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Original Article

Chemical Properties of Briquettes from Forest Woody Biomass in Kurdistan Region of Iraq

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ABSTRACT

The chemical characteristics of briquettes made in Duhok Province from various forest-woody sources of biomass are examined in this study. Briquetting is a practical technique for turning forest leftovers into effective biofuels, and energy produced from biomass is a sustainable substitute for fossil fuels. The study looks at how briquette quality is affected by species kind, moisture content, size of particles, and pyrolysis temperature. Under various conditions (ranges of moisture content of 6%, 9%, and 12%; sizes of particles of 2 mm and 4 mm; and temperatures of pyrolysis of 330°C and 350°C), two species—*Quercus infectoria* and *Pinus brutia*—were examined. This study evaluated key characteristics such as moisture content percentage, volatile matter percentage, ash content percentage, fixed carbon percentage, and calorific value MJ/kg. The results show that the briquettes of *Quercus infectoria* with particle size of 2 mm, moisture content of 6%, and pyrolysis temperature of 350°C had higher fixed carbon, higher calorific value, and lower moisture and ash content, making them an excellent fuel source. On the other hand, *Pinus brutia* briquettes used less energy because they retained more moisture and volatile materials. The results emphasize how crucial it is to optimize biomass selection as well as processing parameters to improve fuel efficiency and sustainability. This study advances the utilization of biomass techniques for the generation of renewable energy.

Keywords: Briquettes, Renewable Energy, Forest, Woody Biomass and Chemical properties.

1 Introduction

Forests used as a source of energy are becoming generally accepted as a sustainable alternative to fossil fuels. Among the conversion technologies that turn forest waste into a high-energy-density fuel source, briquetting seems to be the most promising. Briquettes, compressed biomass material, can reduce greenhouse gas emissions, promote sustainable forest management, reduce waste generation, and enhance handling, storage, and transportation. Hence, they can be used in either a domestic or commercial setting [1-4].

Branches, bark, sawdust, and so forth are commonly underused and, when poorly managed, may impose environmental problems. There is an urgent need to harvest forest woody biomass sustainably-with little or no environmental repercussions. However, most of these wastes are either burnt or left to decompose, thus becoming poorly managed and unsustainably utilized and creating an environmental threat and pollution. Still, investigations confirm that these wastes have great potential energy [4,5].

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Two tree species have been studied for the manufacture of biomass briquettes, namely *Quercus infectoria* & *Pinus brutia*. Solid wood of Quercus infectoria, called Aleppo oak, is valued for producing high-quality charcoal. The tannin-rich galls of the tree can also be used as a binder in producing briquettes. For its resinous content that combusts well and generates substantial heat, *Pinus brutia*-the Latin name for the Turkish pine-is yet another species demonstrating promise for charcoal manufacture. Due to their availability in the Mediterranean region, both species might become renewable sources of biomass for the making of charcoal briquettes [6-8].

There have been numerous studies on how moisture content, particle size, and pyrolysis temperature affect the performance and quality of biomass briquettes. Moisture content significantly influences briquette stability and combustion efficiency, with ideal moisture content ranging between 6 and 12% to facilitate bonding and release the energy content of briquettes [9].

Particle size influences briquettes' mechanical strength and density, where compactness and combustibility of finer particles are enhanced, while too fine a particle size may inhibit air permeability for burning. Pyrolysis temperature is paramount in influencing the calorific value and fixed carbon content; temperatures above 300 °C favor carbonization and energy generation but might, at the same time, compromise internal strength [10]. The interplay of these factors influences the overall performance of biomass briquettes and is therefore of utmost importance for optimization in sustainable energy applications [11].

Briquettes from forest woody biomass are produced by many processes, namely biomass disposal, preparation, densification and post-processing. Much with respect to the quality and characteristics of the end briquettes is influenced by selecting the biomass feedstock and its processing methods [12,13]. Binder-less briquetting is defined as compaction of loose biomass sources to densified solid fuels without the use of external binders [14].

Briquette characterization involves analyzing their chemical and combustion characteristics to determine whether they would be fit for certain applications. Some of the key parameters which are usually characterized for determining quality and performance of briquettes are calorific value, moisture content, volatile matter, ash content, and fixed carbon. These characteristics allow for an optimization of the production methods and also ensure consistent quality products [15,16].

This study aims to evaluate the fixed carbon, ash, and volatile matter differences of commonly selected species for better burning and calorific value; evaluate the quality of biomass briquettes made from selected species; compare the selected species to determine which species is of best quality; assist charcoal production companies in identifying the superior species in their products plus encourage setting up a laboratory for testing wood briquettes before they enter the market and the sellers where every quality has a different price; to ease the process for buyers in classifying the high-quality briquette.

2 Materials and Methods

2.1 Raw Material Collection and Sample Production Process

The biomass was used in this study which was available in Zawita and Hojava in Duhok province, (forest residues of Hardwood and Softwood trees: sawdust - branches - twigs). The production process involved optimizing factors such as raw material (wood chips types) from (*Quercus infectoria* and *Pinus brutia*), moisture content (6, 9 and 12) %, particle size (2 and 4) mm, and temperature of briquetting machine (330 and 350) °C, without any binder agents to achieve briquettes with desirable physical properties. The production of briquette was done at the bery-mazi factory in kashi- sub district- industrial area in Duhok by the extrusion process through the use of screw press briquetting machine (model – ZZXM-4) and compact drum chipper (model – INTIMIDATOR 15XPC).

2.2 Sample Preparation for Testing

The important thermal properties of briquettes include calorific value, moisture content, volatile matter, ash content, fixed carbon [17]. All wood-briquettes specimen were collected in bags of polyethylene and thereafter taken to laboratory where the sample tests were prepared, milled, particles that passed through a No. 20 (850-µm) sieve and stayed on a No. 100 (150-µm) sieve were seized, and stored in air tight plastic bags before taking for analysis of combustion and fuel-related parameters [18].

2.2.1 Moisture Content

The oven-dry method was utilized to induce the biomass's moisture content. The specimen with the known weight was first placed in an oven (brand: Gemmy Industrial Corp. / model: YCO-N01) set to 105 ºC for an hour. The oven-dried sample was then weighed in accordance with [19]. The following formula was used to determine the sample's moisture content:

$$M.C\ (\%wb) = \frac{W2-W3}{W2-W1} \times 100 \quad (1)$$

Where W1 = Weight of empty crucible, g

W2 = weight of crucible + sample, g

W3 = weight of crucible + sample, after drying, g

2.2.2 Volatile Matter

The crucible's dry sample was sealed with a lid and kept in a muffle furnace (brand: Carbolite - model: ELF 11/14B) for ten minutes at 950 ± 20 ºC [20]. After cooling in air and then inside the desiccator, the crucible was weighed once again. Weight loss was reported on a percentage basis as volatile matter.

$$\text{Volatile Matter } \% = \frac{W4-W3}{W2-W1} \times 100 \quad (2)$$

Where W1= weight of empty crucible, g

W2 = weight of crucible + sample taken

W3= weight of crucible + sample from stage (I), g

W4 = weight of crucible + weight of after heating in muffle furnace, g

2.2.3 Ash Content

The residual sample in the crucible was heated with lid in a muffle furnace at 700 ± 50 ºC for 2 hours [21]. The crucible was then taken out, then cooled in the desiccator and weighed. The residue was reported as ash on percentage basis.

$$\text{Percentage of Ash Content} = \frac{W5-W1}{W2-W1} \times 100 \quad (3)$$

Where W1= weight of empty crucible, g

W2 = weight of crucible + sample taken from stage (II),

W5 = weight of crucible + ash left in crucible, g

2.2.4 Fixed Carbon

The residue remaining after volatile matter release has been expelled, contains the fixed carbon. The fixed carbon was thus calculated as follows [22].

$$\text{Fixed Carbon } (\%) = [\,100 - \%\,M.C + \%\,V.M + \%\,A.C\,] \quad (4)$$

Where M.C = Moisture Content

V.M = Volatile Matter

A.C = Ash Content

2.3 Calorific Value

The higher heating value of material was determined by using of bomb calorimeter (model: IKA - C2000). Where the combustion as carried out in environment with 25 atmospheric pressure of oxygen to ensure complete combustion. Water equivalent of the apparatus was determined by burning a known weight about (1gm) in the bomb calorimeter [22]. The higher heating value of solid fuel using the bomb calorimeter experiment was determined as:

$$\text{Calorific value (MJ/ kg)} = \frac{(W+w)\times(T1-T2)}{x} \times 10 \quad (5)$$

Where W = weight of water in calorimeter (kg),

w = water equivalent of apparatus,

T1 = initial temperature of water (o C),

T2 = final temperature of water,

X = weight of fuel sample taken (kg).

3 Results and Discussions

3.1 Chemical (Proximate) Properties

3.1.1 Moisture Content (MC)

From the results presented in (Table 1), species, particle size, raw material moisture content, and briquette temperature were revealed to be the major parameters influencing moisture content, with a 5% significance level. The briquettes made from *Quercus infectoria* shown in (Figure 1), which had 2 mm particle size and was subjected to 350 °C with 6% moisture content, showed MC of 3.08%. Results indicate that higher particle size leads to higher moisture retention, and *Pinus brutia* retains more moisture than *Quercus infectoria*. The samples with high moisture content lose water slowly, whereas those with high temperature lose moisture rapidly. This corresponds to the previous research results on thermal properties and drying of biomass [23,24].

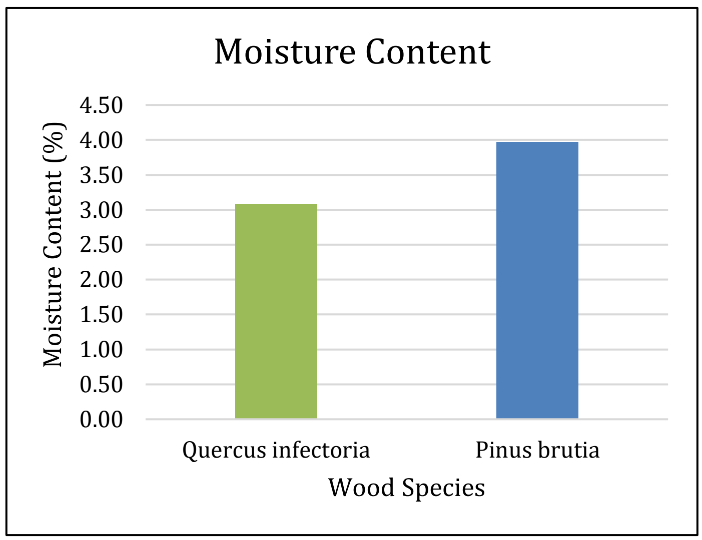

Figure 1: Effect of wood species on Moisture Content.

Table 1: Effect of studied factors on the Moisture Content of the produced Biomass Briquettes.

Moisture Content (%)									
Species	Particle size	Moisture content	Temperature 330 °C	Temperature 350 °C	Species * Particle size	Species * Moisture content	Particle size * Moisture content	Species * Particle size * Moisture Content	Species
Quercus infectoria	2 mm	6%	2.00 i	1.00 j	2.67 c	2.00 d	2.00 d	1.50 f	3.08 b
		9%	3.00 h	2.33 i				2.67 e	

		12%	4.33 de	3.33 hg		3.08 c	3.08 c	3.83 c	
	4 mm	6%	3.00 h	2.00 i	3.50 b			2.50 e	
		9%	3.00 h	4.00 fe		4.17 b	4.25 b	3.50 dc	
		12%	4.33 de	4.67 dc				4.50 b	
Pinus brutia	2 mm	6%	3.00 h	2.00 i	3.56 b	2.92 c	2.92 c	2.50 e	3.97 a
		9%	4.00 fe	3.00 h				3.50 dc	
		12%	5.33 ba	4.00 fe		4.00 b	4.00 b	4.67 b	
	4 mm	6%	3.67 fg	3.00 h	4.39 a			3.33 d	
		9%	5.00 bc	4.00 fe		5.00 a	4.92 a	4.50 b	
		12%	5.67 a	5.00 bc				5.33 a	
Temperature			3.86 a	3.19 b	Particle size		Moisture content		
Species * Temperature		Quercus Infectoria	3.28 b	2.89 c					
		Pinus Brutia	4.44 a	3.50 b					
Particle size * Temperature		2 mm	3.61 b	2.61 c	2 mm	3.11 b	6%	2.46 c	
		4 mm	4.11 a	3.78 b	4 mm	3.94 a	9%	3.54 b	
Moisture content * Temperature		6%	2.92 e	2.00 f			12%	4.58 a	
		9%	3.75 c	3.33 d					
		12%	4.92 a	4.25 b					

3.1.2 Volatile Matter (VM)

The volatile matter was also significantly (5 %) affected by the four-factor combinations. Further Duncan's test (Table 2) evidenced that lowest values belong to *Quercus infectoria* species, 2 mm particle size, moisture 6 %, and briquetting temperature 350 °C. The present study has found out briquetting species to have strong (5 %) influence on VM (Table 2). Relative resistance to VM of panels made from *Quercus infectoria* was higher (60.67%) compared to panels made from *Pinus brutia*, which were recorded with highest VM value (62.03%) (Figure 2). The results were consistent with findings by [25,26], stating the softwood species negatively affected the briquettes' volatile matter characteristics due to resinous content.

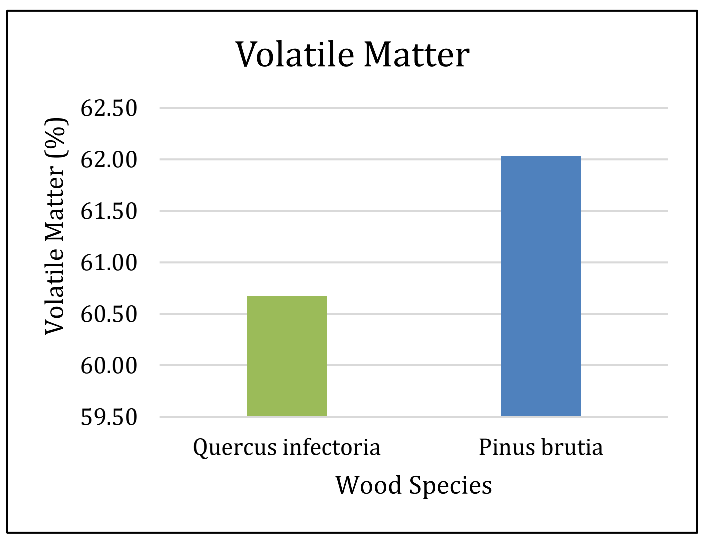

Figure 2: Effect of wood species on Volatile matter.

Table 2: Effect of studied factors on the Volatile Matter of the produced Biomass Briquettes.

Volatile Matter (%)									
Species	Particle size	Moisture content	Temperature 330 °C	Temperature 350 °C	Species * Particle size	Species * Moisture content	Particle size * Moisture content	Species * Particle size * Moisture Content	Species

Quercus infectoria	2 mm	6%	59.00 h	58.00 i	59.83 c	59.00 f	59.00 f	58.50 h	60.67 b
		9%	60.00 g	59.00 h				59.50 g	
		12%	62.00 d	61.00 f		60.50 d	60.58 d	61.50 e	
	4 mm	6%	60.00 g	59.00 h	61.50 b			59.50 g	
		9%	62.00 d	61.00 f		62.50 b	62.50 b	61.50 e	
		12%	64.00 b	63.00 c				63.50 b	
Pinus brutia	2 mm	6%	60.00 g	59.00 h	61.56 b	60.00 e	60.00 e	59.50 g	62.03 a
		9%	62.00 d	61.33 e				61.67 d	
		12%	64.00 b	63.00 c		62.08 c	62.00 c	63.50 b	
	4 mm	6%	61.00 f	60.00 g	62.50 a			60.50 f	
		9%	63.00 c	62.00 d		64.00 a	64.00 a	62.50 c	
		12%	65.00 a	64.00 b				64.50 a	
Temperature			61.83 a	60.86 b					
Species * Temperature		Quercus Infectoria	61.17 c	60.17 d	Particle size		Moisture content		
		Pinus Brutia	62.50 a	61.56 b					
Particle size * Temperature		2 mm	61.17 c	60.22 d	2 mm	60.69 b	6%	59.50 c	
		4 mm	62.50 a	61.50 b	4 mm	62.00 a	9%	61.29 b	
Moisture content * Temperature		6%	60.00 e	59.00 f			12%	63.25 a	
		9%	61.75 c	60.83 d					
		12%	63.75 a	62.75 b					

3.1.3 Ash Content (AC)

According to the findings, factors four, including combinations of two and three that have influenced the ash content percentage significantly at 5% (Table 3). Highest AC in briquettes of *Pinus brutia* species (4.89%) (Figure 3) was found; highest AC (5.54%) was found in briquettes made at moisture content of 12%; and the best one with lowest was (2.00%) with the combination of the four major factors observed in all briquettes made from Quercus infectoria with 2 mm particle size, 6% moisture content and 350 °C. This was confirmed by earlier literature [27,28] on the influence of biomass characteristics on combustion characteristics.

3.1.4 Fixed Carbon (FC)

The factor combinations of the four have greatly influenced (5 %) the dependent variable, which was AC (Table 4). Maximum 39.00 % was found in most others in the briquettes of *Quercus infectoria* species (Figure 4), particle size (2 mm), (6 %) moisture content and temperature (350 °C). This correlates with other studies which state that hardwood species tend to have a higher fixed carbon due to their highest lignin content [29]. This also backs research which states that smaller particles help better heat transfer, hence uniform carbonization [30]. Higher moisture will require much more energy for evaporation thus lowering carbonization efficiency [31]. Again, it agrees to the view that higher temperature promotes thermal degradation with retention of fixed carbon [32]. Whereas a relevant study [33] states that, with decrease in moisture content, volatile matter, and ash contents there is increase in fixed carbon which promotes calorific value and combustion efficiency of briquettes..

Table 3: Effect of studied factors on the Ash Content of the produced Biomass Briquettes.

Ash Content (%)									
Species	Particle size	Moisture content	Temperature 330 °C	Temperature 350 °C	Species * Particle size	Species * Moisture content	Particle size * Moisture content	Species * Particle size * Moisture Content	Species

Quercus infectoria	2 mm	6%	3.00 f	2.00 g	3.72 c	3.00 e	3.00 d	2.50 e	4.14 b
		9%	4.00 e	3.00 f				3.50 d	
		12%	5.67 b	4.67 dc		4.08 d	4.00 c	5.17 b	
	4 mm	6%	4.00 e	3.00 f	4.56 b			3.50 d	
		9%	5.00 c	4.33 de		5.33 b	5.25 b	4.67 c	
		12%	6.00 b	5.00 c				5.50 b	
Pinus brutia	2 mm	6%	4.00 e	3.00 f	4.44 b	4.00 d	4.00 c	3.50 d	4.89 a
		9%	5.00 c	4.00 e				4.50 c	
		12%	5.67 b	5.00 c		4.92 c	5.00 b	5.33 b	
	4 mm	6%	5.00 c	4.00 e	5.33 a			4.50 c	
		9%	6.00 b	4.67 dc		5.75 a	5.83 a	5.33 b	
		12%	6.67 a	5.67 b				6.17 a	
Temperature			5.00 a	4.03 b	Particle size		Moisture content		
Species * Temperature		Quercus Infectoria	4.61 b	3.67 d					
		Pinus Brutia	5.39 a	4.39 c					
Particle size * Temperature		2 mm	4.56 b	3.61 c	2 mm	4.08 b	6%	3.50 c	
		4 mm	5.44 a	4.44 b	4 mm	4.94 a	9%	4.50 b	
Moisture content * Temperature		6%	4.00 c	3.00 d			12%	5.54 a	
		9%	5.00 b	4.00 c					
		12%	6.00 a	5.08 b					

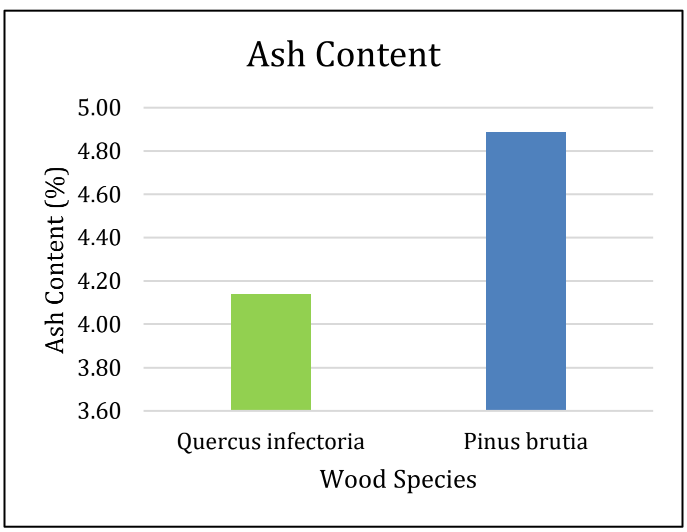

Figure 3: Effect of wood species on Ash Content.

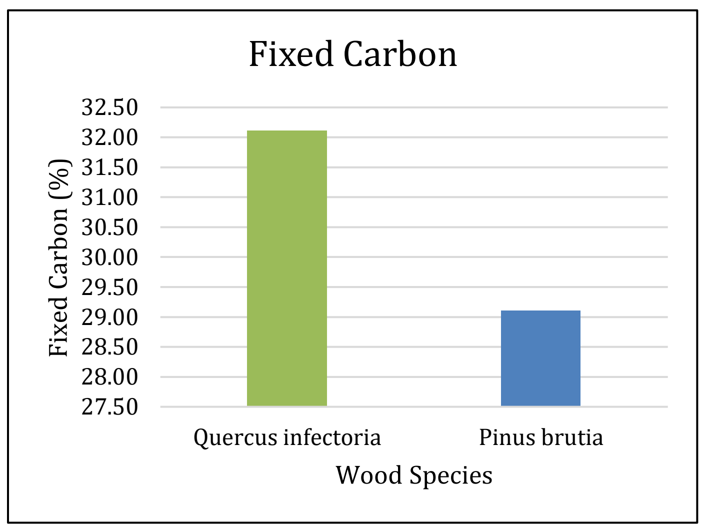

Figure 4: Effect of wood species on Fixed Carbon.

Table 4: Effect of studied factors on the Fixed Carbon of the produced Biomass Briquettes.

Fixed Carbon (%)									
Species	Particle size	Moisture content	Temperature 330 ℃	Temperature 350 ℃	Species * Particle size	Species * Moisture content	Particle size * Moisture content	Species * Particle size * Moisture Content	Species

Quercus infectoria	2 mm	6%	36.00 b	39.00 a	33.78 a	36.00 a	36.00 a	37.50 a	32.11 a
		9%	33.00 c	35.67 b				34.33 b	
		12%	28.00 i	31.00 ed		32.33 c	32.33 c	29.50 e	
	4 mm	6%	33.00 c	36.00 b	30.44 b			34.50 b	
		9%	30.00 gf	30.67 ef		28.00 e	28.00 e	30.33 d	
		12%	25.67 kj	27.33 i				26.50 g	
Pinus brutia	2 mm	6%	33.00 c	36.00 b	30.44 b	33.08 b	33.08 b	34.50 b	29.11 b
		9%	29.00 h	31.67 d				30.33 d	
		12%	25.00 k	28.00 i		29.00 d	29.00 d	26.50 g	
	4 mm	6%	30.33 ef	33.00 c	27.78 c			31.67 c	
		9%	26.00 j	29.33 gh		25.25 f	25.25 f	27.67 f	
		12%	22.67 l	25.33 kj				24.00 h	
Temperature			29.31 b	31.92 a	Particle size		Moisture content		
Species * Temperature		Quercus Infectoria	30.94 b	33.28 a					
		Pinus Brutia	27.67 d	30.56 c					
Particle size * Temperature		2 mm	30.67 b	33.56 a	2 mm	32.11 a	6%	34.54 a	
		4 mm	27.94 d	30.28 c	4 mm	29.11 b	9%	30.67 b	
Moisture content * Temperature		6%	33.08 b	36.00 a			12%	26.62 c	
		9%	29.50 d	31.83 c					
		12%	25.33 f	27.92 e					

3.2 Calorific (Heating) Value

The combination effects of the four factors on FC showed that (5 %) significantly affected the percent AC (Table 5). *Quercus infectoria* consistently showed higher calorific values (19.11 MJ/kg) than *Pinus brutia* (17.16 MJ/kg) (Figure 5), confirming better energy potential. Having smaller particle size (2 mm) slightly raises calorific value (18.19 MJ/g) over 4 mm (17.95 MJ/kg), possibly due to better combustion efficiency [34]. Higher moisture content decreases calorific value, while low values were noted at 12% moisture. This concurs with studies that observe higher moisture contents as contributors to energy loss during combustion [35]. Higher combustion temperature (350°C) slightly increased calorific value to prove that enhanced thermal decomposition favors energy yielded [36].

Table 5: Effect of studied factors on the Calorific Value of the produced Biomass Briquettes.

Calorific Value (MJ/kg)									
Species	Particle size	Moisture content	Temperature 330 ℃	Temperature 350 ℃	Species * Particle size	Species * Moisture content	Particle size * Moisture content	Species * Particle size * Moisture Content	Species
Quercus infectoria	2 mm	6%	19.36 c	19.66 a	19.11 a	19.42 a	18.75 a	19.51 a	18.98 a
		9%	19.02 e	19.23 d				19.12 c	
		12%	18.55 h	18.86 f		18.99 b	18.16 c	18.70 e	
	4 mm	6%	19.24 d	19.44 b	18.85 b			19.34 b	
		9%	18.68 g	19.04 e		18.52 c	17.67 e	18.86 d	

		12%	18.21 j	18.48 i				18.34 f	
Pinus brutia	2 mm	6%	17.97 l	18.02 k	17.28 c	17.87 d	18.54 b	18.00 g	17.16 b
		9%	17.09 p	17.29 o				17.19 i	
		12%	16.50 s	16.79 r		17.15 e	17.99 d	16.64 k	
	4 mm	6%	17.57 n	17.92 m	17.04 d			17.74 h	
		9%	16.98 q	17.26 o		16.46 f	17.31 f	17.12 j	
		12%	16.11 u	16.44 t				16.28 l	
Temperature			17.94 b	18.20 a					
Species * Temperature		Quercus Infectoria	18.84 b	19.12 a	Particle size		Moisture content		
		Pinus Brutia	17.03 d	17.29 c					
Particle size * Temperature		2 mm	18.08 c	18.31 a	2 mm	18.19 a	6%	18.65 a	
		4 mm	17.80 d	18.10 b	4 mm	17.95 b	9%	18.07 b	
Moisture content * Temperature		6%	18.53 b	18.76 a			12%	17.49 c	
		9%	17.94 d	18.20 c					
		12%	17.34 f	17.64 e					

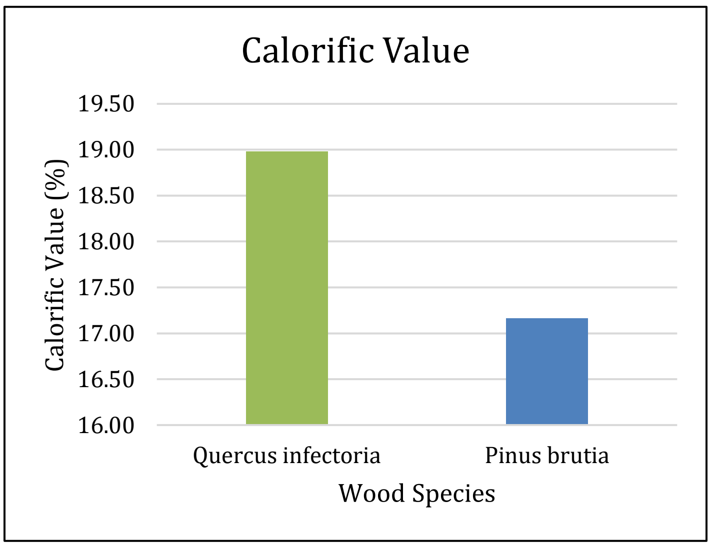

Figure 5: Effect of wood species on Calorific Value.

Conclusion

The study, therefore, confirms that biomass of *Quercus infectoria* species is more efficient for biomass briquette production as opposed to *Pinus brutia* on account of its higher fixed carbon content and calorific value. The results accentuate the importance of particle size (2 mm), moisture content (6%), and pyrolysis temperature (350 °C) in determining briquette quality. Lower levels of moisture and ash contents increase combustion efficiencies, while higher fixed carbon contents improve energy yields. This research will greatly assist biomass briquette manufacturers in their choice of the best raw materials and conditions to manufacture briquettes. The other purpose this research will serve in is to contribute to the eventual development of sustainable energy alternatives that help to reduce reliance on fossil fuel whilst minimizing environmental degradation.

Conflict of Interests

None.

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