Thermochemical characterization of invasive Axonopus compressus grass as a renewable energy source

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Abstract. The necessity of energy is increasing massively, whereas fossil fuel resources are diminishing with time, and produce greenhouse gasses while burning. To resolve these issues, lignocellulosic biomass such as Axonopus compressus that is available in Brunei Darussalam have been investigated. For characterization analysis, dried 0.25 mm samples were utilized. The moisture content (4.56%), volatile matter (72.04%), fixed carbon (17.11%), and ash contents (6.29%) of the sample were achieved from the proximate analysis result. The HHV (Higher heating value) of 17.96 MJ/kg and the moisture content value is an indication of a reasonable source for biofuel production. The ultimate analysis showed the carbon (C), hydrogen (H), nitrogen (N), sulfur (S), and oxygen (O) contents were 43.46%, 5.68%, 1.45%, 0.13%, and 49.10%, respectively. From the thermogravimetric analysis (TGA) and derivative thermogravimetry (DTG) results, the highest decomposition rate was found to be 6.03 wt. %/min at 334 °C temperature in pyrolysis and 30.63 wt. %/min at 443 °C temperature in combustion condition.

1. Introduction
Currently, in the sound world, energy represents the main factor for development, and the principal sources of energy obtain fossil fuel, which is depleting day by day [1]. Fossil fuel has limited storage and also produces greenhouse gases (GHG) while burning, which remains the leading contributor to global warming [2]. Lignocellulosic biomass can be a useful renewable energy source that can reduce carbon dioxide (CO₂) gas emission [3]. The main sources of biomass are trees and grasses, where some of them are invasive. These invasive plants are risky for the ecology, community health, and economies because they can damage the local plants by dislocating and hybridizing [4]. In the invasive grasses, A. compressus is available around the world (Figure 1) [5]. A. compressus is a perennial grass (C4) from...
the Poaceae family and commonly recognized as carpet grass [6]. The C4 species can retain more CO$_2$ than the C3 plants for their leaf configuration and the mechanisms of photosynthesis [7]. According to the PIER analysis (Pacific Islands ecosystems at risk), the score of the *A. compressus* grass is 15 [8], which is more (>6) to be an invasive species [7]. The biomass converting methods are suggested as one of the effective procedures to control the invasive plants by transforming them into energy by minimizing the greenhouse gas emission [9]. Some available invasive grasses like elephant grass [10], *Imperata cylindrica* [11], switchgrass [12] have shown a significant role in bioenergy production. The *A. compressus* from Brunei Darussalam can be a reliable source of bioenergy as the average production of this grass in this country was found to be 18.7 Mt/ha/yr [13].

![Figure 1. World distribution diagram of *A. compressus* grass [5].](image)

The pyrolysis, combustion, gasification, and hydrothermal procedure are the major thermochemical procedures that are used normally for converting biomass into bioenergy. Among them, pyrolysis is an easy and effective process that can produce a variety of products (biochar, bio-oil, and biogas) in different quantities depending on the operating conditions [14]. It is a thermal degradation process of any biomass sample at a higher temperature in limited oxygen or inert atmosphere [15]. The biogas or syngas are used normally to produce electricity. The bio-oils are utilized directly in the low-grade heating purpose or in the diesel engine after refinement. Biochar has been recommended for the soil amendment, and its storage in soils is one possible measure of decreasing the CO$_2$ concentration [16]. Other than that, the applications of biochar as activated carbon in water treatment, air cleansing, catalyst support, vehicle exhaust emission, and solvent recovery are promising due to its large surface area, adequate porosity, and strong structural strength [17]. To date, very few researches have been done to evaluate the *A. compressus* grass sample for bioenergy production. The main purpose of this research is to characterize the *A. compressus* grass, which is available in Brunei Darussalam to be a potential source of renewable energy by minimizing its invasiveness.

2. Experimental
The *A. compressus* grasses were collected from the campus area of Universiti Brunei Darussalam. After cleaning, the samples were dried under sunlight directly for 1 week. After sundry, the samples were blended and sieved (No 60) to get the uniform element size of less than 0.25 mm [7]. American Society of Testing Materials (ASTM) standards were performed to analyze the proximate analysis of the grass sample. ASTM D 3173-11[18] for moisture content (MC), ASTM D 3175-07 [19] for volatile matter (VM), and ASTM D 3174-04 [20] for ash content (AC) were used. The weight percentages of the fixed carbon (FC) was calculated by the Equation (1) [21].

$$\text{Fixed carbon (wt\%) = 100} – (\text{moisture contents + volatile matter + ash contents})$$  \hspace{1cm} (1)
The ultimate analysis of *A. compressus* grass was conducted by a CHNS analyzer (Flash EA 1112 Series) made by Thermo Quest, Italy. From this analysis, the weight proportion of carbon, hydrogen, nitrogen, and sulfur was achieved. The percentage of oxygen was estimated by deducting the C, H, N, and S total from 100. Gross calorific value (GCV) or higher heating values (HHV) of the dried sample was measured by a bomb calorimeter (C-200), made by P.A. Hilton, UK, through ASTM D 5468–02 procedures.

The thermogravimetric analysis (TGA) was performed by a thermogravimetric analyzer (TGA7) manufactured by Perkin Elmer, USA. The TGA experiment was executed for 40 to 900 °C temperature with a constant heating rate (10 °C/min) under pyrolysis and combustion conditions [7]. Constant nitrogen gas flow was maintained for pyrolysis conditions and oxygen gas for sustaining combustion conditions [21].

### 3. Result and discussions

From the proximate analysis, the MC, VM, AC, and FC of the *A. compressus* grass were found to be 4.56%, 72.04%, 6.29%, and 17.11%, respectively (Table 1). The VM and FC represent the combustible matter, whereas the MC and AC represent the noncombustible matter. The higher values of VM, FC, and lower values of MC, AC are the acceptable properties for a higher quality of biomass fuel [23]. The amount of MC was less than the values found for elephant grass (10.63%) [10], *Imperata cylindrica* (7.50%) [11], and switchgrass (8.40%) [12]. MC represents the quantity of water available per unit mass of dry samples. Higher MC affects adversely in the pyrolysis process, yield, and quality of the products [24]. The MC value is less than 10%, which is an important parameter to be a potential source for thermochemical conversion via pyrolysis [25].

![Table 1. Proximate, ultimate, and heating value analysis.](image-url)

| Analysis            | Type                | This work | Elephant grass [10] | *Imperata cylindrica* [11] | Switchgrass [12] |
|---------------------|---------------------|-----------|---------------------|---------------------------|------------------|
| Proximate analysis  | Moisture content (MC)| 4.56      | 10.63               | 7.50                      | 8.40             |
|                     | Volatile matter (VM)| 72.04     | 72.54               | 76.58                     | 84.20            |
|                     | Fixed carbon (FC)   | 17.11     | 19.20               | 15.09                     | 11.90            |
|                     | Ash content (AC)    | 6.29      | 8.26                | 0.83                      | 3.90             |
| Ultimate analysis   | Carbon              | 43.46     | 39.63               | 43.19                     | 42.00            |
|                     | Hydrogen            | 5.68      | 6.31                | 5.92                      | 6.10             |
|                     | Nitrogen            | 1.45      | 1.70                | 0.59                      | 0.40             |
|                     | Sulfur              | 0.13      | 0.20                | 0.14                      | 0.10             |
|                     | Oxygen              | 49.10     | 52.16               | 50.17                     | 47.40            |
| HHV (MJ/kg)         | HHV-dry basis       | 17.96     | 15.77               | 17.03                     | 19.80            |

The percentage of VM varies from 60 and 85% for any biomass, whereas the value obtained in this study is 72.04%. This value is comparable with elephant grass (72.54%) [10], and *Imperata cylindrica* (76.58%) [11]. The higher percentage of VM boosts the reactivity of biomass in the pyrolysis, and other thermochemical processes producing light hydrocarbons, methane, carbon monoxide (CO), carbon dioxide (CO₂), hydrogen, and tars [26]. For containing the weaker C-H and C-O bonds, the VM reacts easily in the direct or indirect combustion process [27]. The AC of 6.29% in this study is highly comparable with elephant grass (8.26%) [10]. The lower percentages of AC are favorable for thermochemical conversion processes because higher AC creates the slagging and clogging in the pyrolytic chamber [28]. One of the factors for this value is the soil condition where the plants are grown, as the main constituents of the ash are minerals [29]. However, a certain proportion of AC could show catalytic performance and influence the quality of pyrolysis products [30]. A percentage of FC for the biomass sample was calculated 17.11%, which can be effective for biochar production. The FC value is competitive with the values for elephant grass (19.20%) [10], *Imperata cylindrica* (15.09%) [11], and...
switchgrass (11.90%) [12]. The higher FC in any biomass demonstrates better energy released during the combustion process [31].

The percentage of carbon (43.46%), hydrogen (5.68%), nitrogen (1.45%), sulfur (0.13%), and oxygen (49.10%) was achieved from the ultimate analysis. These values are similar to other invasive grasses like elephant grass [10], *Imperata cylindrica* [11], and switchgrass [12]. The carbon content represents the most significant component when the biomass will be used as heating fuel. In any biomass, higher carbon with lower oxygen enhances the heating/calorific value [7]. Nitrogen and sulfur contents are vital for the environment as they create NOx and SOx. As the proportion of sulfur is less than 1%, this grass may be helpful for bioenergy yield by saving the atmosphere [32]. The atomic ratio of H/C (1.608) and O/C (0.848) is also a good indication of higher energy from this feedstock. Because of lower values of H/C and O/C, represent higher carbon to carbon (C-C) bond rather than carbon to oxygen (C-O) and carbon to hydrogen (C-H) bonds. In the biofuel production process, the C-C bonds contain higher energy than C-O and C-H bonds [33].

The HHV of *A. compressus* biomass was found to be 17.96 MJ/kg, which is comparable with elephant grass (15.77 MJ/kg) [10], *Imperata cylindrica* (17.03 MJ/kg) [11], and switchgrass (19.80 MJ/kg) [12]. The literature suggested that the HHV of the biomasses are increased with more carbon and hydrogen content, whereas decrease with nitrogen content. Sheng et al. in 2005 described that the HHV reduces with higher ash content of the biomass sample [34].

The thermogravimetric and derivative thermogravimetry (TGA-DTG) analysis result of the *A. compressus* grass has shown in Figure 2 for both conditions. The initial weight loss was around 4.5% from 40 °C to 200 °C temperature for both pyrolysis and combustion conditions. It occurred mainly for the removal of moisture and weak volatile matters present in the grass sample [35].

![Figure 2](image-url)

**Figure 2.** TGA-DTG graph of *A. compressus* grass in pyrolysis and combustion conditions.

The significant degradation occurs from 200 to 450 °C temperatures due to the breakdown of hemicellulose, cellulose, and some part of lignin [7]. In this stage, the weight loss was found 60.98% under pyrolysis condition with the highest degradation rate of 6.03 wt.%/min at 334 °C temperature. Whereas, the weight loss was found as 81.25% with the maximum decomposition rate of 30.63 wt.%/min at 443 °C temperature under combustion condition. From 450 to 900 °C, the decomposition pattern is almost similar for both states due to the degradation of lignin in the sample [36]. The rate of losses in this stage is low because of the slow degradation of the complex lignin components in the
biomass [16]. After 900 °C temperature, the residue was found to be 23.03% for pyrolysis, which is principally the biochar, and 6.12% for combustion condition, which is the ash content of biomass [4].

4. Conclusions
The results indicate that *A. compressus* is an invasive grass that is a suitable source for bioenergy via thermochemical conversion. The low moisture content and high volatile matter of this sample are important for higher quality biofuel production. The small quantity of sulfur (0.13%) is the sign of lower SOx emission in the atmosphere. The HHV value of 17.96 MJ/kg shows that the *A. compressus* is comparable with other biomass. TGA and DTG showed a solitary peak with a lower degradation rate in pyrolysis. Whereas in the combustion processes, double peaks with higher decomposition rates were found for the virtuous chemical reactions. A biochar amount of 23.03% from pyrolysis and the residue of 6.03% from combustion show a considerable amount suitable for the various applications such as activated carbon and catalyst support, respectively. As the growth of *Axonopus compressus* is high in Brunei Darussalam, it can potentially aid the country in achieving the renewable energy target by minimizing the greenhouse gas emissions and the negative impact of biodiversity.

Acknowledgment
Authors are grateful to the Brunei Research Council (UBD/BRC/11) for supporting this work.

References
[1] Afroze S, Binti Haji Bakar A N, Reza M S, Salam M A and Azad A K 2018 Polyyvinylidene fluoride (PVDF) piezoelectric energy harvesting from rotary retracting mechanism: Imitating forearm motion *IET Conference Publications* vol 2018 (Institution of Engineering and Technology) p page (4 pp.)
[2] Hossain M A, Shams S, Amin M, Reza M S and Chowdhury T U 2019 h *Buildings* 9 79
[3] Ahmed A, Abu Bakar M S, Azad A K, Sukri R S and Mahlia T M I 2018 *Renew. Sustain. Energy Rev.* 82 3060–76
[4] Reza M S, Ahmed A, Caesarendra W, Abu Bakar M S, Shams S, Saadur R, Asl fattahi N and Azad A K 2019 *Bioengineering* 6 33
[5] Anon Map of *Axonopus compressus*: info from PIER (PIER species info)
[6] Arunbabu V, Sruthy S, Antony I and Ramasamy E V 2015 *J. Water Process Eng.* 7 153–60
[7] Reza M S, Islam S N, Afroze S, Bakar M S A, Sukri R S, Rahman S and Azad A K 2020 *Energy, Ecol. Environ.* 5 118–33
[8] Anon *Axonopus compressus*: info from PIER (PIER species info)
[9] Reza M S, Afroze S, Bakar M S A, Saadur R, Asl fattahi N, Taweekun J and Azad A K 2020 *Biochar* 2 239–51
[10] De Conto D, Silvestre W P, Baldasso C and Godinho M 2016 *Bioresour. Technol.* 218 153–60
[11] Oladokun O, Ahmad A, Abdullah T A T, Nyakuma B B, Bello A A H and Al-Shatri A H 2016 *Appl. Therm. Eng.* 105 931–40
[12] Imam T and Capareda S 2012 *J. Anal. Appl. Pyrolysis* 93 170–7
[13] Damit H, Bagol A H and Woodford J G 1984 *Brunei Chamb. Commer. J.* 23–31
[14] Radenahmad N, Tasfiah A, Saghir M, Taweekun J, Saiful ah M, Bakar A, Reza S and Kalam A 2020 *Renew. Sustain. Energy Rev.* 119 109560
[15] Reza M S, Hasan A B M K, Afroze S, Muhammad S, Bakar A, Taweekun J and Azad A K 2020 *Int. J. Integr. Eng.* 12 233–44
[16] Ahmed A, Abu Bakar M S, Azad A K, Sukri R S and Phusunti N 2018 *Energy Convers. Manag.* 176 393–408
[17] Reza M S, Yun C S, Afroze S, Radenahmad N, Bakar M S A, Saadur R, Taweekun J and Azad A K 2020 *Arab J. Basic Appl. Sci.* 27 208–38
[18] ASTM International 2011 *ASTM D 3173-11 Standard Test Method for Moisture in the Analysis Sample of Coal and Coke* (West Conshohocken, PA 19428-2959, United States)
[19] ASTM International 2007 ASTM D 3175-07 Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke (West Conshohocken, PA 19428-2959, United States)
[20] ASTM International 2010 ASTM D3174-04 Standard Test Method for Ash in the Analysis Sample of Coal and Coke from Coal (West Conshohocken, PA 19428-2959, United States)
[21] Ahmed A, Hidayat S, Abu Bakar M S, Azad A K, Sukri R S and Phusunti N 2018 Biofuels 7269 1–12
[22] ASTM International 2007 ASTM D5468-02 Standard Test Method for Gross Calorific and Ash Value of Waste Materials (West Conshohocken, PA 19428-2959, United States)
[23] Baloch H A, Nizamuddin S, Siddiqui M T H, Riaz S, Jatoi A S, Dumbre D K, Mubarak N M, Srinivasan M P and Griffin G J 2018 J. Environ. Chem. Eng. 6 5101–18
[24] Hidayat S, Abu Bakar M S, Yang Y, Phusunti N and Bridgwater A V 2018 J. Anal. Appl. Pyrolysis 134 510–9
[25] Williams C L, Westover T L, Emerson R M, Tumuluru J S and Li C 2016 BioEnergy Res. 9 1–14
[26] Demirbas A 2004 Prog. Energy Combust. Sci. 30 219–30
[27] Tahir M H, Çakmak G, Goldfarb J L, Topeu Y, Naqvi S R and Ceylan S 2019 Bioresour. Technol. 279 67–73
[28] Gravalos I, Xyradakis P, Kateris D, Gialamas T, Bartzialis D and Giannoulis K 2016 Nat. Resour. 07 57–68
[29] Vassilev S V., Baxter D, Andersen L K, Vassileva C G and Morgan T J 2012 Fuel 94 1–33
[30] Abu Bakar M S and Titiloye J O 2013 J. Anal. Appl. Pyrolysis 103 362–8
[31] Sadiku N A, Oluyege A O and Sadiku I B 2016 Lignocellulose 5 34–49
[32] Odetoye T E, Afolabi T J, Abu Bakar M S and Titiloye J O 2018 Energy, Ecol. Environ. 3 330–7
[33] McKendry P 2002 Bioresour. Technol. 83 37–46
[34] Sheng C and Azevedo J L T 2005 Biomass and Bioenergy 28 499–507
[35] Afruze S, Torino N, Henry P F, Sumon Reza M, Cheok Q and Azad A K 2020 Mater. Lett. 261 127126
[36] Reza M S, Islam S N, Afruze S, Bakar M S A, Taweekun J and Azad A K 2020 Data Br. 30 105536