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Impact of Biomass Moisture Content on the Physical Properties of Briquettes Produced from Recycled *Ficus nitida* Pruning Residuals

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Abstract: Despite its vital importance for life and societal development, energy is a source of conflict and war in many places worldwide. It is also a source of pollution and harmful natural phenomena that affect human life and the environment. These factors have led scientists to consider alternative clean, cheap, and eco-friendly renewable energies. Examples include briquettes consisting of compressed agricultural waste, such as pruning residuals. Hence, this study aimed to evaluate the characteristics of briquettes derived from the pruning residuals of *Ficus nitida* trees. The results indicate that moisture content was the main factor affecting the physical properties of the produced briquettes. The ideal moisture content for producing high-quality briquettes was 8%. With this moisture content, the briquette durability was 96.9%, the bulk density was approximately 0.18 g·cm^3, the compressive strength was 18.5 MPa, and its calorific value was 3250.7 Kcal/kg (17.38 MJ/kg). In conclusion, our research confirms the high quality of briquettes made from the pruning residuals of *F. nitida* and their promising potential as an energy source.

Keywords: briquettes; bulk density; calorific value; compressive strength; durability; *Ficus*

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1. Introduction

An energy-based economy is a foundation for the development and progression of nations [1]. The industrial sector has undergone great transition and growth as civilization has progressed, which has been influenced by the implementation of artificial intelligence and smart technologies guiding workflow. Since energy is the cornerstone of all technological progress, the steady increase in energy demand in recent times has led to an increase in its prices. The fast-growing demand for fossil fuels has imposed several environmental problems, such as the continuous increase in the atmosphere's temperature. As a result, there has been increased interest in new and renewable energy sources that have the potential to reduce harmful environmental emissions [2]. Examples of alternative energy sources include biomass, solar, and wind energy, which provide cheap and environmentally friendly energy. In addition, they provide an opportunity to dispose of a large portion of the huge quantities of waste produced in the world, reaching approximately 292.4 million tons of waste per day [1].

Globally, fossil fuels, coal, and natural gas are the traditional energy sources. Fuels play a substantial role in daily activities. In addition to their use in homes as domestic fuels, they are used for transport, in the industrial sector, and to generate electricity. Fuels such as mineral oil, coal, and electricity are expensive for most people, and they also harm the environment. They cause soil erosion and deforestation in addition to polluting the air and reducing agricultural productivity. In this context, it is necessary to search for other forms of domestic fuels that are sustainable, cheap, environmentally friendly, and available [3,4]. A shortage of these energies would pose a significant problem for the world's energy supply, as predicted in the BP Review of World Energy in 2003 [5,6]. As oil reserves decline and some regions of the world have passed their peak points of oil production, the world is trying to reduce its dependency on oil as an energy source [7]. Likewise, other non-renewable sources of energy, such as fossil fuels, oil, and natural gas, may be diminished in the future [8]. The remaining petroleum supply is sufficient to meet the needs of the population for another 40.6 years. Further to the diminished availability of fossil fuels, the environmental impact of their use also plays an influential role. The carbon cycle has been adversely affected as a result of harmful substances being released into the environment. A significant environmental problem associated with the industrial sector's excessive use of fossil fuels is the emission of CO_2 and the resulting greenhouse effect [9]. According to statistics, the annual amount of CO_2 emissions increased from 200 million tons in 1850 to 29 billion tons in 2004. In addition to the harmful effects of NOx emissions on the ozone layer, SOx emissions cause acid rain and fuel snowfall upon reacting with atmospheric oxygen [8,10].

Over the past four decades, diminishing fossil fuel resources and concerns associated with climate change have led the world to replace crude oil with new and renewable energy sources [6]. Examples of renewable energies that have replaced fossil fuels since the 1970 world energy crisis include solar, tidal, and wind energy [11]. Biomass is promising as an alternative feedstock because it is renewable, abundant, and environmentally friendly and releases low levels of carbon dioxide and sulfur into the atmosphere. Biomass is a precious renewable energy resource with low production costs, low greenhouse gas emissions, and low acidic gas emissions, and it has the advantage of being a carbon-neutral source of energy [5,12,13]. There is no doubt that bioenergy will play a crucial role in the global energy supply and emission reduction, but its most considerable contribution will be in the heat sector, as outlined in a report by the International Energy Agency [14]. Globally. Approximately 292.4 million tons of waste is produced daily, making it imperative to reuse this waste for energy production [15]. Developing renewable energy sources is one of the EU's energy policy priorities. The EU energy policy aimed to meet 20% of its energy needs with renewable sources by 2020 [16].

In recent years, biomass has been studied as an additive to cooking blends to reduce CO_2 [9]. In addition to not adding CO_2 to the atmosphere, crop residues contain a low level of sulfur compared with fossil fuels [17]. This is why biomass is considered an environmentally friendly, carbon-neutral energy source [13]. Climate change and the decrease in fossil fuel resources have encouraged researchers to find substitutes for fossil fuels, such as biomass. There is evidence that biomass can be used to produce heat and electricity, and it can provide environmental as well as economic benefits when converted into other bio-products [18]. The use of lignocellulosic materials has become essential in modern industrial societies, wherein a large amount of waste is generated from various agricultural practices and industrial activities. In developing countries, lignocellulosic biomass is burned for disposal, which is a problematic practice. In recent years, lignocellulosic biomass has attracted considerable attention in research due to its renewable nature [19]. In China's rural areas, space heating using straw briquette fuel is an important method for replacing fossil fuels and reducing greenhouse gas emissions [20]. In addition to being the second most abundant biomass in the world, lignin is also the most abundant material made of aromatic fractions in nature [21]. Many ornamental trees are widely cultivated in tropical and subtropical regions, including *Ficus nitida* L. (Moraceae), which yields massive amounts of waste yearly due to continuous shaping and pruning. Because of their environmental impact, it is also difficult to dispose of many agricultural wastes, such as tree and crop residues [22].

Considering the high moisture content, irregular shapes, varying sizes, and low bulk density of bulky biomass material, managing its transport, storage, and utilization is difficult [23]. By densifying these bulky materials into briquettes, transportation, and storage costs are reduced, their physical properties are improved, and their energy density (energy per unit of volume) is increased [24–26]. To obtain energy from biomass briquette fuel (BBF), raw materials are compressed into solid fuels of high densities, which are used to provide power via direct combustion in industrial boilers, heating boilers, and other combustion equipment. In the densification process, biomass materials are dried, chopped, and briquetted at elevated temperatures and pressures in screw or piston press machines [27–29]. Biomass briquettes can be classified in terms of their physical, mechanical, and biochemical characteristics, including their moisture content, calorific value, compressive strength, water resistance, and bulk density [30,31]. Under high compression pressures, the intervals between adjacent particles are improved via enhanced attraction forces, such as H-bonding and Van der Waals forces, producing briquettes with excellent mechanical strength [32]. The durability of a briquette is determined by its ability to withstand crushing forces such as compression, impact, and shear [23,33,34]. The densification of biomass in the shape of briquettes or pellets has many advantages. This process reduces the moisture content, increases the energy content, and improves the combustion efficiency of briquettes. Thus, the produced briquettes have greater compositional homogeneity than the raw biomass [16].

Our objective in this study was to convert pruning residuals from *Ficus nitida* trees into briquettes and evaluate their quality characteristics, including moisture content, durability, bulk density, and compressive strength.

2. Materials and Methods

2.1. Pruning Residuals of Ficus nitida Trees

The *Ficus nitida* tree is one of the most cultivated shade trees in Egypt, a hot country in which the sun shines almost all year round. *Ficus nitida* is, therefore, planted heavily in the streets, as shown in Figure 1. Due to its importance for tree health, the pruning process takes place annually and results in a huge amount of pruning residuals, as shown in Figure 1.

Figure 1. Pruning residuals of *Ficus nitida* trees.

The raw materials used for this study were branches obtained by pruning *Ficus nitida* trees, which averaged 5.0 cm in diameter. Branches were collected and dried in the sun at an average temperature of 30 °C.

2.2. Determination of Branch Moisture Content

The branches were piled up and left to dry in the open air under the sun for at least 2 weeks because freshly cut branches have a high moisture content, reaching approximately 45%. Then, the dried branches were milled in a hammer mill. Following the drying and milling processes, the wood particles were laid on the floor in a thin layer approximately five centimeters thick and air-dried for a second period. In this study, 3 levels of moisture content (8, 10, and 15%) were used to evaluate the effect of the moisture content on the properties of the produced briquettes. These moisture content levels are generally suitable for briquetting plant residues, as indicated by Temmerman et al. [33], Kakitis et al. [35], and Oladeji and Enweremadu [30]. The moisture content of the milled wood particles was determined using a digital apparatus (Protimeter TF 63007) regularly, twice a day. When the milled wood particles reached the desired moisture content, they were pressed to produce briquettes. To ensure the accuracy of the measurements for briquetting, 100 g samples of milled branches were dried in a hot air oven for 48 h at 70 °C to determine their moisture contents, as mentioned by Ryan et al. [36]. The plant materials were dried at 70 °C to avoid burning at higher temperatures, in which part of the plant tissue turns into charcoal and carbon dioxide rises, which reduces their weight. Thus, dry weight loss is not only due to drying but also charring and plant damage. The experiment was conducted in a completely randomized design with three replicates. We observed substantial amounts of vapor rise as a result of the moisture content of the pressed materials having increased by more than 8%. Cracks appear in pressed briquettes when the moisture content of the pressed material increased to 15%. As the moisture content increases, the briquettes break and stick to the press die. The vapor contained in the press die rises until it overcomes the adhesive force between the die wall and the briquette. After forcefully pushing the stuck briquette, the briquette exits the die like a bullet.

2.3. Preparing Branches for Milling

Because of the wide range of tree branch diameters, branches with an average diameter of 5 cm were selected to be easy to mill in the hammer mill without loss in the energy consumed for the milling. The selected branches were well-dried and categorized into three categories according to the average dimensions of the tree branches prepared for milling and the average lengths of the particles produced (Table 1).

Table 1. The average dimensions of the milled branches.

Parameter	Sample		
	1	**2**	**3**
Length (cm)	100	100	100
Average diameter (cm)	1.4	3.6	5.2
Average produced particle length (mm)	5.0	5.0	7.0

2.4. Branch Milling

The tree branches were milled using a rotary hammer mill powered by a 13 kW electric motor. The machine rotor was equipped with ten cutting knives that were systematically arranged. The particles that were produced were sieved and their average particle lengths were measured (Table 1). To produce high-quality briquettes, a smaller particle size is recommended. This reduces the spaces between interior particles and creates strong bonds during compression, as mentioned by Yank [26].

2.5. Briquette Pressing

Following chopping, the particles were pressed in a screw-type press machine (Shimada SPMM-850 KS, Shimada, Japan). The machine had 2 heaters and was powered using a 30 kW electric motor with an average production capacity of 400 kg per hour (Figure 2). The screw press machine continuously extruded the pressed materials via the taped screw to the die. The die was heated to approximately 170–200 °C, which was sufficient to fuse the lignin content in the pressed materials without needing to add any binding materials since lignin acted as a binder. The lowest melting point of lignin is above 140 °C, as mentioned by Abakr and Abasaeed [37], Chen et al. [38], and Yank et al. [26]. In addition, heating the die reduces friction.

Figure 2. Briquetting machine (Shimada SPMM-850 KS).

The chopped materials were introduced into the feeding hopper, and the screw press then pushed the materials into the machine die, which was surrounded by the heaters. The heaters were preheated to approximately 180 °C. Internal friction occurred between the pressed materials, causing an increase in the temperature. An additional increase in the pressed materials' temperature occurred because of the friction with the die wall. The briquettes were formed and ejected from the die continuously. If the materials' moisture content exceeded the optimum range (8%), condensed vapor rose from the press die, as shown in Figure 2.

2.6. Durability Test

The durability of the briquettes was determined according to ASABE S269.4. Briquette samples of 500 g were centrifuged at 50 rpm for 10 min.

Three randomly selected treated briquettes for each investigated treatment were tested. The average value for each treatment was used as the final value to plot this relationship.

A briquette's durability was then calculated based on the disassembled particles after tumbling in relation to its original mass. Equation (1) illustrates a Briquette's durability:

$$\text{Briquette durability} = \frac{m_a}{m_b} \times 100 \quad (1)$$

where m_a denotes the mass of the briquette after tumbling (g), and m_b denotes the mass of the briquette before tumbling (g).

2.7. Briquette Compressive Strength

This test was conducted in the Laboratory of Properties and Testing of Materials, the Faculty of Engineering, Menoufia University, Egypt. The longitudinal compressive strengths (MPa) of the processed briquettes were measured using a universal testing machine (Shimadzu, UH-500KN, Kyoto, Japan), which is presented in Figure 3.

Figure 3. The universal testing machine (Shimadzu, UH-500KN).

An average of 3 treated briquettes taken from every treatment was identified to illustrate this relationship.

2.8. Material Density

2.8.1. Loose Material Bulk Density

The loose material bulk density was calculated using the standard method under the ISO 17828:2015 guidance for determining the bulk densities of solid biofuels [39].
A container with specific dimensions was weighed, dried, emptied, and cleaned.
The volume of the container was calculated.
The container was filled with the loose material of every studied moisture content level in turn.
The container was shaken to fill it with the material and weighed.
The density for every studied moisture content level was calculated.
This work was repeated five times to assure the results and the average value was taken as the final result.

2.8.2. Briquette Density

The produced briquettes were cube-shaped with a hole in the center, and the edges were trimmed as presented in Figure 4 so the briquettes' densities could be measured using the displacement method, as detailed by Bhagwanrao and Sinfaravelu [40] and Raiber et al. [41].

Figure 4. A wax-coated briquette.

- First, the briquettes were weighed and then individually coated with paraffin wax to prevent the briquettes from absorbing water, as shown in Figure 4.
- The wax-coated briquettes were weighed one after another.
- The weight of the wax was calculated by subtracting the briquette weight from the waxed briquette weight.
- Each briquette was submerged in water from a measuring cup, and the volume of the displaced water was recorded.
- The volume of the paraffin wax was also calculated using the known paraffin wax density.
- The volume of a briquette was calculated by subtracting the volume of the wax coating from the coated briquette volume.
- The above steps were repeated for ten briquettes.
- The average value of an uncoated briquette's weight was calculated.
- The average value of the displaced water volume was also calculated.
- The densities of the briquettes were determined using the following equation:

$$\text{Briquette Density} = \text{weight of the briquette}/\text{volume of the displaced water}$$

2.9. Briquette Calorific Value

To determine the amount of heat obtained from burning a briquette, it is necessary to determine its combustion calorific value. In the industry sector, briquettes may be used as a solid fuel owing to their high combustion calorific values [31]. The measurement of the calorific values of the briquettes was conducted at the Biomass Laboratories of the New and Renewable Energy Authority in Cairo, Egypt. The results were presented in a report which included the standard and the specifications of the test. The report also indicated that the experiment was conducted with a Gallenkamp Auto Bomb (London, UK). Figure 5 shows the apparatus that was used.

Figure 5. The calorific-value-measuring apparatus (Gallenkamp Auto Bomb).

3. Results and Discussion

3.1. Moisture Content of the Pressed Materials

The moisture content in briquettes has a significant influence on the briquetting process and the quality of the briquettes produced. Based on the results, briquettes produced with a moisture content of 8% were denser, more stable, and more durable. They also had a smooth outer surface and a compact and homogenous structure as shown in Figure 6. Our results are in line with those reported by Oladeji and Enweremadu [30], Temmerman et al. [33], and Antwi-Boasiako and Acheampong [42]. They found that an increase in the moisture content may negatively impact the compaction process because moisture may make the formation of briquettes more difficult. In addition, we observed that pressing the material with an 8% moisture content at a 170 °C pressing temperature resulted in a smooth and uniform briquette production process, with briquettes being produced continuously in a chain. Increasing the moisture content to 10% by heating the press die to 170 °C also led to a smooth and uniform briquetting process. The outer surfaces of the produced briquettes were also smooth and free of cracks, as presented in Figure 6, although some water vapor started to rise and could be collected until an explosion occurred. The pressed briquettes with a higher moisture content (15%) were produced in the same manner, although more water vapor was released. In addition to harming the process atmosphere, this vapor affects the quality of the briquettes, as shown in Figure 2. A moisture content of approximately 17% also led to the formation of large cracks in the briquettes. The briquetting process with this moisture content was unstable because the processed briquettes were stuck in the press die. Consequently, the production of briquettes was prevented from flowing continuously, resulting in a reduced number of briquettes being produced compared with prior conditions. High moisture content levels in briquettes lead to cracks appearing in the products, making these briquettes unstable or too soft for storage or transportation. Moreover, a considerable amount of water vapor rises and collects in the die. This pushes the briquette until it overcomes the adhesive force between the briquette and the die wall. The remaining briquette exits the press die like a cannon shot, causing an explosion-like sound. To conclude, we recommend that briquettes be produced with approximately 8% moisture as increasing the moisture content adversely affects the briquetting process and the quality of the briquettes.

Figure 6. The produced briquettes.

3.2. Effect of Moisture Content on Briquette Durability

The durability of briquettes refers to their ability to remain solid and stable when handled, stored, and transported. As such, the durability of briquettes can also be an indication of their strength and resistance to breakage. It also reflects how the briquettes will behave when exposed to mechanical wear, which leads to the production of fine particles or dust during transport, transshipment, and storage [43]. In this study on the durability of the produced briquettes, 500 g samples were tumbled in a test box for 10 min at 50 rpm, followed by sifting using a No. 5 US sieve. When the relation between briquette durability and moisture was studied, it was found that increased briquette moisture content decreased its durability. The durability value was 96.9% for pressed briquettes with a moisture content of 8%, whereas the durability value was 95.5% for pressed briquettes with a moisture content of 10%. As mentioned by Temmerman et al. [33], only moisture content levels lower than 10% are used in trials to avoid the influence of the moisture content on briquette durability. Increasing the moisture content of the briquettes to 15% resulted in a reduction in the briquette durability to 89.2%. Based on Okot, et al. [44], these results indicate that the quality of the produced briquettes was acceptable. Briquettes with a durability of over 80% are desirable due to the small amounts of dust or fine particles that are produced. As shown in Figure 6, briquette durability varies according to moisture content. According to the data, durability decreased linearly as moisture content increased to 15%. The linear relationship between moisture content (MC) and durability (D) is represented in Figure 7 with regression Equation (2) with R^2 = 0.972 calculated according to Equation (3).

$$y = -1.0885x + 105.74 \tag{2}$$

where (y) indicates the predicted briquette durability, and (x) indicates the moisture content value.

R^2 can be calculated using Equation (3), as mentioned by Yamane [45] and Shen et al. [46].

$$R^2 = 1 - \sum_{i=1}^{n} \frac{\left(Y_i - \hat{Y}_i\right)^2}{\left(Y_i - \bar{Y}\right)^2} \tag{3}$$

where R^2 is the determination coefficient, which is defined as the percentage of the total change in the dependent variable that can be explained by changes in the independent variable. $\hat{Y}_i$ is the estimated value of the dependent variable; $\overline{Y}$ is the mean value of the dependent variable; Y_i is the observed value of the dependent variable; and n is the number of sample observations.

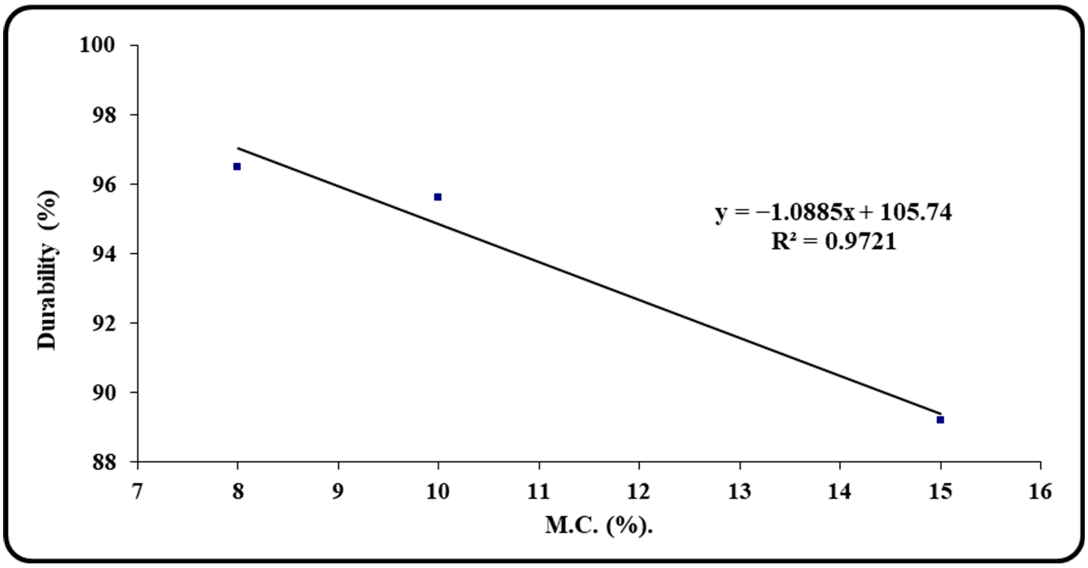

Figure 7. Relationship between briquette durability (%) and moisture content (MC%).

3.3. Loose Materials Density

The moisture content of wood is an important factor influencing its physical and mechanical behavior. Almost all mechanical properties of wood increase as MC decreases [42,47]. In this context, it was necessary and important to study the effect of moisture on the density of the branches of *Ficus nitida* trees, after milling them in the form of loose material as well as after converting them into briquettes. The density of the loose material with an 8% moisture content after milling reached an average value of 0.18 g·cm^{-3}. Increasing the moisture content increased its density. As a result, raising the moisture content to 10% elevated the density of the loose material to 0.21 g·cm^{-3}. As such, raising the moisture content to 15% raised the loose material density value to 0.27 g·cm^{-3}. The relationship between the loose material density and moisture content is presented in Figure 8. It indicates that the loose material density increases linearly with the increasing moisture content of up to 15%. This linear relationship is represented in the regression Equation (5) with R^2 = 0.964.

$$y = 0.045x + 0.13 \quad (4)$$

where (y) is the predicted value of the loose material density, and (x) is the moisture content value.

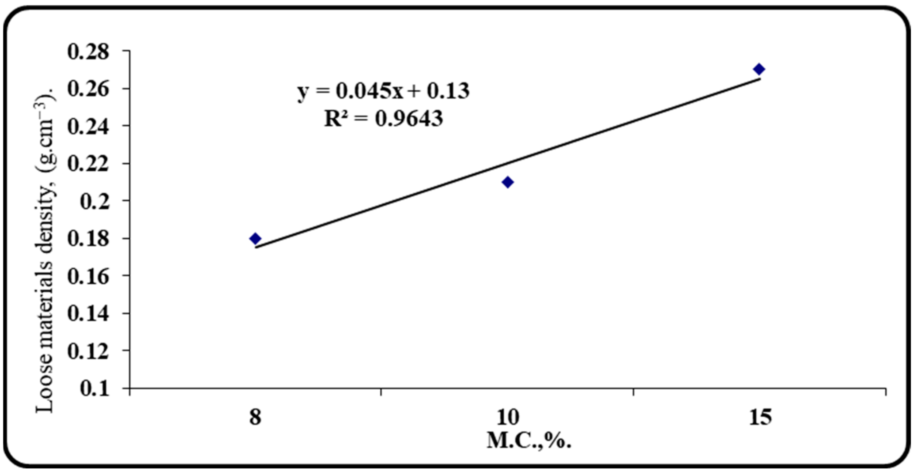

Figure 8. Relationship between loose material density (g·cm^3) and moisture content (MC%).

3.4. Briquettes Density

Regarding the briquette density, a direct correlation between a briquette's moisture content and its density was observed, as mentioned by Saeed et al. [47] and Antwi-Boasiako and Acheampong [42]. The pressed loose material with an 8% moisture content produced briquettes with a density of 1.21 g·cm^{-3}, while the average value for the pressed material with a 10% moisture content was 1.25 g·cm^3. Raising the moisture content to 15% increased the density to 1.61 g·cm^{-3}. The relationship between the briquette density g·cm^{-3} and moisture content is also presented in Figure 9. The graph shows that the briquette density increased from 1.21 to 1.61 g·cm^{-3} with the increasing moisture content from 8 to 15%. The relationship between the moisture content and briquette density was linear and can be represented with regression Equation (5) with R^2 = 0.824.

$$y = 0.2x + 0.9567 \quad (5)$$

where (y) is the predicted value of the briquette density, and (x) is the moisture content value.

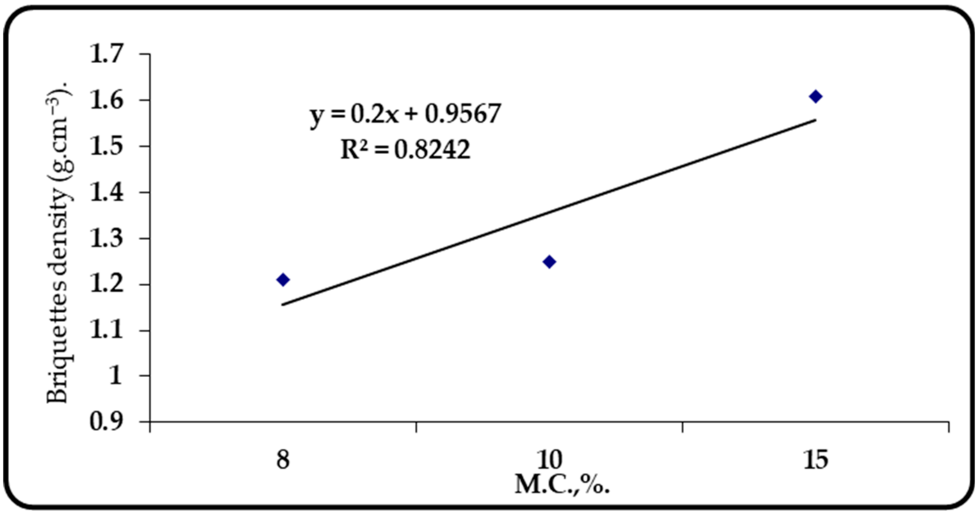

Figure 9. Relationship between briquettes density (g·cm^{-3}), and moisture content (MC%).

Figure 10 shows a comparison of the densities of loose materials and briquettes.

Comparing the density value of the loose material (g·cm^{-3}) and the briquette density (g·cm^{-3}) with an 8% moisture content, it is clear that 0.18 tons of loose material can be stored in 1 m^3, while 1.2 tons of briquettes can be stored in the same volume. Hence, 1 m^3 can contain approximately 6.7 more briquette weight compared to loose material with an 8% moisture content. Alternatively, 1 ton of briquettes occupies approximately 0.83 m^3 compared with 5.5 m^3 for loose material. Accordingly, storing 1 ton of briquettes occupies only 15% of the space needed for storing 1 ton of loose material. This is very economical because it can save storage and transportation costs. This agrees with the research of several authors such as Okot et al. [44], Theerarattananoon et al. [48], Kaliyan et al. [49], and Kaliyan et al. [50]. They stated that biomass has a low density, making it difficult to handle, transport, and store, while biomass densification into briquettes increases its density.

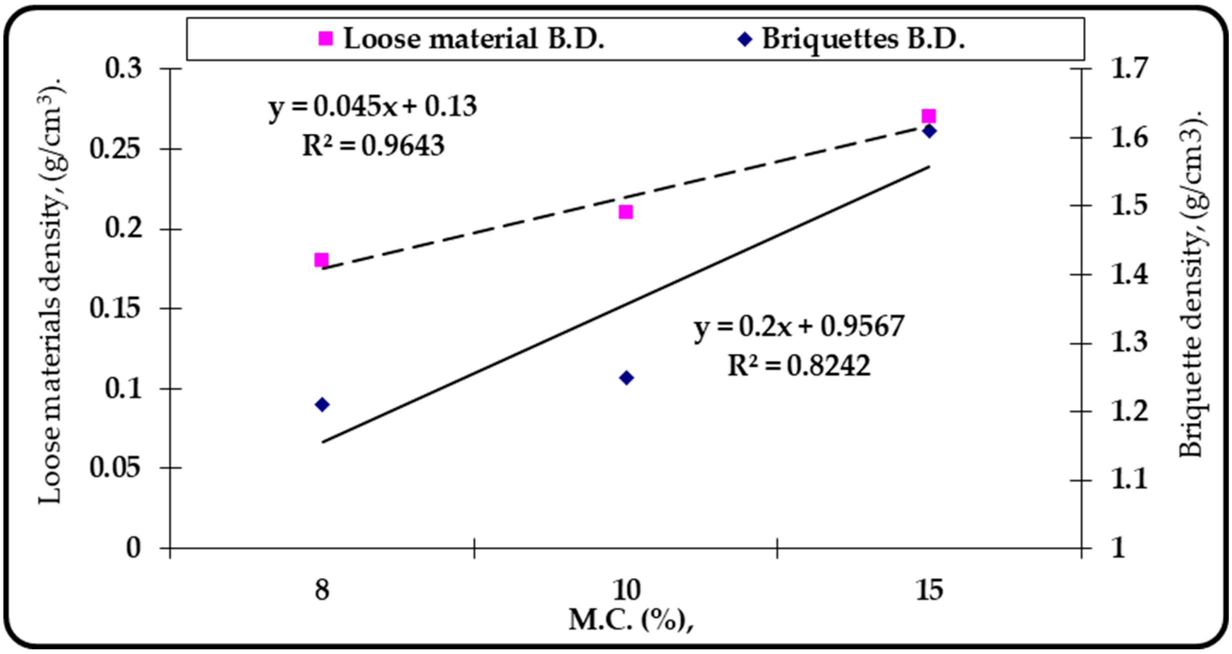

Figure 10. Relationship between loose material density, briquette density (g·cm^{-3}), and moisture content (MC%).

3.5. Briquette Compressive Strength

The quality of the densified biomass depends on several process variables, such as die diameter, die temperature, pressure, usage of binders, and preheating of the biomass. High temperature and pressure, which are normally encountered during the densification process, soften the lignin and improve the binding ability of the biomass. Its low melting point (140 °C) allows lignin to actively participate in the binding phenomenon and show thermosetting properties [51]. Briquette compressive strength is defined as the maximum load a briquette can withstand until it crashes. It is an essential parameter for storing, transporting, and handling briquettes. Biomass is chemically formulated from lignocellulose materials, which increases the strength of briquettes. As one of these materials, lignin works as a glue and strengthens the bonding properties of briquettes. In addition, raising the briquetting process temperature to approximately 170 °C softened the lignin and improved briquette strength. The results indicate that the average measured value of briquette compressive strength was 18.5 MPa for those pressed with an 8% moisture content. Increasing the moisture content of the pressed material to 10% decreased the briquette compressive strength value by approximately 17.6%. The briquette compressive strength decreased to 15.8 MPa when the average moisture content of the processed briquettes increased to 15%. As presented in Figure 11, raising the moisture content of the briquettes decreased their compressive strength. Any further increase in the moisture content will form briquettes with large cracks, which means they will be unstable and not solid enough to handle, transport, and store. The value of the briquette compressive strength can be derived using linear Equation (6) with R^2 = 0.9973.

$$Y = 0.3808x + 21.488 \quad (6)$$

where (y) is the predicted value of the briquette's compressive strength, and (x) is the moisture content value.

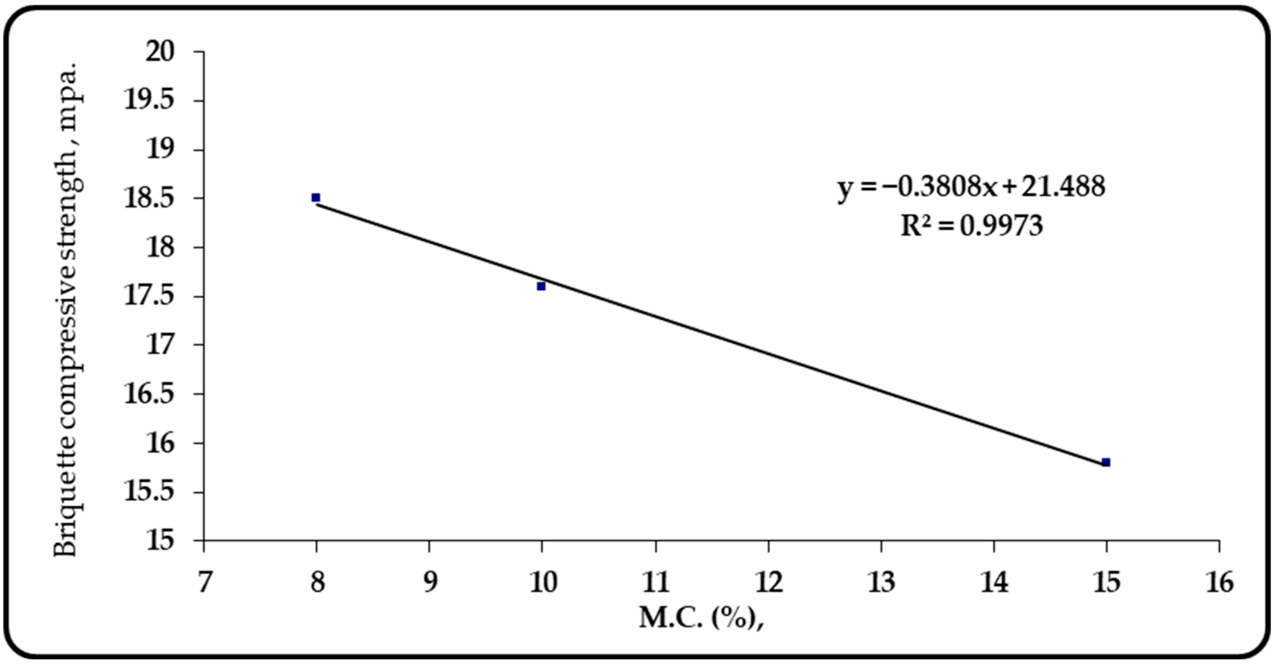

Figure 11. Relationship between briquette moisture content (MC%) and briquette compressive strength.

3.6. Briquette Calorific Values

The calorific value is an essential characteristic of any biomass fuel; it can be an indicator of the market situation for biomass fuel [42]. The calorific value of a briquette depends on several factors, such as the temperature of the press and the particle size [34,52,53]. High carbon values also promote better heating values, as mentioned by [47]. According to Tumuluru and Wright [34], woody materials have calorific values ranging from 17 to 18 MJ/kg. Following this statement, our results indicate that the highest calorific value for pressed briquettes with an 8% moisture content was 3250.7 Kcal/kg (17.38 MJ/kg). This may be due to their low moisture content and because most of the briquettes are non-porous. As a result, the carbon ratio in the woody material was intensified, increasing the calorific value of the briquettes. Furthermore, the results indicate that pressed briquettes with a 10% moisture content had a calorific value of 3812.02 Kcal/kg (15.59 MJ/kg). By increasing the moisture content to 15%, the measured calorific value of the briquettes decreased to 3635.42 Kcal/kg (15.22 MJ/kg). This implies that a briquette's calorific value decreases as its moisture content increases. This allows briquettes to be used as an energy source in many sectors, including domestic household energy and energy-intensive industries, such as cement and steel factories. According to Figure 12, the calorific value of the briquettes increased linearly with the increasing moisture content up to 15%. The linear relationship between the moisture content of briquettes and their calorific value can be expressed using regression Equation (7) with an R^2 of 0.6762.

$$y = 0.2635x + 18.961 \quad (7)$$

where (y) is the predicted calorific value of the briquettes, and (x) is the moisture content value.

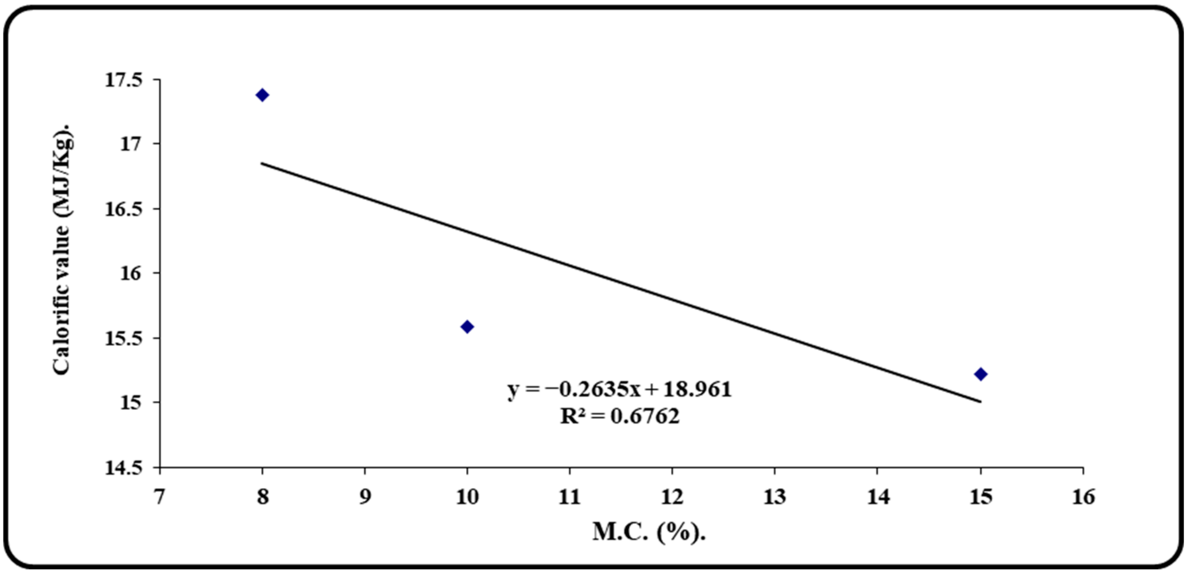

Figure 12. Relationship between briquette moisture content (MC%) and calorific value.

4. Conclusion

The world has been in search of new renewable energies and alternative energies due to expecting the imminent depletion of fossil fuels, the use of which causes significant environmental pollution. In addition, there have been attempts to avoid the use of nuclear energy because of its dangers. These new energies are often available locally, such as solar or wind energy. The abundance of agricultural waste and biomass may cause problems for the environment; however, simple technology is required to convert them into environmentally friendly biofuels.

This study provides an in-depth evaluation of briquettes produced from the pruning residuals of Ficus nitida trees with particular consideration for the impact of the residuals' moisture content. This provides a safe and profitable method of recycling the large quantities of waste produced in the pruning process.

Because this is a pioneering work, it was necessary to judge the briquettes' features to use them as fuel. Therefore, their properties, such as moisture content, density, durability, and strength were studied. Their calorific values were also calculated. The results indicate that the produced briquettes are suitable for use as a biofuel; however, further studies are required to characterize more aspects of the residues that are produced yearly in vast quantities to recycle them into other economic and environmentally friendly products.

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