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High potential organic feedstocks for production of renewable solid briquettes- A comprehensive review

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Abstract:

Briquetting of biomass is an ideal technique for improvising both its volumetric and net energy density; besides, serving as an effective means for reducing pollution. In general, numerous biomass and organic by-products are discarded as wastes, citing their non-edibility, composition of chemical compounds present in their raw form, in addition to their zero usage value. Yet, these biomass wastes hold significant heating values, which promote them into promising solid biofuels, either in their existing or pre-treated form. Accordingly, this review article discusses about the various biomasses used as raw feedstock for briquetting, besides summarising the works carried out in relevance to their respective briquettes. In addition, proximate and lignocellulosic composition of these biomasses, and their pre-treatment techniques followed to prepare them for briquetting, have also been discussed. This study suggested that the heating value of biomasses ranged between 10-20 MJ/kg, whilst, their briquettes reported between 15 and 25 MJ/kg; thereby citing their potential as a viable replacement for existing fossil coals. Besides, factors affecting different thermal and physicochemical properties of these briquettes have also been studied and concluded that these properties play a crucial role in deciding the overall quality of the briquettes. Ultimately, this study proposed that any biomass with good calorific value and lignin content can be processed into briquettes with good strength and durability; however, the choice of biomass will also be accounted for by its availability, geographical distribution, and handleability.

Keywords: *Bio-briquettes; Heating values; lignocellulosic composition; Binders*

Introduction:

Depletion of resource and instable capital background for coal has put the entire power generating units at stake; and has raised concerns over the large scale power generation and fate of small scale units depending on this solid fossil fuel. Besides this, emissions from these non-renewable fuels have resulted in increased concentration of greenhouse gases and also have been found to be a primary source for the increasing global warming (Chen, 2021). Considering these setbacks, scientists and researchers have focused on developing renewable solid biofuel from organic biomasses, with significant energy density and zero sulphur emissions (Yuliansyah et al., 2010). One such solid biofuel is briquette, which is made up of any dry organic biomass compacted in high density product under the application of heavy pressure (Chen et al., 2009).

In general, Briquettes are the resultant compacted products produced using briquetting technique; and are regarded as an ideal customisable solid biofuel. Infact, these briquettes are seen as viable replacement or successful alternatives for existing charcoals (Dinesha et al., 2019). In fact, Rhén et al. [6] have pointed out the similarities between briquettes and petroleum products, in

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terms of their opportunities like automation and optimization, citing their higher combustion efficiencies and lower combustion residues (Rhén et al.,2007). Technically, these briquettes are solid biomass agglomerated or denisifed under the influence of internal forces exerted from the biomass itself and the external forces, which signifies the pressure applied for their compacting. Often, biomass briquettes are developed in different geometries and have been used in numerous industries which include food and industrial fodder industries, mining and chemical industries, besides the biomass industries (Ugwu and Agbo, 2013). Commonly known for applications involved with direct combustion in special boilers or co-firing with unconventional energy carriers (Kubica et al., 2016; Kihedu, 2007), these briquettes are easy to handle and needs very least attention among other known biofuels. Especially, these renewable briquettes work effectively in both grate and fluidized bed furnaces, and showcases higher degree of combustion (Barneto et al., 2010). Inspite of its lower efficiency than coal, these denisifed solids are widely preferred owing to its simplicity, less cost and need for less maintenance, which enables it for remote applications like cooking, heating and even electricity power generation (Dziedzic et al., 2018;Demirbas, A., 2004). Accounting these, this briquette technology can address the problems and challenges related to bio-residue management; and is seen as effective “waste-to-energy method”.

In common practise, briquetting of biomass increases its volumetric density and calorific value, and simultaneously reduces its moisture content (MC)(Sriram et al., 2014); and overcomes the limitation associated with the use of biomass with low bulk density (Ujjinappa and Sreepathi, 2018). Infact, densifying biomass improvises their overall physical and combustion behaviour, thereby allowing different types of lignocellulosic materials to be used as fuels (Wang et al., 2017). In addition, it enhances their handling characteristics, which in turn reduces its transportation costs; besides its suitability for wide variety of applications. Besides, briquetting induces longer burning time to the biomass, in view of its increased volumetric density (Olorunnisola, 2007).

Looking into their science behind it, briquettes are produced as a result of solid bridge developed between two macroscopic particles of the biomass upon the application of high loads; and in general, undergoes densification in three different stages. Firstly, biomass particles are reorganised, followed by air and MC being squeezed out from their porous structures; and is termed as loose stage. Moving on, these particles further break downs and starts filling up the empty voids available between the biomass particles; and can be taken as the transition stage. Lastly at compaction stage, these biomass particles undergo plastic deformation and establish contact with each other through meshing; thereby becoming more compact. To be noted, this deformation occurs perpendicularly to the principal stress; and is limited upto the pressure beyond which these briquettes cannot be compacted (Zhang et al., 2014). Adding to this, MC in these briquettes dough induces Van der Waals forces between these particles, which help in aggregating it (Patil et al., 2021). In fact, binding between these particles are enhanced and accomplished by using briquette binders, whose effectivity depends on the type of binder used, which in turn is decided based on the nature of biomass; and the concentration of the binder used. In general, any briquette binder requires the following properties to be regarded as an ideal binding agent; and are as follows: (i) owing to its renewability, both feedstock and binder should be organic and environmental friendly, (ii) must have good ability to induce strong bonding between the biomass particles, (iii) should not affect the heat release and combustibility of the briquette, and lastly (iv) must be economically feasible (Zhao et al., 2001; Zhang et al., 2018). Upon categorizing, binders can be classified into organic binder, inorganic binder and compound binder; and are decided based on their material composition. Most commonly preferred binders include starch, protein, fibre, fat/oil, lignin, cattle dung, press mud, molasses, and pulp and paper (Patil et al., 2021). Interestingly, any biomass with high lignin content needs very less to no binders during their briquetting process, as these lignin content get released upon applying very high loads on these biomass; which then acts as binding agent and helps in forming a solid bridge between the biomass particles (Kaliyan and Morey, 2009).

Apparently, these biomass and binders give rise to a briquette upon its densification; however, the quality of these briquettes can be judged by understanding their fuel characteristics. Hence, it is always necessary to assess these characteristics before commercializing or bringing them into real time applications. Accordingly, the chararctertsitcs deciding the quality of briquettes have been studied in the following section.

Thermo-physicochemical properties of briquettes:

As mentioned earlier, briquetting is regarded as an effective technique for processing biomass feedstocks with medium to high MC into uniform sized solid biofuels, which can be transported and handled easily. More often, any compacted biomass with good volumetric and net energy density along with significant durability is deemed as a good quality briquette. In turn, these qualities are evaluated based on their briquetting conditions, apart from the physical and chemical properties of the biomass used as feedstock (Okot et al., 2018). Especially, the chemical properties evaluated for these biomass includes their proximate composition such as moisture content (MC), volatile matter (VM), fixed carbon (FC) and ash content (AC), their lignocellulosic (LC) composition which includes cellulose, hemicellulose ad lignin content. On the other hand, the evaluated physical properties include their calorific value (gross and net)/heating value (higher/lower), particle size and its diameter, bulk and particle density. In case of briquettes, the chemical properties evaluated includes their proximate composition such as MC, VM, FC and AC, their ultimate composition that includes carbon (C), hydrogen (H), oxygen (O), nitrogen (N) and sulphur (S) content (Sukarta et al., 2018). Whilst, the evaluated physical properties includes their calorific value (gross and net)/heating value (higher/lower), compressed and relaxed density, bulk density, compressive strength, tumbling and shattering resistance, and durability; which decides their physical integrity. Beside biomass, binders also contribute significantly to these qualities; and are also evaluated based on their physical and chemical characteristics. Even though, these briquettes are assessed from various fuel characteristics discussed above; only certain characteristics like CV, VM, MC and AC, density, compressive strength and durability predominantly decides their quality and also their usage (Dziedzic et al., 2018).

To begin with, all biomasses comprise of lignocellulosic components like cellulose, hemicellulose and lignin; and these organic compounds are widely distributed in form of hydrocarbons. Following this, the average composition of these lignocellulosic compounds in plant biomass range between 30-50% for cellulose, 20-30% for hemicellulose, and 15-30% for lignin (Achinas and Euverink, 2016). On average, a typical plant biomass reports its volatile content and calorific content in a range of 65-80% (Rybak, 2006) and 17.31-18.84 MJ/kg, respectively, with its AC ranging between 4 and 5% (2% in case of solid biofuels), in their analytical and working state (Dziedzic et al.., 2018). In case of moisture free and ash free basis, this biomass records 80% of VM and 20% of FC; in contrast to a bituminous grade coal that states its VM and FC as 20-30%, and 70-80%, respectively (Maciejewska et al., 2006). Comparatively, coal samples exhibit superior calorific value and higher AC, owing to their higher concentration of non-combustible and inorganic content. On the contrary, biomass samples exhibited rapid ignitability and faster burning rate citing their higher porosity, which ensures the infiltration of oxygen and out flow of combustion products (Akuma and Charles, 2017). Worth mentioning, lignin and cellulose content in biomass plays a crucial role, by acting as natural binder during their high load briquetting process (Gangil, 2014).

Moving on, moisture content (MC) in briquettes quantifies the amount of water available in it; and are attributed by the biomass and binder used (Yuliah et al., 2017). As per ASTM standards, MC for any briquette must be maintained below 8% (Waluyo and Pratiwi, 2018); however, commercially used briquettes can report their MC upto 30%, following which they can be classified as low moisture (12%) and high moisture (29%) content briquettes (Mkini and Bakari, 2015). Here, the briquettes with low MC exhibits improvised rate of combustion and enhanced rate of ignition, in addition to its prolonged storage life (Suprianto et al., 2017). On the contrary, briquette with high MC displays relatively low calorific value and reduced combustion temperature, and prolonged residence time; uneventfully resulting in partial combustion along with increased quantity of flue gas (Maciejewska et al., 2006). Adding to this, higher MC increases the density of briquettes, and favours mould growth thereby shortening their storage life (Waweru and Chirchir, 2017; Ishii and Furuichi, 2014). Also, finely ground biomass with reduced particle size tends to absorb and retain more water content into them; hence, these briquettes require additional drying and more conditioning (Adappa et al., 2009). About drying these briquettes, sun drying is seen as the most simple and cost effective technique; with an efficiency of reducing these MC from 70.56% to 8% in a time span of 2 weeks (Sawadogo et al., 2018). However, rate of drying depends on the weather condition, and are adversely affected during rainy and winter season; but, this can be overcome by using mechanical dryers, which are proven to be effective irrespective of the ambient and weather conditions (Ifa et al., 2020). In short, the MC of the biomass must be limited to 10-15%, so as to allow their briquettes to undergo complete combustion (Maciejewska et al., 2006; Adappa et al., 2009).

Next up, volatile matter (VM) of any briquette illustrates the volume of organic matter with boiling temperature lesser than or equivalent to 250°C, available in it; and in turn, predominantly contributes to their thermal behaviour. In general, biomass exhibiting high VM have less concentration of FC, and vice versa; thereby stating that both biomass and their briquettes torrefied at high temperatures (> 250°C) will yield high FC and calorific content. Moreover, high volatility in these solid briquettes enhances their rate of ignitability; but, causing them to burn with smokey flame citing the presence of combustible gases in form of methane and other volatile hydrocarbons (Thabuot et al., 2015). As mentioned earlier, VM in both biomass and their briquettes can reach upto 80% (Dziedzic et al., 2018); and are also contributed by the binders used during compaction. Relating to this, usage of starch as binders at higher dosage led to increased concentration of VM in the resultant briquettes (Yuliah et al., 2017).

About their ash content (AC), these residues comprises of metal oxides formed as a result of combustion of non-evaporable minerals in the briquettes; and is used an indicator for deciding the quality of briquettes. Explaining this, briquettes with high AC tend to report low calorific content and produce less amount of heat. On average, briquettes developed from plant biomass produces their average AC in between 1 and 20%; and are entirely dependent on the mineral composition of both biomass and binders. in specific, starch based binders help reducing the AC; however, higher concentration of both starch based and mineral based binders increases it owing to their inorganic content like silica, Fe, MgO, and Fe_2O_3 (Yuliah et al., 2017). Besides, these ashes are highly

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hygroscopic and absorb MC, which solidifies it upon cooling. In addition, these ashes exhibit their fusion temperature ranging between 1200 and 1300°C; and briquettes with high calorific value, cellulose and inorganic content produce high AC and results in higher ash fusion temperature.

In relevance to their Thermal behaviour, heating value (HV) of briquettes defines about the maximum amount of heat liberated per unit mass of the biofuel during its combustion. In other words, it demonstrates the maximum amount of energy stored in the briquettes; and are determined using a bomb calorimeter. In general, the HV ranges between 14.23 and 23.01 MJ/kg for the commercially available biomass briquettes; and in turn, are decided by the calorific value of the biomass itself. In common practise, HV of these briquettes can be improved by mixing two biomasses together prior to compaction, with either one reporting higher calorific value than the other; or formulating their blending composition. Besides, it can also be improvised by following certain pre-treatment techniques on biomass during preparation stages like carbonization/torrefaction and pulverization (Yuliah et al., 2017; Akogun et al., 2022). Again, binders also contribute to the overall calorific value (CV) of briquettes; hence, identifying the most suitable binder is a highly selective process during the early stages of briquette production. Though small dosages of binders contribute positively to these CVs; however, high dosage of binders, especially water activated have undesirable effect on these calorific content, as a part of heat is used for evaporating the water content in the briquettes (Yuliah et al., 2017). In addition, high calorific content of these briquettes increases their burning temperature (Haryati et al., 2018).

Besides CV, briquettes are also evaluated for their ignitability and ignition time, with former defining how fast the briquettes ignites, while the latter specifies the rate at which the briquettes burns or combusts. Being influenced by the organic matter in the biomass used in briquetting, ignitability increases with increasing organic matter in the biomass; whereas, ignition time (also known as burning time) decreases for the same. Together, both CV and burning characteristics decides the water boiling time of the briquette, where lesser time signifies higher efficiency. Explaining this, water boiling test defines about the volume of fuel consumed and time taken in raising a known quantity of water upto its boiling point (Akuma and Charles, 2017).

Into their physical characteristics, density of briquettes relates to the amount of biomass that occupies for a unit volume; and is classified as bulk density, relaxed density and particle density. Here, bulk density refers to the value measured immediately after compaction, while relaxed density refers to the value measured after a time period (Falemara et al., 2018); whereas, particle density refers to the mass of biomass particles alone excluding the pore space, for an unit volume. Moreover, Density has significant influence on their burning characteristics, with high density briquettes reporting longer burning time and high HRR. Besides, it is also influenced by the particle grain size of biomass used and their MC. Explaining this, briquettes developed from biomass with smaller particle size accommodates larger volume, thereby increasing their density. On the other hand, MC has negative effect on density as it causes voids and empty pockets post evaporation thereby reducing its density and also making the briquettes brittle. Also, high dosage of binders leads upto filling of pores in the biomass which unfortunately increases the overall density of briquettes (Yuliah et al., 2017). In fact, length of briquettes and pellets are also deeply influenced by the bulk density of both biomass and their briquettes (Dziedzic et al., 2018). Put another way, grain size distribution is yet another property of briquettes that explains about the particle size of biomass used in its production. Larger grain size accommodates less biomass thereby reducing its overall

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volumetric and net energy density; however, use of small particle sized grains overcomes this and produces high quality briquettes.

Likewise, Durability of briquettes defines about its ability to withstand any external force or pressure; and is very high for any briquettes having fine particle size, high compaction pressure and high particle density. In addition, high concentration of lignin and cellulosic content in biomass increased the structural integrity of their briquettes; and enhanced their durability. Besides, other parameters like binder type, dosage and composition, glass transition temperature, and compressibility were also found to be contributing in deciding the durability of these briquettes (Karunanithy et al., 2012). On average, the durability of an ideal briquette would range in between 85 and 95%; and is seen as the most optimal value for any commercially used briquettes.

Besides durability, compressive strength estimates the magnitude of force required to deform or crush the briquettes partially or completely. In general, these strengths depend on the factors like particle size, briquette shape, binder dosage, curing temperature and AC produced during combustion. Based on literatures, it is seen that briquettes exhibiting high binder dosage, poor curing temperature, larger particle size and briquettes with high AC performed poorly under external force; thus making briquettes with these setbacks report low compressive strengths. On the contrary, other briquetting parameters like compaction pressure, retention time and MC have no significant effect on the compressive strength of these briquettes (Taulbee et al., 2009). In addition, biomass with high lignin and cellulosic content tend to impart high structural strength to these denisifed briquettes, thus increasing their compressive strength.

Fairly evident, it is definite that fuel characteristics of any briquette depends on the chemical and physical properties of the biomass used for its compaction; and table 1 summarises the fuel characteristics of both biomass and their briquettes, ASTM standards for their evaluation, and the empirical formula used for calculation.

Table 1: fuel characteristics of both biomass and their briquettes, ASTM standards for their evaluation, and the empirical formula used for calculation
(Cunliffe and Williams, 1998; Du et al., 2016)

Fuel Property	**ASTM Standards**	**Formula**
Biomass feedstocks		
Moisture Content (MC)	ASTM D3173	$MC\ (in\ \%) = \frac{Initial\ weight - Dry\ weight}{Initial\ weight} * 100$
Ash Content (AC)	ASTM D3174	$AC\ (in\ \%) = \frac{Weight\ of\ Ash}{Dry\ weight} * 100$
Fixed Carbon (FC)	ASTM D3172	*FC (in %) = 100% – MC(%) – VM (%) – AC(%)*
Volatile Matter (VM)	ASTM D3175	$VM(in\ \%) = \frac{Dry\ weight - weight\ @\ 300^{O}C}{Initial\ weight} * 100$
Ultimate Composition (CHNSO)	ASTM D3176	-
Calorific Value	ASTM D 3286-77	Using bomb calorimeter

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Particle Size	ASTM E 1037-84	-
Cellulose	ASTM D 1103-55T	*Cellulose = Acid detergent fiber (ADF) – Lignin (1)*
Hemicellulose	ASTM D1104-56	*Hemicellulose = Neutral detergent fibre (NDF) – Acid detergent fibre (ADF)*
Lignin	ASTM D 1106-56	*Lignin = Acid detergent lignin (ADL)*
Denisifed Briquettes		
Moisture Content (MC)	ASTM D3173	$MC\ (in\ \%) = \frac{Initial\ weight - Dry\ weight}{Initial\ weight} * 100$
Ash Content (AC)	ASTM D3174	$AC\ (in\ \%) = \frac{Weight\ of\ Ash}{Dry\ weight} * 100$
Calorific Value (CV)	ASTM D 3286-77	Using bomb calorimeter
Density	ASTM D 2395-83	$Density = \frac{Weight\ of\ Briquettes}{Volume\ of\ Briquettes} * 100$
Compressive Strength	ASTM D2166-85	$\sigma\ (\mathrm{in} \frac{\mathrm{KN}}{m^2}) = \frac{Load\ (in\ KN) * Strain}{Area\ of\ briquette\ (in\ m^2)}$
Durability/ Shattering Index	ASTM D440-86	$\frac{Weight\ before\ shatter - Weight\ of\ shatter}{Weight\ before\ shatter}$

Biomasses for briquetting

Approximately 60 Exajoules of total energy demand were supplied from biomass in 2015, and biomass resources contributed about 9–13% of the total global energy supply (Energy, 2016; Wang et al., 2017). In other words, any fuel developed from the biomass displays its potential in contributing to this energy supply; however, the amount of energy supplied depends on the fuel type and its fuel characteristics. Accounting their simplicity, energy equivalence, and flexibility towards accommodating any biomass as raw material, these briquettes have been proven to contribute significantly for this energy supply; especially to meet the demand of domestic and industrial heating applications that required replacement for fossil coals. In general, any biomass with good lignocellulosic content can be deemed suitable for briquetting; however, the suitability of these biomasses can be decided based on its non-edibility, availability, geographical distribution and even their suitability for the process. Besides using these biomasses in their raw form, they are also pre-treated through carbonization or torrefaction (low temperature pyrolysis); which helps in altering the chemical characteristics of these biomasses without altering their calorific content (Basu, 2018). These alterations include depolymerisation of long chain polysaccharide from lignin and hemi-cellulose, and also reduce their oxygen-to-carbon (O/C) ratio; which significantly improves their hygroscopic nature and energy content (Pimchuai et al., 2010; Basu, 2018).With positive and negative effect of briquetting parameters on deciding the quality of briquettes being explained in previous section, further study reviews only the data related to the production of briquettes from different biomass and their fuel characteristics reported by various researchers across numerous literatures. Accordingly, most commonly used ideal biomasses, identified as high potential feedstocks, are discussed briefly in the following section in alphabetical order.

Almond shell

Moisture content (%)	3.3
Ash content (%)	0.6
Fixed carbon content (%)	15.8
Volatile matter content (%)	80.3
Calorific value (MJ/kg)	18.2
Cellulosic content (%)	38.47 ± 0.39
Hemi-cellulosic content (%)	28.82 ± 0.25
Lignin content (%)	29.54 ± 0.11

Almond (*Prunus amygdalus*) is an Iranian native tree belonging to prunus genus and amygdalus subgenus, whose fruit being a drupe has an outer hull and a hard shell enclosing its seed (Ladizinsky, 1999). Though, almond seed is edible, its hard shell is always discarded as wastes. Since, almond holds remarkable spot in multi-cuisine markets; the amount of shells generated as wastes also increases proportionally. Though these wastes are returned back to the soil to maintain its potassium balance, they can be used as solid biofuel for burning owing to their significant biomass content. Supporting this, proximate and LC composition of these shells exhibited higher FC and VM besides their lower MC and AC; in addition to their identical lignocellulosic contents. Following this, Allouch et al., 2014 developed almond shell based biochar briquettes besides studying the different stages of thermal decomposition of these almond shells, based on the data characterized from thermo gravimetry (TGA), derivate thermo gravimetry (DTG) and differential thermal (DTA). For briquetting, the waste shells were oven dried at 105°C for 12 hours, followed by grounding and sieving (particle size between 200 and 600 microns); and were then mixed with 20% of the green clay + 5% of the wheat flour +Water to produce compactable dough. Next up, these dough were turned into briquettes using a simple hammer and hollow cylinder tube (manual compacting); and were evaluated for its combustion properties. Results explained that these briquettes displayed increased holding time and better combustion characteristics, claiming strong devolatilization and particle size reduction enhances their fuel properties; and can be recommended as a sustainable biofuel. In addition, thermal decomposition study showed that almond shell undergoes evaporation and volatilization of lighter molecules between 282 and 398°C, devolatilization involving degradation of biomass, and their oxidation between 397 and 522°C; with major weight loss of ~ 50%, with 9% per min. recorded during the second stage (Allouch et al., 2014).

In another study, Orhevba and Olatunji developed a compound briquette using almond shell along with groundnut shells and rice husk, and were evaluated for its fuel properties. In relevance to that, the biomass wastes were sun dried for 2 weeks, carbonised and pulverised into powder (upto 600 microns) using a hammer mill. with aim of developing an high quality briquette, biomasses were mixed in different composition (almond shell: 10-40%, groundnut shell: 20-70%); and the most optimal composition was noted for groundnut shell- 52%, almond shell- 10%, rice husk- 10%, cassava starch- 20%, clay (filler)- 5%, and water- 3%. Moreover, the compaction pressure and carbonising temperature were optimum at 250 MPa and 650°C; whilst, the drying temperature and dwell time were effective at 160°C and 300 seconds, respectively. Following these briquetting parameters, highest quality briquettes reported their highest CV as 29.99 MJ/kg (Orhevba and Olatunji, 2021).

Barley straw

Moisture content (%)	5.7-20.2
Ash content (%)	2.18-9.87
Fixed carbon content (%)	19.79-24.8
Volatile matter content (%)	65.2-70.34
Calorific value (MJ/kg)	16.42-17.65
Cellulosic content (%)	33.25-35.5
Hemi-cellulosic content (%)	20.36-23.9
Lignin content (%)	10.1-17.13

Barley (*Hordeum vulgare*), a cereal grain based grass plant, grown in temperate climates are mostly commonly used as animal fodder, besides being used as fermentable biomass feedstock for distilleries. As a good source for dietary fibre and vitamins, this barley is also consumed globally, and is regarded as the fourth majorly harvested crop (Zohary and Hopf, 2000). Though, these cereals are edible, other parts of the plants as treated as wastes and are disposed during stubble burning. Though, the barley straws are highly effective for algal growth control in water eco-systems; they exhibit promising features in supplying energy. Looking into their proximate and LC composition, these straws exhibit good HV, which can be used for heating purposes instead of burning it for disposal. Infact, the net energy content of these straws can be enhanced by compacting these wastes and converting them into solid biofuels. Accordingly, Adapaa et al., 2009 used these straws for developing briquettes by using their protein and lignin as natural binders, and compacting them under a compaction apparatus, for a pressure level of 63.2 MPa (Applied load-2000 N; compressive force- 2339 ± 53 N) accounting their minimal rate of specific energy consumption. Here, this study used ground barley straw with an average MC of 6.7% (W.B.); which was then raised to 10% (W.B.) by sprinkling calculated amount of water to it, claiming that the latter MC produced high to very high quality briquettes. Preliminary findings on these ground biomass measured their geometric mean particle diameter, bulk density and particle density as 0.384 ± 0.00^3 mm, 261 ± 2 kg/m^3, and 1484 ± 3 kg/m^3, respectively. Post briquetting, the mean compact density, specific energy and total specific energy were calculated as 978 ± 14 kg/m^3, 5.42 ± 0.33 MJ/t and 5.81 ± 0.36 MJ/t, respectively (Adapaa et al., 2009).

In similar manner, Tumuluru et al., 2015 developed compacted briquettes from raw barley straw with help of Laboratory-scale briquette press, using its lignin content as natural binder. Again, this study also used ground straw samples, having its MC and bulk density as 9 wt.% (W.B.), and 36-67 kg/m^3, upon drying. Into their physical properties, developed briquettes reported its density (immediately after compaction) as 755.52 kg/m^3 for the die temperature of 129.91°C, feedstock MC of 9.16 wt.% (W.B.), compression pressure of 12.48 MPa, and hammer milled particle size of 31.68 mm. Likewise, highest durability amidst these briquettes were noticed as 95.62 % for the die temperature of 126.21°C, feedstock MC of 9.31 wt.% (W.B.), compression pressure of 12.48 MPa, and hammer milled particle size of 23.51 mm. On the contrary, lowest MC was noted for these briquettes for the die temperature at 127.84°C, feedstock MC of 9 wt. % (W.B.), compression pressure of 8.77 MPa, and hammer milled particle size of 31.69 mm. In short, this study concluded that physical properties like density, MC and durability of these briquettes were dependent on operating parameters like die temperature, compression pressure, and physical properties of the feedstock used (MC and particle size) (Tumuluru et al., 2015).

Besides producing briquettes, these raw biomass can also be processed into solid pellets; and supporting this, Serrano et al., 2011 compacted these barley straws into pellets with help of an annular die pellet mill, by using pine saw dust as additive and also as binder. Ultimate analysis on these straws were estimated to be 44.38% of C, 39.25% of O, 5.64% of H, 0.78% of N and 0.08% of S. On the other hand, proximate composition (wt. %, D.B.) of the produced barley straw pellets were estimated as 69.16% of VM, 20.33% of FC, and 10.51% of AC; whilst their chemical composition (wt. %, D.B.) were calculated as follows: carbon- 43.85%, oxygen- 39.27%, hydrogen- 5.50%, nitrogen- 0.77%, sulphur- 0.1%. Here, the ideal barley straw - pine saw dust mixing ratio for producing high quality pellets was decided as 88 wt.% and 12 wt.%, respectively; with their MC maintained as 12 wt.% (W.B.) while pelleting. And, characteristics of these ideal pellet samples were as follows: durability- 97.2%; density- 1.4 ± 0.1 kg/m3; length- 25.0 ± 4.1 mm; MC- 6.1%; die temperature- 105°C. Following this, ultimate analysis (wt. %, D.B.) on barley straw - pine saw dust pellet recorded 44.94% of carbon, 39.52% of oxygen, 5.6% of hydrogen, 0.72% of nitrogen, and 0.07% of sulphur; while, its VM, FC and AC was estimated as 70.33%, 20.52% and 9.15% (wt. %, D.B.), respectively. Lastly, barley straw pellets and barley straw - pine saw dust pellets recorded their gross CV as 17.43 and 17.94 MJ/kg, respectively (Serrano et al., 2011).

Coconut shell

Moisture content (%)	6.34-9.4
Ash content (%)	0.655-0.66
Fixed carbon content (%)	21.94
Volatile matter content (%)	73.96-77.7
Calorific value (MJ/kg)	17.31-21.41
Cellulosic content (%)	44.12 ± 0.2
Hemi-cellulosic content (%)	30.21 ± 0.11
Lignin content (%)	21.24 ± 0.31

In general, Coconut tree (*Cocos nucifera*) belongs to Arecaceae family, under the genus of cocos; and its palm is regarded botanically as drupe, citing its inner flesh enveloped with hard shell, which in turn is enclosed by fibrous husks. These coconut palm trees needs regular rainfall, moderate temperature, high humidity and abundant sun light for its enhanced growth; as low temperatures and lack of sufficient water inhibited its growth and does not bear fruit. This explains the wide distribution of coconut trees across coastal and salty beaches (Dziedzic et al., 2018). These trees serves many useful purposes; with the coconut palm holding both cultural and religious significance (Nayar, 2016). In specific, its edible flesh is used in both medicinal and cooking; whilst discarding its outer shell as wastes. Occasionally, these shells are used as fuel in traditional stoves at rural parts of the globe; however, its potential can be improvised by following certain pre-treatment techniques. Most commonly followed technique involves carbonising the shells prior to briquetting; and has been proven to be highly effective. Supporting this, numerous studies have used these coconut shells as raw material for producing either raw or composite briquettes; and reported numerous findings which were significant with existing literatures, including their proximate and LC composition (Rodiah et al., 2021; Dziedzic et al., 2018).

To begin with, Dziedzic et al., 2018 used ground coconut shell as feedstock for developing compacted briquettes by using their lignin and protein content as natural binder, with an average diameter of 50 mm using a briquetting press. For this purpose, waste shells were ground into two different sieve sizes namely: 8mm and 12 mm; and briquettes developed from these grounded particles were evaluated for its fuel properties individually. Accordingly, bulk density of these briquettes were measured as 341.5 ± 4.94 kg/m^3 for 8mm samples and as 312.5 ± 4.24 kg/m^3 for 12 mm sample; which were slightly higher than the bulk density of wood chip briquettes (250-280 kg/m^3). Next up, the mechanical durability of these waste coconut shell briquettes were measured as 96.8% (8 mm) and 92.1% (12 mm), for a briquetting pressure of 47 MPa and 37 MPa, respectively. Ultimately, this study concluded that lower degree of fragmentation and a higher pressure of the agglomeration increase the mechanical durability and specific density of the shell (Dziedzic et al., 2018).

Furthermore, Rodiah et al., 2021 *developed composite briquettes by mixing* rice husk and coconut shell char, using mucilage (mango sap) as adhesive and starch as binder. This present study idealised the optimum coconut shell char to rice husk char mixing ratio as 2:1 (w/w); while, molten mango sap and starch were mixed in equivalent blend, and mixture of adhesive-binder and water as 1:10. Furthermore, preparation of biomass involved with torrefaction and carbonization of rice husk and coconut shell; whereas, preparation of briquetting dough associated with mixing of raw materials at 60-70°C. Proximate analysis on these coconut shell-rice husk char briquettes, reported their VM, FC, MC and AC as 48.99%, 44.05%, 3.55%, and 3.41%, respectively; and, their highest CV as 26.18 MJ/Kg. Looking into emission chararctertsitcs during their combustion, the average CO and NOx emission of these developed composite briquettes were measured as 416 and 2 PPM, respectively. Meanwhile, the proximate composition of plain coconut shell char briquettes were found to be as follows: 67.02% (FC), 22.58% (VM), 5.91% (AC), 4.49% (MC), and 28.38 MJ/kg (CV)(Rodiah et al., 2021). Similar results were reported by Yuliah et al., 2017 upon briquetting coconut shell and rice husk char into composite briquettes with help of a hydraulic compression tool using Tapioca Starch as binder. Here, the most optimal mixing ratio between coconut shell and rice husk char were decided as 1:1; with binder and water concentration as 6% and 7.63%, respectively. Post briquetting, the developed briquettes were evaluated for its fuel characteristics (D.B.); and were as follows: MC- 7.63%, VM- 23.12%, FC- 49.04%, AC- 20.21%, CV- 20.78 MJ/kg, and average briquette diameter- 20mm and length- 19.4 to 23.9 mm (Yuliah et al., 2017). Concluding this, it is highly evident that coconut shell can be either taken as primary feedstock or as an additive for enhancing the overall fuel properties of resultant briquettes. Besides shells, fibrous husk in their fruit also serves similar purpose by proving significant amount of energy during its combustion.

Cashew Nut Shell (CNS) Wastes

Moisture content (%)	6.47
Ash content (%)	1.05
Fixed carbon content (%)	20.48
Volatile matter content (%)	72
Calorific value (MJ/kg)	20.18-20.46
Cellulosic content (%)	9.6 ± 1.3

Hemi-cellulosic content (%)	28.3 ± 0.2
Lignin content (%)	28.8 ± 2.3

Cashew tree (*Anacardium occidentale*), a tropical evergreen tree belonging to Anacardiaceae family, under Anacardium genus; and is widely grown for its cashew seed, a snack nut, and occasionally for its cashew apple being an accessory fruit (Morton, 2007). Here, the seeds are separated from its shell by means of roasting and drying, and then are processed in edible nuts, which produces large amount of waste in form of shell, then processed into press cake and nut shell liquid (CNSL); and have a high potential for fuel. Though, the Proximate and LC composition suggests the suitability of these shells for converting into solid biofuel, it can't be used for heating directly owing to the higher concentration of anarcardic acid and smoke from its CNSL causing carcinogenic effects. Infact, 20% of CNSL must be removed from these shells prior processing them into fuel, in order to reduce the toxicity of the raw material and production of tars (Sawadogo et al., 2018). Accordingly, Ifa et al., 2020 used waste cashew nut shells for developing briquettes by adding tapioca flour as binder; and were compacted using simple hydraulic press. in this regard, waste shells were sun dried and torrefied into bio char, which were then compacted into briquettes at compression pressure of 29.4 MPa (300 kgf/cm^2) for 5 minutes. Upon completion of compaction, these briquettes were oven dried for 4 to 6 hours at 50^{o}C, and were flipped at regular intervals to distribute heat evenly. Evaluation of fuel properties of these briquettes presented their CV as 29.49 MJ/kg, MC as 5.3%, AC as 4.96%, VM as 17.16%, and C as 72.62%; and were in accordance with the bio-briquettes standard (SNI 016235-2000, Japanese, English and ISO 17225). This study also shed light on the resultant products produced during the torrefaction of cashew nut shells; and accordingly, 41% of biochar, 39.3% of liquid smoke and 19.7% of gas were produced upon torrefying at 350^{o}C, later on followed in that study (Ifa et al., 2020).

Again, Sawadogo et al., 2018 carbonized left over press cake of cashew nut shell, pyrolyzed at 350°C and cassava starch as biomass feedstock and binder for producing high quality briquettes, by compacting using a mechanical screw press. For this purpose, the residual char was ground to its minimal particle size of 0.5 mm; wherein, water itself acted as a binder besides being used for activating the starch binder. The ideal composition of dough for high quality briquettes was chosen as 55% of CNS cake charcoal, 10% of cassava starch, and 35% of water; and accounted their fuel properties as net CV- 25.7 MJ/kg, density - 0.91 kg/m^3, compressive strength index- 382.89 kPa, impact resistance index- 61.10, and water boiling tests reporting similar performance to that of wood charcoal. Furthermore, this study recorded the mass and thermal efficiency of press cake carbonisation as 30% and 41%, respectively (Sawadogo et al., 2018). Next up, Chungcharoen and Srisang, 2020 developed composite briquettes from cashew nut shells (CNS), carbonised at 300^{o}C and areca nut shells (ANS)(MC: 11-12% W.B.) as biomass feedstock, using an electrically operated mechanical screw press, with cassava flour as binder. Here, the optimum blend (by weight) was taken as 65% of cashew nut shell, 25% of areca nut shells and 10% of cassava flour briquetted at rotary speed of 90 rpm; and were decided based on their higher production rate (245 pieces/h or 52 kg/h), besides their fuel properties. Accordingly, the developed briquettes measured their diameter and length as 50mm and 100mm,respectively; with their fuel characteristics as follows, maximum hardness value: 141 HB (62.7 N), CV: 18-21 MJ/kg, density: 2-3 g/cm^3, flame temperature: 570^{o}C, AC:

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2.4-5.8%, FC: 17.23-20.62%, VM: 70-75%, and MC below 10%. Infact, addition of ANS contributed to the increased porosity in the resultant briquettes (Chungcharoen and Srisang, 2020).

Canola Straw

Moisture content (%)	7.64
Ash content (%)	2.1-6.47
Fixed carbon content (%)	na
Volatile matter content (%)	na
Calorific value (MJ/kg)	na
Cellulosic content (%)	42.39
Hemi-cellulosic content (%)	16.41
Lignin content (%)	14.15

Canola, a cultivar of rapeseed (*Brassica napus*), belongs to Brassicaceae family, usually occurring as flowering plant; and been cultivated exclusively for its euric acid rich oil seeds. Amongst canola and rapeseed based seeds, the former reports low concentration of euric acid; and is widely consumed by both humans and animals, citing its high protein and oil content (Tan et al., 2011). Apart from seeds, these plants don't hold any use and are commonly disposed using stubble burning. However, results from Proximate and LC composition showcased these canola straws as potential biomass with significant CV, which can be utilized for energy purposes. Accordingly, Adapaa et al., 2009 also used canola straws for developing briquettes by using their protein and lignin as natural binders, and compacting them under a compaction apparatus, for a pressure level of 94.7 MPa (Applied load- 3000 N; compressive force- 3381 ± 42 N) accounting their minimal rate of specific energy consumption. Here, this study preferred using ground canola straw with an average MC of 6.7% (W.B.); which was then raised to 10% (W.B.) by sprinkling calculated amount of water to it, claiming that the latter MC produced high to very high quality briquettes. Preliminary findings on these ground biomass measured their Geometric mean particle diameter, bulk density and particle density as 0.391 ± 0.017 mm, 273 ± 11 kg/m^3, and 1551 ± 47 kg/m^3, respectively. Post briquetting, the mean compact density, specific energy and total specific energy were calculated as 980 ± 17 kg/m^3, 6.91 ± 0.25 MJ/t and 7.26 ± 0.3 MJ/t, respectively (Adapaa et al., 2009).

Also again, Tumuluru et al., 2015 developed compacted briquettes from raw canola straw with help of Laboratory-scale briquette press, by using their lignin content as natural binder. Again, this study also used ground straw samples, having its MC and bulk density as 9 wt.% (W.B.), and 48-58 kg/m^3, upon drying. Into their physical properties, developed briquettes reported its density (immediately after compaction) as 976.61 kg/m^3 for the die temperature of 129.97^{o}C, feedstock MC of 9.88 wt.% (W.B.), compression pressure of 11.52 MPa, and hammer milled particle size of 31.39 mm. Likewise, highest durability amidst these briquettes were noticed as 99.7% for the die temperature of 128.87^{o}C, feedstock MC of 14.52 wt.% (W.B.), compression pressure of 7.86 MPa, and hammer milled particle size of 31.61 mm. On the contrary, lowest MC was noted for these briquettes for the die temperature at 129.88^{o}C, feedstock MC of 9 wt. % (W.B.), compression pressure of 7.54 MPa, and hammer milled particle size of 31.52 mm. As concluded earlier, physical properties like density, MC and durability of these briquettes were also dependent on operating parameters like die temperature, compression pressure, and physical properties of the feedstock used (MC and particle size) (Tumuluru et al., 2015).

Cotton Waste Residues

Moisture content (%)	8.22-13.34
Ash content (%)	2.93-14.74
Fixed carbon content (%)	11.31-20.53
Volatile matter content (%)	61.88-75.14
Calorific value (MJ/kg)	16.01
Cellulosic content (%)	34.92-66.2
Hemi-cellulosic content (%)	15.35-18.4
Lignin content (%)	15.4-26.81

Cotton (*Gossypium species*), a shrub plant native to tropical and subtropical regions belonging to family Malvaceae under the genus Gossypium; and is cultivated exclusively for its soft, fluffy staple fibre , rich in cellulose, with traces of water, waxes, pectins and fats (Khadi et al., 2010). In general, these staple fibres are spun into yarn for making cotton fabrics, and hold a significant place in the textile markets and industries. With growing demand for these fabrics, the number of plants grown also increases proportionally, thereby accommodating upto 2.5% of aerable lands; which in turn produces proportionate quantity of both cotton stubble and its residues. Owing to their VM and CV, these wastes can be used for energy applications in form of briquettes.

Using these waste stalk biomass, Song et al., 2020 developed high quality briquettes by means of briquetting press, using the feedstock bound lignin and protein content as natural binders. in this regard, the cotton stalks were treated via hydrothermal treatment for 30 minutes at 200-260oC, wherein hot compressed subcritical water induced mild thermal degradation of its physical structure leading to degradation of its macromolecules (Sasaki et al., 2003). Here, hydrothermally treated cotton stalk briquettes at 200°C (CS-HT200-B) and 230°C (CS-HT230-B) were seen as the most ideal briquettes; developed under the briquetting conditions of 75°C and 80 MPa. Looking into their ultimate analysis, these cotton stalks reported their chemical composition (D.B.) as: carbon- 49.56%, hydrogen- 3.2%, oxygen- 45.94%, nitrogen- 0.86%, sulphur- 0.44%; and their ash composition as: SiO_2- 11.7%, Al_2O_3-1.8%, Fe_2O_3- 1.1%, CaO- 30.8%, MgO- 13.9%, TiO_2- 1.4%, SO_3- 6.3%, K_2O- 18.9%, Na_2O- 10%, P_2O_5- 4.1%. On the other hand, these briquettes measured their length and diameter as 20 ± 1 mm and 33 ± 1 mm, respectively; and their fuel properties evaluated as per standards are summarised as follows, MC- 6.9 to 8.4%, AC- 2.1 to 3.1%, VM- 69.9 to 78.2%, FC- 11.8 to 19.6%, HV- 18.41 to 20.23 MJ/kg, ignition temperature- 267.8 to 269.41°C, and burnout temperature- 457.8 to 469.88°C. Lastly, this study concluded that the hydrothermal pre-treatment significantly improvised the physical characteristics of both biomass and its briquettes, by softening their lignin content (Gilbert et al., 2009, Song et al., 2020).

Spent Coffee Ground (SCG) Wastes

Moisture content (%)	1.31-6.64
Ash content (%)	0.66-1.78

Fixed carbon content (%)	16.53-19.83
Volatile matter content (%)	72.15-81.98
Calorific value (MJ/kg)	21.22-25.4
Cellulosic content (%)	11.6-13.2
Hemi-cellulosic content (%)	37.2-41.0
Lignin content (%)	22.2-25.6

Coffea (*Coffea arabica*), a tropical and southern African and tropical Asian shrub falling under the family Rubiaceae and genus coffee; and is most commonly known for yielding coffee beans, which are predominantly used is numerous edible and non-edible products. Though, they occur in wide varieties, only certain species are accounted for producing these caffeine rich beans; hence, stating them as most valuable commodity crops. on average, one tone of coffee beans produces about 650Kg of these spend coffee ground wastes; and almost 7-9 million tons of SCG were produced against 166.63 million 60 kg bags of fresh coffee powder, during year 2021 (Santos et al., 2017; Girotto et al., 2018; García-García et al., 2015; Kim et al., 2022). Eventually, these wastes are widely celebrated for its high energy content, and have received less attention in processing them into fuel source. From their Proximate and LC composition, higher HV, and elemental composition (C: 54.33-57.29%, H: 6.59-7.52%, O: 33.18-35.66%, N: 2.01-3.97%, on D.B.); it is fairly evident that these wastes can be suggested as promising feature to meet the energy demand. Accordingly, Espuelasa et al., 2020 used these raw spent coffee ground (SCG) wastes as base feedstock for producing briquettes with help of lab scale briquetting press, using xanthan and guar gum as binders. This study aimed at developing these briquettes under low-pressure and low-temperature briquetting conditions; and was achieved at room temperature and 12 MPa compaction pressure, along with binder concentration, MC content and loss of mass as 5%, 30% and 3.9%, respectively. Moreover, this study produced results related to fuel properties of both raw SCG and gum added SCG samples; and showcased significant variation, thus concluding that addition of binders improvised the overall quality of these briquettes. For better understanding variation, fuel characteristics of these briquettes samples are tabulated in table 2 (Espuelasa et al., 2020). Addition of xantum gum with SCG showed rise in their volatile peak from 61.54 mW to 81.94 mW and, volatile stage from -0.0178 mg /s to -0.0184 mg /s during their thermo gravimetric analysis (Seco et al., 2020).

Table 2: Proximate and elemental composition of raw and gum binded briquettes samples (Espuelasa et al., 2020)

Analysis	Raw SCG	SCG + 5% of Xanthan	SCG + 10% of Xanthan	SCG + 5% of Guar	SCG + 10% of Guar
Proximate Analysis (wt. %)					
MC	2.46	3.84	4.14	3.93	3.96
AC	0.66	0.81	0.97	0.57	0.52
FC	18	19.01	19.05	19.07	19.2
VM	78.88	76.35	75.85	76.43	76.33
CV	25.4	24.5	23.5	24.4	24.32
Ultimate Analysis (wt. %)					
C	57.29	57.23	57.2	55.79	54.5
O	33.18	33.25	33.24	35.04	36.46
H	7.52	7.78	7.84	7.48	7.37

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N	2.01	1.74	1.72	1.69	1.67

Even more, Fehse et al., 2021 carried out an interesting study relating the briquetting characteristics of briquettes developed from raw SCG, binder added SCG, solvent treated SCG and SCG pyrolyzed at 850oC; using a hydraulic stamp press operated at a compression rate of 10 mm/s, and briquetting temperature of 60°C. This study used 5% cellulose and 10% tapioca starch as binders for raw SCG and pyrolyzed SCG, toluene as solvent, and varied the compaction pressure and MC as 120-160 MPa, and 5-10%, respectively. Interestingly, all three dough mixtures required similar compaction pressure of 120 MPa; however, each briquette sample reported different physical characteristics depending on their binder concentration and MC. Explaining this, 5 raw SCG with 5% of MC and 5% of cellulose, yielded briquettes with highest raw density of 1097 kg/m^3; while, 10% of tapioca starch with SCG bio char, yielded briquettes with highest raw density of 1106 kg/m^3. On the other hand, solvent treated SCGs recorded their highest raw density as 1114 kg/m^3, which were similar to that of SCG char briquettes and were explained by the removal of coffee extract (upto 12.41%, for hexane and 16.52%, for toluene). In conclusions, briquettes developed from pre-treated SCG by extraction have exhibited superior fuel qualities (Fehse et al., 2021).

Another study by Potip and Wongwuttanasatian, 2018 focused on understanding the combustion behaviour of composite briquettes developed from spent coffee ground (SCG) and crude glycerol, mixed in ratio of 90:10 (G10). Related to this, briquettes were developed using hydraulic briquettizer operated at a compaction pressure of 10 MPa; which yielded briquettes with a density and CV were measured as 872.12 kg/m^3, and 21.55 MJ/kg, for dimension of 52 mm in length and 53 mm in diameter. In relevance to this study, these SCG briquettes required 850% of theoretical air for effective combustion, and resulted in highest temperature and combustion rate of 533.4°C and 0.20 g/s, respectively. Besides, addition of crude glycerol enhanced the rate of burning and combustion temperatures by 53.8% and 10%, respectively. Adding to this, these briquettes recorded their emission levels in the following concentrations: CO- 1,262.3 mg/m^3 , NOx- 38.1 mg/m^3 , SO_2- 0.0 mg/m^3 , HC- 270.3 mg/m^3 , O_2- 20.6% and CO_{2max}- 19.0%. This study concluded that combustion of these briquettes were affected by supplied air and concentration of crude glycerol due to their high carbon (52.8%) and oxygen (36.2%) content; and also proposed that denisifed briquettes can be combusted efficiently by maintaining its theoretical air requirement as 800–1000% (Potip and Wongwuttanasatian, 2018).

Cow Dung Wastes

Moisture content (%)	4.57
Ash content (%)	21.42
Fixed carbon content (%)	13.34
Volatile matter content (%)	60.67
Calorific value (MJ/kg)	15.43
Cellulosic content (%)	27.2
Hemi-cellulosic content (%)	17.2
Lignin content (%)	20.6

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Cow dung or cow pats are the faecal wastes of bovine animal species, which includes domesticated cattle (cows and buffalos), rarely yaks. For ages, these wastes have been used in numerous applications such as biogas production, fermentation medium, compost, fuel and carbon material (Wan et al., 2018; Bhattacharjya and Yu, 2014; Vijayaraghavan et al., 2015). In general, these wastes consist of undigested plant residues passed through their guts, and are usually enriched with minerals besides their high biomass content. Even though, these mineral rich wastes have high potential for natural manure and fertilizers; they are used as fuel for supplying heat in rural and remote geographies for a very long time. Supporting this, proximate and LC composition displayed higher FC and VM content for this biomass, along with its CV as 15.43 MJ/kg; which suggested it as high potential raw feedstock for developing solid biofuel with promising features.

In response to that, Song et al., 2019 used these Cow dung wastes as biomass feedstock for producing briquettes along with anthracite as an additive, by means of cold-press briquetting technique. As additives, composite of potassium nitrate (KNO_3), manganese dioxide (MnO_2) and citric acid monohydrate ($C_6H_8O_7{\cdot}H_2O$) were added as combustion promoter; whilst, mixture of calmogastrin ($Al(OH)_3$) and ammonium molybdate $(NH)_4Mo_7O_{24}{\cdot}4H_2O$) was mixed as smoking suppressor. In addition, sodium humate and red clay acted as binder, wherein acidified calcium oxide was used as desulphurizer. Here, ideal mixing ratio and composition includes cow dung to anthracite as 1:3.5, potassium nitrate to manganese dioxide to citric acid as 1:0.7:0.3, aluminium hydroxide to ammonium molybdate as 2:1, acidified CaO to red clay as 4:1 and sodium humate to red clay as 3:1; whereas, the dosage of binder, combustion promoter, smoke suppressor and desulphurizer were taken as 17.0%, 6.0%, 4.5% and 6.5%, respectively. Looking into their fuel characteristics, briquettes developed with 6% dosage of combustion promoter stated its comprehensive combustion characteristic index (SN) as 2.11×10^{-7} $\%^2$ $min^{-2}{\cdot}℃^{-3}$, stable burning characteristic index (DW) as 4.77 × 10-5 $\%{\cdot}min^{-1}{\cdot}℃^{-2}$ and burnout index (C_b) as 50.95%2 min-1 . With an average dosage for smoke suppressor as 4.5%, the specific optical density (DS) of the developed cow dung briquettes was noted as 3.58. When aluminium hydroxide and ammonium molybdate was compounded with the ratio of 2:1 as the smoke suppressor and the dosage is about 4.5%, the specific optical density (DS) of CDB is 3.58. Furthermore, addition of desulphurizer upto 6.5% dosage helped reducing the rate of sulphurization by 70.02%. Moreover, the fuel characteristics of these developed cow dung briquettes were evaluated as 28.6% of AC, 17.1% of VM and 19.8 MJ/kg of CV, respectively. Lastly, this study was fairly evident that cow dung briquettes performed well upon introducing additives in form of combustion promoters and smoke suppressors (Song et al., 2019). Besides being used as raw feedstock for briquetting, these wastes can also be used as binders while compaction; and consequently, Patil et al., 2021 used Cow and buffalo dung as binders while compacting sugarcane bagasse into briquettes (Patil et al., 2021).

Cassava Stalks

Moisture content (%)	8-23.46
Ash content (%)	4-5.48
Fixed carbon content (%)	13.23-27
Volatile matter content (%)	45.72-69.1
Calorific value (MJ/kg)	12.4-25.83
Cellulosic content (%)	33.7

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Hemi-cellulosic content (%)	31.61
Lignin content (%)	27.04

Cassava (*Manihot esculenta*), a native south American woody shrub plant belonging to spurge family, whose starchy tuberous root is globally consumed in its boiled form; besides being used as raw material for tapioca (cassava starch) on account of its high carbohydrate content. Being the third-largest source of food carbohydrates, cassava is identified as the major staple food for many developing and famine driven countries owing to their extreme drought tolerance (Fauquet and Fargette, 1990). Since, only cassava roots are consumed, its stalk are often treated as wastes and used as fuel for heating. However, these stalks require more time for its ignition and perform poorly, thus requiring certain pre-treatment techniques for enhancing its fuel properties. Though, these stems serves as source for nutrients to soil; proximate and LC composition suggested the use of these stalks as fuel in form of briquettes. Especially, after Wilaipon, 2008 assessed the net energy availability from these wastes across the northern province of Thailand as 289 TJ/year, accounting their availability and CV as 18 kton/year and 16.39 MJ/kg, respectively (Wilaipon, 2008).

Thus, Ikelle et al., 2020 blended cassava stalk along with coal dust to produce composite briquettes using manual briquetting machine operated under force and compression pressure of 276.36 N and 31.67 N/m2, respectively; with starch and $Ca(OH)_2$ as binder and desulphurizing agent. Firstly, both cassava stalk and coal lumps were carbonized at 160°C, followed by pulverization, and later on were mixed in varying proportions. Post mixing, the dough was briquetted and sun-dried for five days; and, then was evaluated for its fuel properties. And, the most optimum blend was found to be 40% of cassava stalk char and 60% of coal char; having fuel properties as follows: MC-3.36 %, AC- 25.13 %, VM- 30.15 %, FC- 41.36 %, CV- 25.9 MJ/kg, water boiling test- 2.98 min, burning time- 22.79 g/min, ignition time- 36.68 s and compressive strength- 10.78 N/mm^2. Here, the coal dust used in this study presented its proximate composition as MC- 3.25 %, AC- 10.12 %, VM- 20.12 %, and CV- 29.57 MJ/kg (Ikelle et al., 2020). Again, Wilaipon, 2008 used cassava stalk for developing briquettes with their densities ranging between 0.40-0.77 g/cm^3; and concluded that this density increased with compaction pressure during briquetting (Wilaipon, 2008).

Beside stalks, even cassava peel were also found as potential raw feedstock for producing briquettes; and accordingly, Akogun et al., 2020 used cassava peel and saw dust as waste biomasses to develop composite briquettes. These briquettes displayed their FC as 26.42%, VM as 59.9%, AC as 5.42%, MC as 8.26%, CV as 15.56 MJ/kg, compressive strength, water resistance and density ranging between 0.55-0.8 N/mm^2, 86.5–89.3%, and 0.9-1.0 g/cm^3 of density (Akogun et al., 2020). Likewise, Anggraeni et al., 2021 used ground torrefied cassava peels (CPs) and rice husks (RHs) chars for developing briquettes and evaluated its performance. Both 50:50 and 90:10 of CP and RH exhibited better CVs and relaxed densities, lower MC, high water resistant, and less ignition time (Anggraeni et al., 2021).

Durian Peel

Moisture content (%)	0.01-15.30
Ash content (%)	18.18
Fixed carbon content (%)	77.87

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Volatile matter content (%)	3.94
Calorific value (MJ/kg)	26.25
Cellulosic content (%)	60.45
Hemi-cellulosic content (%)	13.09
Lignin content (%)	15.45

Durian (*Durio zibethinus*), an edible fruit belonging to genus Durio, grown in trees that are native to south Asian countries; and are predominantly found in Thailand and Malaysia. Looking into its anatomy, this round to oblong shaped fruits consists of sweet fragrant flesh enclosed in a thorn covered rind. These fleshes hold a special recipe in Southeast Asian cuisines, and are consumed at different stages of its ripeness (Morton, 1987). In view of increasing consumption of this fruit, the volume of its peel discarded is also increases considerably. Owing to its strong odour, these waste peels are left unattended and rarely, used as remediating medium for various dyes and pollutants. In most cases, these durian shell or peel wastes are used for fuelling furnace else burned away; nonetheless, both practises leads to air pollution. However, valorising these wastes into fuel helps reducing its exploitation, and can help meeting the energy needs (Nuriana and Anisa, 2014). Agreeing to this, these wastes exhibits higher HV, and increased concentration of FC and cellulose content.

Considering these, Nuriana and Anisa, 2014 developed briquettes from waste durian peel carbonized at 450°C for 1.5 hours, and 10% of cooked starch water as binder with help of a simple briquetting press. Evaluation on fuel properties of these briquettes reported its FC as 77.87%, MC as 0.01%, VM as 3.94% of and AC as 18.18%, density as 990 kg/m^3, CV as 26.25 MJ/kg, and compressive strength as 15.10 N/cm^2, for its grain size maintained at 100 mesh or 150 microns (Nuriana and Anisa, 2014). Moving on, Haryati and Putri, 2018 used durian peel waste torrefied at 350°C for 30 minutes for developing compound briquettes using manual cylinder tube pressing technique with its diameter as 63.5 mm and length as 100 mm. Besides producing briquettes using tapioca glue as binder, it was also evaluated for its CV and rate of combustion. Responding to this, developed briquettes exhibited higher CV upto 25.76 MJ/kg, and their combustion rate as 0.0398 g/s. worth mentioning, increased numbers for calorific content was explained by their higher concentration of FC and cellulose content (Haryati and Putri, 2018).

Groundnut Shell/Husks

Moisture content (%)	9.2-11.12
Ash content (%)	2.89-6
Fixed carbon content (%)	19.3-29
Volatile matter content (%)	54.7-67.7
Calorific value (MJ/kg)	18.81
Cellulosic content (%)	44.8
Hemi-cellulosic content (%)	5.6
Lignin content (%)	36.1

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Groundnut or peanut (*Arachis hypogaea*), belonging to family Fabaceae (or Leguminosae) under the genus Arachis, are grown as legume crop for its edible seeds. Interestingly, the root nodules of the groundnut plant serves as host for symbiotic nitrogen-fixing bacteria, which reduces the plants nitrogen necessity remarkably and increase the fertility of the soil (Tekulu et al., 2020). Looking into their consumption, these nuts are used as consumed globally across various cuisines under different recipes; however, they are predominantly regarded as culinary nut, just like walnuts and almonds. Owing to this, these nuts are treated as oil crops and used for extracting groundnut, which are rich in mono and poly unsaturated C18 fatty acids. In common, only these nuts are edible, while its shell/husk is discarded as wastes; yet, these shells hold good HV (18 MJ/kg) which can be utilized as fuel for heating. For instance in Uganda, availability of this HV sums upto 5.38 PJ per year, and can be utilized as fuel effectively for energy generation (Okello et al., 2013). Inspite of Proximate and LC composition suggesting higher HV of 18 MJ/kg, a part of this energy is lost due to its reduced volumetric density and light weightiness. However, it can be overcome by compacting these wastes into briquettes. And Accordingly, Ikelle et al., 2020 used ground groundnut husk and coal dust for developing compound briquettes, with starch as binder and $Ca(OH)_2$ as de-sulphurizing agent; and was compacted using manual hydraulic briquetting machine. Post compaction, these briquettes were evaluated for its fuel properties; and were measured as follows- MC: 2.43-6.44%, compressive strength: 7.72-10.85 N/mm2, AC: 24.18-29.15 %, CV: 21.71-25.02 MJ/kg, FC: 16.77-53.22%, ignition time: 22.23-45.20 s, water boiling test: 1.50-4.99 min and burning rate: 16.10- 28.32 g/min. Eventually, all reported properties were in good agreement with thermal properties of the bio-briquettes (Ikelle et al., 2020).

Again, Lubwama and Yiga, 2017 used carbonized Groundnut shells and bagasse for developing compound briquettes, with cassava and wheat starch as binders. For this purpose, electric briquetting machine was used; and was operated at following conditions: die temperature between 280 and 290^{o}C, and compaction pressure- 230 MPa. Comparatively, Non-carbonized briquettes had higher drop strength at 99%, average HHV of 16MJ/kg, whereas average HVs for carbonized groundnut shell and bagasse briquettes were between 21 and 23 MJ/kg. In addition, raw Groundnut shells and bagasse briquettes recorded less water boiling time owing to their volatile content, and carbonized briquette with binders measured its highest flame temperature as 890^{o}C. Worth mentioning, Bulk density for groundnut shells and bagasse were 258.8 kg/m^3 and 182.7 kg/m^3 (Lubwama and Yiga, 2017). Similar results were noted by Akuma and Charles, 2017 upon using finely ground carbonised groundnut shell and coal dust for developing composite briquettes in a mixing ratio of 40%:60%; with clay/rice starch as binder and $Ca(OH)_2$ as de-sulphurizing agent. Following this, fuel properties were measured as follows: AC as 32.5%, FC as 51.50%, MC as 7%, density as 0.71 g/cm^3, VM as 9.0%, porosity index as 48.12%, higher CV as 12.10 MJ/kg, lower CV as 8.04 MJ/Kg water boiling test as 20 mins, ignition time as 13 mins, and burning time as 56.14 mins (Akuma and Charles, 2017). Summing up this, groundnut shell wastes are recommended as potential feedstock for developing solid briquettes owing to their higher MC and VM.

Hazel Nut Shell

Moisture content (%)	8.7
Ash content (%)	1.3
Fixed carbon content (%)	27.6
Volatile matter content (%)	62.4

Calorific value (MJ/kg)	17.36-18.5
Cellulosic content (%)	42.6 ± 0.99
Hemi-cellulosic content (%)	28.7 ± 0.14
Lignin content (%)	44.4 ± 0.43

Hazel nut tree (*Corylus avellana*), belonging to genus Corylus; yields hazel nuts found in both spherical and oval shapes (Martins et al., 2014). With Turkey and Italy being the prime producers, these fruits, rich in protein, monounsaturated fat, multi vitamins and nutrients, comprises of a hard shell enveloping the nut seed, which is edible; and are used in desserts and bakery products, along with chocolates. N the other hand, the hard shells lacking no proper applications, are discarded as wastes; however, they can be used as fuel for heating applications based on their favourable proximate and LC composition. In specific, these nut shell wastes can be converted into briquettes for prolonged burning time and enhanced CVs. Responding to this, Demirbas, 1999 used torrified hazelnut shells as feedstock for developing briquettes with pyrolysis oil or tar as binding agent, using a briquetting press operated at an optimum pressure and temperature of 800 MPa and 400 K, respectively. This study proposed that any fuel characteristics of the briquettes are dependent on the briquetting pressure and binder concentration. Supporting this, these Hazel char briquettes, for a binder dosage of 18 wt.%, reported their density and compressive strength as 0.7-0.8 g/cm^3 and 40-45 MPa, respectively; wherein, raw hazel briquettes reported their density and compressive strength as 0.75-0.8 g/cm^3 and 35-40MPa, respectively. To be noted, the proximate composition of pyrolyzed hazel nut shell was calculated as FC- 77.11%; VM- 20.61%; AC- 2.28%; HHV- 28.71 MJ/kg. Worth mentioning, these briquettes exhibited reduced ignitability owing to their reduced porosity as a result of high level compaction of these shell particles (Demirbas, 1999).

Kenari Shell

Moisture content (%)	4.3-8.19
Ash content (%)	1.08-12.85
Fixed carbon content (%)	55.9-69.68
Volatile matter content (%)	21.05-27
Calorific value (MJ/kg)	18.36
Cellulosic content (%)	39.24
Hemi-cellulosic content (%)	9.25
Lignin content (%)	38

Kenari (*Canarium ovatum*), a fruit bearing tropical tree native to Philippines, belonging to family Burseraceae under the genus Canarium; and are used as edible nuts (Pham and Dumandan, 2015). Into its anatomy, these fruits have fibrous fleshy pulp enclosing a hard shell (endocarp); which in turn envelopes the edible seed wrapped in a fibrous seed coat. Since, only seed are taken for consumption, the shell enveloping it is discarded and thrown as wastes; which has been identified as high potential 'feedstock for solid biofuel based on their proximate and LC composition. Accordingly, Papuangan and Jabid, 2019 used Kenari shell char as feedstock for developing briquettes, using starch, cocoa pulp, and sago flour as binders with help of a briquetting press. This study presented three different set of results corresponding to the fuel properties of briquettes developed using different binders. To begin with, briquette developed using Kenari shell char with starch reported its MC as 4.3%, AC as 12.85%, FC as 55.9%, VM as 27%, time taken to reach boiling point for 100 ml of water as 26 minutes. Next up, briquette developed using Kenari shell char with sago flour stated its MC, AC, FC, VM, and time for reaching boiling point as 3.03%, 10.55%, 67.18%, 20.25%, and 26 minutes, respectively. Lastly, briquette developed using Kenari shell char with brown pulp recorded its MC, AC, FC, VM, and time for reaching boiling point as 3.58%, 8.55%, 67.5%, 21.9%, and 27 minutes, respectively. Also, this study commented on similarities in physical and chemical characteristics between Kenari shell and coconut shell (Papuangan and Jabid, 2019).

In another study, Widodo et al., 2021 compacted carbonized Kenari shell and coal dust into composite briquettes using a simple push tool, with tapioca starch as binder; and were developed in four different mixing ratios between Kenari shell char and coal dust by maintaining binder concentration and water content as 12.5 g and 50 ml in all cases. Accordingly, bio-briquette type I was produced from 250 g of plain charcoal dust, followed by bio-briquette type II produced using 250 g of Kenari shell char. Likewise, bio-briquette type III was developed by mixing 62.5 g of canary shell char and 62.5 g of coal dust, whereas, bio-briquette type IV was made up of 93.75 g of canary shell char and 31.25 g of coal dust. Study related to their thermal properties outlined the CV of these briquettes as 23.18 MJ/kg, 26.59 MJ/kg, 25.19 MJ/kg, and 25.51 MJ/kg, respectively. Also, proximate composition of carbonised Kenari shell was calculated as follows: MC-1.92%, AC- 3.83%, FC- 66.46%, VM- 27.79%, CV- 28.41 MJ/kg (Widodo et al., 2021). Meanwhile, mixing carbonized canary shell and coal of particle size 80 mesh, in equivalent ratio with tapioca flour as binder yielded briquettes with a compressive strength of 10.110 kg/cm^2, CV of 25.04 MJ/kg, and burning time as 1 hour 56 minutes (Widodo et al., 2019).

Maize Residues (Cob and Straw)

	Maize cob	Maize Straw
Moisture content (%)	8.73	5.36-8.22
Ash content (%)	1.77-3.2	6.78-14.74
Fixed carbon content (%)	14.89-20.7	13.44-15.16
Volatile matter content (%)	76.1-80.36	61.88-75.95
Calorific value (MJ/kg)	17.11	17.31
Cellulosic content (%)	39.74	35-40
Hemi-cellulosic content (%)	37.38	21-25
Lignin content (%)	14.74	11-19

Maize (*Zea mays*), a cereal grain native to South Mexico belonging to genus Zea under family Poaceae (Benz, 2001), is a staple food consumed by both humans and animals in form of direct maize, corn based oil and ethanol, maize based products like starch and syrup, and even as animal feed. In specific, sweet corn, rich in sugar content is cultivated for human consumption and is edible; whilst, field corns are used as raw feedstock in oil companies and alcoholic beverages based distilleries. Besides that, it is regarded as the primary raw material for producing variety of liquid biofuels (especially, bio-ethanol and biodiesel). On average, the global maize production was estimated as 1,162 million thousand tonnes during year 2020, and is expected to increase in forth coming decades. For instance, annual production rate of these maize cobs across Thailand region was calculated as approximately 220 kton year −1 (Wilaipon, 2008). Despite this volume, only maize kernels are found edible and are predominantly used; whereas, other parts of this plants which includes cob, stalk or straw are either discarded as wastes or burned as stubbles. Eventually, these wastes stores significant energy content, and accordingly, both proximate and LC composition of these wastes showed higher VM and cellulosic content, along with higher CV (~17 MJ/kg). As a matter of fact, Wilaipon, 2008 estimated the annual energy availability of these maize cobs across Thailand region over 874 TJ/year, considering the net HV of maize cob as 14.2 MJ/kg (Wilaipon, 2008). And also, these cobs tends to exhibit high MC between 30.3 and 73.9% (Umogbai and Iorter, 2013), due to its freshness, along with high volatile content (76%) and CV (18.9 M/kg), beside their low ash content (3.2%) (Shah et al., 2012; Du et al., 2015). Looking into their chemical composition (on D.B.), these cobs showed their carbon, oxygen, hydrogen and nitrogen content as 46.9 ± 0.01%, 42.2 ± 0.33%, 8.1 ± 0.39%, and 2.8 ± 0.06% respectively. Following this, Okot et al., 2018 used these maize cob for developing briquettes, using their lignin as natural binders; and were compacted using hydraulic bench press operated under a compaction pressure and temperature range of 150-250 MPa, and 20-80°C, respectively. From results, it was noted that briquette density ranged between 516 and 1058.2 kg/m^3, impact resistance ranged between 17.7 and 99.8%, and mechanical strength ranged between 10 and 40 MPa; and were deeply influenced by briquetting parameters like particle size, MC of feedstock, and compacting pressure and temperature. In fact, high quality briquettes with good mechanical strength and resistance, and high density were produced from raw material having coarse particle size (~7 mm) and relatively low MC (7–8%), upon maintaining the compaction temperature as 80°C, and pressure between 200 and 250 MPa. However, increase in MC beyond its threshold point (for reducing friction and inducing binding force between particles) and grain size of biomass particles had a negative effect on briquette quality (Okot et al., 2018).

Again, maize cob was used as raw material along with bean straw as additive for developing composite briquettes, using hydraulic bench press for compaction and their lignin as natural binders; and were mixed in an optimal ratio of 25:75 w/w (bean straw: corn cob). Post briquetting, the fuel characteristics were assessed as follows: compaction pressure and temperature- 200 MPa and 80°C (density- 1154.2 kg/m^3, impact resistance- 99.4%, compressive strength- 83.6 MPa), and compaction pressure and temperature- 150 MPa and 50oC (density- 1052.9 kg/m^3, impact resistance- 99.5%, compressive strength- 69 MPa). Besides, these briquettes recorded its proximate composition as 5.4%, 76.9%, 17.7% of AC, VM and FC; and its CV as 17 MJ/kg. As a matter of fact, all these results were reported for biomass with its grain size upto 4mm, above which it yielded poor quality briquettes. Endorsing this, it was evident that higher pressure and small particle size helped in reducing the compaction temperatures; while, high pressure and temperature enhanced the overall fuel characteristics of these briquettes. And again, addition of bean straw improved the overall mechanical properties of maize cob briquettes and besides reducing their compaction pressures and enhancing compatibility with larger particle size. Of particular interest, raw bean straw used in this study had a HHV of 17.6 MJ/kg, and was made up of 6.8% of AC, 69.1% of VM, 24.1% of FC, 21.4 of cellulose, 19.6% of hemicellulose, 10.2% of lignin content; whilst their briquettes had its density ranging between 886 and 1123.3 kg/m^3 (Okot et al., 2019). In another similar study, Wilaipon, 2008 added alkali treated maize cod powder with fine coal dust (< 2mm) to produce composite briquette using a hydraulic punch press operated at 4-6 MPa compaction pressure, and maintained coal to maize cob mixing ratio as 1:3 and to yield briquettes with density of 0.98 to 1.12 g/cm^3 (Wilaipon, 2008).

Besides maize cobs, maize straws were also noticed as high potential biomass waste feedstock for briquetting; and acknowledging this, Wang et al., 2017 developed briquettes using maize straw pyrolyzed at 250-650°C using a laboratory compaction apparatus. Compaction pressure of 15 MPa forced out lignocellulosic compounds out of biomass and acted as natural binders; and helped in developing high quality briquettes. Accordingly, the fuel characteristics of these briquettes were found in the following ranges- FC: 15.59-59.36%, AC: 9.36-25.82%, VM: 15.46-75.04%, carbon: 42.33-58%, oxygen: 12-41%, hydrogen: 1.82-5.78%, nitrogen: 1.06-1.45%, sulphur: 0.23-0.31%, HHV: 16.92-21.05 MJ/kg, density: 49-913 kg/m^3, volumetric energy density: 10-15.45 GJ/m^3 . In specific, the briquettes developed using the maize straw pyrolyzed at optimum temperature of 550°C, had their FC as 53.37%, AC as 25.82%, VM as 20.81%, carbon as 57.75%, oxygen as 10.79%, hydrogen as 2.53%, nitrogen as 1.28%, sulphur as 0.25%, HHV as 21.05 MJ/kg, density as 525 kg/m^3, volumetric energy density as 11.05 GJ/m^3, mass yield ratio as 33.32%, energy yield ratio as 41.46% and energy-mass co-benefit (EMCI) index as 8.14. Summing up, increase in pyrolysis temperature reduced briquettes' density and durability, but increased its HV; thus suggesting 550°C as the best pyrolysis temperature, in the aspect of energy, for maize these straws. Worth mentioning, the ultimate composition of these raw maize straw was estimated as carbon- 41.84 ± 0.11%, hydrogen- 5.41 ± 0.06%, oxygen- 28.22 ± 0.15%, nitrogen- 1.30 ± 0.08%, sulphur- 0.27 ± 0.02%; and with their mineral composition as potassium: 10.11-14.86%, Sodium: 0.1-1%, Aluminium: 0.45-0.58%, Calcium: 5.93-9.06%, Silicon: 32.58-30.35%, Phosphorous: 0.01-0.63%, Oxygen: 45.36-46.13%, Magnesium: 1.31-1.65% (Wang et al., 2017).

Olive Residues (Pomace and Husk)

Moisture content (%)	10
Ash content (%)	4.31-9.49
Fixed carbon content (%)	15.30-23.4
Volatile matter content (%)	61.86-79.10
Calorific value (MJ/kg)	19.5 ± 0.2
Cellulosic content (%)	32.7
Hemi-cellulosic content (%)	16.2
Lignin content (%)	30.6

Olive (*Olea europaea*) shrub, is a tree native to Mediterranean Basin, belonging to family Oleaceae under genus olea; and are cultivated for its oil bearing fruits. Spread across Australian, American, and African continent, these fruits are mainly sourced for their oil, besides as table olives; with former being used in cooking, cosmetics and pharmaceutical industries (Fernández et al., 1997). Besides, this oil has its unique medical benefits, which further increases its market value and also its demand. Accordingly, this demand boosted up the production rate of olive oil; leaving behind a large volume of husk and pomace as wastes (upto 70% of fruit weight). From the proximate and LC composition, it was evident that olive pomace exhibits higher CV and VM, along with high lignin content which made these wastes as ideal feedstock for producing high quality briquettes.

Accordingly, Khlifi et al., 2020, developed high quality briquettes using these olive mill solid wastes as raw feedstock by means of hydraulic briquetting press operated for a compaction pressure and temperature of 150 MPa and 35oC, respectively; using corn starch as binder, with its dosage optimised as 15%. With respect to this mixing ratio, the developed briquettes reported their proximate composition as follows, VM- 64.65%, FC- 18.39%, MC- 10.44%, and AC- 6.72%; and their fuel characteristics as HHV- 16.92 MJ/kg, unit density- 2950 kg/m^3, bulk density- 1200 kg/m^3, and compressive strength- 4581 KN. Besides, other fuel characteristics like unit density, bulk density, and compressive strength increased with compaction pressure from 100 to 150 MPa; while, HV increased with binder concentration from 0 to 15%. Moreover, thermo gravimetric analysis (TGA) proposed that increasing binder concentration in these briquettes enhanced their rate of thermal degradation and activation energy during the non-isothermal pyrolysis (Khlifi et al., 2020).

In another case, waste olive press cakes were compacted into olive cake briquettes using a simple hydraulic press, considering their compaction pressure and MC of feedstock as briquetting parameters. Here, the influences of these parameters were decided by accounting the fuel characteristics of briquettes such as relaxed density and durability. From experimental results, highest relaxed density and durability was noted as 1284.93 kg/m^3 and 99.25%; with former being compaction pressure and MC of 35 MPa and 35%, and 25 MPa and 35%, respectively. Moreover, both relaxed density and durability increased with compaction pressure and MC; thus, concluding that these parameters have significant contribution towards briquettes quality. Summing up this, most ideal compaction parameters were decided as follows: pressure- 35 MPa, MC of feedstock- 30 to 35%, and dwell time- 5 seconds; and have produced briquettes with relaxed density ranging between 1100 and 1300 kg/m^3, twice the density of loose press cakes (Al-Widyan et al., 2002). Besides, raw olive mill solid waste briquettes was made up of 44.99% of carbon, 7.17% of hydrogen, 46.49% of oxygen, 0.89% of sulphur and 0.46% of nitrogen; while, raw olive mill solid waste briquettes with corn starch as binder comprised 43.43% of carbon, 6.87% of hydrogen, 48.5% of oxygen, 0.78% of sulphur and 0.42% of nitrogen. Even more, briquettes with binders displayed high combustion efficiency and reduced emission concentration of methane, carbon monoxide, NOx and sulfur dioxide, than for briquettes without binders. And, flame propagation of olive mill solid waste briquettes with and without binders reached upto 8.54 mm/s and 11 mm/s, respectively (Khlifi et al., 2020a). Apart from starch, paraffin waxes were also used as binders for briquetting olive residues; and accordingly, the breaking force, durability and density of these developed briquettes were measured as 40.18 to 349.39 N, 70.98 to 460.66 N/mm, and 844 to 970 kg/m^3, respectively (Fennir et al., 2014). In conclusion, , any olive biomass with particles size less than 100 µm can be used for producing briquettes for domestic and industrial purposes, by maintaining binder concentration as 15% (Khlifi et al., 2020).

Oat Straws

Moisture content (%)	1.5
Ash content (%)	6.3
Fixed carbon content (%)	16.1
Volatile matter content (%)	76.1
Calorific value (MJ/kg)	15.52
Cellulosic content (%)	37.6

Hemi-cellulosic content (%)	23.34
Lignin content (%)	12.85

Oat (*Avena sativa*) plants, native to Middle East and European countries, are grown for their cereal grains; and belong to family Poaceae under genus Avena (Zhou et al., 1999). In general, oats are consumed as oatmeal and rolled oats by both humans and livestock, while their other products are usually seen as wastes. In general, these straws are also used during the treatment of hard waters to soften it; besides being used as bedding for cattle and horse owing to their high absorbance and softness. Though, these straws are used for domestic purposes; data related to their proximate and LC composition have suggested these straws as a promising biomass with significant energy content. Accordingly, Adapa et al., 2009 used these straws for developing briquettes by using their protein and lignin as natural binders, and compacting them under a compaction apparatus, for a pressure level of 94.7 MPa (Applied load-3000 N; compressive force- 3438 ± 51 N) accounting their minimal rate of specific energy consumption. Here, this study used ground barley straw with an average MC of 5.3% (W.B.); which was then raised to 10% (W.B.) by sprinkling calculated amount of water to it, claiming that the latter MC produced high to very high quality briquettes. Preliminary findings on these ground biomass measured their geometric mean particle diameter, bulk density and particle density as 0.347 ± 0.003 mm, 268 ± 4 kg/m^3, and 1523 ± 15 kg/m^3, respectively. Post briquetting, the mean compact density, specific energy and total specific energy were calculated as 991 ± 63 kg/m^3, 7.09 ± 0.43 MJ/t and 7.62 ± 0.49 MJ/t, respectively (Adapaa et al., 2009).

In similar manner, Tumuluru et al., 2015 developed compacted briquettes from raw oat straw with help of Laboratory-scale briquette press, using its lignin content as natural binder. Again, this study also used ground straw samples, having its MC and bulk density as 9 wt.% (W.B.), and 40-58 kg/m3, upon drying. Into their physical properties, developed briquettes reported its density (immediately after compaction) as 716.65 kg/m^3 for the die temperature of 118.96oC, feedstock MC of 9.19 wt.% (W.B.), compression pressure of 12.16 MPa, and hammer milled particle size of 27.75 mm. Likewise, highest durability amidst these briquettes were noticed as 99.23 % for the die temperature of 123.99oC, feedstock MC of 9.58 wt.% (W.B.), compression pressure of 8.27 MPa, and hammer milled particle size of 19.28 mm. On the contrary, lowest MC was noted for these briquettes for the die temperature at 128.94^{o}C, feedstock MC of 9 wt. % (W.B.), compression pressure of 12.42 MPa, and hammer milled particle size of 24.30 mm. In short, this study concluded that physical properties like density, MC and durability of these briquettes were dependent on operating parameters like die temperature, compression pressure, and physical properties of the feedstock used (MC and particle size) (Tumuluru et al., 2015).

In another interesting study by Gao et al., 2020, oat straw were compacted into pellets, post treating it with fungal species namely: Trametes versicolor 52J and Phanerochaete chrysosporium. This study used Single pelleting unit operated at 4KN compaction pressure and produced pellets with dimension as follows: length-; diameter-. Based on the evaluation of fuel characteristics, raw oat straw briquettes summarised its density (immediate and after 14 days), dimensional stability and Tensile strength as 979 kg/m^3, 968 kg/m^3, 1.14% and 0.147 MPa, respectively. Fuel characteristics of Oat straw pellets treated with Trametes versicolor 52J are as follows: density (immediate and after 14 days)- 1104 kg/m^3 and 1070 kg/m^3, Dimensional stability-1.06 %, Tensile strength-0.395 MPa for a fermentation duration and temperature of 34 days and 22^{o}C, with MC and particle size maintained as 70% and 150 mm, respectively. On the other hand, Fuel characteristics of oat straw pellets treated with Phanerochaete chrysosporium are as follows: density (immediate and after 14 days)- 1108 kg/m^3 and 1068 kg/m^3, Dimensional stability- 1.14 %, Tensile strength- 0.294 MPa for a fermentation duration and temperature of 35 days and 22°C, with MC and particle size maintained as 70% and 50 mm, respectively. Overall, this study concluded that pre-treating biomass using microorganisms also helped in improvising the fuel characteristics, upon compaction (Gao et al., 2020).

Orange Peels

Moisture content (%)	8.62
Ash content (%)	3.6
Fixed carbon content (%)	20.6
Volatile matter content (%)	75.8
Calorific value (MJ/kg)	15.22
Cellulosic content (%)	11.93
Hemi-cellulosic content (%)	14.46
Lignin content (%)	2.17

Orange (*Citrus sinensis*), a tree yielding citrus fruit belonging to family Rutaceae under the genus citrus; and are native to Southern China, Northeast India, and Myanmar region. These fruits are mainly cultivated for its juice filled vesicles, often found in segments that are delimited by membrane; and are consumed for its rich c-vitamins, besides for its anti-oxidants and anti-inflammatory nature (Morton, 1987; Xu et al., 2013; Velasco and Licciardello, 2014). Besides, these vesicles are attached and enveloped inside the fruit's rind; however, the latter is discarded as wastes, in most cases except being used as an active ingredient in natural cosmetics. To be precise, the annual production of orange peel was around 79 million tonnes (during 2019), with Brazil leading by 22% followed by China and India (Mohsin et al., 2021). Interestingly, proximate and LC composition of this waste peel suggest high VM and CV, thereby making it ideal for making briquettes.

Accordingly, Aliyu et al., 2020 used this orange rind/peel as raw feedstock, along with maize cobs as additive for producing composite briquettes using pasty starch as binder (dosage- 80 g). Here, maize cobs were added to enhance the CV, besides enhancing the concentration of lignin content. To begin, both peel and cob wastes were sun dried, milled using milling machine and were sieved through a 2.36 mm sieve; and were mixed in the following ratios (peel: cob)- 20:80 (sample A), 80:20 (sample B), and 50:50 (sample C). All the mixed samples were compacted into briquettes using manually operated hydraulic jack briquetting machine, and were dried using an oven to remove its MC. Post drying, the developed briquettes were evaluated for its fuel characteristics; and following were the results reported for all the tested samples. To begin with, sample C recorded highest MC (5.28%) followed by sample A (4.64%) and B (4.19%), claiming that maize cob contributes high MC to the resultant briquettes. Moving on, sample C showcased highest VM (4.77%), while sample B showed lowest VM (0.76%), thus explaining that orange peel has highly volatile compounds which can be removed using simple milling process. next up, sample B recoded its highest AC and FC content as 4.64% and 90.42%, respectively; with sample A producing least AC as 2.39% and sample C comprising of 86.05% of FC. Eliciting from previous statement, adding maize cobs with orange peel enhanced their collective CV; and accordingly, sample A, rich in maize cob biomass, recorded highest CV of 31.89 MJ/kg, followed by sample B (31.3 MJ/kg) and sample C (31.14 MJ/kg). Next up, sample A recorded shortest ignition time and water boiling time (8.20 minutes); with sample B taking the longest boiling time of 14.28 minutes. Ultimately, this study recommends addition of any suitable biomass additive upon choosing orange peels as biomass for briquetting, to achieve solid biofuel with superior fuel characteristics (Aliyu et al., 2020).

Palm Wastes (Empty Fruit Bunch, Fibres, and Kernel Shells)

	Empty Fruit Bunch	Kernel Shell	Palm Fibre
Moisture content (%)	2.44	4.7-7.96	2.33
Ash content (%)	5.26	1.1-11.75	4.28
Fixed carbon content (%)	18.67	13.7-19.1	21.26
Volatile matter content (%)	73.63	62.82-79.2	72.13
Calorific value (MJ/kg)	17.85-18.84	16.14-23.61	14.51
Cellulosic content (%)	37.26	20.7-35.64	21.8 ± 1.2
Hemi-cellulosic content (%)	14.62	21.39-47.7	36.3 ± 0.3
Lignin content (%)	31.68	42.97-53.4	36 ± 0.7

Palms (*Elaeis guineensis*), the grown Arecaceae in form of climbers, shrubs, tree-like and stem less plants are cultivated in almost all known habitats (from rain forests to deserts), especially for their fruit bunches. With Exception of using these fruits for extracting oil, other parts of this tree are discarded as wastes citing their poor usage and market value in their raw form; and these wastes accounts upto 140 million tons per year (Uemura et al., 2013). However, processed wastes are used for various purposes like constructions and developing fibrous materials; yet, these wastes are under-utilized if considered as raw materials for producing energy. Accordingly, proximate and LC composition suggests that wastes from palm tree like their empty fruit bunch, kernel shell and waste fibres are ideal raw material for developing briquettes citing their high CV and VM content, besides their significant lignin content.

Likewise, Maitah et al., 2016 used these palm oil empty fruit bunches (EFB) as raw material for developing briquettes using a briquetter machine, with their lignin content as natural binder. Post compaction, the EFB briquettes were evaluated for their fuel characteristics; and were calculated as Dry mass content- 93.70%, net CV- 17.61 MJ/kg, AC- 5.9%, nitrogen- 1.7%, carbon- 47.10%, hydrogen- 6.20%, oxygen- 40.54%, gross CV- 18.96 kJ/kg; and its density being measured in between 0.83 g/cm^3 and 0.92 g/cm^3. Preliminary findings suggested that the average MC of raw empty fruit bunch wastes was found to be 14.6%; and were readily subjected for compaction without any drying (Maitah et al., 2016). Lastly, it was noted that valorising these bunches into useful biofuels, helped in reducing the environmental pollution caused by these wastes (Chiew and Shimada, 2013).

Nyakuma et al., 2015 studied the effect of torrefaction on briquettes developed from empty fruit bunch of oil palm trees; and aimed at reporting the effect of torrefaction on fuel characteristics of these briquettes. Accordingly, this study used market ready EFB briquettes, having their proximate composition as follows: MC- 8.04%; VM- 72.37%; FC- 14.38%, AC- 5.21%, and HHV as 17.57 MJ/kg. Following this, these EFB briquettes were torrefied in a muffle furnace for duration of 60 minutes for different torrefaction temperatures as follows: 250°C, 275°C, and 300°C. Upon torrefaction, these EFB briquettes experienced slow yet steady rate of drying and devolatization owing to their solid and uniform compaction nature; which in turn helped in enhancing the overall quality of these briquettes. Supporting this, the HV of these briquettes improved significantly from 17.57 MJ/kg to 26.24 MJ/kg, upon torrefying at 300°C. On the contrary, the mass and energy yield of these briquettes reduced from 79.70 % to 43.03 %, and 89.44 % to 64.27 % while increasing the torrefaction temperature from 250°C to 300°C; and were explained by drying, partial devolatization and the breakdown of hemicellulose (Basu, 2018). Post torrefaction, both oxygen to carbon and hydrogen to carbon ratio were reduced from 1.07 to 0.48 and 0.13 to 0.08, respectively; while, nitrogen and sulphur content increased from 0.54 to 1.07, and 0.2 to 0.43, respectively (Nyakuma et al., 2015).

In addition, even palm fibres have also been used as feedstock and also as a binder, for developing briquettes; and exhibited superior fuel characteristics owing to their good calorific content. Accordingly, Yuhazri et al., 2012 developed compound briquette using these waste fibres along with waste papers as additive and binder, using a hydraulic press machine having cylindrical moulds. This study showed that briquette developed for a mixing ratio of 60:40 (fibres:paper) presented their highest heat release rate as 162.77 kJ, and 40:60 (fibres:paper) exhibited good burning time; however, the mean CV of these briquettes ranged between 13.01 and 14.93 MJ/kg (Yuhazri et al., 2012). On the other hand, Thabuot et al., 2015 used 20 wt. % of palm fibre palm fibre as additive along with 20 wt.% of molasses as binder, for developing briquettes from Bamboo sawdust, eucalyptus sawdust, corn cob wastes using a hydraulic press. For a compaction pressure of 70 kg/cm^2, the developed briquettes recorded their density between 260-416 kg/m^3, CV as 21.26 MJ/kg for bamboo briquettes, and slowest burning rate of 2.01 g/min for rubber wood residue briquettes (Thabuot et al., 2015).

Besides their fibre and empty bunches, these palm trees yield their kernel shell as wastes, which also can be valorised into useful fuel owing to their satisfactory proximate and LC composition. Besides, the elemental composition of these biomass evaluated using ultimate analysis were measured as carbon- 45.19 ± 0.78%, oxygen - 48.49 ± 0.64%, hydrogen-5.95 ± 0.36%, Nitrogen- 0.33 ± 0.01%, sulphur-0.04 ± 0.01% (Faizal et al., 2018); wherein, their specific heat, specific gravity, bulk density, thermal conductivity, and phase change were measured as 1.983 ± 0.01 kJ/kg-K, 1.26 ± 0.07, 560 ± 17.4, 0.68 ± 0.05 W/mk, and 101.4oC, respectively (Ikumapayi and Akinlabi, 2018). Responding to this, Ugwu and Agbo, 2011 used ground Palm kernel shell char with a calorific content of 9.12 MJ/kg, along with Cassava Starch as binder, to develop briquettes using manual compaction technique. Here, the most optimal blend was taken as 59% of Palm kernel shell char powder, 38% of water, and 3% of starch; and were compacted into briquettes, with following fuel characteristics, density- 1.65 g/cm^3; CV- 23.6 MJ/kg, MC- 6.67%, burning rate- 3.2 g/min, specific fuel consumption-

0.7 kg (Ugwu and Agbo, 2011). Again palm kernel shell biochar along with starch as binders were used for developing briquettes using a customised briquetting press; and yielded highest tensile crushing strength (37.5-40 kN/m^2) for the following optimum parameters: water mass fraction- 30%, compaction pressure- 100 MPa, feed particle size- less than 300 mm. following this, these briquettes reported their apparent density as 747 ± 31 kg/m^3, true density as 2040 ± 9 kg/m^3, and briquette porosity as 0.62 to 0.65; with their elemental mass as follows: magnesium- 2.7%, aluminium- 1.2%, silicon- 17.7%, phosphorous- 2.7%, sulphur-1.6%, potassium- 29.8%, calcium- 41.4%, and iron- 2.6%. This study hinted that addition of starch improvised the tensile crushing strength of these briquettes, which enhanced further with evaporation of water from compacted dough citing the better cementing of the starch and palm kernel shell char (Bazargan et al., 2014).

Moving on, Faizal et al., 2018 used studied the effect of torrefaction on denisifed PKS briquettes, by varying the temperature between 250 and 300°C for a residence time of 40 minutes. Here, the optimum torrefaction temperature was decided as 250°C owing to their high efficiency; and briquettes torrified at this temperature reported their fuel characteristics as follows: gross CV- 21.68 MJ/kg, MC- 5.55%, and AC (W.B.)- 3.53%. Moreover, increase in torrefaction temperature enhanced the FC, AC and gross calorific content of these treated briquettes; but, reduced their VM, relaxed density and compressive strength. However, MC and GCV remind well inside the permissible standards required for commercialization (Faizal et al., 2018). Lastly, Mohammed and Olugbade, 2015 used palm kernel shell and rice bran for developing composite briquettes with cassava starch as binder, using a manually operated briquette machine with briquetting efficiency as 85%. Looking into their fuel characteristics, these composite briquettes calculated MC, VM, fixed carbon, AC, HV, compressive strength, and density as 18.97%, 64.54%, 21.30%, 14.16%, 14.25 MJ/kg, and 1.08 kN/m^2, respectively; and their elemental composition measured as 45.67 %, 5.80 %, 0.05 %, 1.78 % and 46.70 % for carbon, hydrogen, sulphur, nitrogen and oxygen respectively (Mohammed and Olugbade, 2015). Inferring from these results, it was fairly evident that these palm wastes (waste fibres, empty fruit bunches and kernel shell) can be valorised into good energy content biofuel, suitable for both domestic and industrial applications.

Pongamia and Tamarind Shells

	Pongamia shell	**Tamarind shell**
Moisture content (%)	9.97-12	8.44
Ash content (%)	4.09-5.7	9.56
Fixed carbon content (%)	11.71-18.95	13.44
Volatile matter content (%)	66.99-71.21	68.56
Calorific value (MJ/kg)	16.81-17.65	16.3
Cellulosic content (%)	51.73	18.55
Hemi-cellulosic content (%)	-	47.6
Lignin content (%)	21.71	4.04

Tamarind (*Tamarindus indica*) is a leguminous-hardwood tree native to tropical Africa; belonging to family Fabaceae, under genus Tamarindus. These trees bear an edible fruits usually brown in colour, with appearance resembling like pods; and contains sweet and tangy pulp, used globally across different cuisines as an active ingredient. Besides this, these pulps are widely used in metal polishing works and also in traditional medicines. Beyond this, wood from this hardwood tree is widely used for various wood and furniture works; whereas, its seed oil are used for various medicinal purposes. Hence, these trees are cultivated globally, predominantly in tropical and subtropical zones (Rao and Mathew, 2012). Considering their global consumption, these fruits tend to produce a large of volume of wastes, in form of their peels; which can be used as feedstock for developing biofuel, upon considering their proximate and LC composition.

Likewise, Pongamia (*Millettia pinnata*) is also a leguminous tree belonging to family Fabaceae under genus Millettia, and are native to tropical zones on the earth, especially to Asia, Australia, and Pacific islands. Often termed as Indian beech and Pongame oil tree, these trees are highly tolerant to drought, intense heat and sunlight; and helps retarding the surface water evaporation due to their dense shades, besides promoting nitrogen fixation. Though drought resistance, these trees can also survive in freshwater floods for a longer time, thus enabling their existences even in swamp forests. Inspite of all these benefits, these trees are widely preferred for its oil-rich seeds, which normally exists inside a shell. On global scale, Pongamia oil biodiesel has a very good value in renewable biofuel markets, and is seen as the most commonly preferred and cheap alternative to existing diesel. With increasing energy demand, a large volume of seeds are being used for oil production, leaving behind a proportionate volume of shells as wastes (Yadav et al., 2011). With good CV and cellulosic content, these wastes have also been seen as a potential feedstock for developing solid biofuels.

With an attempt of utilizing this calorific and cellulosic composition of these two shells, Ujjinappa and Sreepathi, 2018 used pongamia shell (PS) and tamarind shell (TS) for developing composite briquettes using an universal testing machine, with Pongamia cake (PC) taken as binders. this study developed four different samples prepared by mixing different concentrations of Pongamia shell, tamarind shell and Pongamia cake; and their respective mixing ratios were as follows: sample 1 (60:40:00), sample 2 (60:30:10), sample 3 (60:20:20),and sample 4 (60:10:30). Here, the most optimum compaction pressure was decided as 200 MPa amongst other pressures (100 ad 150 MPa), and the most ideal mixing ratio was decided with sample 1; owing to their ability to produce high quality briquettes. Accordingly, sample 1 briquettes developed at 200 MPa reported their compressed density between 1026 and 1108 kg/m^3, relaxed density between 947 and 1023 kg/m^3, compressive strength between 6.26 and 20.18 N/mm2, and shattering index as 96.42%; with a dimension of diameter as 36 mm and length between 45 to 55 mm. Moreover, the proximate and elemental composition of the briquettes developed using optimal parameters were as follows: MC-5.03%, VM- 76.86%, FC- 15.4%, AC- 2.71% , CV- 16.74 MJ/kg, carbon- 65.79%, hydrogen- 7.06%, nitrogen- 0.56%, oxygen- 18.67%, sulphur- 0.18%. Furthermore, this study discouraged used of Pongamia cake as binders, as it created an adverse effect on the properties of these briquettes; and concluded that these compacted fuels were in good agreement with the standards (Ujjinappa and Sreepathi, 2018).

Likwise, tamrind shell was used as an additive along with onion peel, upon developing composite briquttes with cassava stach as binder using a compressed hydraulic system operated under a compaction pressure of 200 KN. Blending peel and shell wastes in different concentrations yielded briquettes with varying fuel properties, which are listed in the form of ranges. As a result, MC was between 4.01 and 8.42%, AC was between 3.83 and 11.14%, VM was between 64.28 and 80.12%, FC was between 9.36 and 13.87%, CV was between 18.24 and 21.05 MJ/kg, carbon was between 39.79 and 56.27%, hydrogen was between 4.8 and 5.60%, and oxygen was between 35.87 and 45.94% (Velusamy et al., 2022).

Rice Wastes (Straw and Husks)

	Rice Husk	**Rice Straw**
Moisture content (%)	4.07	10.3-26.63
Ash content (%)	17-17.39	7.56-13.41
Fixed carbon content (%)	7.06	11.23-14.57
Volatile matter content (%)	71.47	64.07-79.71
Calorific value (MJ/kg)	13.38	6.38-17.6
Cellulosic content (%)	33.43-35	38.02
Hemi-cellulosic content (%)	20.99-25	18.3
Lignin content (%)	18.25-20	21.6

Rice (*Oryza sativa or Oryza glaberrima*) are monocotic seed yielding grass species belonging to family Poaceae under the genus Oryza; and are grown for its cereal grain annually, especially for consumption as staple food. Infact, rice is regarded as the third largest cultivated agricultural commodity, after sugarcane and maize; and is consumed by almost over half of the world's human population, especially in Asia and Africa for its nutrition and caloric intake. Inspite of its nativity to Asia and certain parts of Africa, this crop can be grown in almost every known terrain to humans (Smith, 1995); and is estimated to produce 4% of global greenhouse gas emissions during various stages of its production and consumption during 2010. Looking into their edibility, only the rice cereal are consumed as food, followed by its bran being used as raw material for extracting rice bran oil; whilst, other parts are often discarded as wastes. Especially, these wastes includes rice husk and straw, which are disposed by means of stubble burning, however, exhibit good potential as fuel for energy applications. Accordingly, proximate and LC composition suggested significant CV and VM content, thereby making these wastes as ideal feedstocks for making briquettes. Supporting this, Oladeji and Enweremadu, 2012 developed high quality briquettes by compacting these rick husks with help of a prototype briquetting machine, and by adding starch as binder. In this present study, the waste husks were compacted into square briquettes, having the sides and thickness as 75mm and 8mm, respective; and were tested for their fuel properties upon drying under sun for 1-2 weeks. Accordingly, fuel characteristics of these developed briquettes were reported as follows: briquette weight- 0.025kg, compaction pressure- 2.1 MPa, carbon- 42.1%, hydrogen- 5.8%, oxygen- 51.67%, sulphur- 0.05%, AC- 18.6%, nitrogen- 0.38%, VM- 67.98%, FC- 13.4%, MC- 12.67%, compressive strength- 1.07 KN/m^2, HV- 13.389 MJ/kg, initial density- 138 kg/m3, maximum density- 524 kg/m^3, relaxed density-240 kg/m^3, density ratio- 0.45, compaction ratio-3.80, relaxation ratio- 2.22, after glow time- 354 sec, flame propagation rate- 0.10 cm/s. This study stated that all the above mentioned characteristics were in agreement with established international briquette standards; and concluded that a good briquette from an agro-biomass requires low MC, high density and compressive strength, slow flame propagation, low AC, high amount of hydrogen, and substantial HV (Oladeji and Enweremadu, 2012).

Following this, Yank et al., 2016 used rice husk and bran as raw feedstock and additive for developing briquettes using a manual briquetting press operated at 4.2 MPa, with cassava wastewater and okra stem gum taken as binders. Preliminary findings suggested the MC (W.B.) and CV (D.B.) as 9.2% and 16.08 MJ/kg, respectively; and this study aimed at understanding the effect of binder type and their dosage, water concentration and bran content on briquette qualities. In relevance to that, briquette developed using rice dust binder displayed highest durability of 91.9%, and a compressive strength of 2.54 KN; while, briquettes using 10% of cassava starch wastewater and 10% bran recorded its highest density as 471.3 kg/m^3. Besides, the HV of these briquettes varied between 16.01 and 16.45 MJ/kg, and were widely influenced by the biomass used and the compaction pressure; wherein their MC varied proportionally (4.64 and 7.42 %) with the binder concentration. Lastly, this study concluded that addition of bran content has least significance on the fuel characteristics of rice husk briquettes, except for their density (Yank et al., 2016). Likewise, starch and gum Arabic were used as binders for developing briquettes from these rice husk, for a mixing ratio of 6:1 w/w (husk:gum and husk: starch),by means of manual compaction under dead weight. This study stated that these rice husks displayed high carbohydrate (30%), AC (20-22.4%), and traces of crude protein (1.0%) and fat content (0.3%). Post compaction, the briquettes were sun dried to remove its excess MC; and were evaluated for their thermal properties, which showed their maximum time required for boiling 2 Liters of waters using 1 kg of these briquettes samples as 15 minutes, during their water boiling test. This was explained by the porous nature of these briquettes which allowed the volatile matters to penetrate towards their surface and enhance the rate of combustion; than compared to denisifed hardwoods which needed 1.2 kg of wood samples and 21 minutes to boil the same quantity of water. This study commented on the Hair-like cracks in the developed briquette samples due to low compaction pressure from manual briquetting; and recommended for the use of briquetting machines (Yahaya and Ibrahim, 2012).

Besides simple briquettes, composite briquettes were also developed by using these wastes; and, supporting this, rice husk was mixed with banana residue in an ideal ratio of 60:40, and were compacted into composite briquettes by using the starch in banana residue as natural binder. Here, maintaining the particle size of this biomass as 75 µm, 150 µm and 300 µm, produced mixed results related to their fuel characteristics like moderate density, longer ignition and combustion time, and low volatile content. Moreover, the net CV of the briquette developed using these optimum parameters was calculated as 16.4 MJ/kg (Nazari et al., 2019). In similar manner, Rodiah et al., 2021 developed composite briquettes by mixing rice husk and coconut shell residue char torrefied at 300oC along with mango sap as binder, and compacting the dough using a simple die press. here, The optimum mixing ratio between these char resides were decided as 1:2 (w/w)(husk:shell chars),based on their lowest MC; and briquettes developed using this mixing ratio had the following proximate composition, MC- 3.55%, VM- 48.99%, FC- 44.05%, AC- 3.41%, and their CV as 26.18 MJ/kg (Rodiah et al., 2021). Apart from raw husk, even torrified husk have also been used for briquetting; and accordingly, Rodiah et al., 2021 used torrified Rice husk to produce briquettes, which reported its MC as 5.14%, VM as 31.8%, FC as 58.36%, AC as 4.71%, and CV as 18.87 MJ/kg; concluding that fuel characteristics like FC and calorific content were higher for torrified briquettes than its untreated counterpart (Rodiah et al., 2021).

On the other hand, Rhofita et al., 2018 used ground rice straw for developing briquettes using a manual hydraulic press briquetting machine; and aimed at understanding the effect of particle size, and compaction pressure and temperature on the fuel characteristics of developed briquettes such as density and compressive strength. Upon evaluating these fuel characteristics, rice straw presented its bulk density between 106.89 and 112.87 kg/m^3; whereas, highest density for rice straw briquettes along with its corresponding compressive strength were measured as 1178 kg/m^3 and 2.05 MPa, achieved for a compaction pressure and temperature of 40 MPa and 175°C, and particle size as 3 mm. on the other hand, highest compressive strength along with its corresponding density were measured as 2.45 MPa and 888 kg/m^3, achieved for a compaction pressure and temperature of 10 MPa and 175oC, and particle size as 3mm. However, the most optimum parameters with respect to compaction pressure and temperature and particle size, for briquetting of these ground rice straws were 40 MPa, 100°C, and 3 mm, respectively (Rhofita et al., 2018).

Likewise, Jittabut, 2015 used rice straw and sugarcane leaves for producing compound briquettes, by maintaining their mixing ratio as 50:50; while blending the mixed biomass with binder (molasses) in a ratio of 100:50. Evaluating these briquettes showed their FC as 13.63%, VM as 74.67%, AC as 7.5%, and MC as 4.2%; with their elemental composition as follows: C- 43.2%, H- 6.2%, O- 34.5%, N- 0.37%, S- 0.03%. In addition, these briquettes recorded its gross CV as 17.83 MJ/kg, bulk density as 0.59 g/cm^3, and compressive strength as 45 kg/cm2; which agreed well with standards (Jittabut, 2015). Summing up this, both discussed results and conclusions drawn suggests these rice wastes, especially their husk/bran and straw as biomass with good potential for valorising into solid biofuels that can be used for combustion oriented applications.

Sugarcane Wastes (Bagasse and Leaves)

	Sugarcane Bagasse	**Sugarcane Leaves**
Moisture content (%)	6.83-9.51	6.61
Ash content (%)	0.9-1.94	6.48
Fixed carbon content (%)	12.44-13.57	54.57
Volatile matter content (%)	74.98-86.25	32.34
Calorific value (MJ/kg)	15.69-18.53	14.73
Cellulosic content (%)	42.5	12.57
Hemi-cellulosic content (%)	33.7	14.01
Lignin content (%)	23	5.71

Sugarcane (*Saccharum officinarum*) is a tall, perennial grass belonging to family Poaceae under the genus Saccharum; and is cultivated for producing sugar from its fibrous stalks, rich in sucrose. These grass plants are native to warm temperate and tropical regions of India, Southeast Asia, and New Guinea (Papini-Terzi et al., 2009). In general, these sucrose are converted into sugar leaving behind a large volume of bagasse as biomass; and accordingly, each ton of sugarcane yields 740 kg of juice (135 kg of sucrose and 605 kg of water) and 260 kg of wet bagasse (130 kg of dry bagasse). Apart from producing sugar, these juices are also used for fermenting into ethanol, especially in Brazil, thereby making them also as an energy crop. Owing to its global consumption and extended applications, volume of sugar/ethanol produced from these canes and their bagasse wastes are always proportional; with latter being used commonly as raw material for organic disposable products, animal fodder and even as feedstock for briquettes. Infact, proximate and LC composition have shown higher VM and cellulosic content with good CV for these bagasse; and supporting this, these bagasse showcased high gross CV of 18.72 MJ/kg, energy density of 1.27 GJ/m^3, and bulk density of 95 kg/m3 (Costa et al., 2019). Thus, using these wastes as raw feedstock for producing briquettes are seen as an effective valorization techniques; and supporting this, Brunerová et al., 2020 used these sugarcane bagasse as raw feedstock for developing briquettes using their lignin content as natural binders, and were compacted using a high-pressure briquetting press. This study estimated the average waste ratio as 35.45 for bagasse to whole stem, and as 8.18 for leaves to whole stem; and quantified the gross and net CV of these bagasse as 18.35 MJ/kg and 17.06 MJ/kg. in addition, ultimate composition of these wastes were measured as carbon- 44.35 to 48.16%, hydrogen- 5.52 to 5.99%, nitrogen- 0.35 to 0.38%, oxygen- 41.87 to 45.46%. Following this, compacted bagasse briquettes with average length, diameter and mass of 54.08 ± 2.05 mm, 52.33 ± 0.28 mm, and 118.8 ± 3.98 g, indicated their MC as 7.54 ± 0.51%, bulk density as 1022.44 ± 15.59 kg/m^3, compressive strength as 150.82 ± 15.86 N/mm, mechanical durability as 99.29 ± 0.59%. These results were in good agreement with the standards, and were seen as viable fuel source for producing energy (Brunerová et al., 2020).

Improvising this, Oyibo et al., 2020 used alkali treated sugarcane bagasse for briquetting with help of a simple hydraulic press using starch as binder with a dosage of 20%. Post compaction, these treated bagasse briquettes showed up their MC as 3 ± 0.5%, AC as 7.3 ± 1.7%, VM as 80.7 ± 0.1%, FC as 9 ± 0.25%, compressive strength as 37.77 ± 0.68 N/cm^2, density as 0.81 ± 0.05 g/cm^3, CV as 34.59 ± 0.57 MJ/kg, ignition time as 5.33 ± 1.84 mins., combustibility test as 2 mins, after glow time as 391 ± 10.1 seconds. In contrast, raw bagasse briquettes recorded their fuel characteristics as: MC- 5.25 ± 0.25%, AC- 9.5 ± 0.5%, VM- 81 ± 2%, FC- 4.25 ± 0.25%, compressive strength- 4.21 ± 1.12 N/cm^2, density- 0.4231 ± 0.01 g/cm^3, CV - 31.13 ± 1.7 MJ/kg, ignition time- 2.14 ± 0.48 mins., combustibility test- 3 mins, after glow time- 378 ± 5.7 sec. Comparing these results, it was clearly evident that alkali treated bagasse showcased superior fuel characterises; and was explained by the removal of hemicellulose and lignin content and increase in cellulosic concentration (Oyibo et al., 2020).

Besides bagasse, even their leaves can also be used as feedstock for developing briquettes, especially due to their high volatile content and lignocellulosic content based on their proximate and LC composition. Supporting this, Patil et al., 2021 used these sugarcane leaves as raw feedstock for producing briquettes by adding cow dung, buffalo dung, and press mud as binders; and were compacted into a mould using a simple press operated at different loads depending on the binder. Accordingly, cow dung binder required highest load of 22 KN, and was chosen as the most suitable binder amongst; followed by press mud and buffalo dung binder, which required 12 KN and 11KN, respectively. Post compaction and drying, these briquettes were evaluated for their fuel characteristics; and are tabulated in table 3, compared amongst each other. Results displayed superior fuel characteristics in favour of briquettes binded with cow dung; and exhibited enhanced physical properties, including their CV s but mixed proximate composition. Moreover, these wastes minimised the need for supplementary MC for compaction, citing the sufficient amount of MC already present in these leaves and binders (Patil et al., 2021).

Table 3: Fuel charactertisitcs of sugarcane leaf briquettes for different binders (Patil et al., 2021)

	DSL/Cow Dung	DSL/Buffalo Dung	DSL/Press Mud
Proximate Analysis			
MC, %	25.61	33.89	6.52
AC, %	10.99	9.86	18.88
FC, %	2.93	7.96	6.87
VM, %	60.47	48.29	67.73
Gross CV, MJ/kg	16.26	16.23	15.26

Net CV, MJ/kg	15.36	13.47	13.97
Energy Density Ratio (EDR)	0.93	0.85	0.90
Physical Properties			
Bulk Density(Kg/m^3)	198.1	216.8	191.9
Relaxed Density (Kg/m^3)	169.47	174.95	171.31
Degree of Densification	0.033	0.132	0.002
Compression Ratio	1.033	1.131	1.002
Split Tensile Strength (kN/m^2)	7.164	5.59	6.98
Tumbling Resistance (%)	87.84	84.13	86.66
Shatter Resistance (%)	12.75	Disintegrated after seven drops	Disintegrated after six drops
*DSL- Dry Sugarcane Leaves			

In conclusion, these sugarcane plant wastes are seen as naturally occurring high potential biomass available in abundance owing to their numerous applications; and these studies have proposed that these wastes can be valorised into useful biofuels to satisfy the energy demand.

Switch Grass Wastes

Moisture content (%)	2.65-5.71
Ash content (%)	2.54-7.6
Fixed carbon content (%)	13.81
Volatile matter content (%)	81.2
Calorific value (MJ/kg)	19.06
Cellulosic content (%)	27.8-44.3
Hemi-cellulosic content (%)	20.30-30
Lignin content (%)	7.4-22.5

Switchgrass (*Panicum virgatum*), a perennial bunchgrass grown in warm temperatures belonging to family under genus, and is found widely across its native North American continent. In specific, these grasses are found commonly in North American prairie eco-systems; and are primarily used for in soil conservation, environmental phytoremediation, carbon dioxide bio-sequestration and as raw material for fibres. Besides, these grass are used in supplying heat for generating power, producing bio-alcohols (ethanol and butanol); and was accounted by its VM and CV. Owing to their non-edibility, and superior proximate and LC composition, these wastes are seen as potential feedstock for producing compacted solid biofuels meant for combustion based applications. Accordingly, Karunanithy et al., 2012 denisifed these switch grass into briquettes via compaction, using a simple horizontal briquetting press using their lignin and protein content as natural binders. Initial findings on these switch grass reported their geometrical mean diameter (GMD) as 0.736 mm, bulk density between 115–182 kg/m^3, and their glass transition temperature as 82.5^{o}C. On the other hand, their briquettes estimated their concentration of glucose, xylose, lignin, AC and extractives as 36%, 19%, 24.8%, 3.7%, and 16.5%, respectively; with their bulk density between 946–1173 kg/m^3, and MC between 6-8% (W.B.). This study claimed that durability of briquettes depends on the chemical composition, glass transition temperature, and compressibility of the biomass used (Karunanithy et al., 2012).

Moving on, briquettes were developed from these switch grass biomass using corn stover and starch as both additive and binding agents, respectively; and were compacted using a uniaxial, piston-cylinder densification apparatus for a compaction pressure and preheating temperature of 150 MPa and 100°C. Next up, this study identified 80 wt. % of switch grass and 20 wt. % of corn stover as the most optimal mixing ratio; and fuel characteristics were evaluated for the briquettes developed under this composition. Results included the densities noted immediately and one week after compaction as 1135.5 ± 21.9 and 1096.5 ± 20.8 kg/m^3, MC (W.B.) as 7.9 ± 0.2% and durability after 7 days as 77.8 ± 2.1 %, for the particle size of 0.56 ± 0.29mm and grind MC of 10.4 ± 0.1%. In case of plain switch grass briquettes without any binders, the densities noted immediately and one week after compaction were measured as 1099.7 ± 12.5 and 1053.5 ± 61.7 kg/m^3, MC (W.B.) as 6.1 ± 0.4% and durability after 7 days as 67.3 ± 1.5 %, for the particle size of 0.56 ± 0.29mm and grind MC of 9.8 ± 0.2%. Besides, this study suggested that briquettes compacted without pre-heating showed very poor durability, as an external heat source was required for activating the natural binders in these biomasses and also the externally added binding agents (Kaliyan et al., 2009; Kaliyan and Morey, 2009). Besides briquettes, this waste biomass can also be denisifed into pellets which also exhibits similar fuel characteristics exhibited by the switch grass briquettes. For instance, these pellets tends to report their bulk density ranging between 536 and 708 kg/m^3 (Karunanithy et al., 2012), with their length and diameter reaching upto 24 mm and 9.8 mm, respectively for higher durability (Kaliyan and Morey, 2009). In short, it can claimed that both pellets and briquettes developed from switch grass biomass, holds significance fuel qualities that can be utilised for supplying energy.

Soybean Straw

Moisture content (%)	6.77-8.45
Ash content (%)	2.8-5.03
Fixed carbon content (%)	14.59-16.95
Volatile matter content (%)	71.8-73.61
Calorific value (MJ/kg)	16.9-18.23
Cellulosic content (%)	44.2
Hemi-cellulosic content (%)	5.9
Lignin content (%)	19.2

Soybean (*Glycine max*), an native east Asian legume plant belonging to family Fabaceae under genus Glycine, that are cultivated for its edible bean which serves many purposes in food industries. These beans are used for preparing soy milk from its beans, tofu from its skins, soy sauce and bean pastes; besides being used as textured vegetable proteins (TVP), an active ingredient in many meat and dairy substitutes, and as animal fodder (Riaz, 2005). Besides, edible beans, these plants don't hold any values thereby considering its stalks and leaves as wastes, thus disposing them as stubbles. However, these straws hold certain calorific content which can be converted into useful energy, meant for heating or its related applications. Explaining this, Kiš et al., 2009 illustrated about the energy content available in these soybean straws, with data and variables corresponding to Croatia; and were as follows: Available Mass (@ 15% MC) - 2928.884 kg/ha, energy value – 15.22 MJ/kg, total energy value – 44593.84 MJ/ha, total energy value @ η= 80% - 35675 MJ/ha, Natural Gas

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Equivalent- 1002.432 m3/ha, liquid light fuel equivalent- 847.638 kg/ha, Mazut equivalent- 870.47 kg/ha (Kiš et al., 2009). Besides their significant calorific content, these straws also exhibited good amount of lignocellulosic content, which makes them as suitable feedstock for producing briquettes.

Supporting this, Makarynska and Turpurova, 2020 developed briquettes from these straws, which reported its Bulk mass, MC, particle size and density as 55 kg/m^3, 11.5 %, 22 mm, and 750 kg/m^3, respectively. Here, these straws were dried and milled until the particle size reached 5-6 mm; following which were compacted with help of a briquetting press using its lignocellulosic compounds as natural binders. Post briquetting, these compacted briquettes were evaluated for their fuel characteristics; and were calculated as follows: Length- 200 mm, diameter- 50 mm, mass fraction of moisture (dried at 40oC and 105°C)- 1.96% and 6.58%, AC- 6.96%, sulfur content- 0.246%, total carbon content- 47.05%, VM- 80.20%; and their HV ranging between 14.85 and 17.75 MJ/kg. Lastly, this study concluded that briquetting of these soybean straws helped in increasing their CV per unit volume by 10 times than compared to their raw form (Makarynska and Turpurova, 2020).

Sorghum (Guinea corn) Straw

Moisture content (%)	7.72-9.08
Ash content (%)	7.13
Fixed carbon content (%)	19.77
Volatile matter content (%)	65.38
Calorific value (MJ/kg)	16.05-20.58
Cellulosic content (%)	35.4
Hemi-cellulosic content (%)	19.4
Lignin content (%)	10.35

Sorgum (*Sorghum vulgare*), a genucs comprising of 25 different flowering plants under the family poaceae and sub family Panicoideae, are either cultivated for its cereals, consumed by humans; or for its fodder/pastures, to be consumed by animals. Most commonly known species includes sorghum bicolour, an African native plant grown globally for its grains and fodder; and are predominantly cultivated in warm climates or in pasture lands (Bhattacharya et al., 2011). Above discussions briefly describes about its unsuitability for any edible purposes, especially their stalks or straw portions; thereby signifying their potential as raw material for briquettes. In relevance to that, proximate and LC composition suggests higher concentration of VM and lignin content, and CV for these wastes, thus making them idle for producing briquettes. In addition, this straw biomass weighs their volume weight between 800 and 870 kg/m^3, compressive force between 40 and 60 N/mm, and compaction pressure between 31 and 35 MPa (Plíštil et al., 2005). Accordingly, Wang et al., 2013 used sorghum straw for developing briquettes by using their lignin content as natural binders, with help of hydraulic operated universal testing machine. In relevance to this study, the briquetting parameters like MC, compaction pressure and temperature were optimized as 20%, 50 MPa and 90°C, respectively; and, briquetting were carried out using these parameters. Post briquetting, these samples were evaluated for their fuel characteristics; and all the results were reported with respect to their confined and relaxed density. To begin with, confined and relaxed density of these straws having 20% MC, compacted at 10 MPa were measured as 1.4 and 0.58 g/cm^3, respectively; whereas, straws compacted at 50 MPa pressure and 90°C temperature, presented their confined and relaxed density as 2.25 and 0.78 g/cm^3, respectively. with respect to the source of heat, dough heated using ordinary heating filament resulted in briquettes having their confined and relaxed as 1.6 g/cm^3, and 0.6 g/cm3, respectively; and dough heated using microwave resulted in briquettes having their confined and relaxed as 1.4 g/cm^3, and 0.6 g/cm^3, respectively. Explaining these results, MC of dough as 20% and compaction pressure of 50 MPa helped in softening and plasticizing the lignin content available in them. Besides, both electric and microwave heating helped in preheating the dough, with microwave heating being preferred considering their local overheating phenomenon (Wang et al., 2013).

In another similar study, Bamgboye and Bolufawi, 2009 used ground sorghum straw for developing briquettes with diameter of 56 mm, using a hydraulic press for compaction and starch mucilage as binders. Accordingly, this study was carried out on biomass grinded for different particle sizes (4.7 mm (D1), 1.7 mm (D2) and 0.6 mm (D3), different binder concentration (40, 45, 50 and 55 wt.%), and different compaction pressure (7.5, 8.5, 9.5 and 10.5 MPa). Preliminary findings showed the MC (D.B.) and bulk density of ground straw particles as 9.08% and 46.03 kg/m^3; and for developed briquettes as 7.15% and 208.15 kg/m^3, respectively. Furthermore, density of compacted briquettes were in range of 789 and 1372 kg/m^3; with highest value being noted for the following parameters: binder ratio- 40%, compaction pressure- 10.5 Mpa and particle size- 4.7 mm. on the other hand, relaxed density were in range of 235 and 435 kg/m^3; with highest value being reported for the following parameters: binder ratio- 40%, compaction pressure- 10.5 MPa and particle size- 0.6 mm. In conclusion, this study proposed that increase in volume of fixed mass resulted in reduced densities; and claimed that briquettes expanding more, post briquetting, displayed low relaxed densities. Besides, this study also concluded that density biomass into briquettes, reduced its volume by 450% (Bamgboye and Bolufawi, 2009). Besides briquetting, these straws were also used for developing pellets; and were acknowledged by Theerarattananoon et al., 2011 upon compacting these straws into pellets with bulk density, true density and durability ranging between 365.2 and 478 kg/m^3, 435.5 and 541.7 kg/m^3, 85.7 and 93.5%, respectively. This study used straw biomass with MC maintained at 14%, and was compacted using single pelleting unit operated at 4 KN; which eventually increased its bulk density by 9-12 folds (Theerarattananoon et al., 2011).

Wood Saw Dust

Moisture content (%)	3.07
Ash content (%)	3.38
Fixed carbon content (%)	12.68
Volatile matter content (%)	80.87
Calorific value (MJ/kg)	18.88
Cellulosic content (%)	41.58
Hemi-cellulosic content (%)	32.81
Lignin content (%)	33.56

Sawdust (or wood dust), is the by-product produced during various stages and different process of wood working operations like sawing, sanding, milling, planing, and routing; and predominantly consists of wood chips and shavings. In most cases, these dusts tend to be organic biomass, yet, their proximate and LC composition varies with the plant or tree from which the woods are derived from. Besides industrials sources, these wood dust are produced by certain birds and animals like woodpecker and carpenter ants; however, they are least considered as their source. Most importantly, these wood dust acts as primary source for fire hazard in most cases and their particulate nature contributes to air pollution in form of PM emission, thereby creating an occupational dust exposure. Even though, these particulate dusts are harmful to humans, they can be processed into value added products, especially as briquettes owing to their higher CV. Accordingly, Antwi-Boasiako and Acheampong, 2016 developed briquettes from saw dusts of three tropical hardwoods of different densities namely *Cylicodiscus gabunensis* (heavy), *Antiaris toxicaria* (medium) and *Ceiba pentandra* (light), using a Hydraulic Sawdust Briquette Press machine at 60 kN. Post compactions, all the briquette samples were evaluated for their fuel characteristics; and are presented in form of comparisons. To begin with, CV of these briquettes were in order of *C. gabunensis* (52.81 MJ/kg), followed *by A. toxicaria* (17.75 MJ/kg) and C. pentandra (16.02 MJ/kg); whereas, highest density was recorded for *C. gabunensis* (0.56 g/cm^3), again followed by *A. toxicaria* (0.53 g/cm^3) and *C. pentandra* (0.49 g/cm^3). Next up, other physical properties like Compressive Strength, Swelling Value (i.e., less resistance to humidity), and Shatter Index were reported in order of *C. pentandra* (305 MPa, 70.88%, 99.16%) > *A. toxicaria* (143 MPa, 60.04%, 79.71%)> *C. gabunensis* (121 MPa, 8.9%, 22.21%); with briquettes compacted from low density hardwood sawdust exhibiting higher numbers. Thus, it is can be plainly seen that briquettes developed using saw dusts from high density hardwoods displays superior fuel characteristics, along with promising storing and handling features (Antwi-Boasiako and Acheampong, 2016).

Following this, Sánchez et al., 2014 developed sawdust briquettes by following the drying and compaction, and produced briquettes with fuel properties as follows, CV: 19.8 MJ/kg, MC: 10%, bulk density: 894 kg/m3, AC: 1.3%, FC: 15.29%, and VM: 83.41%. Here, these briquettes exhibited positive results than compared to their raw materials; especially in terms of their emission level, thereby promoting a healthier environment for both the consumer and environment. Comparatively, these briquettes have similar energy potential of a sugarcane bagasse but with higher bulk density; thus recommending these solid fuels for domestic use in low-income sectors (Sánchez et al., 2014).

Furthermore, Yang et al., 2021 used Pinus radiate saw dust torrefied at 300^{o}C for 6 minutes for producing briquettes, and were compacted using a Baldwin press by maintaining the MC as 10%. Here, the torrefaction temperature was decided based on its ability to produce char with a higher HV of 22.35 MJ/kg and maximum energy recovery of 85.7% under less time period. Preliminary studies on fuel characteristics of these raw and torrefied saw dusts reported their MC, AC, and HHV as 14.7% and 2.1%, 0.71% and 0.79%, 19.74 and 22.35 MJ/kg, respectively. Post compaction, fuel characteristics of raw and torrefied saw dusts briquettes were measured as follows- density: 1.03 kg/m^3 and 1.10 kg/m^3, and higher HV: 19.26 MJ/kg and 22.35 MJ/kg, respectively. Eventually, fuel characteristics of both briquette samples were in good agreement with established standards; and were highly suitable energy based applications (Yang et al., 2021). Though this sawdust appears as wastes meant for discarding, they tend to have significant amount of calorific content which can be used in energy applications. Results from these studies are highly evident that denisifed sawdust can be used as a high energy renewable biofuel for both domestic and commercial purposes.

Wheat Straws

Moisture content (%)	8.38
Ash content (%)	9.49
Fixed carbon content (%)	8.11
Volatile matter content (%)	74.02
Calorific value (MJ/kg)	17.22
Cellulosic content (%)	34.2
Hemi-cellulosic content (%)	23.68
Lignin content (%)	13.88

Wheat (*Triticum aestivum*) is a seed yielding grass plant belonging to family under the genus triticum; and is regarded as the highly consumed staple food globally. In specific, these cereals based grains are primarily used in numerous food industries for producing wide varieties of food recipes; and is a well proclaimed source of carbohydrates, multiple nutrients and dietary fibres. Besides, wheat grains hold vital role in processed food industries owing to their unique viscoelastic and adhesive properties exhibited by their gluten; thereby increasing its global consumption besides their market value (Shewry, 2009). In view of increased consumption, the rate of cultivation of these plants and their wastes generation have also been increasing propotionally, making the disposal of latter very challenging. In fact, major portion of these wastes are constituted by their stalks, which in often are disposed during stubble burning; however, this practise increases air pollution. Considering their potential as energy feedstock based on their proximate and LC composition, this raw material can be used for producing briquettes for controlled combustion instead of open burning. Accordingly, Adapa et al., 2009 also used wheat straws for developing briquettes by using their protein and lignin as natural binders, and compacting them under a compaction apparatus, for a pressure level of 63.2 MPa (Applied load- 2000 N; compressive force- 2383 ± 50 N) accounting their minimal rate of specific energy consumption. In specific, this study used ground wheat straw with an average MC of 4% (W.B.); which was then raised to 10% (W.B.) by sprinkling calculated amount of water to it, claiming that the latter MC produced high to very high quality briquettes. Preliminary findings on these ground biomass measured their geometric mean particle diameter, bulk density and particle density as 0.398 ± 0.006 mm, 269 ± 09 kg/m^3, and 1585 ± 46 kg/m^3, respectively. Post briquetting, the mean compact density, specific energy and total specific energy were calculated as 929 ± 30 kg/m^3, 5.28 ± 0.98 MJ/t and 5.53 ± 0.98 MJ/t, respectively (Adapaa et al., 2009).

Also again, Tumuluru et al., 2015 developed compacted briquettes from raw canola straw with help of Laboratory-scale briquette press, by using its lignin content as natural binder. Again, this study also used ground straw samples, having its MC and bulk density as 9 wt.% (W.B.), and 37-58 kg/m^3, upon drying. Into their physical properties, developed briquettes reported its density (immediately after compaction) as 795.38 kg/m^3 for the die temperature of 125.47^{o}C, feedstock MC of 9.04 wt.% (W.B.), compression pressure of 10.64 MPa, and hammer milled particle size of 31.60 mm. Likewise, highest durability amidst these briquettes were noticed as 99.2% for the die temperature of 127.7^{o}C, feedstock MC of 11.81 wt.% (W.B.), compression pressure of 12.35 MPa, and hammer milled particle size of 31.56 mm. On the contrary, lowest MC was noted for these briquettes for the die temperature at 92.8^{o}C, feedstock MC of 9 wt. % (W.B.), compression pressure of 7.50 MPa, and hammer milled particle size of 31.62 mm. As concluded earlier, physical properties like density, MC and durability of these briquettes were also dependent on operating parameters like die temperature, compression pressure, and physical properties of the feedstock used (MC and particle size) (Tumuluru et al., 2015)

In another study, Smith et al., 1977 developed briquettes from wheat straw pre-heated and heated during compaction for 20 minutes, by means of a briquetting press operated at a load of 56.3 MN/m2. Post briquetting, the fuel characteristics of the compacted briquettes were evaluated, and were reported with respect to relative density and durability. To begin with, wheat straw heated at 75°C prior to compaction had its MC (during compaction as 12%, during durability test as 10.5%), relative density as 1.19 g/m^3, and durability as 90%; whereas, raw straw with MC as 15%, was heated at 21oC during compaction and presented its MC (during compaction as 15%, during durability test as 12%), relative density as 1.20 g/m^3, and durability as 81%. Next up, raw straw with MC reduced below 10%, was heated at 21°C during compaction and had its MC (during compaction as 10%, during durability test as 9%), relative density as 1.13 g/m^3, and durability as 73%. Lastly, completely dried wheat straws were heated at 21°C and 120°C during compaction, and yielded their relative density as 0.80 g/cm^3 and 0.70 g/m^3, respectively; with zero MC and durability. This study concluded that presence of MC, until its threshold value helped in developing briquettes with high durability; whereas briquettes with low MC yielded very low durability (Smith et al., 1977).

Water Hyacinth Wastes

Moisture content (%)	5.7-6.35
Ash content (%)	13.21-38.11
Fixed carbon content (%)	6.28-16.02
Volatile matter content (%)	49.9-64.38
Calorific value (MJ/kg)	13.39-14.4
Cellulosic content (%)	24
Hemi-cellulosic content (%)	30
Lignin content (%)	16

Water hyacinth (*Pontederia crassipes*; formerly *Eichhornia crassipes*) is an aquatic plant belonging to family Pontederiaceae under genus Eichhornia; with amazon basins as its nativity; and is regarded as the most chaotic invasive plant species in the world. Having their habitat ranging from desert regions to rain forests, these aquatic plants have highly buyout leaves connected to its long, spongy and bulbous stalks with their flowers at the top of their stalks and free floating roots at the bottom (Penfound and Earle, 1948). Being regarded as the highly invasive plant, they are often removed from the water bodies to restore its oxygen levels; and cause various challenges in disposing it. However, looking into their proximate and LC composition, it can be concluded they have sufficient calorific and lignin content fairly enough for producing high quality briquettes. Rezania et al., 2016 *used* water hyacinth (WH) as raw feedstock with empty fruit bunch (EFB) fibres as additive to develop composite briquettes with help of a briquetting press, using cassava starch as a binder. Here, the most optimal mixing ratio was decided as 25:75 (WH:EFB); and were evaluated for fuel characteristics post briquetting. Accordingly, the proximate composition of the developed WH-EFB composite briquettes were calculated as follows: MC- 9.3%, FC- 15.97%, AC- 3.73%, VM- 70.87%, and

CV- 17.17 MJ/Kg. Explaining this, increase in concentration of WH increased the MC, AC and FC content, and decreased VM and CV of the resultant briquettes. Likewise, emission concentration of WH-EFB composite briquettes were measured as O_2- 20.60%, CO- 25.67 ± 1.45 ppm, CO_2- 0.23 ± 0.33 ppm, NO- 13 ± 2 ppm, NO_2- 0.33 ± 0.33 ppm, SO_2- 28.67 ± 6.33 ppm; claiming that increase in WH concentration resulted in decreased O_2 and CO level, and increased CO_2 and NO, NO_2 and SO_2 levels. In conclusion, both water hyacinth and empty fruit bunch fibres were proposed as high potential feedstocks that can be valorised into solid fuels (Rezania et al., 2016).

Furthuremore, Carnaje et al., 2018 used water hyacinth char carbonised at 425°C, for producing briquette with molasses (optimal dosage-80%) as binder, using a briquette moulding machine operated at 8.27 bar. Post briquetting, these compacted fuels were oven dried at 105°C for 8 hours; and were evaluated for their fuel properties. Accordingly, 20:80 was decided as the most optimum mixing ratio; and its corresponding briquettes reported their proximate composition as 16.8 ± 0.8%, 48 ± 2.2%, 18.6 ± 0.2%, and 16.5 ± 2.3% of FC, VM, MC and AC, respectively. Besides, the fuel characteristics of these briquettes were calculated as follows: CV - 13.45 ± 1.6 MJ/kg, Bulk density- 0.85 ± 0.02 g/cm^3, compressive strength- 7.4 ± 0.4 kg/cm^2, burning rate- 0.007 ± 0.002 g/s, ignition time- 198 ± 8 seconds. For other mixing ratios (40:60 and 30:70), it was noted that volatile combustible matter and FC increased, while AC decreased with increasing binder concentration; thus claiming that variation in molasses to charcoal ratio had adverse effect on quality and characteristics of the briquettes. Overall, the results have shown positive significance of considering these water hyacinths as potential source for alternative fuels, which also helps in reducing the environmental problems caused by these invasive weeds in water bodies (Carnaje et al., 2018).

Conclusion

Thus, the comprehensive study on understanding the potential of organic biomass feedstocks for developing high quality renewable solid briquettes, have been carried out successfully; and have been presented as a detailed review. Following are the major conclusions drawn from this all-inclusive study, and are as follows:

(i) Any biomass with significant amount of fixed carbon (7.56-55.59%) and volatile matter (27-81.2%) can be used as raw feedstock for producing high quality briquettes; and tend to exhibit similar fuel characteristics as that of fossil coal.

(ii) And, biomass compacted into briquettes under high pressure and temperature, report superior fuel characteristics like significant energy density and good mechanical properties. Yet, these pressure and temperature are dependent on the physical entities like particle grain size, moisture content of mixture dough, binder material and the briquette geometry.

(iii) Besides pressure and temperature, binders contribute significantly during the biomass briquetting; and helps in establishing adhesion between the biomass particles. Amidst different binder materials, lignin content from the biomass is seen as the most effective binder; and helps introducing high mechanical strength to these briquettes, besides contributing to their calorific value. And, biomass with medium to high lignin content can be used for briquetting without any external binders; however, this may require high compaction pressure and temperature. Moreover, dosage and concentration of these external binders are decided based on the nature of biomass used, and their applications.

(iv) Predominantly, any briquette is accounted as high quality fuel depending on its calorific value, which in turn is contributed by the biomass used in its compaction. In specific, they are contributed predominately by its lignocellulosic compounds, especially by its cellulose and lignin content. Since, lignin in biomass contributes to the major share to this calorific value, use of untreated biomass is highly recommended for briquetting as any pre-treated biomass yields reduced lignin content. However, high concentration of lignin might lead to increased ash content, which in turn reduces this calorific value; hence, biomass with good calorific content and adequate lignin content is highly recommended.

(v) From their fuel properties, average density was measured in between (700-1100 kg/m3), compressive strength calculated in between (6-20 N/mm2), and ash content between (1-20%); which were in good agreement with permissible standards for commercial solid fuels. With these superior fuel characteristics, these briquettes and also, pellets can be simply seen as a viable fuel source for industrial and commercial applications, and as an effective alternative for solid fossil coals.

Fairly evident, any briquette with good fuel quality is attributed by its superior fuel characteristics, which are entirely contributed by its raw biomass feedstock. Thus, having a good understanding on these technical aspects enables one to choose the most efficient biomass for producing briquettes, focused exclusively for a particular application along with desired results. Upon bringing this into a common practise, this allows many industrial and energy production sectors to produce necessary amount of energy under controlled emission levels, beside serving as an effective means of disposing abundantly available waste biomass; thereby paving a way for sustainable development.

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