Available online at sjuoz.uoz.edu.krd
journals.uoz.edu.krd
Science Journal of University of Zakho
Vol. 13, No.3 pp426–434July-September,2025
p-ISSN: 2663-628X
e-ISSN: 2663-6298

STUDY OF SOME PHYSICAL PROPERTIES OF BRIQUETTES FROM DIFFERENT FOREST WOODY BIOMASS COLLECTIONS IN KURDISTAN REGION OF IRAQ

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Received: 19 Mar 2025 Accepted:15 May 2025 Published:7 Jul 2025 https://doi.org/10.25271/sjuoz.2025.13.3.1515

ABSTRACT:

By using forest waste, energy sustainability can be improved, and biomass briquettes offer a sustainable and eco-friendly substitute for fossil fuels. This study examines the physical characteristics of briquettes made from various woody biomass species, as a result of assessing factors including the amount of moisture, density, shatter resistance, tumble resistance, and resistance to water penetration. Also, to identify ideal production circumstances, in both tree species (*Quercus infectoria* and *Pinus brutia*). Factors were particle size (2 and 4 mm), moisture levels (6, 9, and 12%), and briquetting temperature (330 and 350 °C). According to the results, *Quercus infectoria* briquettes processed at 350 °C, with particle sizes of 2 mm and moisture levels of 6%, showed enhanced physical characteristics and combustion efficiency. Longer burning times were caused by higher compactness, and storage stability was improved by resistance to water penetration. These results offer insightful information for the biofuel sector, assisting producers in improving their methods of production to produce premium, environmentally friendly biomass briquettes. The study advances the larger objective of lowering reliance on energy sources that are not renewable and advancing sustainable energy solutions by enhancing the durability and efficiency of biomass fuels. The findings support more investigation into improving biomass briquetting procedures for increasing environmental and financial advantages.

KEYWORDS*:* Forest Woody Biomass, Briquettes, Physical Properties, Density, Water, And Tumbling Resistance

1. INTRODUCTION

With enormous potential for energy production, biomass has become an energy source that is both renewable and sustainable. Utilizing forest wastes, such as sawdust, branches and twigs, provides an eco-friendly way to manage waste and produce bioenergy. The selection of raw materials, moisture level, size of particle, and briquetting temperature are the main elements affecting the manufacture of biomass briquettes, they are the topic of this review. Sawdust, branches, and twigs are examples of forest leftovers that are readily available and can be effectively used to produce bioenergy. One proven method for turning these leftovers into compact, high-energy-density fuel is biomass briquetting. The main benefits of employing biomass briquettes are their capacity to improve waste management procedures, lower carbon emissions, and replace fossil fuels (Demirbas, 2001; Kaliyan & Morey, 2009).

The physical combustion characteristics of biomass briquettes are greatly influenced by the choice of raw ingredients. The oak species (*Quercus infectoria spp*). and the pine species (*Pinus brutia spp*) are taken into consideration in this study. The high lignin concentration of *Quercus infectoria* is well-known for improving durability and briquette binding (Sokhansanj *et al*., 2005; Shahbaz *et al*., 2015). Due to its good calorific value and combustion characteristics, *Pinus brutia* is commonly available in Mediterranean regions (Garcia *et al*., 2014; Ismail, S. M., & Ahmed, S. M., 2023).

The performance and quality of briquetting are significantly influenced by the moisture content. According to studies, compaction and mechanical qualities are enhanced by an ideal moisture range of (6–12) % (Grover & Mishra, 1996). Levels of moisture: 6% moisture: Creates strong, high-density briquettes. However, processing can require more energy. 9% moisture: Offers the best possible balance between energy use and compaction efficiency. 12% moisture: Could cause too much steam to develop, which would weaken the briquettes and make them more prone to cracking (Mani *et al*., 2006).

The density, resilience, and combustion characteristics of biomass briquettes are influenced by the distribution of particle sizes. The (2 and 4) mm particle sizes used for this investigation are based on earlier research findings: Better compaction, higher density, and enhanced combustion efficiency are guaranteed with 2 mm particles (Tumuluru *et al*., 2011). 4 mm particles: Increase briquette airflow, which speeds up ignition and burning, but they may also weaken the briquette's mechanical integrity (Pérez *et al*., 2019).

On the other hand, the briquetting temperature is another important factor, which is influencing the mechanical characteristics and combustion efficiency of biomass briquettes.

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Research shows that briquettes made at temperatures ranging from 330°C to 350°C, are robust and long-lasting (Arias *et al*., 2008): A sufficient amount of lignin activation is provided for binding at 330°C, resulting in moderate strength and stability. 350°C: Promotes thermal breakdown and increases the durability of briquettes, but it may also cause excessive volatile loss and reduce combustion efficiency.

Briquette performance depends heavily on physical characteristics such as density, moisture content, tumbling resistance, water penetration resistance, and shatter resistance. Greater density guarantees longer combustion times and improved energy efficiency. Ineffective burning may result from air pockets caused by porosity, which is minimized by proper compaction (Sokhansanj *et al*., 2005).

The aim of this study was to assist charcoal producers in determining which species have the highest quality and may also cause to ensure the correct way of biomass briquettes quality before sending them to the market and sellers. Additionally, it was to study of some physical properties such as the percentages of moisture content, density, tumbling resistance, resistance to water penetration, and shatter resistance of commonly selected species that are responsible for better burning and calorific value. Finally, the study will help buyers and consumers choose high-quality wood charcoal with ease.

2. MATERIAL AND METHODS

Raw Material Collection & Sample Preparation:

The biomass used in this study 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 the temperature of the briquetting machine (330°C and 350°C), without any binder agents to achieve briquettes with desirable physical properties. The production of the briquette was done at the bery-mazi factory in kashi- sub district-industrial area by the extrusion process through the use of a screw press briquetting machine (model – ZZXM-4) and compact drum chipper (model – INTIMIDATOR 15XPC).

Physical Properties of Biomass Briquette:

The physical characteristics of biomass charcoal briquettes were assessed, including their density, overall length and diameter, moisture content, resistance to water penetration, shattering, and tumbling. A scale and a vernier caliper were used to measure the briquettes' total length and diameter.

Moisture Content:

The oven-dry method was used to determine the biomass's moisture content. The specimen with the estimated weight was first stored for 24 hours at 105 ºC in the oven. The sample was then dried in the oven and weighed (ASTM D3173-03. 2003). The following formula was used to determine the sample's moisture content:

M.C. (%) = $\frac{W1-W2}{W1}$ *100 (1)

where: MC = Moisture content (%)

W1 = Initial weight of the sample before drying (g)

W2 = Final weight of the sample after drying (g)

Density:

The volume of each individual briquette was measured using the water displacement method. Wax was applied to the briquettes to stop any water from being absorbed during the merging process. After being weighed, each briquette was covered with wax. After weighing the wax-coated briquettes, they were suspended in water, and the weight of the water that was displaced was calculated and recorded as the wax briquettes' volume (Birwatkar et al. 2014).

Volume of sample =Volume of waxed sample–Volume of wax (2)

Sample. of Volume = $\frac{W3-W2}{V}$ (3)

Where, V = Volume of the water displaced

W2 = Weight of sample + string, g

W3 = Weight of waxed sample + string, g

Tumbling Resistance:

Briquetted fuel's durability was assessed using this test. The test was conducted using a metal boox. A known-weight briquette sample was placed inside the box and sealed with a lid. For fifteen minutes, the package was shaken vigorously. The briquettes' weight loss was then recorded, and the following equation was used to determine the tumbling resistance (Tayade *et al.*, 2010).

Percent weight loss (%) = $\frac{W1-W2}{W1}$ *100 (4)

Tumbling resistance (%) =100 - Percent weight loss (5)

Where, W1 = Weight of briquette before tumbling, gm

W2 = Weight of briquette after tumbling, gm

Resistance to Water Penetration:

It measures the proportion of water that a briquette absorbs while submerged in water. For 30 seconds, each briquette was submerged in a 150 mm water column at 27°C. The following formula was used to determine and record the % water gain (Khalil, H. P. S. A., & Sulaiman, F., 2012).

(%) briquettes by gain Water = $\frac{(W1-W2)}{W1}$ * 100 (6)

Where, W1 = Initial weight of briquette, g

W2 = Weight of wet briquette, g

Resistance to water penetration (%) = 100 - % water gain (7)

Shatter Resistance Test:

The purpose of this test was to ascertain the briquettes' hardness. On the concrete floor, a briquette with known weight and length was dropped ten times from a height of one meter. The size and weight of the broken briquette were recorded. The material loss as a percentage was computed. The following formula was used to determine the briquette's shatter resistances (Madhava *et al*., 2012).

Percent weight loss (%) = $\frac{W1-W2}{W1}$ *100 (8)

shatter resistance % = 100- % weight loss (9)

Where: - w_1 = weight of briquette before shattering, g

w2 = weight of briquette after shattering, g

3. RESULTS AND DISCUSSIONS

Physical Properties:

Moisture Content (M.C. %):

Results of the analysis of variance revealed that all four factors together with their interactions had a significant effect on moisture content (MC) (Table 1). It can be observed that the lowest value of MC (1.97 %) was obtained in briquettes made of (*Quercus infectoria*) (Figure 1), Softwoods like *Pinus brutia* typically have higher moisture retention due to their porous structure (Siau, 1984). Similarly, higher initial moisture content 12% results in higher retained moisture, consistent with prior studies on wood pyrolysis (Prins *et al*., 2006). Also, it was noticed that the lower MC value (2.32%) was attained in briquettes manufactured of (2mm), particle size with larger particles retaining more moisture due to reduced heat transfer efficiency (Shen *et al*., 2009). Furthermore, the higher pyrolysis temperatures (350 °C) cause greater moisture loss (White & Dietenberger, 2010).

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%	1.69 m	1.63 n	1.93 d	1.76 f	2.11 f	1.66 j	1.97 b
		9%	1.96 kl	1.92 l				1.94 h	
		12%	2.21 i	2.14 i		1.98 e	2.32 e	2.17 f	
	4 mm	6%	2.04 j	1.66 nm	2.01 c			1.85	
		9%	2.03 j	1.99 kj		2.17 d	2.54 d	2.01 g	
		12%	2.20 i	2.14 i				2.17 f	
Pinus brutia	2 mm	6%	2.59 g	2.50 h	2.72 b	2.62 c	2.27 c	2.55 e	2.89 a
		9%	2.77 e	2.63 gf				2.70 d	
		12%	2.93 c	2.88 c		2.75 b	2.40 b	2.91 b	
	4 mm	6%	2.73 e	2.66 f	3.07 a			2.70 d	
		9%	2.85 d	2.75 e		3.31 a	2.94 a	2.80 c	
		12%	3.80 a	3.64 b				3.72 a	
Temperature			2.48 a	2.38 b	Particle size		Moisture content		
Species * Temperature		*Quercus infectoria*	2.02 c	1.92 d					
		Pinus brutia	2.94 a	2.84 b					
Particle size * Temperature		2 mm	2.36 c	2.28 d	2 mm	2.32 b	6%	2.19 c	
		4 mm	2.61 a	2.47 b	4 mm	2.54 a	9%	2.36 b	
Moisture content * Temperature		6%	2.26 e	2.11 f			12%	2.74 a	
		9%	2.40 c	2.32 d					
		12%	2.78 a	2.70 b					

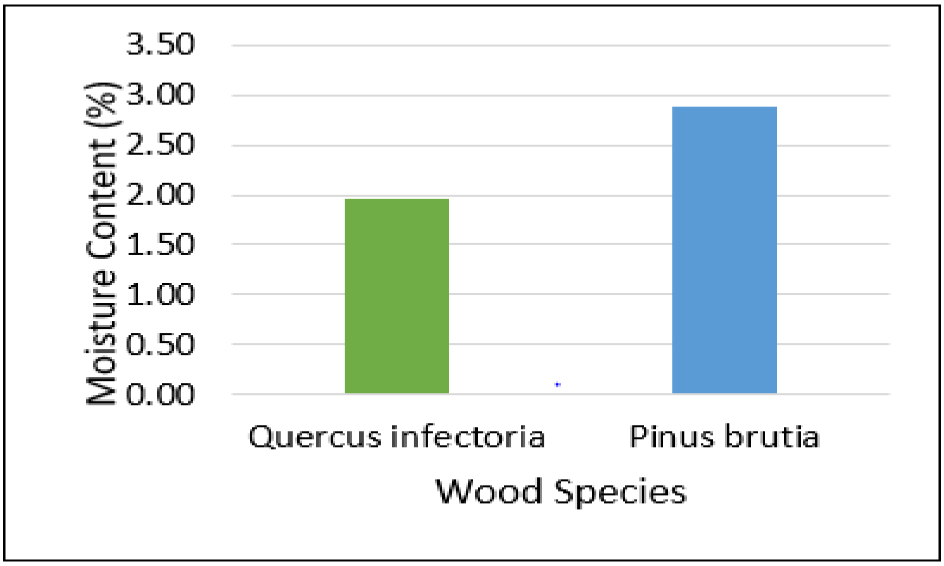

Figure 1: Effect of wood species on Moisture Content

Density:

Results of the analysis of variance for density (Table 2) indicate which there is a significant effect (5 %) for the three main factors, together with their interactions of the main factors. It can be observed that the panels with species of (*Quercus infectoria*) observed a higher value (1300.32 kg/cm^3) as shown in (Figure 2). This result corresponds with other workers (Bowyer *et al*., 2007; Forest Products Laboratory, 2010). On the effects of particle size levels on density (Table 2), It appears that the higher density (1180.32 kg/cm^3) achieved in all treatment combinations manufactured at 2mm particle size. The impact of particle size on density is consistent with studies showing that smaller particles retain more structural integrity during pyrolysis, while larger particle develop more void spaces, reducing density (Schellenberger *et al*., 2019) The reduction in density with increasing temperature confirms findings that thermal decomposition reduces mass while increasing porosity (Ronsse *et al*., 2013). Similarly, the influence of initial moisture content on density reduction aligns with research indicating that higher moisture accelerates thermal degradation and results in lower final density (Babu, 2008).

Table (2): Effect of studied factors on the Density of the produced Biomass Briquettes.

Density (kg/m^3)									
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%	1340.21 b	1358.37 a	1313.23 a	1327.74 a	1249.86 a	1349.29 a	1300.32 a
		9%	1298.16 d	1310.62 c				1304.39 b	
		12%	1282.79 f	1289.23 e		1297.65 b	1223.41 b	1286.01 d	
	4 mm	6%	1297.70 d	1314.67 c	1287.41 b			1306.18 b	
		9%	1284.11 f	1297.70 d		1275.57 c	1210.36 c	1290.91 c	
		12%	1261.33 h	1268.93 g				1265.13 e	
Pinus brutia	2 mm	6%	1146.60 j	1154.25 j	1142.52 c	1145.70 d	1223.58 b	1150.42 f	1135.66 b
		9%	1138.38 kl	1146.47 j				1142.42 g	
		12%	1135.70 ml	1133.72 m		1135.69 e	1209.93 c	1134.71 h	
	4 mm	6%	1139.06 kl	1142.90 kj	1128.79 d			1140.98 g	
		9%	1124.73 n	1133.19 m		1125.58 f	1190.79 d	1128.96 i	
		12%	1112.54 o	1120.36 n				1116.45 j	
Temperature			1213.44 b	1222.53 a	Particle size		Moisture content		
Species * Temperature		*Quercus infectoria*	1294.05 b	1306.59 a					
		Pinus brutia	1132.83 d	1138.48 c					
Particle size * Temperature		2 mm	1223.64 b	1232.11 a	2 mm	1227.88 a	6%	1236.72 a	
		4 mm	1203.24 d	1212.96 c	4 mm	1180.32 b	9%	1216.67 b	
Moisture content * Temperature		6%	1230.89 b	1242.55 a			12%	1200.58 c	
		9%	1211.35 d	1222.00 c					
		12%	1198.09 f	1203.06 e					

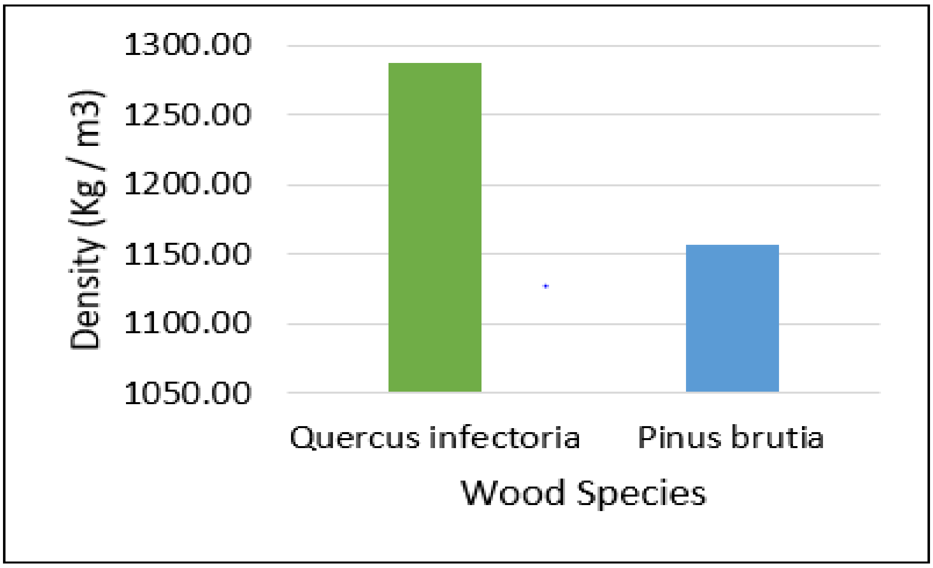

Figure 2: Effect of wood species on Density.

Tumbling Resistance (Tr):

With the exception of the effect of species and particle size, their interactions with moisture content and temperature were significant (5%) as shown in Table 3. It was shown that the greatest rate of TR was achieved in briquettes made at 6% moisture content manufactured from either particle size 2 mm and temperature at 350 °C in both species (*Quercus infectoria*) and (*Pinus brutia*) the proportion of such samples were 99.04 and 98.57 kg/cm^3 respectively (Figure 3). Aligns with its denser structure, as hardwoods generally produce more durable biochar than softwoods (Demirbas, 2004; Antal, M. J., & Grønli, M. 2003). The increase in resistance at 350°C, lowering MC and smaller particle size suggests enhanced particle bonding through carbonization,, which improves mechanical stability (Antal & Gronli, 2003; Sohi *et al*., 2010; Bridgwater, 2012).

Table (3): Effect of studied factors on the Tumbling Resistance of the produced Biomass Briquettes.

Tumbling Resistance (%)									
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%	98.39 b	99.04 a	97.51 a	98.31 a	98.46 a	98.71 a	96.90 a
		9%	96.94 e	97.81 c				97.37 d	
		12%	95.92 h	96.95 e		96.70 c	96.76 c	96.44 f	
	4 mm	6%	97.78 dc	98.03 c	96.30 b			97.91 c	
		9%	95.63 ih	96.42 fg		95.70 d	95.32 e	96.02 g	
		12%	94.67 k	95.25 j				94.96 h	
Pinus brutia	2 mm	6%	97.83 c	98.57 b	96.18 b	97.65 b	97.50 b	98.20 b	95.66 b
		9%	95.92 h	96.39 g				96.15 g	
		12%	93.82 l	94.57 k		95.63 d	95.57 d	94.20 i	
	4 mm	6%	96.76 fe	97.44 d	95.15 c			97.10 e	
		9%	94.79 k	95.44 ij		93.71 e	94.09 f	95.11 h	
		12%	92.49 m	93.95 l				93.22 j	
Temperature			95.91 b	96.65 a	Particle size		Moisture content		
Species * Temperature		*Quercus infectoria*	96.55 b	97.25 a					
		Pinus brutia	95.27 d	96.06 c					
Particle size * Temperature		2 mm	96.47 b	97.22 a	2 mm	96.84 a	6%	97.98 a	
		4 mm	95.35 d	96.09 c	4 mm	95.72 b	9%	96.17 b	
Moisture content * Temperature		6%	97.69 b	98.27 a			12%	94.70 c	
		9%	95.82 d	96.51 c					
		12%	94.23 f	95.18 e					

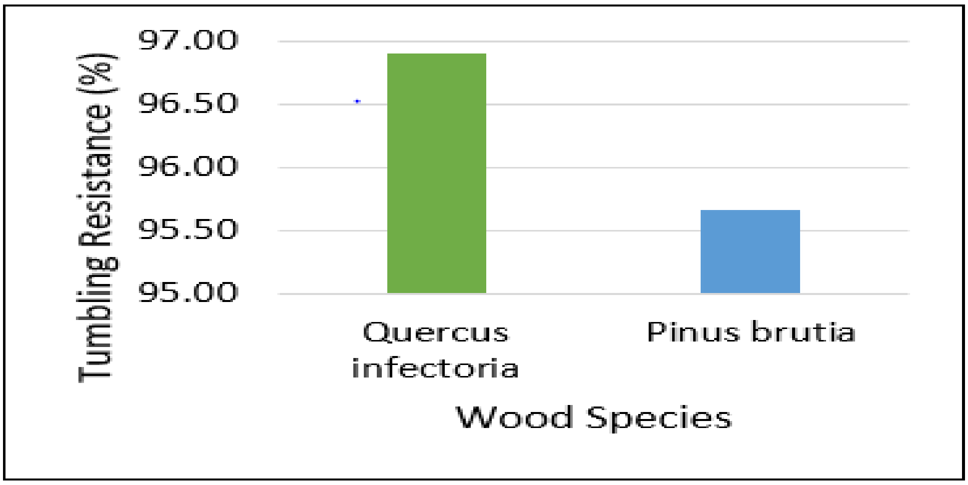

Figure 3: Effect of wood species on Tumbling Resistance.

Resistance to Water Penetration (RWP):

In the current work, results of Duncan's multiple range test (Table 4) revealed that the affecting studied factors along with their interaction had a significant effect ($p < 0.05$) on RWP. The results (Figure 4) revealed that the highest value of RWP was observed in samples manufactured of species (*Quercus infectoria*) (96.54 %) aligns with its higher density, as denser woods generally produce more compact and hydrophobic biomass briquettes (Bhattacharya, S. C., & Sarker, S. C. 1999; Liu *et al.,* 2013). And the maximum value of RWP was (97.98 %) noticed in samples made at 6% moisture content, and particle size 2 mm exhibit better water resistance, which is consistent with findings that finer biochar particles have higher carbon content and lower porosity, improving hydrophobicity (Ahmad *et al.,* 2014; Mohan *et al*., 2014). The increase in water resistance at 350°C supports previous studies showing that higher pyrolysis temperatures promote the formation of non-polar carbon structures, reducing water absorption (Lua *et al*., 2004).

Table (4): Effect of studied factors on the Resistance to Water Penetration of the produced Biomass Briquettes.

Resistance to Water Penetration (%)									
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%	98.36 ba	98.74 a	96.95 a	98.24 a	97.98 a	98.55 a	96.54 a
		9%	96.76 fe	97.05 e				96.90 d	
		12%	94.94 i	95.86 hg		96.50 b	96.60 c	95.40 f	
	4 mm	6%	97.90 bc	97.96 bc	96.14 b			97.93 b	
		9%	95.76 h	96.44 f		94.89 c	94.40 e	96.10 e	
		12%	93.92 j	94.84 i				94.38 g	
Pinus brutia	2 mm	6%	97.20 df	97.63 dc	95.70 c	96.75 b	97.01 b	97.41 c	94.51 b
		9%	95.86 hg	96.73 fe				96.30 e	
		12%	92.81 k	93.97 j		94.77 c	94.67 d	93.39 h	
	4 mm	6%	95.80 h	96.39 fg	93.32 d			96.09 e	
		9%	92.86 k	93.61 j		92.02 d	92.51 f	93.23 h	
		12%	90.06 m	91.22 l				90.64 i	
Temperature			95.19 b	95.87 a					
Species * Temperature		*Quercus infectoria*	96.27 b	96.82 a	Particle size		Moisture content		
		Pinus brutia	94.10 d	94.92 c					
Particle size * Temperature		2 mm	95.99 b	96.66 a	2 mm	96.33 a	6%	97.50 a	
		4 mm	94.38 d	95.08 c	4 mm	94.73 b	9%	95.63 b	
Moisture content * Temperature		6%	97.31 b	97.68 a			12%	93.45 c	
		9%	95.31 d	95.96 c					
		12%	92.93 f	93.97 e					

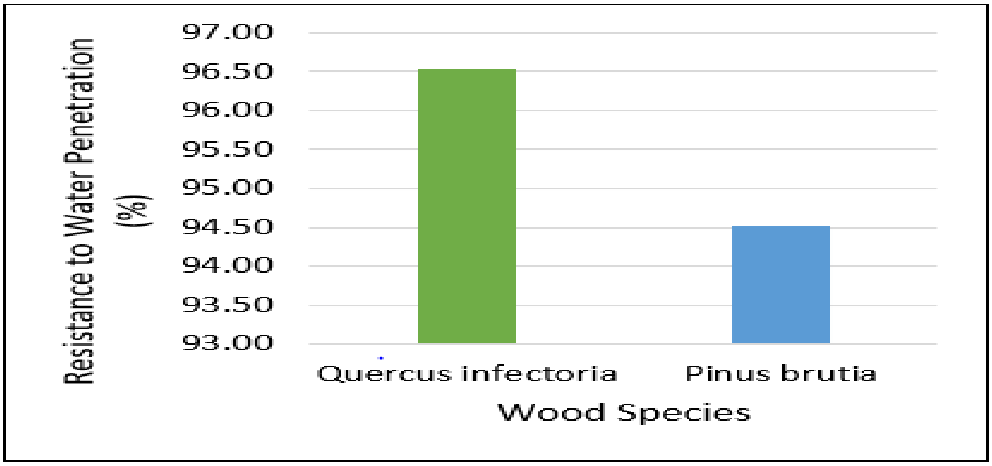

Figure 4 Effect of wood species on Resistance to Water Penetration

Shatter Resistance (Sr):

It has been shown from (Table 5) and (Figure 5) that the maximum value (99.64 %) was recorded in briquettes manufactured from (*Quercus infectoria*) with particle size 2mm, temperature at 350 °C and at 6 % moisture content which enhances mechanical durability after pyrolysis (Gil *et al*., 2010). Although, the (*Pinus brutia*) had a high value (99.06 %) with the same level of particle size 2mm, temperature at 350 °C and at 6 % moisture content. Studies shows that increased pyrolysis temperatures promote carbonization, leading to a more resilient briquettes structure (Pelaez *et al*., 2014). Also, findings indicate that finer particles experience less internal stress during impact, making them more durable (Downie *et al.,* 2009). Additionally, the negative effect of higher moisture content on shatter resistance is in line with studies indicating that increased moisture contributes to greater mass loss and internal void formation, weakening the final product (Carrier *et al*., 2011).

Table (5): Effect of studied factors on the Shatter Resistance of the produced Biomass Briquettes.

Shatter Resistance (%)									
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%	99.12 bac	99.64 a	97.88 a	99.28 a	99.17 a	99.38 a	97.49 a
		9%	97.88 d	98.60 c				98.24 c	
		12%	95.92 g	96.10 g		97.68 c	97.45 c	96.01 f	
	4 mm	6%	98.91 c	99.47 ba	97.11 b			99.19 ba	
		9%	96.89 f	97.35 edf		95.51 e	95.05 e	97.12 d	
		12%	94.94 h	95.10 h				95.02 g	
Pinus brutia	2 mm	6%	98.86 c	99.06 bc	96.57 c	98.53 b	98.65 b	98.96 b	95.92 b
		9%	96.11 g	97.21 ef				96.66 f	
		12%	93.77 j	94.41 i		96.28 d	96.51 d	94.09 h	
	4 mm	6%	97.64 ed	98.56 c	95.28 d			98.10 c	
		9%	95.69 g	96.11 g		92.96 f	93.42 f	95.90 f	
		12%	91.24 l	92.41 k				91.83 i	
Temperature			96.41 b	97.00 a					
Species * Temperature		*Quercus infectoria*	97.28 b	97.71 a	Particle size		Moisture content		
		Pinus brutia	95.55 d	96.29 c					
Particle size * Temperature		2 mm	96.94 b	97.50 a	2 mm	97.22 a	6%	98.91 a	
		4 mm	95.88 d	96.50 c	4 mm	96.19 b	9%	96.98 b	
Moisture content * Temperature		6%	98.63 b	99.18 a			12%	94.24 c	
		9%	96.64 d	97.32 c					
		12%	93.97 f	94.50 e					

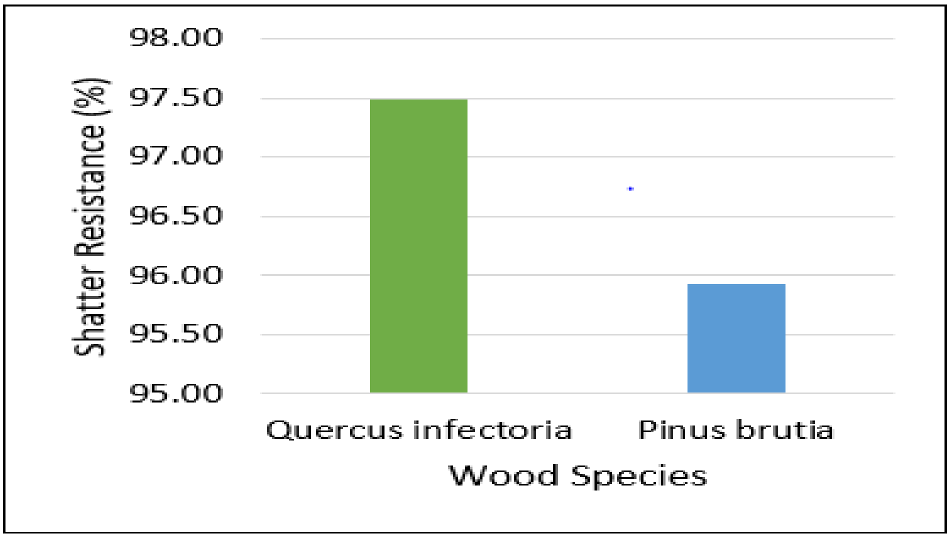

Figure 5: Effect of wood species on Shatter Resistance.

CONCLUSION

The study highlights the impact of raw material selection and processing conditions on the physical properties of biomass briquettes. *Quercus infectoria* outperformed *Pinus brutia* in density, mechanical strength, and water resistance, making it a preferable choice for high-quality briquette production. Optimal briquetting conditions were achieved with 6% moisture content, 2 mm particle size, and a temperature of 350°C, which enhanced durability and combustion efficiency. These findings can assist industries in selecting suitable biomass resources and refining production techniques to develop eco-friendly and efficient fuel alternatives. The results also emphasize the potential for biomass briquettes in sustainable energy applications, encouraging further research on improving production methods and expanding biomass utilization for environmental and economic benefits.

Funding for the Study:

This research did not receive any specific funding from public, commercial, or non-profit organizations.

Conflict of Interest:

None declared.

Author's Contribution Details:

All authors provided critical feedback and helped shape the research, analysis, and manuscript.

Declaration Statement:

We, as authors, state that all information in this article is accurate to the best of our knowledge, and we take full responsibility for its correctness.

Acknowledgment :

We owe a deep debt of gratitude to the University of Duhok and Faculty of Agricultural Engineering Sciences for giving us an opportunity to complete this work. We express gratitude to all of the Forestry Department members for their help and support.

REFERENCES

Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., ... & Ok, Y. S. (2014). Biochar as a sorbent for contaminant management in soil and water: a review. *Chemosphere*, *99*, 19-33. https://doi.org/10.1016/j.chemosphere.2013.10.071

Antal, M. J., & Grønli, M. (2003). The Art, Science, and Technology of Charcoal Production. *Industrial & Engineering Chemistry Research*, 42(8), 1619-1640. https://doi.org/10.1021/ie0207919

Arias, B., Pevida, C., Fermoso, J., Plaza, M. G., Rubiera, F., & Pis, J. J. (2008). Influence of torrefaction on the grindability and reactivity of woody biomass. *Fuel processing technology*, *89*(2), 169-175. https://doi.org/10.1016/j.fuproc.2007.09.002

ASTM International. (2003). ASTM D3173-03: Standard Test Method for Moisture in the Analysis Sample of Coal and Coke. West Conshohocken, PA: ASTM International. https://doi.org/10.1520/D3173-03

Babu, B. V. (2008). "Biomass pyrolysis: A state-of-the-art review." Biofuels, Bioproducts and Biorefining, 2(2), 101-117. https://doi.org/10.1002/bbb.65

Bhattacharya, S. C., & Sarker, S. C. (1999). Physical Properties and Quality of Briquettes Made from Biomass and Charcoal. Renewable Energy, 7(2), 219-228. https://doi.org/10.1016/S0960-1481(97)10032-5

Birwatkar, V. R., Khandetod Y. P, Mohod A. G, and Dhande K. G.(2014). PHYSICAL AND THERMAL PROPERTIES OF BIOMASS BRIQUETTED FUEL, Ind. J. Sci. Res. and Tech. 2(4),pp:55-62. https://doi.org/10.17485/ijst/2014/v2i4.12

Bowyer, J. L., Shmulsky, R., & Haygreen, J. G. (2007). Forest Products and Wood Science: An Introduction (5th ed.). Blackwell Publishing. https://doi.org/10.1002/9780470756379

Bridgwater, A. V. (2012). "Review of fast pyrolysis of biomass and product upgrading." Biomass and Bioenergy, 38, 68-94. https://doi.org/10.1016/j.biombioe.2011.01.048

Carrier, M., Loppinet-Serani, A., Denux, D., Lasnier, J. M., Ham-Pichavant, F., Cansell, F., & Aymonier, C. (2011). Thermogravimetric Analysis as a New Methodology for Determining the Lignocellulosic Composition of Biomass. Biomass and Bioenergy, 35(1), 298-307. https://doi.org/10.1016/j.biombioe.2010.08.067

Demirbas, A. (2001). Biomass resource facilities and biomass conversion processing for fuels and chemicals. *Energy*

Conversion and Management, 42(11), 1357-1378. https://doi.org/10.1016/S0196-8904(00)00137-0

Demirbas, A. (2004). "Effects of temperature and particle size on biochar yield from biomass." Energy Sources, 26(4), 331-340. https://doi.org/10.1080/00908310490429728

Downie, A., Crosky, A., & Munroe, P. (2009). Physical Properties of Biochar. In J. Lehmann & S. Joseph (Eds.), Biochar for Environmental Management: Science and Technology (pp. 13-32). Earthscan. https://doi.org/10.4324/9781849770552

Forest Products Laboratory. (2010). Wood Handbook: Wood as an Engineering Material. USDA. https://doi.org/10.2737/FPL-GTR-190

Garcia, R., Pizarro, C., Lavin, A. G., & Bueno, J. L. (2014). Biomass proximate analysis: Interpretation and comparison of data. *Renewable and Sustainable Energy Reviews*, 36, 158-165. https://doi.org/10.1016/j.rser.2014.04.081

Gil, M. V., Oulego, P., Casal, M. D., Pevida, C., Pis, J. J., & Rubiera, F. (2010). Mechanical Durability and Decomposition of Biomass Pellets During Long Term Storage. Bioresource Technology, 101(3), 939-947. https://doi.org/10.1016/j.biortech.2010.06.062

Grover, P. D., & Mishra, S. K. (1996). Biomass briquetting: Technology and practices. Food and Agriculture Organization of the United Nations. https://www.fao.org/4/AD579E/AD579E00.htm?utm_source=chatgpt.com

Ismail, S. M., & Ahmed, S. M. (2023). The effect of calcination temperatures on the properties of ZnO nanoparticles synthesized by using leaves extracts of pinus brutia tree. *Science Journal of University of Zakho*, *11*(2), 286-297. https://doi.org/10.25271/sjuoz.2023.11.2.1087

Kaliyan, N., & Morey, R. V. (2009). Densification characteristics of corn stover and switchgrass. Biomass and Bioenergy, 33(8), 1145-1150. https://doi.org/10.1016/j.biombioe.2009.05.004

Khalil, H. P. S. A., & Sulaiman, F. (2012). Physical and thermal properties of biomass briquettes from oil palm and rice husk. *Bioresource Technology*, 109, 295-300. https://doi.org/10.1016/j.biortech.2011.10.030

Liu, Z., Quek, A., Hoekman, S. K., & Balasubramanian, R. (2013). Production of Solid Biochar Fuel from Waste Biomass by Hydrothermal Carbonization. Fuel, 103, 943-949. https://doi.org/10.1016/j.fuel.2012.08.056

Lua, A. C., Yang, T., & Guo, J. (2004). "Effects of pyrolysis conditions on the properties of activated carbons prepared from pistachio-nut shells." Journal of Analytical and Applied Pyrolysis, 72(2), 279-287. https://doi.org/10.1016/j.jaap.2004.08.001

Madhava M, Prasad BV, Koushik Y, Rameshbabu KR & Srihari R (2012). Performance evaluation of a hand operated compression type briquetting machine. Journal of Agricultural Engineering, 49(2) 46-49. https://ebook.icar.gov.in/index.php/JAE/article/view/24263

Mani, S., Tabil, L. G., & Sokhansanj, S. (2006). Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets. Biomass and Bioenergy, 30(7), 648-654. https://doi.org/10.1016/j.biombioe.2005.01.004

Mohan, D., Sarswat, A., Ok, Y. S., & Pittman, C. U. (2014). "Organic and inorganic contaminants removal from water with biochar, a renewable material: A critical review." Bioresource Technology, 160, 191-202. https://doi.org/10.1016/j.biortech.2014.01.120

Pelaez-Samaniego, M. R., Smith, A. R., Kashaninejad, N., & Steele, P. H. (2014). Mechanical Properties of Biochar Pellets. Biomass and Bioenergy, 62, 1-7. https://doi.org/10.1016/j.biombioe.2014.01.024

Pérez, J. M., Melgar, M., Benjumea, P., & Ramos, C. (2019). Effect of particle size on bio-briquettes properties. Fuel, 256, 115924. https://doi.org/10.1016/j.fuel.2019.115924

Prins, M. J., Ptasinski, K. J., & Janssen, F. J. (2006). "More efficient biomass gasification via torrefaction." Energy, 31(15), 3458–3470. https://doi.org/10.1016/j.energy.2006.03.008

Ronsse, F., Van Hecke, S., Dickinson, D., & Prins, W. (2013). Production and Characterization of Slow Pyrolysis Biochar: Influence of Feedstock Type and Pyrolysis Conditions. Biomass and Bioenergy, 48, 43-54. https://doi.org/10.1016/j.biombioe.2012.10.007

Schellenberger, S., Schmiedl, D., & Kruse, A. (2019). "Thermal degradation of wood particles: Influence of size and temperature." Journal of Analytical and Applied Pyrolysis, 137, 166-174. https://doi.org/10.1016/j.jaap.2018.11.017

Shahbaz, S. E., Abdulrahman, S. S., & Abdulrahman, H. A. (2015). Use of Leaf Anatomy for Identification of Quercus L. Species Native to Kurdistan-Iraq. *Science Journal of University of Zakho*, *3*(2), 222-232. https://sjuoz.uoz.edu.krd/index.php/sjuoz/article/view/146?utm_source=chatgpt.com

Shen, D. K., Gu, S., Luo, K. H., Wang, S. R., & Fang, M. X. (2009). "The pyrolytic degradation of wood-derived lignin from pulping process." Bioresource Technology, 100(3), 649–655. https://doi.org/10.1016/j.biortech.2008.07.033

Siau, J. F. (1984). Transport Processes in Wood. Springer. https://doi.org/10.1007/978-3-642-69213-0

Sohi, S. P., Krull, E., Lopez-Capel, E., & Bol, R. (2010). "A review of biochar and its use and function in soil." Advances in Agronomy, 105, 47-82. https://doi.org/10.1016/S0065-2113(10)05002-9

Sokhansanj, S., Mani, S., Bi, X., et al. (2005). Binderless pelletization of biomass. ASABE Annual Meeting Paper. https://doi.org/10.13031/2013.19922

Tumuluru, J. S., Wright, C. T., Hess, J. R., & Kenney, K. L. (2011). A review of biomass densification systems to develop uniform feedstock commodities for bioenergy applications. Biofuels, Bioproducts and Biorefining, 5(6), 683-707. https://doi.org/10.1002/bbb.324

White, R. H., & Dietenberger, M. A. (2010). Wood Handbook: Wood as an Engineering Material. USDA Forest Service. https://doi.org/10.2737/FPL-GTR-190