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RESEARCH ARTICLE

Characterization of Corn Stover and Eucalyptus Sawdust for Pellet Production

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ABSTRACT

Reducing the use of fossil fuels and increasing the use of renewable resources is essential in minimizing climate change. As the world progress towards using more renewable resources for energy and other products, biomasses will be crucial to this transition. Utilizing biomass as efficiently as possible is therefore necessary, and this relies on the types of biomasses used in addition to the actual production methods. Biomass residues like corn stover and eucalyptus sawdust could be valuable sources of renewable energy. Corn stovers are herbaceous agricultural residue, whereas eucalyptus sawdust is a woody residue that can be processed into different fuels that have a variety of applications. Pelleting is the cheapest technique for producing fuel pellets that can be employed for heat and electricity production. The overall qualities of pellets can be enhanced by blending biomass materials with different qualities and using additives, such as binders. Corn stovers and eucalyptus sawdust are large waste streams which are more often discarded and underutilized. To ascertain the suitability of these biomass residues as blends on pelletization, determination of their properties through characterization is, therefore, a necessity. The focus of this research was to determine the analysis of both their ultimate and proximate composition of eucalyptus sawdust and corn stover and the higher heating values. These properties were determined using ASTM standards. The results obtained for proximate analysis of corn stover were moisture content, volatile matter, ash content, and fixed carbon were 5.92%, 74.99%, 5.21%, and 20.13%, respectively, and 3.70%, 84.66%, 3.22%, and 12.11% respectively for eucalyptus sawdust. Corn stovers' ultimate analysis for carbon, hydrogen, nitrogen, sulphur and oxygen were 39.54%, 5.70%, 1.38%, 0.07%, and 53.32%, respectively, and 47.16%, 4.97%, 0.08%, 0.03%, and 47.76%, respectively for eucalyptus sawdust. Higher heating values were 17.38 MJ/kg and 17.93 MJ/kg for corn stover and eucalyptus sawdust, respectively. These results indicate that corn stover and eucalyptus sawdust can be blended together, improving the properties of corn stover pellets, such as higher heating value and reduction of ash content.

Keywords: Corn stover, Eucalyptus sawdust, Higher heating values, Ultimate and proximate analysis.

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1. Introduction

Currently, fossil fuel energy accounts for approximately 80% of the total primary energy supply worldwide [1] and is still the dominant fuel energy [2]. The population increase and, consequently, rapidly growing development has increased energy demand by huge margins, resulting in an overuse of coal, gas, and oil [2], [3]. The significant CO_2 emissions from the combustion of these fuels contribute to the greenhouse effect, which has a negative impact on the environment [2], [4]–[6]. Due to their nonrenewable nature, over production and utilization of these fuels inevitably causes their depletion. Due to these challenges, attention has shifted to the research, development, and utilization of clean and renewable energy resources [2], [7]–[10]. Among these renewables are biomasses, which, together with solar, wind, geothermal, tidal, and hydropower, have not been fully utilized [8], [11].

Despite its many uses, biomass does not increase the net atmospheric carbon dioxide concentration [12] via its derived products such as fuelwood, charcoal, pellets, methanol, ethanol, biodiesel, Fischer-Tropsch hydrogen, and methane [13], [14]. Cui *et al*. [15] additionally noted that emissions from combustion and landfills are decreased when biodegradable and agricultural wastes are used as fuel alternatives. Under these conditions, biomass has enormous potential in terms of sustainable, renewable source of bioenergy. However, there have been challenges in the utilization of biomass as an energy source that is renewable, including low bulk density, high moisture content, uneven shape, poor heating value, wide dispersion, and others that have resulted in high handling, shipping, and storage costs [9], [16]. The pretreatment and improvement processes for producing high-quality solid biomass fuels include drying, pelletizing, briquetting, torrefaction, and using binders [16].

In order to maximize the pelletizing processes and quality through co-pelleting, the physico-chemical characteristics of diverse biomass feedstocks can be combined and coordinated by combining multiple feedstock types [17].

Niedziółka *et al*. [10] noted that agricultural biomass, particularly straw from cereal and other crops, has a low calorific content per volume and needs a lot of space for storage and transportation. Straw should be handled properly to enhance its energy efficiency because its chemical composition changes based on the plant type, locality, and growth technique [18]. Thus, attempts are being undertaken to condense these plant resources through briquetting or pelleting in an effort to simplify the transportation and use of this type of biofuel and enhance the concentration of energy and mass per unit of volume. Wood waste, forestry and agricultural wastes, energy crops, and other biomass feedstocks are commonly used to produce solid fuels.

The suitability of biomass for conversion to different biofuels is determined by assessing its properties through characterization [19]. In order to get a proper understanding of biomass and the process of its conversion to biofuel, it is recommended that characterization be done before and after the treatment process [20]. Proximate analysis of biomass and its ultimate analysis are the main expressions of biomass characterization when biomass is used for the production of biofuels applicable in thermochemical processes [21]. Thus, higher heating value (HHV) should be considered in characterization.

One of the raw materials this study investigated was corn stover, a by-product of the manufacture of corn grain that is made up of the stalk, leaves, sheaths, husks, shanks, cobs, tassels, lower ears, and silks. However, a significant portion of agricultural waste, like corn stover, gets burned or left unprocessed in the field; as a result, correct treatment and preprocessing of the feedstock are necessary to turn it into a plentiful source of bioenergy. Another raw material under study is Eucalyptus sawdust which is woody residues derived from sawmills and wood workshops. Being of two different types, corn stover, and eucalyptus sawdust properties were evaluated in this research to ascertain their suitability for pellet production by blending them.

2. Materials and Methods

Corn stover was randomly collected from maize farms around Moi University, Kenya, while eucalyptus sawdust was also collected randomly from workshops and sawmills in Uasin Gishu County, Kenya. The equipment for preparation and analysis of eucalyptus sawdust and corn stover were found in Moi University Laboratory and in Kenya, Industrial, Research and Development Institute (KIRDI). The collected raw materials and ground raw materials are illustrated in Figs. 1 and 2, respectively.

2.1. *Proximate Analysis*

Proximate analysis is the determination of moisture content, volatile matter, fixed carbon, and ash content of the feedstocks, and it is determined by the procedures described below. Before all analysis was done, the feedstock was sampled by use of cone and quarter method. This involved heaping the prepared feedstock to form a cone, and then the tip of the cone was flattened. It was then subdivided into four equal quarters, and the quarters diagonal to each other were taken as a sample while the rest was discarded. This procedure was repeated until the sample was small enough to be used for analysis, and at this stage, it will be a true representative sample for the whole feedstock considered.

2.1.1. *Moisture Content*

The amount of moisture content in raw materials was determined by ASTM E871. By ASTM E871 procedure, a crucible was dried in the oven for 30 m at 103 °C ± 1 °C, then allowed to cool to ambient temperature. Crucible weight was recorded as, w_c, to the nearest 0.02 g. 50 g of sample was placed on the crucible and its weight recorded to the nearest 0.01 g as initial weight, w_i. The sample and crucible were then placed in an oven at 103 °C

Fig. 1. Collected raw materials: Corn stover (left) and Eucalyptus sawdust (right).

Fig. 2. Ground raw materials.

± 1 °C for 16 h. The crucible and the sample were then cooled in a desiccator after removal from the oven and weighed to the nearest 0.01 g. The crucible and sample were then placed in the oven at 103 °C ± 1 °C for 2 h until weight change was less than 0.2% and this weight was recorded as the final weight, w_f. Moisture content was then calculated using (1):

$$\%moisture = \frac{w_i - w_f}{w_i - w_c} \times 100 \tag{1}$$

where w_c is crucible weight, w_i is initial weight, and w_f is final weight.

2.1.2. Ash Content

Ash content was determined by ASTM D1102 (873 K). The procedure of ash content determination was as follows: heating of the crucible was done in an oven at 6000 °C, cooled in a desiccator, and weighed to the nearest 0.1 mg. A sample weighing 2 g was put inside a crucible and weighed, then placed in an oven for drying at 105 °C for 1 h. The crucible and sample were removed and cooled in a desiccator. The procedure was repeated until weight change was within 0.1 mg. This weight (crucible plus specimen less crucible weight) was recorded as oven-dry weight of sample. The crucible and sample were then placed in a muffle furnace and ignited until all carbon was eliminated. Gradual heating was used to a final temperature of 600 °C. Crucible and sample were removed from the furnace, cooled in a desiccator, and weighed. Heating was repeated for 30-minute periods until weight change was less than 0.1 mg. Equation (2) was used to evaluate the ash contents of the biomass samples:

$$\%ash = \frac{w_1}{w_2} \times 100 \tag{2}$$

where w_1 is weight of ash and w_2 is weight of oven-dry sample.

2.1.3. Volatile Content

Volatile content was determined by ASTM E 872. The crucible weight was determined to the nearest 0.01 g and recorded as crucible weight, w_c. Approximately 1 g of sample was placed in the crucible and covered. The sample, cover, and crucible were weighed to an accuracy of 0.01 g and recorded as initial weight, w_i. The sample-filled covered crucible was put inside the furnace chamber, which was maintained at a temperature of 950 °C ± 20 °C. After heating for precisely 7 m in total, the crucible was removed from the furnace without disturbing the cover, and allowed to cool in a desiccator. The covered crucible with sample was weighed as soon as it cooled to the nearest 0.1 mg and recorded as the final weight, w_f. Equation (3) was employed in the determination of volatile content:

$$weight\ loss, \% = \frac{w_i - w_f}{w_i - w_c} \times 100 = A \tag{3}$$

where Wc is weight of crucible and cover (g), w_i is initial weight (g), and w_f is final weight, g.

$$Volatile\ matter\ in\ analysis\ sample, \% = A - B \tag{4}$$

where A is weight loss %, and B is moisture, %, as determined using Method ASTM E 871.

2.1.4. Fixed Carbon

Fixed carbon was determined by difference as follows [22]:

$$\begin{aligned} &Fixed\ carbon \\ &= 100\% - (ash + volatile\ contents)\% \end{aligned} \tag{5}$$

2.2. Ultimate Analysis

Elemental analysis was done to ascertain the proportions of the elements carbon, hydrogen, nitrogen and sulphur was done using ASTM D5375-02 procedures [23]. The biomass samples' oxygen concentration was then determined by difference according to (6) [24]:

$$\%O_2 = 100 - (C + H + N + S + \%Ash) \tag{6}$$

TABLE I: SUMMARY OF PROXIMATE, ULTIMATE AND HIGHER HEATING VALUES OF CORN STOVER AND EUCALYPTUS SAWDUST

Property		Corn stover		Eucalyptus sawdust	
		wt%	STDEV	wt%	STDEV
Proximate analysis					
	Moisture	5.92	1.71	3.70	0.26
	Volatile matter	74.66	2.73	84.66	0.35
	Fixed carbon	20.13		12.11	
	Ash	5.21	0.17	3.22	0.72
Ultimate analysis					
	C	39.54	1.27	47.16	0.25
	H	5.70	0.13	4.97	0.21
	N	1.38	0.01	0.08	0.00
	S	0.07	0.01	0.03	0.00
	O	53.32	1.19	47.76	0.08
HHV (MJ/kg)		17.38	0.12	17.93	0.09

2.3. *Higher Heating Values (HHV)*

Higher heating values of corn stover and eucalyptus sawdust were done using automatic bomb calorimeter (model no. 5E-C5500) at Moi University.

3. Results and Discussion

Table I presents the results of proximate, ultimate, and higher heating values of corn stover and eucalyptus sawdust. It was observed that the moisture contents were 5.92% and 3.70% for corn stover and eucalyptus sawdust respectively. These figures were generally very low for pelletization of both feedstocks using single pellet press. According to Pradhan *et al*. [17], the recommended moisture content for use in single pellet press is 10%. Therefore, to be able to use the feedstocks for pelletization, ultrapure water should be added to the feedstocks to elevate the amount of moisture to 10%. Again, this optimum pelleting moisture content is varied as presented in different texts in literature. For instance, Frodeson *et al*. [25] stated that the ideal level of moisture for pelletization is between 6%–12%, and Kwapong [26] stated that the moisture content range is between 10%–15%.

Volatile matter, fixed carbon and ash content for corn stover obtained from this research was 74.66%, 20.13%, and 5.21%, respectively, while for eucalyptus sawdust was 84.66%, 12.11%, and 3.22%, respectively. These figures and their trends agree with those presented by Williams *et al*. [18]. The trends were also similar in that the ash and fixed carbon contents of corn stover (herbaceous biomass) were greater than those of eucalyptus sawdust (woody biomass), while the volatile content was higher in eucalyptus sawdust than corn stover.

Significant heterogeneity exists within particular feedstock categories, even though a high degree of variability is anticipated within broad categories like lignocellulosic biomass and municipal solid waste [18]. According to Williams *et al*. [27], numerous variables, including feedstock varieties, component analysis methodologies, environmental variables, harvesting techniques, storage conditions, and preprocessing techniques, contribute to biomass variability. While some of these characteristics can be managed by standardization procedures, others may be more challenging to manage. Since environmental factors are influenced by daily and seasonal temperature swings, changes in local soil conditions (e.g., sand, clay, nutrient content, rock and pH), and fluctuations in the amount and timing of water supplies, it is especially difficult to manage how these factors affect biomass composition.

The ultimate analysis quantified the elements in corn stover and eucalyptus sawdust samples. Corn stovers' elemental analysis was carbon (39.54%), oxygen (53.32%), hydrogen (5.70%), nitrogen (1.38%), and sulphur (0.07%), while eucalyptus sawdust's was carbon (47.16%), oxygen (47.76%), hydrogen (4.97%), nitrogen (0.08%), and sulphur (0.03%). According to Mostazur Rahman *et al*. [28], ultimate analysis assists in determining the heat of biomass combustion in addition to the volume and makeup of the combustion gases. In the ultimate analysis, the main components of the elemental compositions are carbon, oxygen, and hydrogen. Typically, carbon is found in partially oxidized state, which highlights biomass's lower heating value when compared to coal. The biomasses' heating value is significantly influenced by the hydrogen content. The oxygen needed for the combustion reaction is partially met by the organically bound oxygen in biomass that is released during thermal breakdown; the remaining oxygen is supplied by air injection. However, the evolution of harmful emissions is primarily attributed to sulphur and nitrogen emissions like nitrogen oxides (NOx) and sulphur oxides (SOx) during combustion, which are the major causes of acid rain and particulate matter emissions (PM). The elemental compositions of corn stover along with eucalyptus sawdust in this research were observed to be in between the ranges presented in literature, especially that of Williams *et al*. [18]. There were slight variabilities in nitrogen and oxygen contents of corn stover in which they were higher than those presented in the literature. It is possible that the high nitrogen concentration in the soil where the corn stover was harvested contributed to the excessive nitrogen contents, while the excessive oxygen could arise from some of the reasons presented by Williams *et al*. [27] for biomass composition variability.

4. Conclusions

Due to the low moisture content of corn stover along with eucalyptus sawdust, it can be concluded that its suitability for pelleting can be improved by the addition of ultra-pure water to raise the moisture content to the recommended levels. From ash content analysis, it can be concluded that both feedstocks analyzed are suitable for pelleting since the recommended ranges for wood residues are around 3% and below and less than 5%–7% for agricultural residues. The higher heating value of eucalyptus sawdust was higher than that of corn stover. This indicates that eucalyptus sawdust can be blended with corn stover in pelleting to improve the higher heating value of corn stover pellets.

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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