

Article

Valorization of Vine Tendrils Resulted from Pruning as Densified Solid Biomass Fuel (Briquettes)

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Abstract: Concerns over the past few decades have focused, more than ever, on finding and implementing efficient, handy, and renewable sources to reduce pollution. Biomass, in general, and biomass from annual vine cuttings, are renewable sources that can be used by a large amount of the population. Biomass densification in the form of briquettes is an efficient method of obtaining a biofuel with the same characteristics as wood. The production of densified material as a briquette consists of sampling, drying naturally, chopping, grinding and briquetting the vine cuttings. The obtained results showed that the size of the briquettes met the requirements imposed by the standard, with a length between 185 mm and 400 mm and a diameter of 58 ± 0.75 mm, the humidity of the briquettes varying between 5.42%, at Sauvignon Blanc and 7.98% for Pinot Noir, while the durability of the briquettes registered minimum values of 98.17% for Muscat Ottonel and a maximum of 99.14% for Feteasca Neagra, and a unit density with values between 1227 kg/m³ for Feteasca Alba and 1389 kg/m³ for Pinot Noir. The conclusions of these experiments are promising, showing that the densification of biomass from vines cuttings qualifies within the standard requirements for obtaining a valuable biofuel.

Keywords: briquettes; renewable energy; vine tendrils biomass; densification



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1. Introduction

In recent decades, the dependence on fossil fuels has become critical due to several factors: the continuous growth of population, urbanization, depletion of oil reserves, continuous increase in oil price, global warming. Non-renewable fuel (coal, natural gas, coal)-dependent industries have caused a dramatic increase in greenhouse gas emission effects and this has resulted in high levels of environmental pollution [1–5]. This crisis has stimulated the use of renewable energy resources like solar, wind and geothermal energy, biomass, and agricultural wastes. These energy sources are available anywhere and are well known as alternative energy resources; in the meantime, they are an ecological solution for energy production [2,4,6–9]. This clean and inexhaustible energy has the potential to reduce environmental pollution; nevertheless, its full potential is yet unattained due to manipulation, transportation, storage and combustion-related problems [10].

The EU directive concerning renewable energy (2009/28/CE) has set common objectives for the EU member countries, aiming for renewable energy to represent 30% until 2030. This European treatise promotes a series of initiatives in all the sectors, aiming for the EU to reach climate neutrality until 2025 [11]. The use of biofuels resulting from perennial crops, which may be converted to solid fuel, will certainly help the EU reach this goal.

Solid biomass, represented by wastes from different industries, is the main renewable energy resource in the EU and, according to the Solid biomass energy barometer EurObserv'ER 2020, there was a 102.6 Mtep increase in 2019 compared to 2018, which is probably due to the significant increase in the electric energy production of several countries. The production of electric energy from biomass, in EU 28, was estimated at 106 TWh in 2019, which represented a yearly increase of 5.8% (5.8 TWh) [12]. Nevertheless, biomass is mainly used for the production of heat; 80.4 Mtep was used in 2019 for heating, with a 1.2% increase in heat produced from biomass (11.5 Mtep), mainly due to some new heat and energy production units becoming operational in Holland, France, Finland and Denmark.

The most significant increases in the consumption of fuel from solid biomass were recorded in countries with high levels of electricity consumption: Great Britain (509 ktep), Holland (354 ktep), Poland (320 ktep), Sweden (272 ktep), Czech Republic (267 ktep), Germany (131 ktep) and Finland (125 ktep). The barometer also mentions that the wooden pellet consumption continued to increase in 2019 in EU 28, with a supplemental consumption of 1.8 mil. tons (representing a 6.8% yearly increase), reaching 27.7 mil tons [12].

Biomass has different advantages as it is easy to find, cheap, has a neutral CO₂ characteristic and is widespread [13,14]. Although fuels from biomass are used worldwide, in low-income countries they are directly burned, which presents immediate health dangers, has negative effects on the environment and perpetuates poverty. The use of biomass in its natural state has several disadvantages: low density, lower calorific value per unit of volume, high moisture content compared with the initial material and high ash content especially in biomass containing large amounts of bark [15]; moreover, its use imposes supplementary precaution measures because of the high pollution potential [16].

Considering the issue of reducing air and soil pollution resulting from the combustion of biomass, the use of combustible biomass briquettes is worth taking into account; the heating value (HV) of the briquettes (as defined in the ISO 18125 standard) may increase by 2–5% through torrefaction before briquetting [17], they do not produce smoke when burned and are advantageous from an economic point of view.

The production of briquettes is based on a set of mechanical technologies (screw-type press, rollers type press, piston press—mechanically or hydraulically driven—or manually operated press) in order to convert the vegetable biomass (from different crops) in a uniform and compacted fuel, with a higher density and energy content and lower moisture content compared with the raw material [18–23]. Water acts as a binding and lubrication agent and its presence in biomass favors the gelatinization of starch, denaturation of proteins and the process of fiber solubilisation during briquetting [24]. On the other hand, raw biomass is inclined to absorb humidity from the environment due to its fiber structure and to the presence of hydroxyl groups in polysaccharides [25]. Different studies recommend a moisture content between 5% and 12%, depending on the nature of biomass. A higher humidity content diminishes the thermal efficiency and combustion velocity because more energy is consumed in order to remove moisture. A wet fuel will lead to increased smoke emissions and creates the risk of explosion. Another disadvantage of the high moisture content is that it favors the reproduction of harmful microorganisms. In order to obtain good quality briquettes (in terms of density and long-term storage properties), the moisture content should not be lower than 4% because, otherwise, the briquettes become fragile [26–29].

Leaving apart the issue of biomass being available in large quantities, it has to comply with specific requirements during storage; numerous studies have concluded that a moisture content lower than 15% inhibits the microbial anaerobic activity and allows the safe long-term storage of biomass [30].

The principle of briquette formation implies applying high pressure and temperature over the biomass; thus, the cellular structures liberate lignin, which bonds the individual particles in a compact densified unit [10,31,32].

Generally speaking, briquetting is a pressure-assisted compaction method for powder or granular type materials, with or without bonding substances, resulting in briquettes

with specific geometrical shapes (usually rectangular or cylindrical); the raw material, broken into small pieces, is compacted in a reciprocating piston type press (mechanically or hydraulically actuated) or in a screw-type press [33–35].

Briquettes differ very much in size and shape, but they are usually cylindrical, with a diameter between 25 mm and 100 mm and a length between 10 mm and 400 mm. Briquettes may be produced with an average density of 1200 kg/m³ and a bulk density of 100 to 200 kg/m³; a higher density results in a higher HV (MJ/kg) and a slower combustion process compared to the raw materials. Bulk density is defined as the ratio of the mass of a certain number of briquettes with the same length, placed without any free space between them, and the occupied volume [35–37].

The briquette production process starts from the raw material (chopped vine tendrils in the present study) in the following sequence: harvesting, biomass preparation (chopping, drying, etc.), briquetting, cooling and packaging.

Briquetting is achieved by pressing the biomass in a calibrated die, having a round or square cross-section, using a mechanical or hydraulically actuated piston (hence the name of hydraulic or mechanic briquetting). As a general rule, the briquetting machines do not require the raw material to be broken into excessive small parts; the length of the chopped material should be under 50 mm, but high-quality briquettes are obtained from biomass with a length of 4 to 68 mm. The moisture content of biomass may be comprised between 6% and 15%, but $10 \pm 2\%$ is considered to be the optimum value [37,38].

Briquetting is achieved through a continuous process, when the screw type press is used, or in a discontinuous process when a reciprocating piston is used. The shapes and names of the briquettes depend on the pressing process and the press manufacturer, e.g., *Nestro*, *Nielsen*, *Pini-Kay* or *Ruf* briquettes. In order to obtain *Pini-Kay* briquettes (the ones used in this study), the pressing screw ends with a tronconical head [33].

Screw extrusion briquetting machines are convenient for the low-scale production of briquettes. The briquettes have better combustion characteristics due to a larger specific surface; the briquettes are homogenous and less prone to disintegration and superior quality of the final product [23].

Different literature studies state that briquettes produced from biomass may reach a density of 1200 kg/m³ from free biomass, with an average bulk density of 100 to 200 kg/m³; a higher density leads to a higher HV of the briquettes (MJ/kg), with a slower combustion process in comparison with the raw materials [37–39]. Regarding the potential of biomass from vine tendrils, this is quite high as pruning operations are frequently performed, resulting in large quantities of biomass without high energy inputs and at low operational costs [40,41].

The wine regions of Romania have an ideal climate for wine grapes; to date, there are approximately 1300 companies that grow grapes and produce wine, especially in Vrancea, Bucharest, Prahova, Arad and Iași. Vine wastes that result from the pruning of tendrils are usually burned, thus contributing to global warming through the emission of greenhouse gases [40,42,43].

The International Organization for Vine and Wine publicly announced, at a conference that took place on 23 April 2020, that the surface of the worldwide vineyards represents 7.4 mil. hectares [44]. At the EU level, the vineyards cover 3.2 mil hectares (according to data from 2017), thus representing 45% of the overall surface. Romania covers 5.7% of the overall cultivated area in Europe, with 183.717 ha of vineyards and an average of 0.2 ha/farmer [44]. These data prove the tremendous potential for the use of vineyard residues as biomass.

This study aimed to investigate the production of briquettes from vine tendrils resulted from pruning and their quality characterization.

2. Materials and Methods

The experiments aiming to design the technology for producing densified biomass in the form of briquettes comprised collecting the vine tendrils, their storage and natural

drying and were performed in the vineyard plantation located at the “Vasile Adamachi” farm, belonging to the University for Life Sciences Iași; the plantation is part of the Copou Vineyards, located near the city of Iași.

The vineyard covers 12.48 hectares and comprises grape varieties for the production of quality white and red wines.

The technological process for producing briquettes comprised the following operations (Figure 1): dormant pruning of vine; tendrils collection and transport; storage and natural drying; coarse and fine chopping of the tendrils; sieving and separation of the particles bigger than 8 mm or smaller than 3.15 mm; briquetting, cooling, conditioning and packaging.

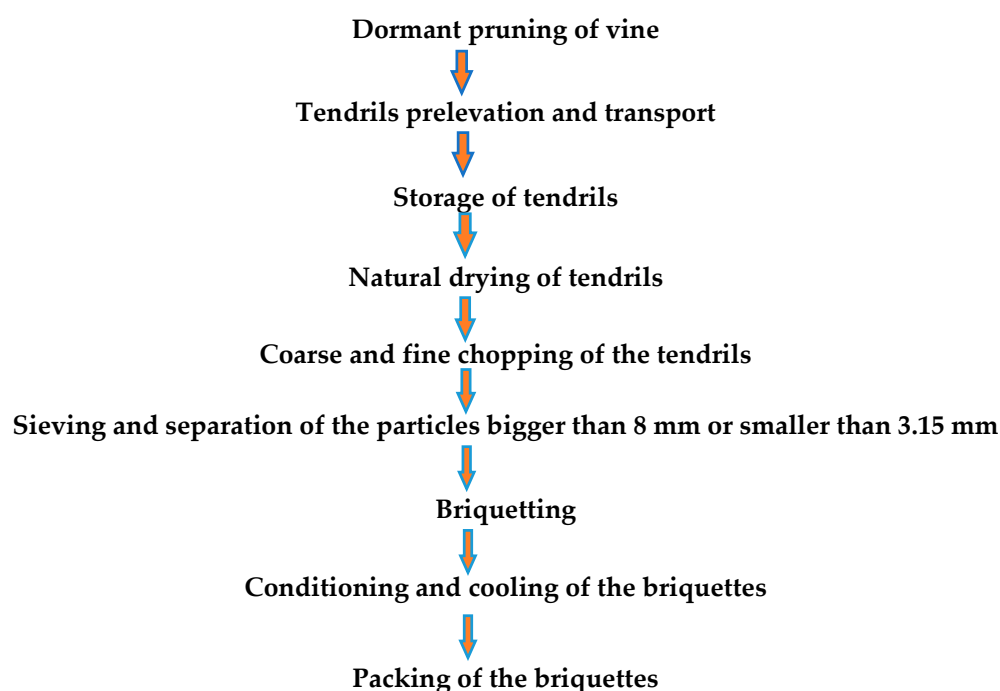


Figure 1. The technological process for producing the briquettes from vine tendrils.

2.1. Collecting the Tendrils

The biological material for producing the briquettes was collected from the tendrils belonging to eight vine varieties: Feteasca Neagra, Feteasca Alba, Feteasca Regala, Muscat Ottonel, Pinot Noir, Cabernet Sauvignon, Sauvignon Blanc and Busuioacă de Bohotin.

The tendrils were cut using a manual scissor and were temporarily stored at the end of the respective plots, where they were labeled according to the vine variety.

2.2. Collecting and Transporting the Tendrils

The tendrils were collected from each of the twelve plots, from five vines placed on the first, middle row and last row of each plot; the tendrils were taken from the middle section of each row. For each variety the average mass of collected tendrils was 60 kg; the tendrils were then transported with a trailer to the designated storage and drying area.

2.3. Storage of Tendrils

Exposure to sun and wind, permanent or temporary covering and a constant flow of air are the basic elements for passive drying. The drying time depends on both the material (shape, dimensions, wood density, the presence of bark) and storage conditions (storage and stacking method, flow of air, temperature, humidity, etc.). In this study the chosen storage area ensured optimum drying conditions; the tendrils were deposited in both open and covered spaces, depending on the meteorological conditions, exposed to sun and wind from March to July.

2.4. Natural Drying of Biomass

For this study, biomass was dried through storage under an awning for 90 days, with continuous monitoring of the moisture content, until the water content reached 8–10%.

The moisture content was monitored to ensure the appropriate physical and mechanical characteristics of the solid biofuel, depending on the particle size, properties of the raw material and parameters of the densification process.

2.5. Coarse and Fine Grinding of the Tendrils

Grinding of the biomass is a preparatory and mandatory operation before briquetting. In our study, grinding was performed in two stages: coarse and fine grinding. It should be mentioned that, when briquettes are produced from particles bigger than 8 mm, their mechanical durability (DU) is low and more ash results when burned, due to the quick combustion process. In this study the tendrils were ground, after drying, using the Caravaggi BIO 90 shredder (Cravaggi, Pontoglio, Italy). This is new generation equipment for grinding vegetable and organic wastes and has a double chipping and shredding system: the first, formed by two chipping blades, serves for chopping up wooden and fiber products such as wood, linden and willow slash, etc.; the second features six reversible mobile hammers and shreds products such as leaves, hedges, soil, kitchen waste, etc. The shredder may be equipped with its own spark ignition engine (Honda GX390, 13 HP, Minato, Tokyo, Japan) or may be coupled to the tractor's PTO, which was the case in our study. Some of its characteristics are as follows: operating capacity: 6–7 m³/h; maximum diameter to be cut: 80 mm; width: 700 mm; height: 1520 mm; mass: 135 kg; hinged feeder chute; rotor diameter: 340 mm. The shredder was operated by a 50 HP Goldoni tractor and it was equipped with two different sieves: one with 15 mm orifices in diameter, for coarse grinding, and the second one with orifices with a diameter of 10 mm, for fine grinding. The resulting grinded material was collected in separate bags (Figure 2).



Figure 2. Operating the CARAVAGGI BIO 90 shredder used for coarse and fine grinding of the biomass.

It should be noted that the use of the second sieve (with 10 mm orifices) results in a final material with an increased proportion of particles with diameters smaller than 3.15 mm, which is detrimental for the briquetting operation.

After grinding, the granulometric structure of the resulting material was evaluated; in order to achieve this operation, samples were collected according to the requirements of the ISO 18135 (2017) [45] standard for solid biofuels; the volume of each sample was 8 L. In order to separate the granulometric fractions, a laboratory sieving equipment was used (Figure 3); according to the ISO 3310-2 (2013) [46] standard, the diameters of the orifices of the sieves were 3.15 mm, 8 mm, 16 mm, 31.5 mm, 45 mm and 63 mm, respectively.

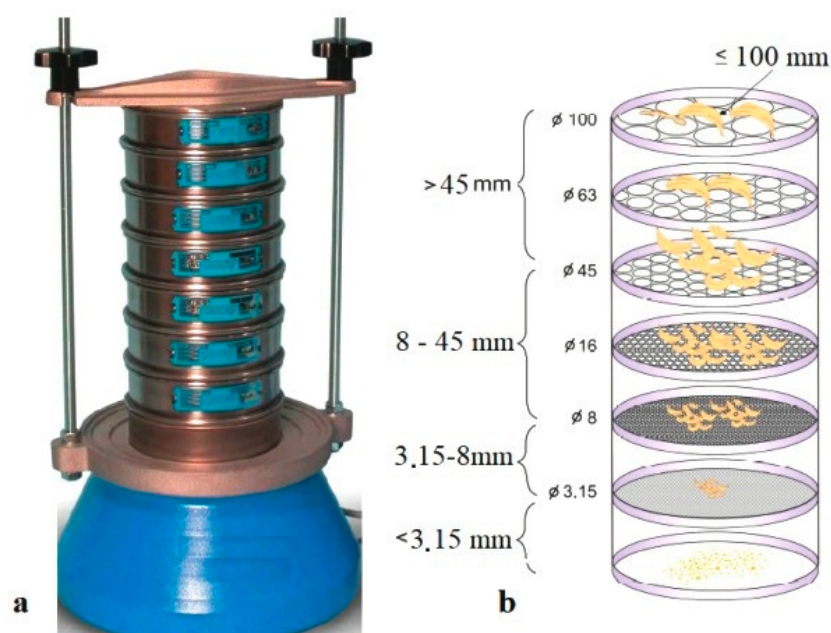


Figure 3. Equipment for the granulometric separation of ground tendrils: (a)—general view; (b)—sieves.

2.6. Sieving and Separation of the Particles Bigger Than 8 mm or Smaller Than 3.15 mm

After the biomass was ground, it was sieved in order to obtain only particles with dimensions between 3.15 and 8 mm. This operation was performed with a mechanical sieving machine (Figure 4), equipped with three sieves with orifices with diameters of 3.15 mm, 8 mm and 16 mm, respectively. The existing biomass was thus divided into four categories: (i) material with particles smaller than 3.15 mm was used for producing pellets [39]; (ii) material with the dimensions of the particles comprised between 3.15 and 8 mm, which was used for producing briquettes; (iii) material with the dimensions of the particles comprised between 8 and 16 mm was ground again and (iv) material containing particles bigger than 16 mm was shredded and ground.

2.7. Briquetting of the Ground Tendrils

In this research, *Pini-kay* briquettes were produced using the GCBA-1 (Figure 5) screw-type briquetting machine.

This equipment may be used for the densification of mixtures with different granulations, obtained by grinding biomass from coniferous trees, poplar trees, oak trees, birch trees, weed crops, etc. The main characteristics of the briquetting machine are as follows: screw rotational speed: 373 rev/min; power consumption: 23 kW; power of the electric motor: 18 kW; power of the electric heater: 5 kW; maximum length of the particles to be densified: 8 mm; density of the ground biomass to be compacted: 0.5–0.8 kg/dm³; raw material moisture content: 10–14% and weight: 580 kg.

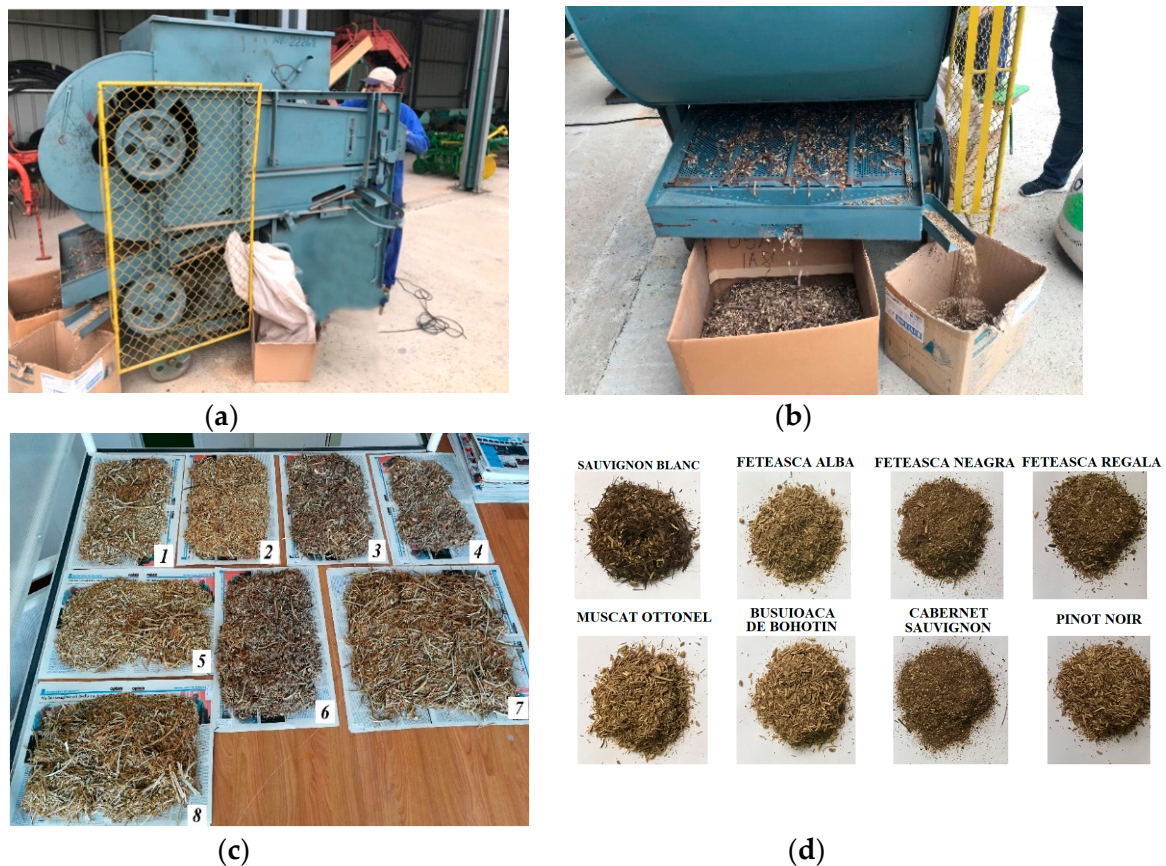


Figure 4. Sieving of the ground tendrils: (a,b)—sieving machine; (c)—grinded tendrils, before sieving; (d)—grinded tendrils, ready for briquetting.

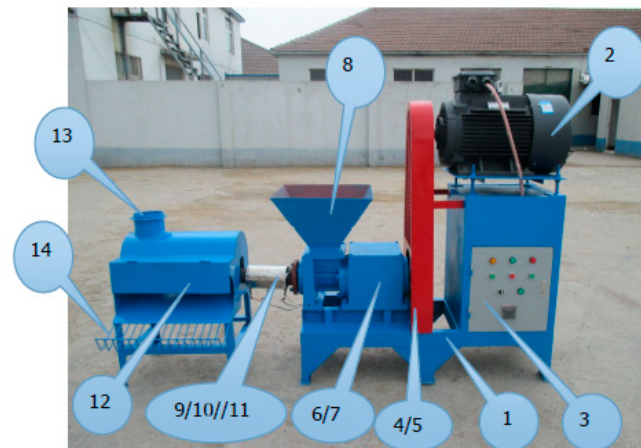


Figure 5. Briquetting machine: 1—frame; 2—electric motor; 3—electric panel; 4, 5—belt transmissions; 6, 7—bearings and main shaft; 8—feeding chute; 9, 10, 11—electric heater, screw and profiled densification chamber; 12—briquettes discharge device; 13—smoke discharge; 14—briquettes cooling grate.

The densification contraption (Figure 6) is composed of a pressing chamber (b) and a tronconical screw (a), ending with a cone-shaped tip.

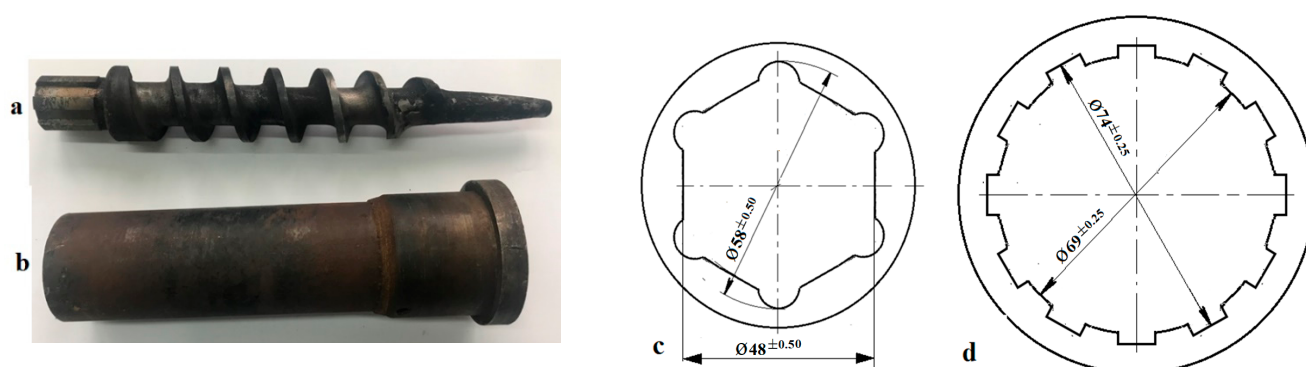


Figure 6. Active parts of the densification device: (a)—triconical screw; (b)—pressing chamber; (c)—cross-section of the briquettes discharge die; (d)—inlet cross-section of the pressing die.

The pressing chamber is composed of two dies, with different profiles of the inner surface. The first die, placed in the feeding area, has a tronconical fluted shape (starting with 12 splines, Figure 6d, and ending with six splines) and it allows the transit and compression of biomass. The inner surface of the second die has a hexagonal shape with rounded corners (Figure 6c) and it is aimed to give the final shape of the briquettes. It should be mentioned that the spaces between the splines of the first die are continued by the semispherical cavities in the second die. Before starting the briquetting process, the device was heated at 170 °C–180 °C using its electric heater. The equipment has a temperature monitoring device in order to set and adjust the briquetting temperature.

During the operating process, the biomass is taken by the tronconical screw and then densified in the profiled dies. The densified biomass is continuously discharged (Figure 7a) and is then cut into fragments with a length of 200, 300 or 400 mm (Figure 7b).

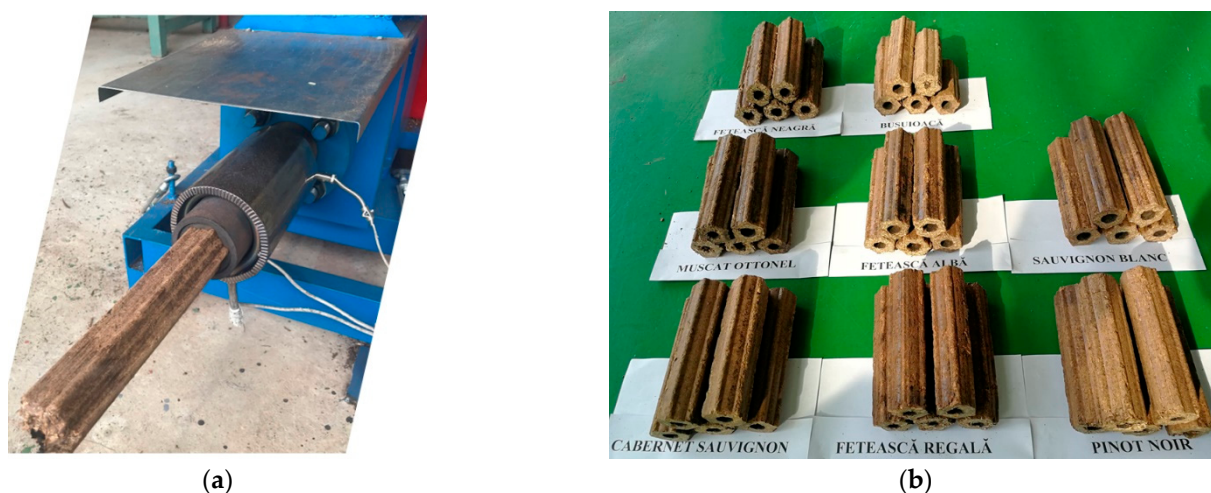


Figure 7. Briquettes from vine tendrils: (a)—briquetting machine; (b)—briquettes produced from the studied varieties.

2.8. Methods and Equipment for the Assessment of Quality Indices

After performing the densification of the ground tendrils, the following quality indices of the briquettes were evaluated: length and diameter, moisture content, briquetting coefficient, DU, bulk density, volumetric density and calorific value.

2.8.1. Dimensions of the Briquettes

Depending on the equipment, the biomass briquettes may have different shapes and dimensions. The ISO 17225-7 (2014) [47] takes into account seven shapes and provides values for the diameter (D) and length (L_1). The standard defines seven dimensional classes: (i). D 40, with $25 \leq D \leq 40$; (ii). D 50, with $D \leq 50$; (iii). D 60, with $D \leq 60$; (iv). D 80, with

$D \leq 80$; (v). $D 100$, with $D \leq 100$; (vi). $D 125$, with $D \leq 125$; (vii). with $D 125+$, $D > 125$. As far as the length is concerned, the same standard defines six classes as follows: (i). $L 50$, with $L_1 \leq 50$; (ii). $L 100$, $L_1 \leq 100$; (iii). $L 200$, $L_1 \leq 200$; (iv). $L 300$, $L_1 \leq 300$; (v). $L 400$, $L_1 \leq 400$; (vi). $L 400$, $L_1 > 400$. In the present study the following dimensions of briquettes were measured (Figure 8), ISO 17829 (2015) [48]: maximum diameter (D), diameter of the hexagon inscribed circle (d_1), diameter of the orifice (d_2), width (b) and length (L_1).

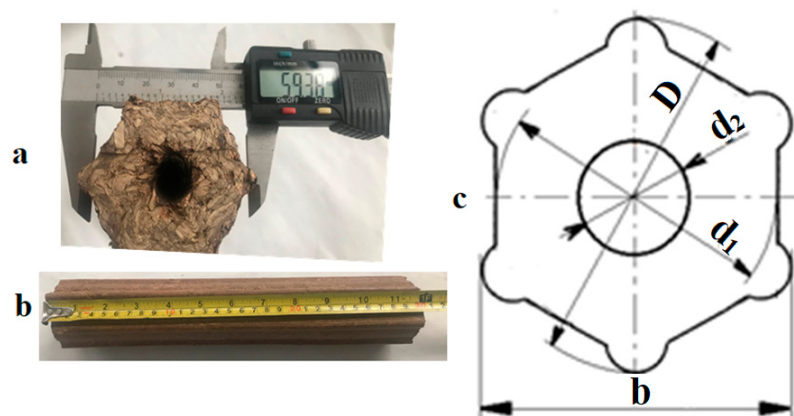


Figure 8. Dimensions of the briquettes: (a)—cross-section measurement; (b)—length measurement; (c)—cross-section dimensions.

2.8.2. Evaluation of Moisture Content

The thermal balance method was used in order to evaluate the moisture content of the raw material, ground matter and briquettes, using the AGS 210 moisture analyzer (Figure 9). The method is based on the evaporation of water from the heated sample ($105\text{ }^{\circ}\text{C}$), under intensified air circulation; the drying process was considered to be complete when the mass of the sample remained constant.



Figure 9. The equipment used for measurement of moisture content.

2.8.3. Coefficient of Briquetting

The briquetting coefficient was calculated as a percentage of biomass converted into briquettes from the overall quantity of biomass ground for densification. The briquetting coefficient was evaluated for different moisture contents of the vine tendrils used in this study: 6–10%; 10–12%; 12–15% and also for two cases:

- sieved ground tendrils, with the dimensions of the particles comprised between 3.15 and 8 mm;
- non-sieved ground tendrils, containing particles smaller than 8 mm.

It should be mentioned that an energy-efficient densification process requires values higher than 90% for the briquetting coefficient.

2.8.4. Evaluation of the Mechanical Durability of the Briquettes

Mechanical durability represents the property of densified solid biofuels to withstand exterior forces and shocks during maneuvering/transportation. The DU was evaluated according to ISO 17831-2 (2015) [49], using the equipment shown in Figure 10; the test drum (1) has a volume of 160 dm³ and has an interior baffle, while the interior surface is smooth. The dimensions of the drum are: inner diameter—598 ± 8 mm; length—598 ± 8 mm. The baffle has a rectangular shape and is placed on the generating line of the interior cylindrical surface; the height of the baffle is 200 ± 2 mm and has a length of 598 ± 8 mm.

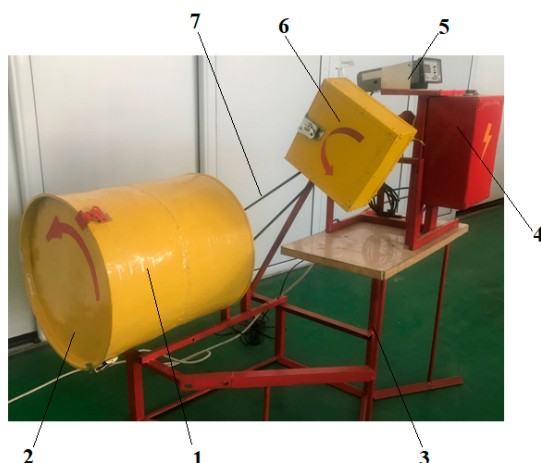


Figure 10. Mechanical durability measurement equipment: 1—rotating drum; 2—cover; 3—frame; 4—electric panel; 5—revolutions counter; 6—electric engine and gear transmission; 7—belt transmission.

During the tests, the drum was rotated with a speed of 21 ± 0.1 rev/min by the means of an electric engine, a planetary gear and a belt transmission; a revolutions counter (5) was used in order to measure the total number of revolutions and the rotation speed of the drum.

The samples for testing were weighted with an electronic scale (precision 0.1 g), were placed inside the rotating drum and the cover was closed. The drum was rotated at 21 ± 0.1 rev/min for a total number of 105 ± 0.5 revolutions. The remainings of the briquettes were discharged from the drum, sieved on a 45 mm sieve and weighted again. The DU was calculated using Equation (1):

$$DU = \frac{m_A}{m_E} \times 100 \quad (1)$$

where m_A is the initial weight of the briquette and m_E is the final weight.

In order to evaluate the bulk density 20 briquettes were stacked in order to form a block (Figure 11) and their dimensions (length, width, height) were measured. The bulk density was calculated as the ratio between the mass and volume of the stack.



Figure 11. Evaluation of bulk density of the obtained briquettes.

2.8.5. Evaluation of Briquettes Density

The unit density of the briquettes was determined using a graduated cylinder (62 mm in diameter, 440 mm in height) and an electronic scale with a precision of 0.01 g. First, the cylinder filled with 500 mL of distilled water was weighted (Figure 12a); then the briquette was immersed into the cylinder and the displaced water volume and weight of the cylinder were measured. The unit density was then calculated using Equation (2):

$$\rho_p = \frac{m_b - m_a}{V_a} \quad (2)$$

where m_a is the initial mass of the cylinder, m_b is the mass of the cylinder with the briquette immersed into the water and V_a is the displaced volume of water.

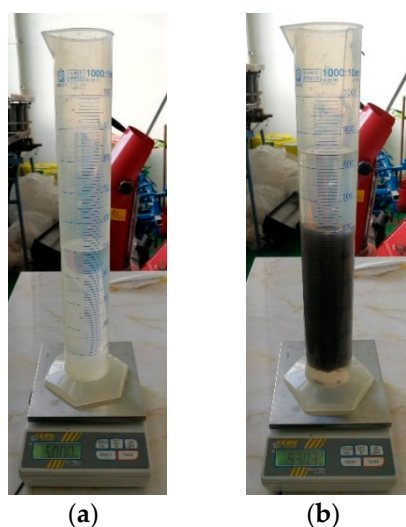


Figure 12. Evaluation of unit density of the obtained briquettes (a)—before the immersion of the briquette; (b)—after the immersion of the briquette.

2.8.6. Determination of the Heating Value

The higher heating value (HHV) was determined with a 6200 Isoperibol calorimeter (Parr Instrument, Moline, IL, USA), calibrated by combustion of certified benzoic acid. The dried biomass was analyzed as given in the ISO 18125 (2017) method [50]. The weighted sample containing 0.4 g biomass and 0.6 g benzoic acid was placed in the sample holder of the bomb. The bomb was assembled, filled with oxygen for 30 s at a pressure of 400 psi,

and placed in the calorimeter. The sample was burned under controlled conditions for 15 min (the temperature was recorded during combustion). The lower heating value (LHV) was obtained by calculation, taking into account the moisture, hydrogen and ash content of the samples.

3. Results and Discussion

3.1. Grinding of the Vine Tendrils

Grinding of the biomass is a preparatory and mandatory operation before briquetting, aiming to produce technological fractions with optimum dimensions. Table 1 presents the experimental results regarding the dimensions of the particles that resulted in the two grinding stages (coarse and fine grinding).

Table 1. Results regarding the grinding of the vine tendrils.

Vine Variety	Moisture Content of Tendrils (%)	Grinding Operation	Fractions (%)			
			>45 (mm)	45–8 (mm)	8–3.15 (mm)	<3.15 (mm)
Pinot Noir	9.48	Coarse grinding	18.7	32.9	46.80	1.60
		Fine grinding	-	2.33	93.89	3.78
Muscat Ottonel	8.76	Coarse grinding	17.63	34.72	45.78	1.87
		Fine grinding	-	3.52	92.86	3.62
Feteasca Neagra	9.05	Coarse grinding	18.12	32.93	52.78	1.73
		Fine grinding	-	3.36	93.46	3.18
Feteasca Alba	7.99	Coarse grinding	16.92	33.69	52.73	2.12
		Fine grinding	-	2.33	94.05	3.62
Feteasca Regala	9.25	Coarse grinding	19.21	33.2	46.07	1.52
		Fine grinding	-	2.46	93.58	3.96
Cabernet Sauvignon	8.04	Coarse grinding	17.80	34.56	46.32	1.32
		Fine grinding	-	3.21	93.82	2.97
Sauvignon Blanc	7.54	Coarse grinding	19.29	32.13	46.5	2.08
		Fine grinding	-	3.27	93.06	3.67
Busuioaca de Bohotin	8.03	Coarse grinding	17.69	31.37	48.96	1.98
		Fine grinding	-	3.14	93.4	3.46

The data presented in Table 1 show fractions that are unsuitable for briquetting (particles smaller than 3.15 mm or bigger than 8 mm have resulted after coarse grinding); the fractions that are suitable for briquetting (with particle dimensions between 8 and 3.15 mm) were between 45.8% for the Muscat Ottonel variety and 52.78% for the Feteasca Alba variety. After the fine grinding, 92.0% of the resulting particles were suitable for the following briquetting process (dimensions between 8 and 3.15 mm).

3.2. Briquetting of the Vine Tendrils

3.2.1. Briquetting Coefficient

The results presented in Table 2 regarding the briquetting coefficient show that this index is significantly affected by the moisture content. Thus, for low values of the moisture content (6–10%), the briquetting coefficient reached values higher than 98.24% for the ground biomass consisting of particles between 3.15 and 8 mm. For the ground biomass with the same humidity, but which also contained particles smaller than 3.15 mm, the briquetting coefficient decreased by 4–5%. This behavior was a consequence of the fact that high local temperatures (380–450 °C) were achieved during the compaction process, due to the friction between the particles of biomass and the operating parts of the press (screw, inner surfaces of the dies). These temperatures were high enough to cause the self-ignition of small biomass particles (especially the ones in the form of dust), thus generating micro-explosions that shatter the briquettes and disrupt the normal operating process. For the biomass with a moisture content of over 10%, the briquetting coefficient decreased significantly, especially for the non-sieved mixtures which contain vegetable dust (Table 2).

Table 2. Briquetting coefficient (%) of briquettes obtained from vine tendrils depending on moisture content.

Vine Variety	Ground and Seived Tendrils, Size of Particles Between 3.15 mm and 8.0 mm			Ground, Non-Seived Tendrils, Size of Particles Lower Than 8.0 mm		
	Moisture Content (%)					
	6–10	10–12	12–15	6–10	10–12	12–15
Sauvignon Blanc	98.46	94.56	84.51 *	93.36	94.56	76.23 *
Pinot Noir	98.67	93.58	83.88 *	92.43	93.58	75.37 *
Feteasca Alba	98.89	93.83	83.78 *	92.86	93.83	75.12 *
Feteasca Regala	98.53	94.15	84.65 *	93.55	94.15	76.37 *
Feteasca Neagra	98.46	94.64	85.32 *	93.31	94.64	75.69 *
Busuioaca de Bohotin	98.24	94.12	84.51 *	93.21	94.12	76.62 *
Cabernet Sauvignon	98.41	93.88	83.29 *	92.98	93.88	74.93 *
Muscat Ottonel	98.35	93.93	84.21 *	91.32	93.93	74.88 *

* Briquettes produced from biomass with a moisture content higher than 12% have the DU lower than the one imposed by the ISO 17225-7 (2014) [47] standard (94.3%).

In this case, the high moisture content and high temperatures (180–220 °C) caused the water in the ground tendrils to evaporate, generating high-pressure steam, which accumulated inside the material and caused the fragmentation of briquettes. Under these conditions, the operating process was discontinued, the quality of the briquettes was affected and the productivity of the briquetting machine decreased. As for the non-sieved tendrils, the cumulated effect of vapor and of micro-explosions created by the self-ignited dust led to a significant reduction in the briquetting coefficient—lower than 95% for a moisture content between 10% and 12% and under 76% for a moisture content over 15%. These results clearly show that, when the moisture content of the ground material is higher than 10%, the quality of the briquetting process decreases dramatically, briquettes are no longer produced continuously and their external surface becomes affected by pitting and peeling.

3.2.2. Dimensions of the Briquettes

The measurements show that the briquettes produced from vine tendrils fall into the Pini-kay category, third class, D 60 (according to the specifications of the ISO 17225-7 (2014) standard [47]) as far as the diameter and length are concerned (Table 3).

Table 3. Dimensions of the briquettes (mean $\pm$ standard deviation, $n = 5$).

Variety	Dimensions of the Briquettes				Shape
	D (mm)	d ₁ (mm)	d ₂ (mm)	L ₁ (mm)	
Pinot Noir	58.0 $\pm$ 0.32	49.5 $\pm$ 0.28	16.1 $\pm$ 0.28	200.2 $\pm$ 2.0	3
Muscat Ottonel	58.1 $\pm$ 0.45	49.2 $\pm$ 0.36	15.8 $\pm$ 0.36	200.0 $\pm$ 1.5	3
Feteasca Neagra	58.2 $\pm$ 0.32	48.1 $\pm$ 0.45	15.6 $\pm$ 0.42	199.8 $\pm$ 1.7	3
Feteasca Alba	58.6 $\pm$ 0.54	48.7 $\pm$ 0.53	15.8 $\pm$ 0.21	199.7 $\pm$ 1.6	3
Feteasca Regala	58.5 $\pm$ 0.36	49.5 $\pm$ 0.62	16.0 $\pm$ 0.18	199.3 $\pm$ 1.8	3
Cabernet Sauvignon	57.9 $\pm$ 0.37	48.2 $\pm$ 0.72	16.1 $\pm$ 0.41	199.2 $\pm$ 1.8	3
Sauvignon Blanc	57.6 $\pm$ 0.68	49.8 $\pm$ 0.83	16.6 $\pm$ 0.57	200.0 $\pm$ 2.0	3
Busuioaca de Bohotin	58.6 $\pm$ 0.75	48.2 $\pm$ 0.34	16.2 $\pm$ 0.62	200.1 $\pm$ 2.5	3

The obtained briquettes have the following dimensions: (i) maximum diameter $D = 58.6$ mm, with a maximum size variation of ± 0.75 mm for the ones obtained from the variety Busuioacă de Bohotin variety; (ii) diameter of the inscribed circle around $d_1 = 49$ mm for all the varieties, with a maximum size variation of ± 0.83 mm for the ones obtained from the Sauvignon Blanc variety and (iii) inner diameter $d_2 = 16$ mm, with a maximum size variation of ± 0.62 mm for the ones obtained from the Busuioacă de Bohotin variety.

The length of the briquettes depends on the precision of the cutting device and was between 199.2 ± 1.5 mm for the tendrils from the Cabernet Sauvignon variety and 200.1 ± 2.5 mm for the Busuioacă de Bohotin variety.

3.2.3. Moisture Content of the Ground Tendrils and Briquettes

The briquetting procedure is a complex one and the moisture content of the biomass is a key element for the densification process, with a significant impact on the quality indices of the final product (briquettes).

Table 4 presents the experimental data regarding the moisture content of the ground tendrils and briquettes resulting from material-containing particles with a diameter of 3.15 to 8 mm. The results show that the moisture content of the ground tendrils differs from one vine variety of vine to another, with the lowest value (7.54%) being recorded for the Sauvignon Blanc variety and the highest (9.48%) for the Pinot Noir variety; nevertheless, these values are within the recommended limits [41,44].

Table 4. Moisture content of the ground tendrils and briquettes (mean $\pm$ standard deviation, $n = 5$).

Vine variety	Moisture Content of Ground Tendrils (%)	Moisture Content of Briquettes (%)
Pinot Noir	9.48 ± 0.14	7.98 ± 0.12
Muscat Ottonel	8.76 ± 0.12	7.10 ± 0.11
Feteasca Neagra	9.05 ± 0.15	7.25 ± 0.14
Feteasca Alba	7.99 ± 0.20	5.63 ± 0.15
Feteasca Regala	9.25 ± 0.11	7.39 ± 0.23
Cabernet Sauvignon	8.04 ± 0.19	5.98 ± 0.10
Sauvignon Blanc	7.54 ± 0.21	5.42 ± 0.20
Busuioaca de Bohotin	8.03 ± 0.20	6.25 ± 0.16

After densification, the moisture content of the resulted briquettes decreased by approx. 2% due to heat produced during the compression of the material, which led to temperatures of 170 to 220 °C. The extreme values of moisture content were recorded for the same two vine varieties: 5.24% for Sauvignon Blanc and 7.98% for Pinot Noir.

Considering the requirements of the ISO 18134-1 (2015) [51] and ISO 18134-2 (2015) [52] standards, it was concluded that, with a moisture content less than 12%, the briquettes obtained from vine tendrils belong to the quality class A1.

3.2.4. Mechanical Durability, Bulk Density and Unit (Volume) Density of Briquettes

Mechanical durability represents the property of densified solid biofuels to withstand exterior forces and shocks during maneuvering/transportation. On the other hand, an adequate DU proves that the briquette production process was properly conducted. The ISO 17225-7 (2014) [47] defines several quality classes for the briquettes, depending on their DU: class A1, for a durability higher than 97.0%; classes A2 and B, for briquettes with a DU higher than 95.0%.

The experimental results presented in Table 5 show that the DU of the briquettes made of ground vine tendrils exceeded 97%, which means that they belong to the quality class A1. The highest DU (99.14%) was achieved by the briquettes obtained from the Feteasca Alba vine variety.

Table 5. Mechanical durability, bulk density and unit density of the briquettes (mean $\pm$ standard deviation, $n = 5$).

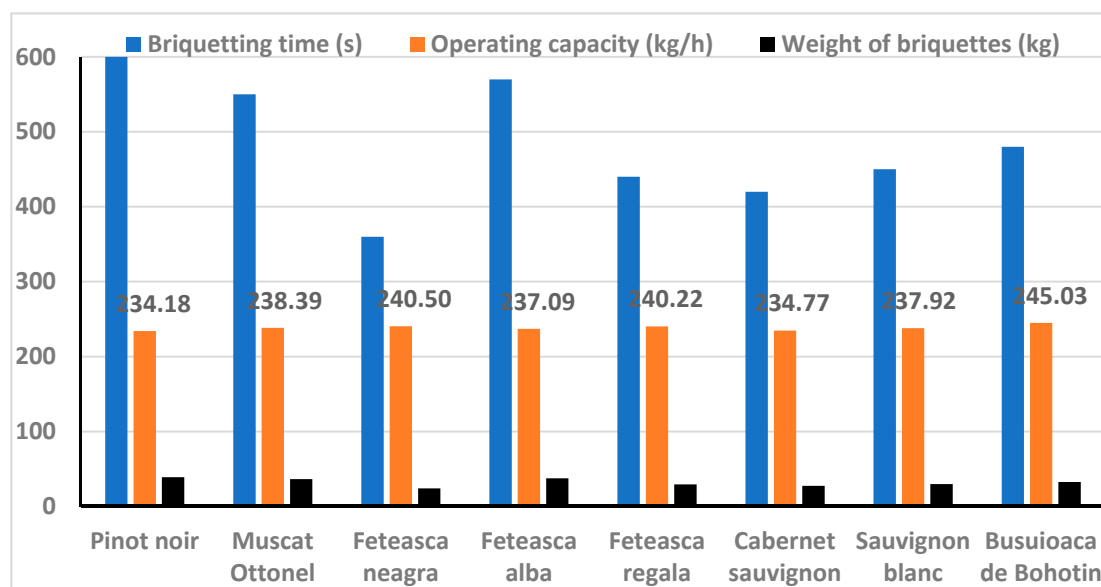
Vine Variety	Bulk Density (kg/m ³)	Unit Density (kg/m ³)	Mechanical Durability (%)
Pinot Noir	682.24 $\pm$ 2.5	1312.0 $\pm$ 0.12	99.13 $\pm$ 0.10
Muscat Ottonel	722.28 $\pm$ 3.9	1389.0 $\pm$ 0.10	98.17 $\pm$ 0.11
Feteasca Neagra	693.68 $\pm$ 1.9	1334.0 $\pm$ 0.09	97.34 $\pm$ 0.21
Feteasca Alba	658.04 $\pm$ 2.0	1227.0 $\pm$ 0.10	99.14 $\pm$ 0.20
Feteasca Regala	681.20 $\pm$ 1.8	1310.3 $\pm$ 0.13	97.97 $\pm$ 0.18
Cabernet Sauvignon	708.50 $\pm$ 1.0	1362.5 $\pm$ 0.11	99.00 $\pm$ 0.14
Sauvignon Blanc	702.00 $\pm$ 1.6	1370.3 $\pm$ 0.08	99.02 $\pm$ 0.15
Busuioaca de Bohotin	700.26 $\pm$ 1.8	1349.0 $\pm$ 0.10	98.85 $\pm$ 0.16

Bulk density is an important parameter for the packaging, storage and transportation of the briquettes. The requirements of the standards impose a minimum bulk density of 650 kg/m³. The results presented in Table 5 prove that all the briquettes fulfilled the requirements regarding bulk density (values higher than 650 kg/m³). The lowest value (658.04 kg/m³) was recorded for the briquettes obtained from the Feteasca Alba vine variety.

Concerning the unit density, the values obtained for this index were higher than 1227 kg/m³; this is proof that this type of biomass is very well-suited for densification as it fulfills the ISO 18847 (2016) standard [53] requirements for the quality class A1.

3.2.5. Operating Capacity of the Briquetting Machine

In order to evaluate the operating capacity of the briquetting machine when used for the production of briquettes from vine tendrils, the briquetting time (s) and the weight of the briquettes (kg) were measured; then, the operating capacity (kg/h) was calculated. Figure 13 presents these results, showing that the operating capacity of the briquetting machine was between 234.18 kg/h and 245.03 kg/h.

**Figure 13.** Briquetting time, weight of the briquettes and operating capacity of the briquetting machine.

3.2.6. Heating Value of the Briquettes

The HV was expressed as HHV and LHV. The HHV represents the heat generated by the combustion of 1 kg of biomass; the latent heat of condensation of water vapor from the exhaust gases was extracted from the HHV in order to obtain the LHV. Table 6 presents the results referring to the HV of the briquettes.

Table 6. Heating value of briquettes waste (Data represent means $\pm$ standard deviations, $n = 5$ parallel measurement).

Vine Variety	Higher Heating Value (MJ/kg)	Lower Heating Value (MJ/kg)
Pinot Noir	18.89 $\pm$ 1.2	17.45 $\pm$ 1.1
Muscat Ottonel	18.35 $\pm$ 1.3	16.92 $\pm$ 1.0
Fetească Neagra	19.06 $\pm$ 1.5	17.63 $\pm$ 1.5
Feteasca Alba	19.01 $\pm$ 1.7	17.62 $\pm$ 1.6
Feteasca Regala	19.12 $\pm$ 1.3	17.77 $\pm$ 1.5
Cabernet Sauvignon	18.99 $\pm$ 1.4	17.62 $\pm$ 1.2
Sauvignon Blanc	19.27 $\pm$ 1.2	17.95 $\pm$ 1.1
Busuioacă de Bohotin	19.04 $\pm$ 1.1	17.71 $\pm$ 1.7

A1 and A2 grade briquettes, the quality standard for woody briquettes (LHV $\geq$ 15.5 MJ/kg for A1 grade and LHV $\geq$ 15.3 MJ/kg for A2 grade).

From the experimental results shown in Table 6, it was concluded that, as far as the HV was concerned, there were no significant differences between the briquettes produced from different vine varieties.

Taking into account the requirements of the ISO 17225-3 (2014) standard [54] for the LHV, all the tendrils correspond to the A1 quality class, with values higher than 15.5 MJ/kg.

4. Conclusions

The tendrils resulting from the dormant pruning of vines are an important source of renewable energy, with high calorific value, and are able to satisfy an important part of the energy needs of the present and future generations. The present study evaluated the technological phases for the production of densified biomass in the form of briquettes.

Specialized equipment was designed and purchased in order to produce the briquettes starting from agricultural waste (vine tendrils) and to evaluate the quality indices of the briquettes. The results of the experimental tests show that the briquettes from vine tendrils satisfy the requirements of the quality class A1, according to the specifications of the ISO 17225-3 (2014) standard. One of the significant findings of this study is that the presence of particles smaller than 3.15 mm (especially dust-like particles) in the briquettes' composition diminishes the quality of the final product (briquettes) because of self-ignition during densification, which leads to micro explosions that disrupt the normal operating process of the briquetting machine, resulting in the damaged structural integrity of the briquettes and lower briquetting indices. This phenomenon occurred even when the moisture content of the tendrils was within the accepted limits. When the moisture content of the tendrils was increased, the high-pressure water vapor added its negative effects and serious damage to the final product occurred.

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