Biomass Energy from Agricultural Waste: Evaluating Groundnut Vines and Pumpkin Straws for Combustion Performance

Abstract

Energy demand has risen significantly in developing countries due to rapid population growth and increase in economic activities such as industrialization, automation manufacturing and digitalization. Dependency on conventional sources of energy in both rural and peri-urban is high. Traditional energy resources lead to environmental degradation due to carbon oxide release leading global warming and deforestation which results to hydrological decline; therefore, need to come up with renewable resources from other sources such as agricultural wastes to meet the demand and solve environmental pollution problems. This study carried out an investigation on combustion and performance analysis of pumpkin straws and groundnut vines to establish their energy potential.ASTM standards were used to determine the proximate and ultimate properties. This analysis revealed moisture content (8.7-12.4%), volatile matter (63-69%), fixed carbon (11.5-18.5%), ash content (6.3-8.2%), Sulphur (0.09-0.13%), nitrogen (1.02-1.03%), oxygen (5.01-55.88%), carbon (41.8-43%) and hydrogen (5.96-6.3%). Calorific values for the briquettes were above 4389 kCal, which is above most biomass. The density and compressive strength were above 0.63 g/cm^3 and 17N/mm^2 respectively from compaction pressure of 150, 250 and 350 kg/cm^2. The burning time was between 4 and 5.3 min, showing an increase with compaction pressure, burning rate ranged between 4.3 and 2.9 g/min, a decrease with compaction pressure increase. The specific fuel consumption portrayed an inverse relationship with calorific value and a direct relationship with compaction pressure, ranging between 166 to 176 grams per litre. Temperature-weight analysisrevealedthermo stability of this feedstock, portraying resemblance to proximate analysis. Having exhibited close relationship to other agricultural wastes used for fuel, groundnut vines and pumpkin straws are a solution to environmental degradation by reducing deforestation and emissions.It is recommended that further research on mixing this feedstock with other agricultural wastes as well as making and testing of pellets be carried out to maximize energy output.

Keywords

Environmental degradation, Compaction pressure, Proximate and Ultimate analysis

1.0. Introduction

Third world countries continue to struggle with skyrocketing fuel prices for households in and environmental degradation effects associated with the use of fossil fuels, (Kimtai and Kiriamiti, 2019). In Kenya, there is limited alternative sources of energy for household, (Sarkodie and Adom, 2018). Conventional energy resources such as firewood and charcoal, pose healthy hazard due to emissions, as well as adverse environmental effects due to vegetation clearance, (Bruce, 2000 and Pode, 2010).

Research done at Uasin Gishu county in Kenya exhibited that in both rural and peri-urban, majority of the population still utilize traditional sources of energy for cooking. Table 1, shows energy percentage of energy consumption in the said county, (Kimtai and Kiriamiti, 2019).

Table 1: Cooking energy sources in Uasin Gishu County - Kenya

Energy sources	**Rural (%)**	**Peri-urban (%)**
Biogas	11.6	12.9
Electricity	19.7	19.2
LPG	29.6	39.7
Kerosene	38.8	54
Charcoal	74	73.2
Firewood	86.3	72.3

The data above shows that there is need for research to bring in a broader energy mix to safe our population from healthy hazard such as respiratory diseases associated with these conventional sources and effects of climate change.

There is a promising potential alternative energy resource in some agricultural wastes, (Werther et al., 2009 and Sonu et al., 2023). These resources can be utilized in household fuels hence easing pressure on traditional ones, (Sotannde et al., 2010).

Agricultural wastes, (biomass) are utilized by diverse technologies in the market. The technologies include pyrolysis, gasification, direct combustion, co-firing, cogeneration, liquefaction and densification, (Swapan et al., 2020 and Sirbas and Abdul, 2016). Densification that is briquetting and pelleting has gained much attention due to the numerous benefits associated with them: assessable production technologies, competitive levels of calorific values, ease of transportation and storage, availability of feedstocks and accommodative nature to a variety of devices used to combust it, (Wilaipon, 2007).

Briquette can be made by carbonization or compressing raw feedstock after collecting, sorting, drying, crushing and compressing, (Salah, 2007 and Hesborn et al., 2015).

Groundnut (Arachis hypogaea) vines and Pumpkin Straws are potential energy resources with limited information. This research intended to bring out scientific information of these prospective resources.

Agricultural wastes exhibited potential as energy resource; however, limited information was available on possibility of utilizing groundnut vines and pumpkin straw as energy sources. Performance analysis and characterization of briquettes should be established before utilization, (Hesborn et al., 2015). The ratio of mixture also influences characterization of briquettes for the case of variety feedstock in briquetting, (Jindaporn and Sonchai, 2017).

Agricultural wastes are available in abundance especially in agricultural regions and have exhibited potential energy resource yet not fully exploited despite the fact that the world continue to struggle with energy related challenges such as scarcity and environmental degradation as a result of conventional sources such as firewood and charcoal utilized in households. This study brings out scientifically proven energy resources from pumpkin straws and groundnut vines through characterization and performance analysis.

Plate: 1 photos showing (a)ground nut vines, (b) pumpkin straws

Pumpkin (disambiguation) belongs to the genus Cucurbita. There are several varieties of pumpkin grown for food, aesthetic and recreational purposes, (Wolford et al., 2008). They have numerous nutritional values such as minerals and various vitamins, (Moira, 2022).

In Busia, Gucha and Tarime, 96.4%, 98.1% and 59.5% respectively of the farmers adopt pumpkin farming for domestic purposes. Their maturity ranges between three to five months, (Alice et al., 2008). Quick maturity implies that within a short time there will be abundance of wastes which can be utilized as feedstock for briquetting.

Groundnut (Arachis hypogaea), initially grew in Paraguay, they have spread and grown over 93.95 million hectares worldwide, where the major producers include China, India, Nigeria, USA and Myanmar, (Janila and Mula, 2015). The widespread assures plenty of feedstock from these wastes for briquetting. Talawar et al., (2005), in his research argues that by 2005, 92% of the world's groundnut production was from 3rd world countries. Africa and Asia contribute 91% of the world's total groundnuts. Western and Nyanza are Kenya's foremost producers of groundnut, (Loice et al.,2023).

2.0. Methodology

2.1. Raw material and their preparation

Groundnut vines and pumpkin straws, collected from Homa Bay and Kisii counties (Kenya).

Both groundnut vines and pumpkin straws were dried in open sun for a week to ensure realization of right moisture content. They were then crushed separately using a manual miller to the required sizes. Through cleaning of miller was done during exchange to avoid contamination.

The dry crushed groundnut vines and pumpkin straws were then sieved to obtain a 0.60mm particle size required for this research.

2.2. Equipment

Equipment used during this research included mould, piston die, base plate, extruder, sieves, digital weighing machine, Bomb calorimeter and vernier callipers.

2.3. Characterization of milled groundnut vines and pumpkin straws

2.3.1. Proximate and Ultimate analysis

Characterization involved proximate analysis where the moisture content, volatile matter, ash content and fixed carbon content were determined by ASTM D4442 and ASTM E1755 standards.

Ultimate analysis was also carried out to determine Nitrogen, Sulphur, Carbon, Hydrogen and Oxygen present in these feedstocks

Sulphur was determined using the bomb calorimeter exhaust, Nitrogen was determined by titre method, (% N = Titre * 6.25), while Carbon, Oxygen and Hydrogen were determined by calculation as per the formulae: -

$$\%H = 0.036FC + 0.086\,(VM - 0.1A) - 0.0035M^2\,(1 - 0.02M)$$

$$\%O = (100 - (\%C + \%N + \%S + \%H)$$

$$\%C = \frac{T*0.2*0.273}{Sample\ weight}$$

2.3.2. Calorific value

The Calorific values of these samples were determined at the Kenya Industrial and Research Development Institute (KIRDI) using the ballistic bomb calorimeter. Standard procedures were used.

2.4. Briquette production

The feedstock were carbonized, and then compressed to make the briquettes. Compression pressures at three levels: (150, 250 and 350 kg/cm^2) were employed.

Four sets samples of briquettes were made, two each containing either, 100% groundnut vines and 100% pumpkin straws, one with 25% pumpkin straws and 75% groundnut vines, while the last one had 75% pumpkin straws and 25% groundnut vines.

2.5. Determination of briquette characteristics

2.5.1. Density

The density was determine by find the volume of the respective briquette (the height and the diameter found by measuring by vernier callipers, hence volume calculated by multiplying the cross-sectional area, $\{л\frac{d^2}{4}\}$ and height). Mass was measured by a digital weighing machine.

$$Density = \frac{mass}{volume}$$

2.5.2. Compression strength

A compressive testing machine was used to determine the compressive strength at KEBS laboratory.

2.5.3. Combustion testing

2.5.3.1. Water boiling test (W.B.T.);

Time taken to boil water under same conditions was determined. This time was to aid determination of specific fuel consumption and rate at which heat released. 100 g of briquette was put in a stove and ignited to burn; this was used to boil 100 cm^3 of water in the aluminium cup. Time taken to boil an equal amount of water under this same condition was recorded for various briquette samples.

2.5.3.2. Burning rate (B.R.);

Burning rate was calculated by the formula: -

$$\text{B.R.} = \frac{Mass\ of\ fuel\ consumed}{Total\ time\ taken}$$

2.5.3.3. Specific fuel consumed (S.F.C.)

The specific fuel consumed is determined by the formula: -

$$\text{S. F. C.} = \frac{Mass\ of\ fuel\ consumed}{Total\ mass\ of\ boiling\ water\ (litre)}$$

2.6. Temperature – weight analysis

A carbolite type of oven was used during temperature-weight analysis. Five grams of each sample was heated at constant temperature and weight loss determined using a digital weighing balance and recorded. This was then converted into a percentage of the original weight and a graph drawn for presentation.

3.0. Results and discussion

3.1. Proximate analysis

The proximate analysis was as per figure 1 shown below.

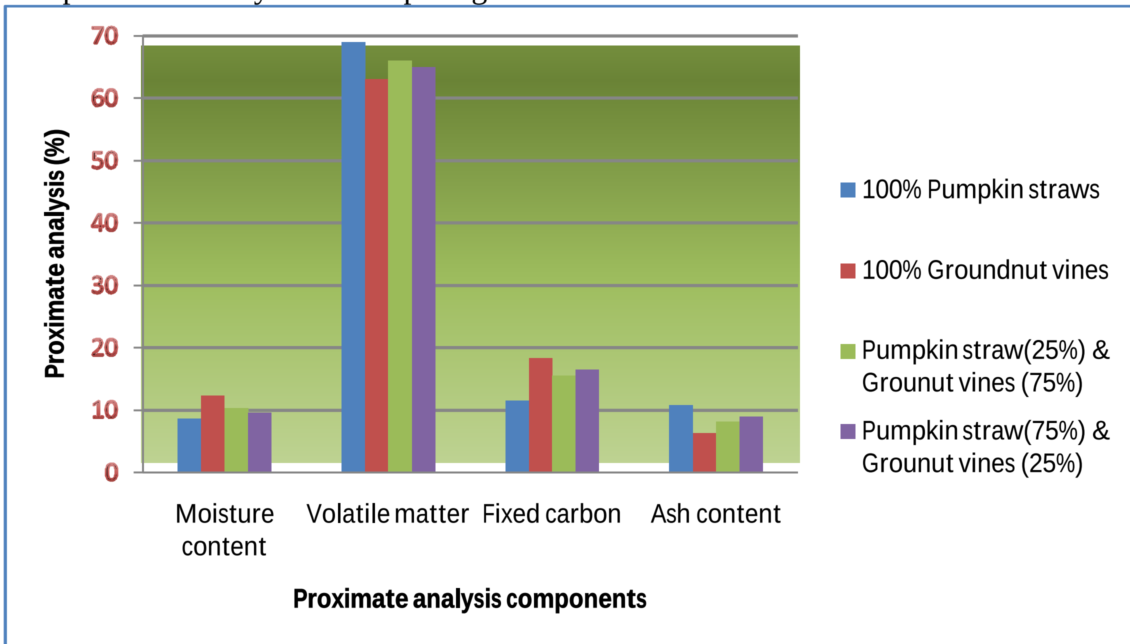

Figure 1: Proximate analysis of the feedstock for briquettes

Moisture content ranged between 12.4 and 8.7%, while the ash content was between 10.8 and 6.3%. These two components need to be minimal as they negatively impact performance of biomass fuel. High moisture content leads to increase in energy required to dry fuel and formation of volatiles, (Werther et al., 2000).

Ash content determination is vital because, agglomeration results from high ash content, (Bapat et al., 1997) and in boilers, ash from fuels (biomass) melts at elevated temperatures causing fouling in combustion chamber, (Bianca et al., 2014). Best biomass fuel therefore is one with least amount of ash, (Oladeji, 2010). The expected values for ash in commercial fuels need to be between 0.6% and 9.8%, fuels from cereals have ash content ranging from 1.8% to 4.8%, while for waste from industries are between 0.4% and 22.6%. Averagely the ash content expected to be not more than 20%, (Garcia et al., 2012).

Volatile ranged between 69% (pumpkin straws) and 63% (groundnut vines). Fixed carbon 18.3% (groundnut vines) and 11.5% (pumpkin straws), these are essential components in a biomass fuel. High volatile allows quick burning and ignition to take place, (Werther et al., 2000). Fixed carbon gives the economic value of the fuel as the have direct influence to calorific value, (Omwando, 2016).

3.2. Ultimate analysis

The ultimate analysis, that is the hydrogen, carbon, oxygen nitrogen and Sulphur were recorded as shown in figure 2

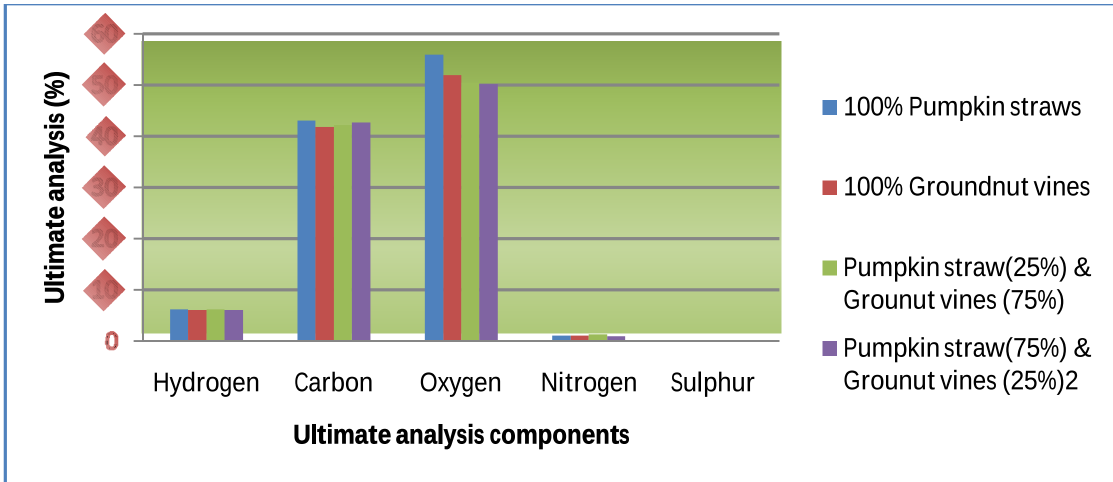

Figure 2: Ultimate analysis of the briquette feedstock

Ultimate analysis involves determination of hydrogen, carbon, oxygen, nitrogen and Sulphur. Hydrogen and carbon are crucial in biomass fuel since they aid combustion. There quantities exhibited in this study are in line with other biomass fuels. Oxygen supports volatile release, while nitrogen and Sulphur leads to pollution (NO_2 and SO_2). For any fuel to be considered, amount of Sulphur and nitrogen should be minimal or nil, (Hesborn et al., 2015), which was the case of the two feedstocks considered here.

3.3. Calorific values

The calorific values of briquettes from different feedstock were recorded as in Figure 3

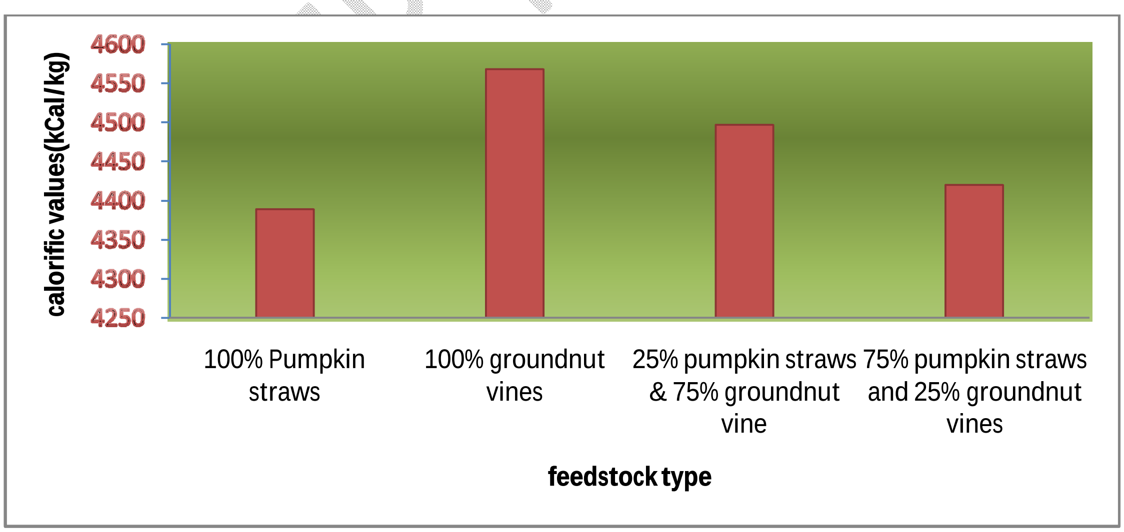

Figure 3: Calorific values of briquettes

Calorific values for these briquettes ranged between 4568 kCal/kg (groundnut vines) and 4389 kCal/ kg (pumpkin straws). These were within the range of other biomass. For instance, finger millet 4213 kCal/kg and 4662 kCal/kg, (Hesborn et al., 2015), wheat husks 4060 kCal/kg, bagasse 3996 kCal/ kg, rice husks 3678 kCal/kg and wood 4538 kCal/kg, (Stahl et al., 2006). This ranges therefore shows that groundnut vines and pumpkin straws are ideal energy resources.

3.4. Briquette combustion characteristics

3.4.1. Density

The results of the densities for the briquettes determined were as shown in figure 4.

Figure 4: Densities for the briquettes at different compaction pressures

For the three different pressure levels, it was observed that as the compaction pressure increased, the density also increased. Highest density exhibited for groundnut vines and least with pumpkin straws. Highest compaction pressure, leads to decrease in volume as the particles are forced together hence increase in density, (Longjian et al., 2009). Reducing volume (high density), means easy transportation and storage as minimal space is required.

3.4.2. Compressive strength

The results of the compressive strength for the briquettes determined were as shown in figure 5.

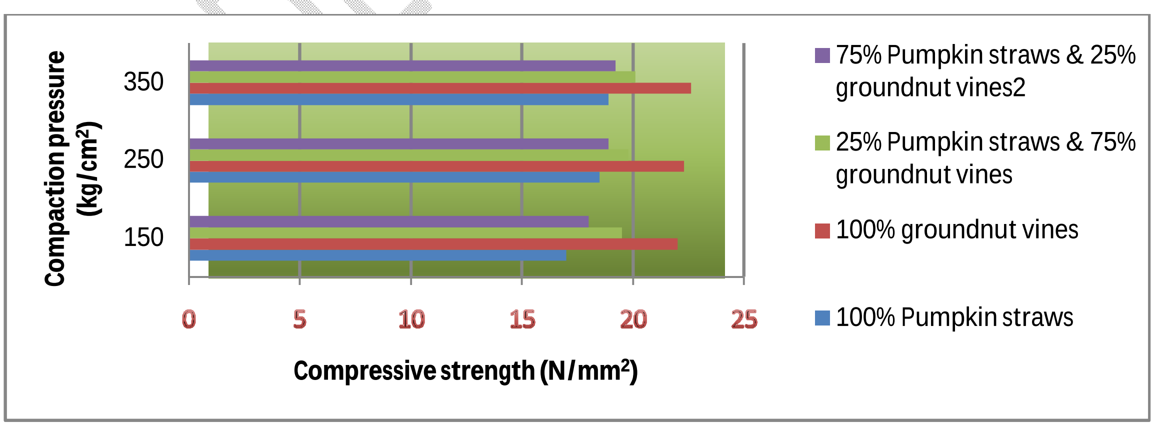

Figure 5: Compressive strength for the briquettes at different compaction pressures

Close analysis showed that, compressive strength of the entire feedstock sample increased with compaction pressure. High pressure leads to elimination of voids initially present in the briquettes hence making them to be firmly bonded, (Kaliyan et al., 2009).

3.4.3. Burning time

The results of burning time for the briquettes determined were as shown in figure 6.

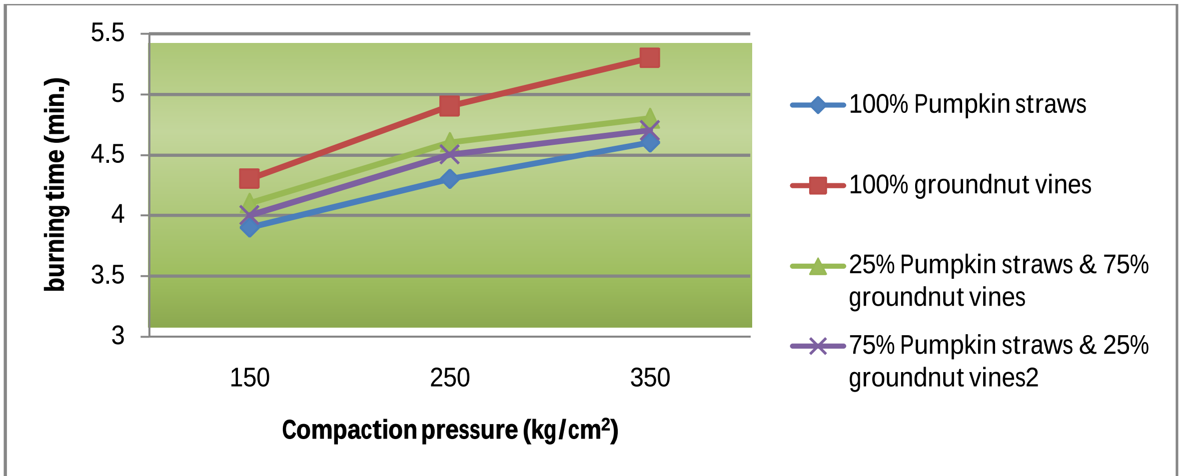

Figure 6: burning time for briquettes of different compaction pressures

Burning time was directly proportional to compaction pressure for all the feedstock levels (types). When the briquettes are highly compacted, particle-to-particle distance decreases, consequently air space is reduced between the particles. The compaction attributes to the reason behind long burn time of high pressure compacted briquettes.

3.4.4. Burning rate

The results burning rate for the briquettes determined were shown in figure 7.

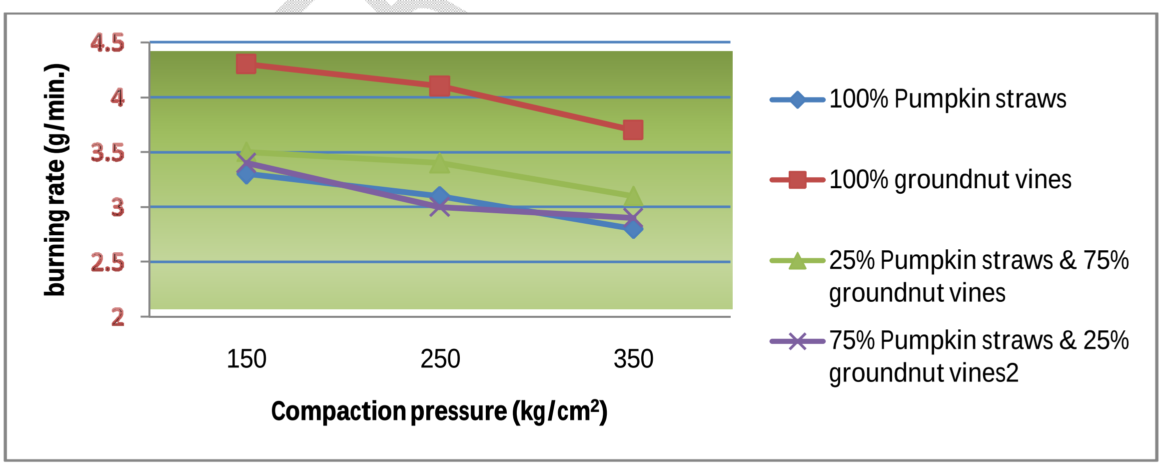

Figure 7: Burning rate of briquettes of different compaction pressures

Increase in compaction pressure leads to a decrease in burning rate. This can be attributed to the fact that when compaction pressure is increased, the particles are pressed together, reducing particle-to-particle distance. Since the space between the particles has been reduced, burning takes place with difficult, because high energy is required to break the bond.

3.4.5. Specific fuel consumed

The results obtained from the determination of the specific fuel consumed are shown in figure 8.

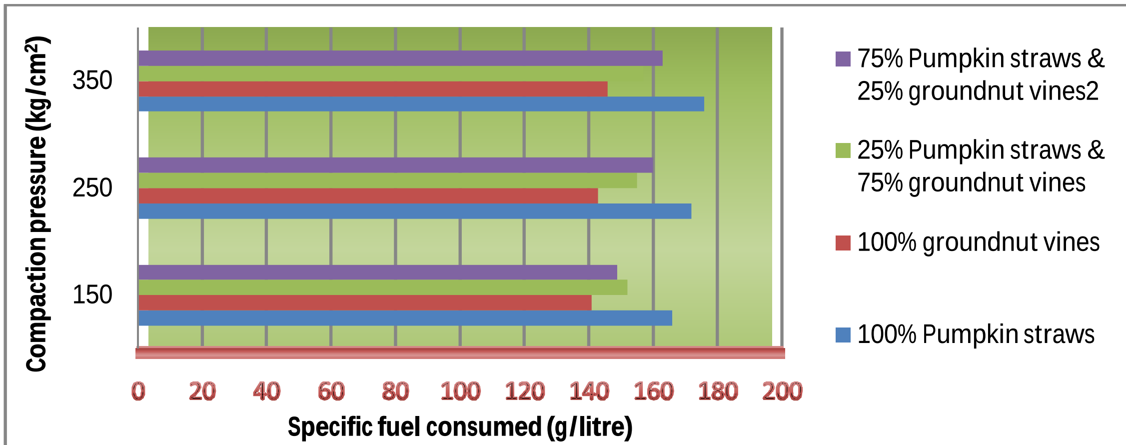

Figure 8: specific fuel consumption of different feedstocks at different compaction pressure

The result obtained here showed that there is a relationship between calorific value and specific fuel consumed for different feedstock. Feedstocks with highest calorific values presented lowest specific fuel consumption and vice versa, it can then be concluded that the higher the calorific value, the lower the rate of consumption on heating same amount of water.

Specific fuel consumption decreased with a decrease in combustion pressure for all the feedstocks.

3.5. Thermogravimetric analysis

Thermogravimetric analysis (TGA) helps in analyzing the thermal stability of a fuel. It displays weight change due to temperature at constant rate, (Lokesh and Arvind, 2009).

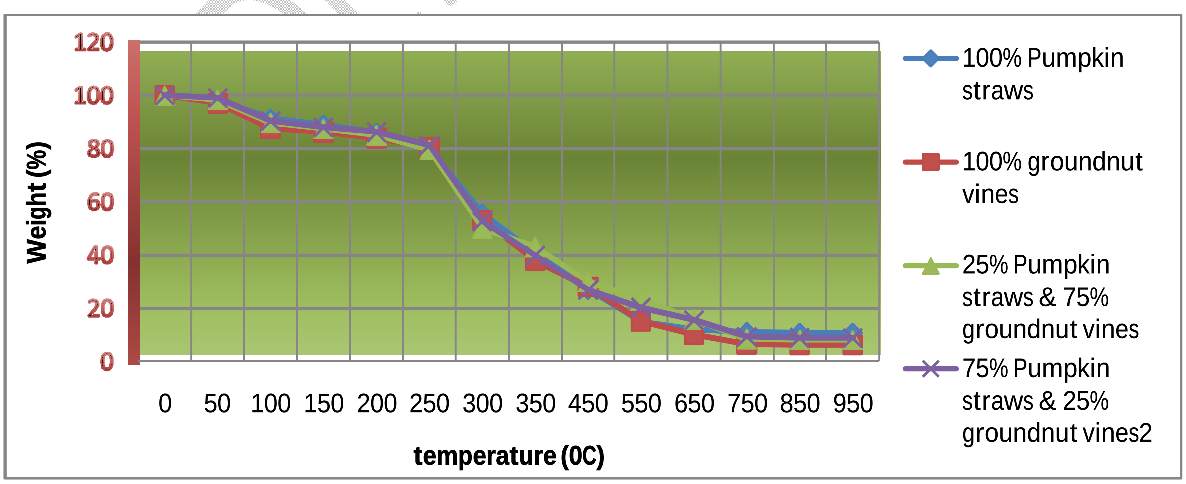

Figure: 9 Weight – Temperature analysis graph

From figure 9, it was noted that for the first 50 ^{0}C, very minimal weight loss occurred. At this time more energy was used to warm the fuel. The following 50 ^{0}C, that's up to 100 ^{0}C the loss experienced, was 8.7, 12.4, 10.3 and 9.6%. These were the respective moisture loss experienced from proximate analysis. At this point drying is also taking place (Tarus, 2013), then a negligible loss up to 250 ^{0}C, followed by devolatilization (Ondari, et al., 2021), where thermal decomposition took place releasing combustibles, (Datin, 2006). This resulted to rapid loss up to a point where char decomposition was over and the remaining ash for the respective briquette sample was recorded as 10.8, 6.3, 8.2 and 9.0 %. (Anwar et al., 2021), in their experiment of blended rice husks noted a similar trend to this study. There was negligible loss between 50 ºCand 200 ºC, while maximum loss was noted between 250 ºC and 300 ºC.

4.0. Conclusion

Pumpkin straws and groundnut vines portrayed potential energy resources. The moisture content, volatile matter, fixed carbon and ash content ranged between 8.7 - 12.4%, 63 - 69%, 11.5 - 18.3% and 6.3 - 8.2% respectively. All these values were within the range of other biomass utilized for fuels. The Sulphur and Nitrogen were minimal in these feedstocks; 1.3 and 0.13% respectively. These being undesirable components for household fuels, their minimal amounts make this an ideal energy resource since they pose no danger to the environment. Calorific values of 4560 kCal and 4389 kCal obtained, indicated a competitive resource. Maximum density and compressive strength of 0.79g/cm^3 and 22.6 N/mm^{2}was recorded. This therefore offers a good fuel that can be transported and stored easily. Burning time, burning rate and specific fuel consumption showed a maximum of 5.3 minutes, 4.3 g/min and 176 g/litre respectively. All thise values were within the range obtained from other energy resources. From these results, pumpkin straws and groundnut vines are recommended for exploitation as potential energy resource. Communities need to be sensitized on the use of briquettes from agricultural wastes.

5.0. Recommendations

It is recommended that further research be carried out on other agricultural wastes and the blending of pumpkin straws and groundnut vines with other wastes for optimization. Pellets manufacturing from these wastes also need to be exploited to maximize energy output. There is also need to investigate the economic visibility of these feedstock as well as assessing for further environmental impacts.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

2. The authors declare no competing interests

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