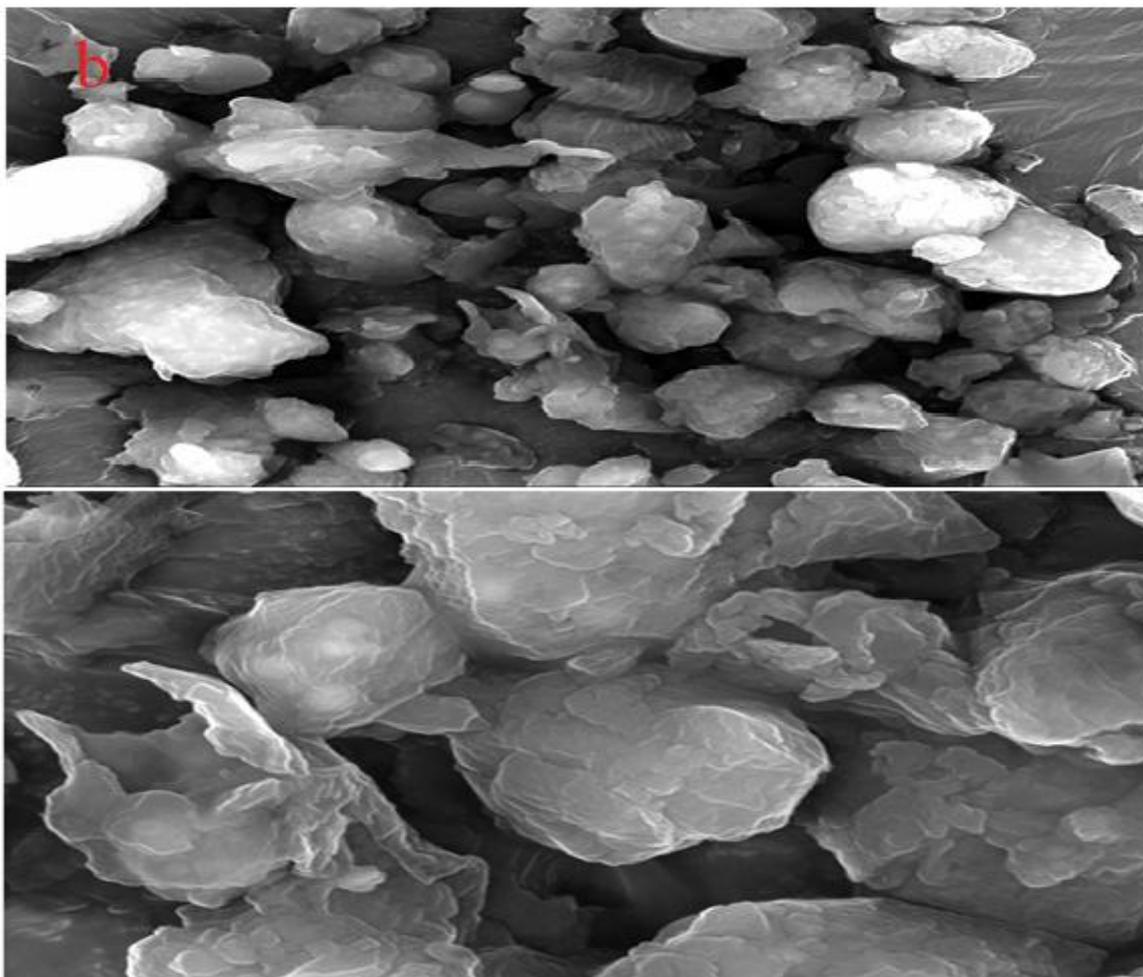
**Fig. 1.** TGA/DTG of the Delonix regia Pod.



**Fig. 2.** TGA/DTG of Delonix regia seed.

### **Morphological Characterization**

The morphological characterization of the seed and pod was revealed by the SEM photography. The pod was revealed to be composed of rod-like long piles of fiber with different lengths and sizes, but the seed seems to look like aggregate of the roundish ball like and flat shaped materials. This revelation could have contributed to the differences in the chemical and instrumental analysis of the pod and seed.



**Fig. 3.** SEM of Delonix regia pod (a) and seed (b)

### Kinetics Analysis

The kinetic analysis allows the evaluation of the activation energy which provides the threshold energy biomass fuels needs to overcome during the reaction process (White et al., 2011). However, in relation to the aims of this research, the activation energy provides the energy required for a decomposition reaction to take place. As clearly showed in Table 5, the activation energy recorded for the seed (6.57 kJ/mol) is lower compared to that of the pod (9.86 kJ/mol) but the pre-exponential factor is relatively higher in seed ( $7.513 \times 10^{-5} \text{s}^{-1}$ ) compared to the ( $1.596 \times 10^{-5} \text{s}^{-1}$ ) for the pre-exponential factor. The difference has been tied to their chemical nature, a statement corroborated by Yang et al (2006). From the stated result, we can infer that the rate of decomposition of the components of seed during pyrolysis will be faster compared to the pod due to the low activation energy. The higher the activation energy, the lower the rate of reaction. Kinetic study on biomass fuels claimed that depolymerization of cellulose by transglycosylation mostly occur at around that reported in this research (Mamleev et al., 2006).

**Table 5.** Kinetics Analysis.

Parameters	Seed	Pod
Activation Energy, Ea (kJ/mol)	6.57	9.86
Pre-exponential factor, A ( $\text{s}^{-1}$ )	$7.513 \times 10^{-5}$	$1.596 \times 10^{-5}$

### IV. Conclusions

Characterization of the under-utilized *Delonix regia* seeds and pods was carried out comprehensively in this research to elucidate on its potential as a bioenergy feedstock. The proximate and ultimate analysis revealed

that the plant materials are extremely rich in volatile matters, higher heating value, and carbon coupled with low ash content, which is an indication that it is a good candidate for bio-energy production.

More so, Cellulose, Hemicellulose and lignin content are within the limit for biomass fuels attesting to its suitability for pyrolysis process. A key finding showed by this research work is that Calcium, Phosphorus, Potassium, and Magnesium has a nutritional value, which can be adapted through integration to daily staples to enhance bone formation; a claim that has never been reported before by any scientist on the plants. However, it was recommended that the biomass should be subjected to necessary pre-treatment processes prior to pyrolysis because of the high content of alkaline metals and alkaline earth metals in the biomass ash.

The pyrolysis characteristics from the thermo-gravimetric studies under a nitrogen atmosphere with a flow rate of 20 mL min<sup>-1</sup> at a temperature (30 and 900 °C) and heating rate 10 °C min<sup>-1</sup> showed that active pyrolysis of the seeds and pods occurred at the maximum degradation temperature of 334.41 °C and 310.49 °C respectively. Activation energy evaluated for the materials indicated rapid cellulose decomposition.

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