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A Review On Physicochemical Characterization Of Pigeon Pea Stalk (Cajanus Cajan)

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Abstract

Agriculture is the economic backbone of any nation. The leftovers of these crops can have capabilities to produce energy and also partially satisfy energy demands. India is noted for being the world's largest producer and consumer of pigeon peas. Pyrolysis is a possible method for turning trash into renewable charcoal and biofuels in the current situation. To evaluate the potential for pyrolysis of the Pigeon Pea Stalk (PPS) (*Cajanus Cajan*) and its physicochemical parameters were considered. The current review provides a comparison of the physicochemical characteristics of PPS and others biomass in term of proximate and ultimate analyses, lignocellulosic content and thermogravimetric analyzer, which will aid researchers in selecting the most appropriate biomass for pyrolysis process.

Keywords: Pigeon pea stalk, TGA, proximate analysis, ultimate analysis

1. Introduction

The amount of energy consumed today is tremendous which plays an important role in the development of any nation. Economic expansion of any country is not possible in absence of energy sources (Mofijur et al., 2013). Despite the significant importance of contemporary energy services, it remains unfortunate that not everyone has access to them (Dalal-Clayton et al., 2002). The rising global population, ongoing economic development, and technological global energy demands have increased as a result of developments (Li et al., 2019; Zhang et al., 2020). Fossil fuels have become the dominant source of energy as a result of their high heating values, knock-resistance, and calorific properties. Nevertheless, it's crucial to acknowledge that fossil fuels supplies are finite since they are considered conventional energy sources. Thus by developing the alternative energy sources can help in lowering the consumption of fossil fuels (Rahman et al., 2017). On the other hand, global warming is becoming worse every day. The risky carbon dioxide levels in the atmosphere already have been exceeded earlier than the 10-year prediction (Damanik et al., 2018). The lookout for non-traditional and alternative energy sources that can supply the necessary energy requirement, the use of fossil fuels running out and the catastrophic effects of climate change have all added to the urgency of reducing greenhouse gas emissions, preventing pollution, and maintaining a stable global temperature (Jahirul et al., 2012).

As agriculture is the economic backbone of many nations, its leftovers can have capabilities to produce energy and also partially satisfy energy demands. Arhar/Tur/Redgram, another name for PPS (Pigeon pea stem), is a kharif crop. PPS has much potential as a biomass source from agricultural waste, but relatively little research has been done on its torrefaction and pyrolysis. For instance, currently, India generates a staggering annual quantity of 611 million tons of agricultural waste. This substantial amount of agricultural waste is a result of various agricultural activities and practices across the country (Mathur and Srivastava, 2019). This could be used to establish future bio-based enterprises. Today, biomass accounts for 10% of all primary energy consumed worldwide. India possesses a significant quantity of coal reserves; however, a notable challenge is that a considerable portion of these reserves is of low quality. The high sulphur concentration 0.4 wt%, high nitrogen content 2.49 wt%, high ash content 38.39 wt%, and comparatively low gross heating value 16.15 MJ/Kg of this low-quality coal are its distinguishing features (Cardoen et al., 2015). These quality limitations pose various difficulties, the effects on the environment, combustion efficiency, and utilization for energy production (Cardoen et al., 2015).

India is noted for being the world's largest producer and consumer of pigeon peas. This status positions India as a highly qualified candidate for effectively utilizing the crop waste derived from pigeon peas. Pigeon peas are known to generate a substantial quantity of agricultural residue, with an average production of 2.9 tons per hectare (ha). Given the significant cultivation and consumption of pigeon peas in India, there is a considerable opportunity to harness this agricultural residue for various purposes, including biofuel production (Seepana et al., 2018).

The pyrolysis method, which uses biomass as its raw material to create energy, has a large market potential. Thus, much research is being done to enhance this energy generation process. As compared to digestion, fermentation, and mechanical conversion, thermo-conversion is a relatively new technology to generate energy from biomass in a commercial. Nevertheless, it is garnering greater attention due to its technological and strategic benefits. Also, trash generation is always growing, and the associated economic activity is becoming more significant. Eliminating or lessening environmental issues while achieving profits via their management is a highly positive move. Since it produces other fractions that may be recovered in addition to energy, pyrolysis is a viable alternative method of energy recovery.

2.Source of biomass Pigeon pea stalk (PPS)

Pigeon pea stalk (PPS) biomass is a byproduct of the pigeon pea (*Cajanus Cajan*) crop. It is the discarded residue of the pigeon pea seeds that have been harvested. PPS biomass is obtainable from the fields and used for a variety of purposes, including bioenergy production, bioproduct production, and animal feed. India, Myanmar, Kenya, China, Nepal are the major countries were the PPS are produced (Hameed et al., 2007). These countries account for a significant portion of the global pigeon pea production. As a result, they also produce an enormous quantity of PPS biomass. In addition to the major producers listed above, PPS biomass is also produced in other countries where pigeon pea is grown, such as the United States, Australia, and Brazil. India produces PPS, which is estimated to be nearly 28.95 million tonnes per year (FAO, 2018). This makes India the world's largest producer of PPS. India's top producing states include Maharashtra, Madhya Pradesh, Karnataka, Rajasthan, Uttar Pradesh and Andhra Pradesh (NBPGR, 2022).

PPS biomass can be used to produce biofuels such as ethanol, biodiesel, and biogas. It can also be used to generate electricity through direct combustion, gasification, or pyrolysis. Moreover, a variety of bioproducts such as paper, pulp, board, biofertilizer, and biocomposites are also produced. The utilization of PPS biomass for bioenergy and bioproduct production is still developing and in its early stages in India. However, the potential of this biomass is significant, and it is predicted to perform an important contribution to the switch to a sustainable energy future in the country.

3. Physicochemical properties of PPS

PPS biomass physical and chemical properties are important for its use in biomass conversion procedures like torrefaction, gasification, and pyrolysis. The moisture level of PPS biomass affects its transportability and storability. The amount of ash in PPS can cause problems in biomass conversion processes, such as slagging and fouling. The amount of fixed carbon and volatile substances in PPS affect its combustion and pyrolysis behavior.

To choose biomass as a feedstock for turning it into bio products, it must have certain physical, chemical, and thermal properties (Majumder et al., 2008).

3.1 Proximate analysis of PPS

A variety of tests known as "proximate analysis" are performed for determining a biomass material's moisture content, ash content, volatile matter content, and fixed carbon content (Bach et al., 2017). These properties are important for determining the biomass's abilities for various methods of conversion. **Table 1** shows the proximate evaluation of PPS and other biomass.

Table 1. **Proximate evaluation of PPS and other biomass.**

Biomass	Proximate analysis /wt. %				References
	Moisture content	Volatile Matter	Ash content	Fixed carbon content	
PPS	–	83.45	1.80	14.75	(Katyal & Iyer, 2000)
PPS	3.28	80.67	1.39	17.94	(Manjunath & Palled, 2018)
PPS	5.43	82.12	1.49	10.96	(Singh et al., 2019)
PPS	9.89	65.9	12.3	21.8	(Tanquilut & Elauria, 2019)
PPS	7.59	76.71	2.00	13.70	(Sahoo & Vijay, 2021)
Cotton Stalk	6.98	80.20	1.43	18.37	(Manjunath & Palled,2018)
Bamboo	10.74	71.65	1.58	16.03	(Sahoo & Vijay, 2021)
Rice	8.70	67.40	17.90	14.70	(Capareda & S.C, 2014)
Paddy Straw	7.30	60.80	22.60	16.60	(Lee et al., 2017)

The proximate analysis results for PPS biomass are similar to those of other agricultural residues, like cotton stalk, paddy straw and rice straw. This makes PPS biomass a suitable feedstock for a number of transformation techniques, including combustion, gasification, and pyrolysis.

3.2 Ultimate analysis of PPS

A series of tests known as ultimate analysis are conducted to figure out the elemental composition of a biomass material (Bach et al., 2017). Usually, carbon (C), hydrogen (H), nitrogen (N), oxygen (O), and sulphur (S) are the fundamental substances that are examined in biomass. **Table 2** shows the ultimate evaluation of PPS and others biomass.

Table 2. Ultimate evaluation of PPS and others biomass with their heating value.

Biomass	Ultimate analysis /wt. %					References
	carbon	hydrogen	nitrogen	oxygen	HHV (MJ/Kg)	
PPS	46.75	6.55	0.62	44.28	15.00	(Katyal & Iyer, 2000)
PPS	41.62	6.10	0.71	51.57	–	(Sahoo & Vijay, 2021)
PPS	41.1	6.17	0.854	51.90	17.13	(Tanquilut & Elauria, 2019)
PPS	46.12	6.73	0.73	46.42	16.67	(Singh et al., 2019)
Bamboo	46.98	6.21	0.16	46.65	–	(Sahoo & Vijay, 2021)
Rice Straw	39.90	6.00	1.30	24.70	67.50	(Capareda & S.C, 2014)
Paddy Straw	48.75	5.98	1.99	43.28	17.89	(Lee et al., 2017)

The ultimate analysis results for PPS biomass are similar to those of other agricultural residues. PPS has a high carbon content, which makes it an appropriate feedstock for several biomass conversion processes such pyrolysis, gasification, and combustion. The high carbon content of PPS makes it a good source for bioenergy production.

4. Chemical Compositional properties of PPS

The chemical composition of PPS is important for its use in biomass conversion processes. The cellulose content of PPS affects its suitability for biofuel production. The hemicellulose content of PPS affects its suitability for pyrolysis process. PPS lignin content affects its thermal stability and combustion characteristics (Attia et al., 2013). PPS essentially comprises cellulose, hemicellulose, and lignin (Bach et al., 2017).The chemical compositional properties of PPS can be impacted by several factors, including the variety of pigeon pea, the growing conditions, and the harvesting and storage methods.

4.1 Cellulose

A linear polysaccharide composed of glucose units is cellulose. It makes up the majority of the biomass found in PPS, representing between 30% and 50% of the total mass (Singh et al., 2019). Cellulose is a good source of bioenergy, as it can be converted into biofuels such as ethanol and biodiesel (Patrick & Bergman, 2005).

4.2 Hemicellulose

Hemicellulose is a branched polysaccharide composed of a variety of sugars, including glucose, xylose, and mannose. It accounts for about 20-30% of the total mass of PPS (Buchanan et al., 2015; Tanquilut & Elauria,2019). Hemicellulose is a good source of biofuels and bioproducts, such as furfural and xylitol (Patrick & Bergman, 2005)

4.3 Lignin

Lignin is a sophisticated aromatic polymer that gives plant cell walls their strength and rigidity. It accounts for about 15-20% of the total mass of pigeon pea stalk biomass (Singh et al., 2019). Lignin is a good source of bioenergy and bioproducts, such as biochar and activated carbon (Bach et al., 2017). Table 3 illustrates the chemical composition of PPS and other biomass.

Table 3. Analysis of the chemical composition of PPS and other types of common lignocellulosic biomass.

Biomass	Cellulose (Per Weight %)	Hemicellulose(Per Weight %)	Lignin(Per Weight %)	References
PPS	34.0 – 34.6	34.2 – 35.5	17.8 – 18.2	(Tanquilut & Elauria, 2019)
Bagasse	25.0 – 45.0	28.0 – 32.0	15.0 – 25.0	(Cai et al., 2017)
Hardwood (stem)	41 – 50	24.0 – 40	18.0 – 25	(Capareda & S.C, 2014)
Pine Softwood	45.0 – 50.0	25.0 – 35.0	25.0 – 35.0	(Cai et al., 2017)
Rice	29.3 – 34.7	23.1 – 25.9	17.0 – 19.0	(Cai et al., 2017)

PPS consists of 34.26% cellulose, 34.83% hemicellulose, and 17.99% lignin, corresponding to the compositional properties findings (Table 4). A crucial stage in the conversion of different biomass resources involves analyzing the composition focused on the major elements, cellulose, hemicellulose, and lignin in particular (Manjunath & Palled, 2018).

5. THERMAL ANALYSIS TECHNIQUES

Thermal analysis techniques are used to investigate the physical and chemical changes that occur in materials when they are subjected to heat. These techniques can be utilized to describe the physicochemical characteristics of pigeon pea stalk biomass, such as its thermal stability, composition, and reactivity (Lee et al., 2017).

Thermogravimetric analysis (TGA) evaluates the mass of a substance's change as it is heated. This approach can be used for determining the amount of moisture, ash, volatile matter, and fixed carbon of pigeon pea stalk biomass. It can also be used to study the thermal decomposition of pigeon pea stalk biomass. Differential thermal analysis (DTG) is a method for examining the thermal breakdown of materials. It measures the rate of change of mass of a material as it is heated. DTA measures the temperature difference between a sample and a reference material as they are heated. This technique can be used to study the phase transitions and chemical reactions that occur in pigeon pea stalk biomass during thermal treatment.

TGA to identify the optimal conditions for producing biofuels and bioproducts from PPS. They found that the optimal conditions for producing biofuels from PPS biomass were 450°C temperature and a 10°C/min heating rate. (Singh et al., 2019) also conducted TGA to identified the thermal breakdown of pigeon pea stalk biomass at different heating rates. They found that hemicellulose, cellulose, and lignin decompose between 150 to 350 °C, 275 to 350 °C, and 250 to 500 °C, respectively (Attia et al., 2013). Studied conducted by (Singh., et al 2019) shows the different stages of weight loss of PPS. Figures 1 and 2 demonstrate that there are various stages to weight loss of PPS. Surface moisture is lost during the first stage up to 150 C, followed by absorbed or equilibrium moisture. But when compared to torrefied biomass, the first stage only matters when using raw pigeon pea stalk (RPS). When using DTG, RPS peaks are seen in the early stages, prior to 150 C, which is consistent with the elimination of absorbed moisture from the surface. According to this study, there are three stages to the thermal decomposition of PPS biomass: (1) moisture evaporates at temperatures below 100°C, (2) hemicellulose and cellulose decompose between 100°C and 350°C, and (3) lignin decomposes at temperatures above 350°C.

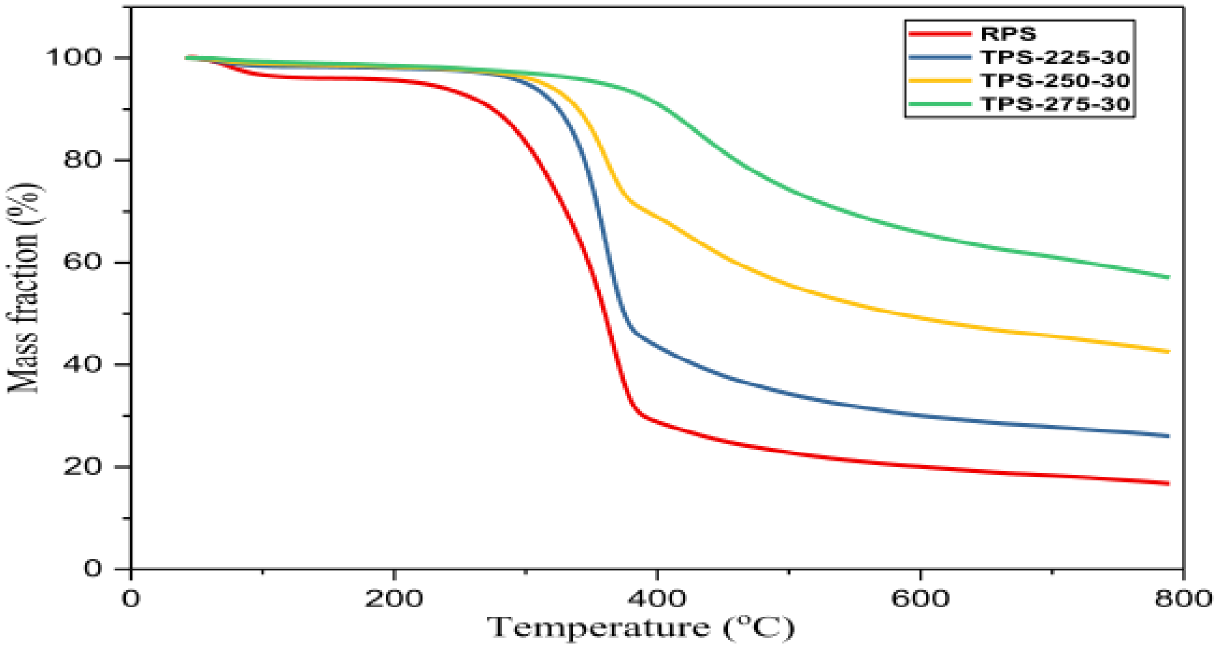

Figure 1: Shows the experimental TGA curves of raw and torrefied pigeon pea stalk (Singh et al, 2019)

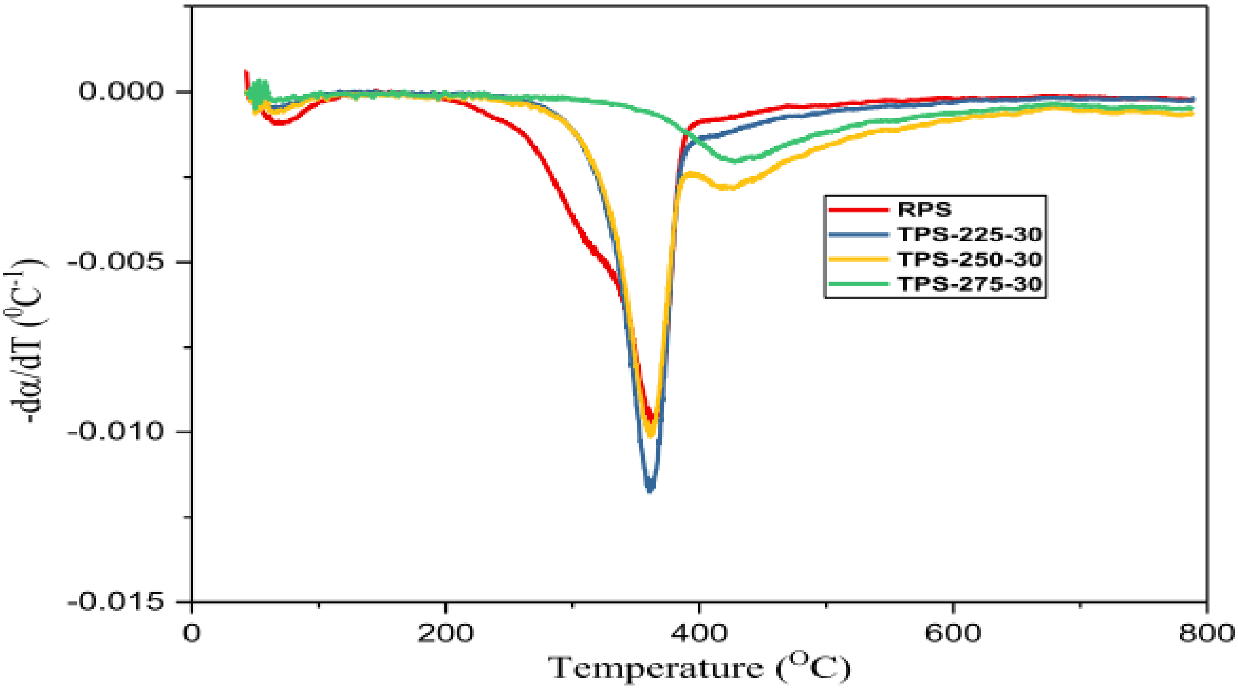

Figure 2: Shows the DTG of raw and torrefied pigeon pea stalk. (Singh et al, 2019)

6. CONCLUSION

Pigeon pea stalk biomass (PPS) is a potential source of renewable energy and bioproducts. It is a plentiful and renewable resource with good physicochemical properties for biomass conversion processes. PPS can be used to produce biofuels such as ethanol, biodiesel, and biogas. It can also be used to generate electricity through direct combustion, gasification, or pyrolysis. In addition, PPS can be used to produce a variety of bioproducts such as paper, pulp, board, biofertilizer, and biocomposites. The PPS contains cellulose in range of 30 to 50 %, hemicellulose from 20 to 40 %, and lignin from 15 to 25 %. PPS has substantially less lignin mass % as compared to other biomass make it a suitable candidate for thermochemical conversion process. In addition to that the low presence of nitrogen in PPS also indicates that less harmful nitrogen oxide species being produced during pyrolysis. Overall the review suggests that PPS has an enormous amount of potential for used as a biomass for biofuels production.

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