

Article

Briquette Production from Vineyard Winter Pruning Using Two Different Approaches

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Abstract: Worldwide, different strategies are being developed in order to ensure optimum conditions for the development and growth of economic competitiveness, as well as for increasing the quality of life and environmental protection. All these strategies are closely linked to the development and modernization of systems for producing energy from clean and renewable sources. In this context, the present paper presents the results of research regarding the evaluation of the sustainability of briquette production using biomass resulting from vine winter pruning as the raw material. An analysis of the scientific literature indicates that nearly 8 Mt of biomass would result from the over 7.4 million hectares of vine plantations in the world, biomass that could be valorized through densification in order to produce solid biofuels with a lower calorific value of more than 17 MJ/kg. This study examines the production of briquettes from vineyard winter pruning with consideration of two types of densification technologies: baling and natural drying of the tendrils, and collection, shredding, and artificial drying of the lignocellulose debris. The quality indices and energy consumption and energy efficiency of the briquettes were evaluated to determine their feasibility as an alternative fuel source. When designing the scientific endeavor, the following aspects were considered: defining the aim and objectives of the research; designing the research algorithm; collecting, preparing, and conditioning the biomass; conducting a chemical analysis of the briquettes; and evaluating the energy consumption and energy efficiency for producing the briquettes, taking into account two drying methods (natural and artificial drying). In the meantime, some specific laboratory equipment was designed and built for the artificial drying of biomass, evaluation of mechanical durability, measurement of energy consumption, etc. Analysis of the experimental data has led to the conclusion that the agricultural waste from vine pruning can constitute an important and sustainable source of energy in the form of briquettes that fulfill most of the requirements imposed by international standards.

Keywords: biomass; renewable energy; briquettes; horticultural waste; sustainability



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1. Introduction

Worldwide, biomass represents a primary carbon source, together with other renewable energy sources. Biomass may be used as raw material for producing biofuels with high energy value or biochemical fuels, used in different economic activities. To date, according to recent reports, biomass contributes more than 14% to the production of primary energy, while in the developed states, it represents 40–50% of the energy requirement [1,2].

As is well known, biomass is a material of organic origin, generated by plants during their development as a result of the photosynthetic processes. In the photosynthetic process, plants assimilate the carbon dioxide emissions produced by the combustion of other plants

in a closed cycle. As a result, the use of biomass for energy purposes leads to carbon dioxide emissions into the atmosphere, which would then be used by plants to produce new quantities of biomass [3–7]. Moreover, biomass is the only renewable resource that can be used directly through combustion [8].

The energy provided by renewable sources has a significant social and economic impact because it encourages and promotes the growth of local industry, creates new jobs, and fulfills the energy demands both locally and internationally [9]. Moreover, worldwide, research has proven that greenhouse gas emissions are diminished when biofuels are used in order to produce energy, compared with the case of coal combustion [10]. For this reason, the specialized literature states that biomass is almost neutral in terms of carbon dioxide emissions and that is available from a wide variety of resources [10].

Biomass has many advantages as an energy source because it may be used both for producing power and heat and for obtaining a large variety of combustible products: liquid fuels for the internal combustion engines used in transportation, solid and gaseous fuels, etc. Biomass, as a raw material, is present in different forms and is abundant on Earth. However, in reality, natural biomass is not very used as an energy source due to some unfavorable characteristics such as low bulk density, high moisture ratio, and low calorific value per unit volume, thus leading to higher transport, storage, and manipulation costs [11]. In order to improve these characteristics, biomass feedstock undergoes several mechanical or chemical processes. As an example, mechanical processing (densification) of biomass as pellets and briquettes leads to valuable biofuels, with high energy value per unit volume and high density and hardness, thus enabling a significant reduction in transport, storage, and manipulation costs. At the same time, this allows the automation of the installations used for producing thermal energy through combustion [12–16]. Studies emphasize the fact that biomass densification is achieved with significant energy consumption, which depends on the nature and moisture of the raw material, the densification technology, the characteristics of the final product, etc. [11,14]. From this point of view, it was proven that the smaller the mass particles are, the higher the energy consumption due to the friction at contact with the surfaces of the active parts of the densification equipment [17]. Moreover, when the dimensions of the biomass particles exceed an acceptable limit, the densification process is slowed down, especially when producing pellets, as the matrix holes may become clogged. Conversely, the use of low-capacity equipment and higher densification pressures than those recommended by the respective technology leads to a significant increase in energy consumption because a part of this energy is converted into heat without any significant improvement in the quality of pellets or briquettes [16,18,19]. Taking into account all these aspects, it may be concluded that the quality of the densified biomass depends on both the nature of the raw material and the parameters of the briquetting process. For these reasons, both the calorific value (which should be between 17 MJ/kg and 20 MJ/kg [20–25]) and the composition (which should correspond to the requirements of the ISO 17225-3 standard) [26] are considered when evaluating the quality of briquettes. As the worldwide requests for densified biomass are continuously increasing, new variants for producing thermal and electric energy from renewable resources are being studied. This is the reason why biomass produced from the yearly winter pruning of vines is gaining increasing attention. Vine is a lignified perennial plant, grown worldwide on over 7.4 million ha (in 2022) [13] due to its economic importance. This figure is also confirmed by the statistics of the International Organization of Vine and Wine. The large interest in growing vines in the temperate climate is due to the fact that it can be cultivated on slopes and sandy soils and less fertile areas, unsuited for other agricultural purposes.

Vines need yearly winter pruning, which results in large quantities of biomass containing lignocellulose, which might be used for producing densified biofuels. This biomass consists of a mixture of tendrils and stems of different lengths, with a diameter up to 40 mm, in quantities reaching 1.5 to 2.5 t/ha, and a moisture ratio of 40 to 50% [12,27,28]. Presently, in most plantations, this biomass mixture is used for soil enrichment and moisture retention. The disposal of biomass can have environmental impacts by releasing particulate

matter, carbon dioxide, and other pollutants into the atmosphere. The paper proposes a new approach for the use of the debris from vineyard winter pruning as raw material for obtaining briquettes [29]. Some plantations, especially large vineyards in Europe, use technologies that convert biomass into chips, pellets, or briquettes, thus contributing to the sustainable development of countryside areas [30,31]. Although biomass from vine pruning might constitute a significant resource for producing renewable energy, with the potential to produce over 7 million tonnes of biofuel, some of its characteristics limit its valorization: seasonal availability (only when pruning takes place); significant costs for transport and manipulation (as vines are placed in limited areas); low efficiency of solar radiation conversion to biomass; high moisture ratio of the resulting biomass, thus requiring operations and equipment with high energy consumptions; and not profitable in scarce surface plantations [13]. Despite all the disadvantages, globally, studies have proved that this biomass, densified as briquettes, may be a reliable source of renewable energy that can successfully provide a proportion of the required electric and thermal energy in certain areas [16,32–37].

The objective of the present study is to assess the feasibility of producing briquettes using vine tendrils derived from the annual winter pruning process, with a particular focus on the energy consumption and chemical, physical, and energetic evaluation of the resulting briquettes.

2. Materials and Methods

Two processing approaches were considered with regard to the densification of the biomass resulting from the mechanized pruning of vine: baling and natural drying of the tendrils, and collection, shredding, and artificial drying of the lignocellulose debris. In the case of the first technology (Figure 1a), the workflow includes the following specific stages: collection of the debris through baling (II), transportation of the baled tendrils (III); storage and natural drying of the tendrils (IV); rough shredding of the tendrils (V); sieving and separation of the large particles (VI); grinding of the large particles (VII); and briquetting (VIII). As for the second technology (Figure 1b), the workflow consists of the following stages: collection of tendrils through shredding and transport of the debris (II); convective drying of the shredded debris (III); biomass storage (IV); sieving and separation of the large particles (V); grinding of biomass particles (VI); and briquetting (VII).

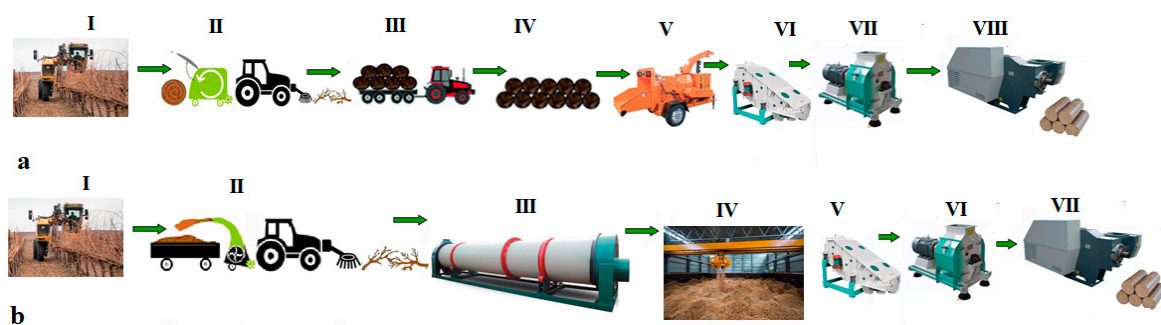


Figure 1. Workflow for the densification of biomass from mechanized winter pruning of vine: (a) baling and natural drying of the tendrils; (b) collection, shredding, and artificial drying of the tendrils.

The analysis of the sustainability of briquette production was based on the following characteristics: yearly quantity of biomass per unit area; calorific value, composition, and quality of the briquettes; and energy balance for biomass densification and energetic efficiency. These indices were evaluated with regard to the vine variety, the harvesting technology, and the briquette preparation technology.

The stages of the research algorithm (Figure 2) were: collection, shredding, and conditioning of the vine tendrils; densification of the biomass as briquettes; chemical

analysis of the composition and evaluation of the calorific value for the densified biomass; evaluation of the mechanical properties of the briquettes; and sustainability analysis for the production process of the briquettes.

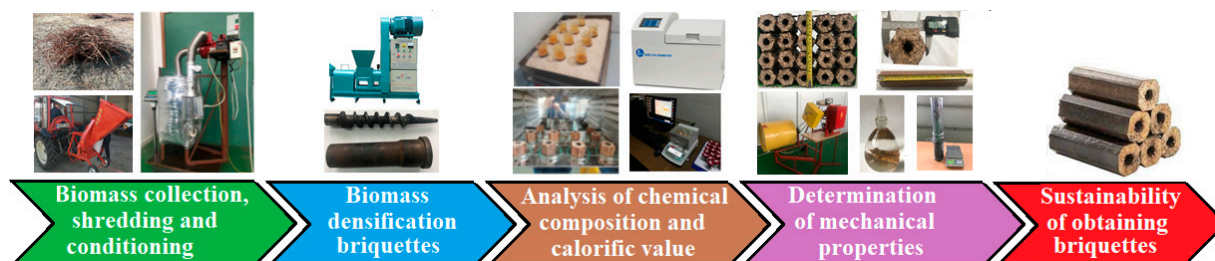


Figure 2. Research algorithm for the analysis of the sustainability of briquette production.

The sustainability analysis for the production of densified biomass from vine tendrils was based on the quality indices, as specified in the ISO 17225-3 standard [26] (which allowed the briquettes to be graded in quality classes) and on the energy balance and energy efficiency, which allowed the evaluation of the overall energy consumption for producing the briquettes, using two different technologies.

The experiments took place in the Agricultural Machinery laboratory of the Iași University of Life Sciences; the biomass was harvested from the vineyard located in the “Vasile Adamachi” farm of the university, with the following specifications:

- Density: 4347 stumps/ha;
- Distance between rows: 2.3 m;
- Distance between the stumps on a row: 1.0 m.

2.1. Collection of the Vine Tendrils

The material for the production of densified biomass was collected from eight vine varieties: Pinot Noir (PN), Muscat Ottonel (MO), Fetească Neagră (FN), Fetească Albă (FA), Fetească Regală (FR), Cabernet Sauvignon (CS), Sauvignon Blanc (SB), and Busuioacă de Bohotin (BB).

The winter pruning was performed manually, with vine scissors; afterward, the tendrils were gathered and temporarily deposited at the end of the plot, where they were labeled according to the variety. Two indices were taken into account when harvesting the tendrils: the average mass of tendrils per stump, for each variety, and the necessary quantity of biomass for producing briquettes. For the first index, the tendrils from five stumps on each row were collected (and from at least five rows for each vine variety) and the resulting biomass was weighed using an electronic 10 kg scale (type SKU-BD10TWYD).

For the production of briquettes, at least 100 kg of tendrils were collected for each vine variety; the biomass was then transported to the test lab, where the moisture ratio was evaluated. The moisture content of the raw material, shredded material, and briquettes was measured using the thermobalance method and an AGS 210 moisture analyzer. The method is based on the measurement of weight loss due to water evaporation from the analyzed sample. The sample was heated at 120 °C, under intense air circulation, and the point at which the drying chart plateaued indicated the final drying time [22].

2.2. Drying of Biomass

In order to densify the collected tendrils, the biomass had to be dried, thus reducing its moisture ratio from 44–46% to 10–12% [17,22,38]. Two drying procedures were used in the present experiments: natural and artificial drying.

Natural, passive drying is a simple method needing no supplementary equipment and power sources; it was achieved by storing the biomass under a canopy for 90 days while continuously monitoring the moisture ratio until the necessary value imposed by the densification process was achieved.

Artificial (convective) drying was performed in laboratory conditions, after the tendrils were shredded, in a novel piece of equipment (Figure 3) that uses hot air as a drying agent. The equipment also allowed the measurement of the energy consumption for drying the biomass [22].

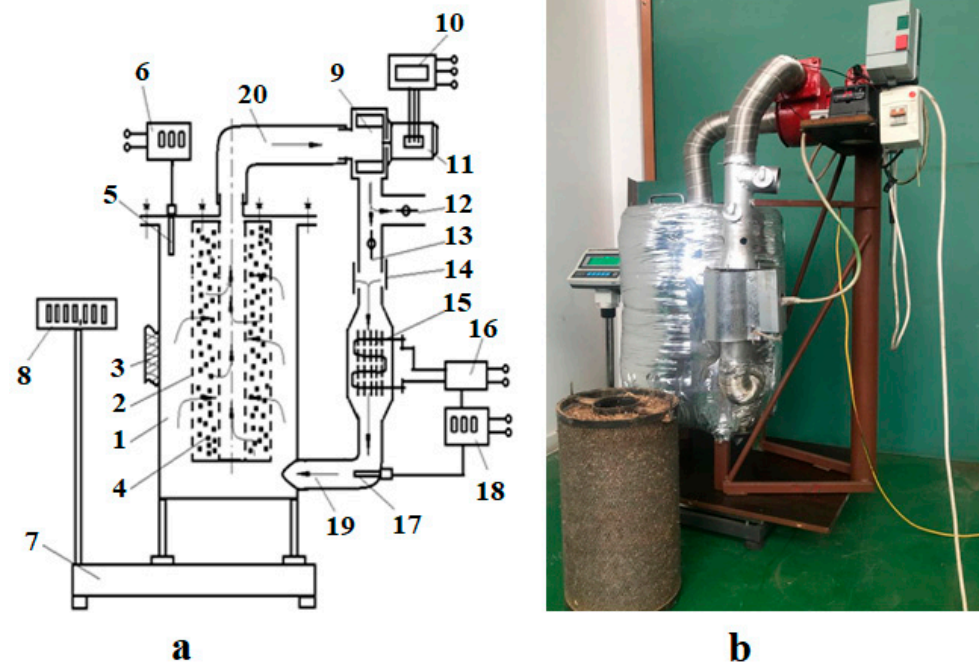


Figure 3. Laboratory test rig for drying of ground tendrils: (a) schematic diagram; (b) general view; 1—drying drum; 2—ground biomass chute; 3—insulation; 4—ground tendrils; 5—anemometer; 6—hot wire probe; 7—scale; 8—display; 9—centrifugal fan; 10—variable frequency drive; 11—electric motor; 12, 13—adjustable flaps; 14—air intake orifices; 15—heating resistance; 16—relay; 17—RTD probe; 18—thermostat; 19—fresh hot air feeding pipe; 20—used hot air intake pipe.

The drying equipment was fitted with automated devices for monitoring and controlling the airflow and air temperature, and an electronic scale was used for measuring the water loss during the operating process. The entire unit is thermally insulated, in order to avoid heat losses.

2.3. Tendrils Shredding–Grinding

The preparation of the biomass for briquetting required shredding–grinding, which was performed in two distinct stages: course shredding and fine shredding (grinding). A Caravaggi BIO 90 shredding machine, driven from a 45 HP tractor PTO was used for shredding the tendrils. The machine is equipped with two types of active parts: radial rotating knives and a counter knife and articulated knives, mounted on the same rotor. Course shredding is achieved in the first stage, with 15–20 mm particles; in the second stage, the dimensions of the particles are reduced to 10–12 mm.

A universal hammer mill was used for the final grinding of the tendrils; the mill was equipped with a sieve with 8 mm diameter circular holes. The naturally dried biomass was shredded after dehydration, while the artificially dried biomass was shredded immediately after being collected. The ground biomass was sieved in order to eliminate the particles with a diameter over 8 mm; these particles were then ground again. A mechanical sieving machine was used for this operation [22]. Finally, the ground biomass (Figure 4a) was collected in separate bags for each vine variety.



Figure 4. Pictures with: (a) dried and ground biomass before densification; and (b) obtained briquettes.

2.4. Densification of Biomass

The shredded and ground tendrils were densified in order to obtain briquettes (Figure 4b), using the GCBA-1 type briquetting machine. This equipment produces Pini-kay-type briquettes in a continuous operating process. The equipment has a truncated screw, with two operating areas (Figure 5a,b): one for biomass feeding and pressing and a second one, with a smooth tip, generating a cylindrical orifice in the central part of the briquette. The screw rotates at 373 rev/min. The pressing chamber is shaped to generate briquettes in the shape of hexagonal prisms. The overall electric power of the equipment is 25 kW [22]. The briquettes (Figure 5c) are characterized by the following dimensions (Figure 5d): thickness (D); diameter of the circumscribed circle (D_1); diameter of the inscribed circle (d_1); and diameter of the central orifice (d_2).

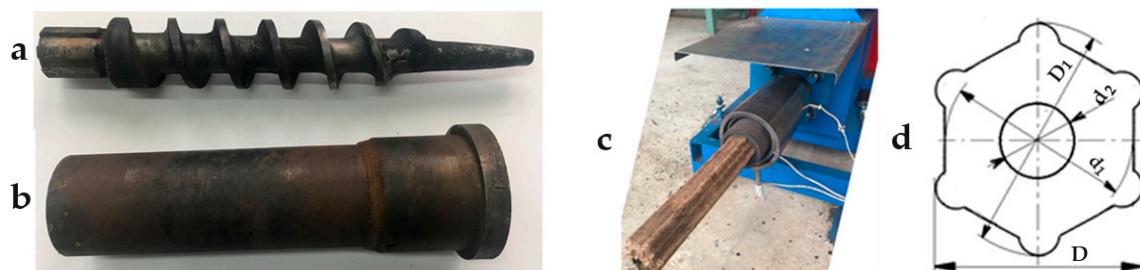


Figure 5. Active parts of the GCBA-1 briquetting equipment (a,b); operating process (c); dimensions of the briquettes (d).

Before starting the densification process, the pressing device was heated to 170–180 °C using the electric resistance placed on the outer surface of the pressing chamber. The briquetting temperature was monitored and adjusted by means of an electronic thermostat.

The ground biomass, with the dimension of the particles not exceeding 8 mm and a moisture ratio of $12.0 \pm 0.5\%$, is taken over by the truncated screw and densified when passing through the inner bushes. The densified biomass is continuously discharged and is then split into briquettes with a length of 200 to 400 mm.

During the experiments at least 50 kg of briquettes were produced from each vine variety.

2.5. Physical and Chemical Characterization of Briquettes

The produced briquettes were evaluated for compliance with the requirements of the ISO 17225-3 standard [26] based on the following indices:

- Dimensions—the width and diameter were measured with a caliper for the smaller dimensions and with the measuring tape, for larger dimensions;

- Moisture ratio of the densified biomass—this was evaluated using the thermal balance method;
- Ash content and chemical composition (N, S, Cl, As, Cd, Cr, Cu, Pb, Hg, Ni, and Zn) for briquettes—measured according to the specifications of the ISO 16948 [39] for nitrogen; ISO 16994 [40] for Sulphur and chlorine; and ISO 16968 [41] for arsenic, cadmium, chrome, copper, mercury, nickel and zinc (analysis performed at ICIA branch in Cluj-Napoca, Romania);
- Unit density—a graduated cylinder (62 mm diameter, 440 mm high) and an electronic scale (precision 0.01 g) were used to measure the unit density; the cylinder, filled with 500 mL of water (m_a) was weighted and the briquette was then immersed into the cylinder, measuring the volume of dislocated water (V_a), and the overall mass of the cylinder (m_b). The unit density was then calculated using the following relation [23]:

$$\rho_p = \frac{m_b - m_a}{V_a} \quad (1)$$

- Mechanical durability—this represents the property of densified biofuels to withstand shocks and wear during manipulation and/or transport, and was tested by subjecting the samples to controlled blows between the samples and with the walls of a rotating drum.

The mechanical durability test was carried out according to the method described in the SR EN ISO 17831-1 standard [42], using the equipment presented in Figure 6. The rotating drum has an inner volume of 160 dm³ (length: 598 ± 8 mm; diameter: 598 ± 8 mm) and an interior radial baffle (length: 598 ± 8 mm; height: 200 ± 2 mm; thickness: 2 mm).



Figure 6. Equipment for mechanical durability tests.

The rotating speed of the drum was 21 ± 0.1 rev/min and the overall number of rotations and the rotating speed were measured using a tachometer.

For each test, two briquettes with a mass lower than 0.5 kg were weighed (m_E) and then introduced into the drum. A total of 105 ± 0.5 revolutions were performed and then, the material was sieved through a sieve with 45 mm diameter holes and the material that remained on the sieve was weighed (m_A). Mechanical durability was evaluated using the formula:

$$DU = \frac{m_A}{m_E} \times 100 [\%]. \quad (2)$$

The durability tests were repeated three times for each vine variety.

2.6. Evaluation of the Overall Energy Consumption for Producing the Briquettes

In order to evaluate the overall energy consumption each technological phase from Figure 1 (shredding, drying, sieving, grinding, briquetting) was assessed from the point of view of the energy input. The following equations were used:

- For the artificial dried biomass:

$$E_{b1} = E_{bcg} + E_{bd} + E_{bs} + k_{b1} \cdot E_{bm} + E_b; \quad (3)$$

- For the naturally dried biomass:

$$E_{b2} = E_{bcd} + E_{bs} + k_{b2} \cdot E_{bm} + E_b; \quad (4)$$

where:

- E_{b1} is the energy consumption for briquetting the artificially dried biomass (MJ/kg);
- E_{bcg} is the energy input for shredding the tendrils with a moisture ratio of 44–46% (MJ/kg);
- E_{bd} is the energy consumption for the artificial drying of biomass to a moisture ratio of 10–12% (MJ/kg);
- E_{bm} is the energy consumption for grinding the fractions bigger than 8 mm (MJ/kg);
- E_{bs} is the energy input for sieving the shredded biomass (MJ/kg);
- E_b is the energy consumption for briquetting the ground biomass (MJ/kg);
- E_{b2} is the overall energy consumption for briquetting the naturally dried biomass (MJ/kg);
- E_{bcd} is the energy consumption for grinding the naturally dried tendrils (MJ/kg);
- k_{b1} și k_{b2} fractions referring to the biomass with particles bigger than 8 mm.

As mentioned above, the shredding of the biomass was performed using the Caravaggi BIO 90 shredding machine, which was driven by a 45 HP tractor PTO. The tractor was equipped with two Contoil VZO 4-RE fuel flowmeters, thus allowing the measurement of the fuel consumption during the shredding process. The energy consumption for shredding the biomass was calculated using the formula:

$$E_{bcg}(E_{bcd}) = \frac{\rho \cdot Q_l \cdot 10^{-3} \cdot P_i}{Q_m} \text{ [MJ/kg]}; \quad (5)$$

where $\rho = 837 \text{ [kg/m}^3\text{]}$ is the density of diesel fuel, Q_l is the fuel consumption for shredding the biomass [liters], $P_i = 42.9 \text{ [MJ/kg]}$ is the calorific value of Diesel fuel, and Q_m is the quantity of shredded biomass [kg].

Equipment powered with electricity was used for drying, sieving, grinding, and briquetting. Therefore, Voltcraft Energy Logger 4000 (manufacturer Voltcraft, Mülheim, Germany) energy meters were used for measuring energy consumption, with one energy meter used for each phase of the electric power grid. These energy meters stored data regarding energy consumption on SDHC cards and the data was then downloaded to a computer for analysis and interpretation.

The energy efficiency for producing briquettes from vine tendrils was calculated using overall energy consumption data, using the following relations:

- For the artificial dried biomass:

$$\eta_{b1} = \frac{Q - E_{b1}}{Q} \cdot 100 \text{ [%]}; \quad (6)$$

- For the naturally dried biomass:

$$\eta_{b2} = \frac{Q - E_{b2}}{Q} \cdot 100 \text{ [%]}; \quad (7)$$

where Q is the calorific value of the briquettes and E_{b1} and E_{b2} is the overall energy consumption (as mentioned above).

2.7. Statistical Analysis

The statistical processing of the data was performed using OriginPro Data Analysis and Graphing Software (version 2020b, OriginLab Corporation, Northampton, MA, USA). The multivariate statistical method of hierarchical cluster analysis was used to find the correlation between variables and is presented as a dendrogram realized with OriginPro Data Analysis. The Tukey method was applied in order to determine the differences between the varieties. Significance was declared at $p < 0.05$ for all statistical analyses. Letters a, b, c, d, and e indicate statistically significant differences at $p < 0.05$.

3. Results and Discussion

3.1. Quantity of Biomass Collected from the Winter Pruning

In order to emphasize the energy potential of the tendrils resulting from the winter pruning of vine, the following indices were evaluated: average quantity of biomass per stump and average quantity of tendrils per hectare (at the initial moisture ratio and after drying the tendrils to 12% moisture ratio), taking into account the density of 4347 plants/ha. From the results shown in Table 1, it was concluded that the MO variety produced the highest quantity of tendrils, in terms of average mass/stump and overall mass (0.433 kg/stump and 1882.2 kg, respectively), while the smallest quantity of tendrils resulted from the CS variety (0.327 kg/stump and 1421.4 kg, respectively). The same variety (MO) produced the greatest amount of biomass with a 12% moisture ratio (1250.8 kg).

Table 1. Biomass harvested after the winter pruning of vine.

Specification	Variety							
	PN	MO	FN	FA	FR	CS	SB	BB
Average quantity of tendrils/stump [kg/stump]	0.420 ^{ab}	0.433 ^a	0.367 ^{ab}	0.347 ^{ab}	0.343 ^{ab}	0.327 ^b	0.370 ^{ab}	0.332 ^{ab}
Quantity of biomass at the initial moisture ratio [kg/ha]	1825.7 ^{ab}	1882.2 ^a	1595.3 ^{ab}	1508.4 ^{ab}	1491.0 ^{ab}	1421.4 ^b	1608.4 ^{ab}	1443.2 ^{ab}
Initial moisture ratio of tendrils [%]	43.86 ^a	45.45 ^a	47.47 ^a	41.87 ^a	44.25 ^a	42.37 ^a	42.71 ^a	45.02 ^a
Quantity of biomass at a 12% moisture ratio [kg/ha]	1244.0 ^a	1250.8 ^a	1029.4 ^{ab}	907.0 ^b	1010.1 ^{ab}	961.3 ^{ab}	1121.5 ^{ab}	966.6 ^{ab}

Note: Different letters of each column show a significant difference at the level of $p \leq 0.05$.

3.2. Preparation of Biomass for Briquetting

The tests performed in this stage aimed at preparing the tendrils according to the technological requirements of the densification process: a moisture ratio lower than 12% and dimensions of the particles smaller than 8 mm in order to allow briquetting. As mentioned above, two technologies were considered: natural drying and artificial drying of biomass.

The shredded biomass was sieved in order to separate the particles of different sizes. Three size fractions were considered, according to ISO 17827-1 [43] and ISO 17827-2 standards [44]: particles that are bigger than 8 mm (which are then ground), particles with dimensions of between 8 and 3.15 mm, and particles smaller than 3.15 mm (Table 2).

Table 2. Fractions resulting from shredding and grinding of biomass.

Vine Variety	Status of Biomass	Operation	>8 mm (%)	8–3.15 mm (%)	<3.15 mm (%)
PN	wet	Shredding	62.30	36.89	0.81
	dry	Shredding	51.6	46.80	1.60
	dry	Grinding	-	96.22	3.78
MO	wet	Shredding	62.91	36.23	0.86
	dry	Shredding	52.35	45.78	1.87
	dry	Grinding	-	96.38	3.62
FN	wet	Shredding	62.23	36.9	0.87
	dry	Shredding	51.05	47.22	1.73
	dry	Grinding	-	96.82	3.18
FA	wet	Shredding	61.48	37.67	0.85
	dry	Shredding	50.61	47.27	2.12
	dry	Grinding	-	96.34	3.66
FR	wet	Shredding	62.83	36.34	0.83
	dry	Shredding	52.41	46.07	1.52
	dry	Grinding	-	96.04	3.96
CS	wet	Shredding	63.39	35.79	0.82
	dry	Shredding	52.63	46.05	1.32
	dry	Grinding	-	97.03	2.97
SB	wet	Shredding	62.48	36.68	0.84
	dry	Shredding	51.42	46.5	2.08
	dry	Grinding	-	96.33	3.67
BB	wet	Shredding	60.89	38.28	0.83
	dry	Shredding	49.06	48.96	1.98
	dry	Grinding	-	96.54	3.46

The experimental data showed that the percentage of particles bigger than 8 mm increased when high moisture ratio tendrils were shredded, while the shredding of dry biomass resulted in a higher percentage of particles smaller than 3.15 mm. The separation of shredded biomass into fractions provided the coefficients k_{b1} (Equation (3)) and k_{b2} (Equation (4)) for particles bigger than 8 mm (which must further be ground), thus allowing the evaluation of the hammer mill operating capacity and energy consumption.

When the shredded biomass containing particles bigger than 8 mm was ground, over 96% of the resulting particles had dimensions of between 3.15 mm and 8 mm, no matter what drying technology was used (natural or artificial).

3.3. Characteristics of the Briquettes Produced from Vine Tendrils

In order to evaluate the sustainability of the briquettes production using vine tendrils as raw material, the requirements of the ISO 17225-3 standard [26] were considered with respect to the characteristics of the briquettes (Table 3).

The measured dimensions (diameter and length) correspond to the Pini-kay-type briquettes, with D representing the diameter of the hexagon inscribed circle and L being the length of the briquette. The briquetting machine used in these experiments operates continuously and allows the adjustment of briquette length.

The moisture ratios of the briquettes were well under the requirements of the standard, comprised between 7.78% for the Fetească Neagră variety and 8.20% for the Busuioacă de Bohotin variety. This was due to the fact that during densification, the biomass is quickly heated to 180–220 °C, thus leading to significant water evaporation in a short period of time.

The density of the briquettes was evaluated according to the specifications of the ISO 18847 standard [45], using Equation (1), and was found to be above that prescribed by the ISO 17225-3 standard [26], due to the higher densification pressures (over 20 MPa) and temperatures achieved by the equipment used. For all the vine varieties used in this study, the unit density was higher than 1389 kg/m³, which is proof that this type of biomass is very suited for densification.

Ash is a combustion product, being composed of incombustible materials, such as mineral salts. These remain as dust residues in the combustion location. Consequently, the ash content is an important quality index, as its presence leads to problems during the processing and combustion of biomass [46–48]. In solid biofuels, the presence of ash diminishes the calorific value and impedes the diffusion of air into the hotbed, forming plastic conglomerates that include large quantities of fuel, which thus becomes unavailable for combustion.

The ash content of the tested briquettes returned values of between 2.09%, for the MO variety, and 3.27%, for the FN variety.

The calorific value of the briquettes is an important characteristic, related to the energy content of biomass, as we discussed in a previous paper [22]. The results of the current study show that the higher calorific value (HCV) of the vineyard waste briquettes is approximately 19 MJ/kg, while the lower calorific value (LCV) is 17 MJ/kg. The calorific value (HCV) is a critical parameter for evaluating the energy potential of vineyard waste briquettes. With an HCV of 19 MJ/kg and an LCV of 17 MJ/kg, these briquettes demonstrate a high energy content, making them an efficient and effective fuel source. The vineyard waste briquettes' calorific values suggest good combustion efficiency, making them suitable for use in residential and industrial heating applications.

The chemical composition of the briquettes was analyzed according to the requirements of the respective standards. The results presented in Table 3 show that the majority of the parameters were within the limits imposed by the ISO 17225-3 standard [26] for Class A1, A2, and B1 briquettes; however, the values for chrome, copper, and cadmium exceed the maximum limits imposed by the standard.

The source of copper in vineyard waste is the pesticides and fungicides used to control fungal diseases. Over time, this compound accumulates in the vineyard soil.

A high chlorine content can result in the formation of corrosive compounds during combustion, which may have an adverse effect on the lifespan of boilers and other equipment. A very low limit is set for cadmium due to its high toxicity and potential for bioaccumulation. The limits for chromium are set to avoid environmental contamination and health hazards. Cadmium contamination in vineyard waste primarily originates from the application of phosphorus (P) fertilizers to the soil. In order to reduce the content of copper, cadmium, and chromium in vineyard waste briquettes, various procedures and technologies need to be implemented, such as pre-treatment (washing, segregation), and processing technologies (blending, additives). All the briquettes produced had high density and complied with the limits required for Class A1, indicating they meet high-quality standards for biofuels [48].

Nevertheless, the biomass produced from vine tendrils, densified as briquettes, is a valuable and useful solid fuel. Moreover, densification of vineyard waste biomass in the form of briquettes leads to high-energy products with high added value and eliminates the burning of agricultural waste in the open air, which negatively impacts the environment.

Table 3. Results regarding the classification criteria for the briquettes produced from vine tendrils (average values $\pm$ standard deviation, for $n = 3$ repetitions).

Parameter	Variety *							
	BB	CS	FA	FN	FR	MO	PN	SB
Diameter (D) [mm]	49 $\pm$ 0.34 ^{ab}	49 $\pm$ 0.72 ^{ab}	49 $\pm$ 0.53 ^{ab}	49 $\pm$ 0.45 ^{ab}	49 $\pm$ 0.62 ^{ab}	49 $\pm$ 0.36 ^{ab}	49 $\pm$ 0.28 ^{ab}	49 $\pm$ 0.83 ^{ab}
Length (L) [mm]	200 $\pm$ 2.5 ^{ab}	200 $\pm$ 1.8 ^{ab}	200 $\pm$ 1.6 ^{ab}	200 $\pm$ 1.7 ^{ab}	200 $\pm$ 1.8 ^{ab}	200 $\pm$ 1.5 ^{ab}	200 $\pm$ 2.0 ^{ab}	200 $\pm$ 2.0 ^{ab}
Moisture ratio [%]	8.20 $\pm$ 0.1 ^{ab}	7.86 $\pm$ 0.2 ^{ab}	8.01 $\pm$ 0.1 ^{ab}	7.78 $\pm$ 0.1 ^{ab}	8.07 $\pm$ 0.1 ^{ab}	7.89 $\pm$ 0.1 ^{ab}	8.02 $\pm$ 0.2 ^{ab}	8.18 $\pm$ 0.1 ^{ab}
Ash content [%]	2.68 $\pm$ 0.04 ^{***a}	3.05 $\pm$ 0.04 ^{***a}	3.08 $\pm$ 0.02 ^{***a}	3.27 $\pm$ 0.03 ^{***a}	2.99 $\pm$ 0.05 ^{***a}	2.09 $\pm$ 0.04 ^{***a}	3.18 $\pm$ 0.02 ^{***a}	3.05 $\pm$ 0.03 ^{***ab}
Density [kg/cm ³]	1349.0 ^{ab}	1362.5 ^{ab}	1227.0 ^{ab}	1334.0 ^{ab}	1310.3 ^{ab}	1389.0 ^{ab}	1312.0 ^{ab}	1370.3 ^{ab}
Additives	-	-	-	-	-	-	-	-
Lower calorific value, Q [MJ/kg]	17.71 $\pm$ 1.1 ^{ab}	17.61 $\pm$ 1.2 ^{ab}	17.62 $\pm$ 0.9 ^{ab}	17.62 $\pm$ 1.1 ^{ab}	17.77 $\pm$ 1.3 ^{ab}	16.92 $\pm$ 1.2 ^{ab}	17.45 $\pm$ 1.1 ^{ab}	17.94 $\pm$ 1.1 ^{ab}
Nitrogen, N [%]	0.95 $\pm$ 0.06 ^{****a}	0.93 $\pm$ 0.08 ^{****a}	0.76 $\pm$ 0.03 ^{****a}	1.15 $\pm$ 0.04 ^{****a}	0.91 $\pm$ 0.02 ^{****a}	0.86 $\pm$ 0.02 ^{****a}	0.94 $\pm$ 0.05 ^{****a}	0.99 $\pm$ 0.07 ^{****a}
Sulphur, S [%]	0.041 $\pm$ 0.01 ^{****a}	0.037 $\pm$ 0.01 ^{ab}	0.038 $\pm$ 0.01 ^{ab}	0.042 $\pm$ 0.01 ^{****a}	0.037 $\pm$ 0.01 ^{ab}	0.036 $\pm$ 0.01 ^{ab}	0.033 $\pm$ 0.01 ^{ab}	0.044 $\pm$ 0.01 ^{****a}
Chlorine, Cl [%]	0.07 $\pm$ 0.01 ^{IVab}	0.06 $\pm$ 0.01 ^{IVc}	0.05 $\pm$ 0.02 ^{****a}	0.07 $\pm$ 0.01 ^{IVbc}	0.06 $\pm$ 0.01 ^{IVab}	0.04 $\pm$ 0.01 ^{****ab}	0.06 $\pm$ 0.01 ^{IVab}	0.07 $\pm$ 0.01 ^{IVa}
Arsenic, Ar [mg/kg]	0.09 $\pm$ 0.01 ^{ab}	0.13 $\pm$ 0.01 ^{bc}	0.14 $\pm$ 0.1 ^{ab}	0.15 $\pm$ 0.01 ^{ab}	0.16 $\pm$ 0.01 ^{ab}	0.12 $\pm$ 0.1 ^{ab}	0.15 $\pm$ 0.01 ^{ab}	0.16 $\pm$ 0.01 ^{bc}
Cadmium, Cd [mg/kg]	2.78 $\pm$ 0.3 ^{IVa}	2.89 $\pm$ 0.5 ^{IVa}	2.78 $\pm$ 0.1 ^{IVa}	2.89 $\pm$ 0.4 ^{IVa}	2.84 $\pm$ 0.4 ^{IVa}	2.78 $\pm$ 0.3 ^{IVa}	2.85 $\pm$ 0.2 ^{IVa}	2.80 $\pm$ 0.4 ^{IVa}
Chromium, Cr [mg/kg]	11.6 $\pm$ 1.2 ^{IVa}	11.5 $\pm$ 1.0 ^{IVa}	12.3 $\pm$ 1.3 ^{IVa}	11.5 $\pm$ 1.0 ^{IVa}	11.5 $\pm$ 0.9 ^{IVa}	11.3 $\pm$ 1.0 ^{IVa}	11.4 $\pm$ 1.2 ^{IVa}	11.9 $\pm$ 1.1 ^{IVa}
Copper, Cu [mg/kg]	23.8 $\pm$ 1.4 ^{IVa}	23.4 $\pm$ 1.6 ^{IVa}	22.7 $\pm$ 1.1 ^{IVa}	25.1 $\pm$ 1.3 ^{IVa}	23.9 $\pm$ 1.0 ^{IVa}	22.3 $\pm$ 1.5 ^{IVa}	25.2 $\pm$ 1.2 ^{IVa}	23.1 $\pm$ 1.5 ^{IVa}
Lead, Pb [mg/kg]	11.8 $\pm$ 0.6 ^{IVa}	10.0 $\pm$ 0.8 ^{ab}	11.0 $\pm$ 0.3 ^{IVa}	10.2 $\pm$ 0.9 ^{IVa}	10.0 $\pm$ 0.2 ^{ab}	9.83 $\pm$ 0.6 ^{ab}	9.80 $\pm$ 0.9 ^{ab}	9.98 $\pm$ 0.7 ^{ab}
Mercury, Hg [mg/kg]	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Nickel, Ni [mg/kg]	9.74 $\pm$ 0.3 ^{ab}	9.81 $\pm$ 0.7 ^{ab}	9.99 $\pm$ 0.5 ^{ab}	10.0 $\pm$ 0.6 ^{ab}	9.86 $\pm$ 0.3 ^{ab}	9.7 $\pm$ 0.5 ^{ab}	10.0 $\pm$ 0.6 ^{ab}	9.73 $\pm$ 0.44 ^{ab}
Zinc, Zn [mg/kg]	16.25 $\pm$ 1.8 ^{abc}	11.0 $\pm$ 0.8 ^{bc}	23.6 $\pm$ 1.8 ^{ab}	22.3 $\pm$ 1.2 ^{ab}	12.8 $\pm$ 1.9 ^{bcde}	9.6 $\pm$ 0.5 ^{bc}	18.0 $\pm$ 0.9 ^{bc}	13.3 $\pm$ 1.5 ^{bcd}

Note: *—class A1; **—class A2; ***—class B; IV—limits exceeded. Limits for Cr $\leq$ 10, Cu $\leq$ 10, Zn $\leq$ 100, Cd $\leq$ 0.5, Pb $\leq$ 10, As $\leq$ 1, and Hg $\leq$ 0.1, according to the ISO 17225-3 standard [26]. Values indicated with different letters are significantly different from each other at the $p \leq 0.05$ level, whereas those indicated with the same letters show no significant differences ($p > 0.05$). Columns with different letters show a significant difference at the level of $p \leq 0.05$.

3.4. Energy Consumption and Energy Efficiency for Producing Briquettes from Vine Tendrils

The energy consumption for the valorization of renewable biomass using the briquetting process is an important parameter for calculating energy efficiency and for the evaluation of the overall energy input. As was shown in the previous section, the electricity consumption (in kWh) for each stage shown in Figure 2 was measured, considering the grinding, drying, sieving, and briquetting processes; the diesel fuel consumption (in liters) for shredding 50 kg of tendrils was also measured. The energy consumption, measured in kWh, was divided by the mass of the final product in order to obtain the specific consumption, in kWh/kg or MJ/kg.

Table 4 presents the experimental results regarding the energy consumption for the shredding, drying, sieving, grinding, and densification of vineyard waste biomass.

Table 4. Energy consumption for the preparation and briquetting of the vine tendrils.

Variety	E_{bcg} (MJ/kg Product)	E_{bd} (MJ/kg Product)	E_{bcd} (MJ/kg Product)	E_{bs} (MJ/kg Product)	k_{b1}	k_{b2}	E_{bm} (MJ/kg Product)	E_b (MJ/kg Product)
PN	0.0842 ^a	2.502 ^a	0.0624 ^a	0.0072 ^a	0.623 ^a	0.516 ^a	0.0987 ^a	0.340 ^a
MO	0.0858 ^a	2.731 ^a	0.0656 ^a	0.0079 ^a	0.629 ^a	0.523 ^a	0.1032 ^a	0.315 ^a
FN	0.0865 ^a	2.752 ^a	0.0664 ^a	0.0081 ^a	0.622 ^a	0.510 ^a	0.0931 ^a	0.322 ^a
FA	0.0829 ^a	2.421 ^a	0.0619 ^a	0.0073 ^a	0.615 ^a	0.506 ^a	0.0983 ^a	0.313 ^a
FR	0.0848 ^a	2.585 ^a	0.0639 ^a	0.0075 ^a	0.628 ^a	0.524 ^a	0.0992 ^a	0.323 ^a
CS	0.0832 ^a	2.465 ^a	0.0631 ^a	0.0074 ^a	0.634 ^a	0.526 ^a	0.0977 ^a	0.335 ^a
SB	0.0838 ^a	2.486 ^a	0.0629 ^a	0.0076 ^a	0.643 ^a	0.514 ^a	0.0976 ^a	0.327 ^a
BB	0.0853 ^a	2.689 ^a	0.0642 ^a	0.0079 ^a	0.609 ^a	0.490 ^a	0.1004 ^a	0.319 ^a

Note: Data are the mean and the same letters show no significant difference ($p > 0.05$).

The energy used for shredding the tendrils with a moisture ratio of 44–46% (E_{bcg}) and of those that were naturally dried to a moisture ratio of 10–12% (E_{bcd}) is mainly affected by the state of biomass. Thus, for the tendrils with a high moisture content, the energy consumption increased by 10–15% in comparison with the dried tendrils. In the meantime, there was no significant effect of the vine variety on energy consumption. These findings are in accordance with the results presented by other authors [49].

The energy required for drying the biomass down to 10–12% moisture content (E_{bd}) represents the sum of the energies involved in the heat and mass transfer between the drying agent and the biomass divided by the quantity of dehydrated tendrils. According to the experimental results, the specific energy consumption for drying was between 2.421 MJ/kg product, for the Fetească albă variety, and 2.731 MJ/kg product, for the Muscat Otonel variety. These results are consistent with those reported by other authors [48,50].

In order to separate the fractions with particles bigger than 8 mm, the shredded biomass was sieved; the energy consumption for this operation was between 7.2 kJ/kg, for the PN variety, and 8.1 kJ/kg, for the FN variety.

The values of the coefficients k_{b1} and k_{b2} (referring to particles bigger than 8 mm), shown in Table 4, are in accordance with the results shown in Table 2.

The energy required for grinding the fractions containing particles bigger than 8 mm (E_{bm}) recorded values of between 0.0976 MJ/kg product, for the CS variety, and 0.1032 MJ/kg product, for the MO variety.

Based on the data presented in Table 4 and using Equations (3) and (4), the overall energy consumption was calculated for the two technologies taken into account: artificial drying (E_{b1}) and natural drying of the raw material (E_{b2}). The results are summarized in Figure 7 and they clearly show that artificial drying significantly increases the energy input for lowering the moisture content from 44% to 12%.

The energy efficiency for briquetting the agricultural waste from vine winter pruning was calculated using the data in Figure 8 (referring to the overall energy consumption), considering the lower calorific value of the briquettes (Table 3) and using Equations (6) and (7). The results are depicted in Figure 8 and they clearly show that artificial drying leads to an average efficiency of 82.52%, while natural drying recorded a higher average efficiency (97.45%). These values are proof that using the vine tendrils as raw material for producing briquettes is a sustainable method and this agricultural waste may be taken into account as an important and reliable source of renewable energy. Moreover, this study emphasizes the idea of using agricultural waste in order to obtain energy carrier products, with high added value, thus avoiding burning them in the open air, with major negative impacts on the environment.

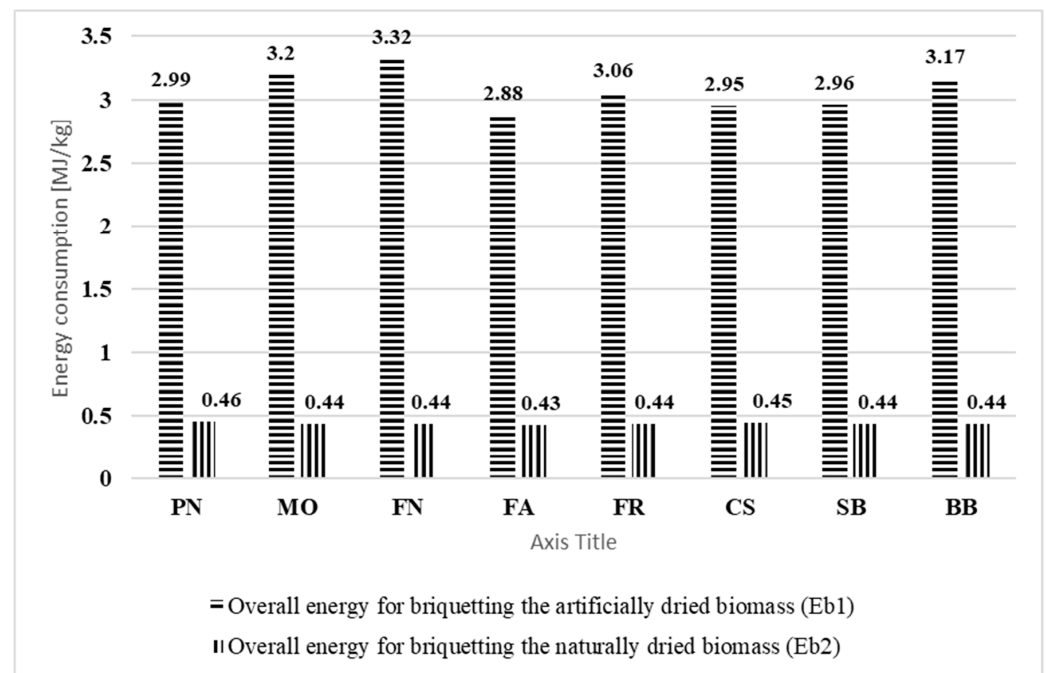


Figure 7. Overall energy consumption for the briquetting of biomass from vine tendrils (MJ/kg product).

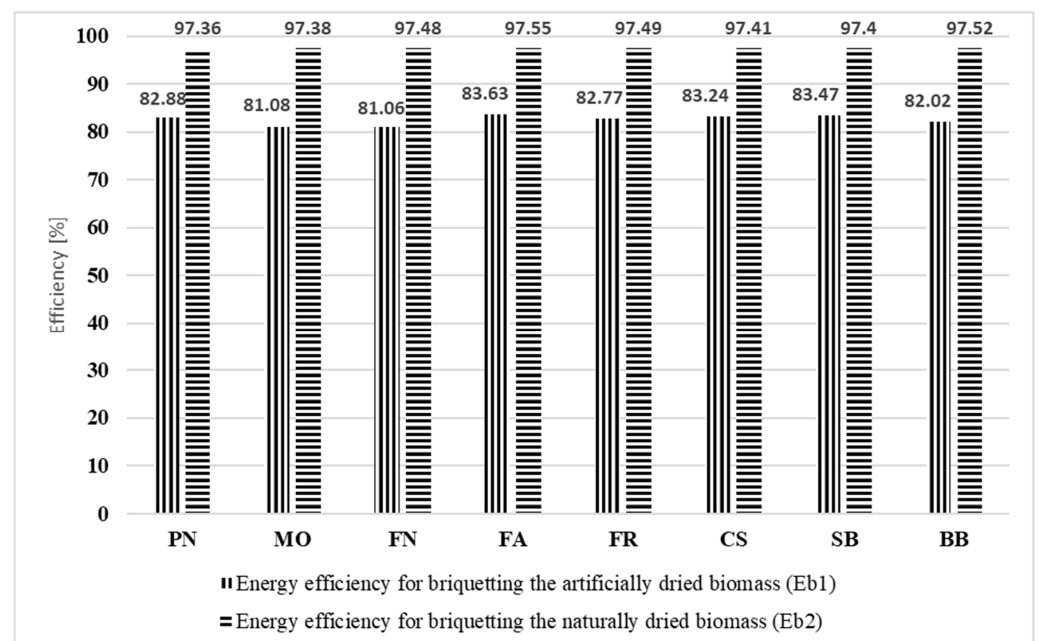


Figure 8. Energy efficiency for the briquetting of biomass from vine tendrils (%).

The briquettes that were produced have high mechanical properties due to the fact that biomass contains 22.4–35.5% lignin, 30.2–36.2% cellulose, and 16.5–24.4% hemicellulose, depending upon the vine variety [38]. Due to the high lignin content, briquetting may be performed without the use of binding substances, and the mechanical durability of the briquettes is higher than 97.0% [22]; thus, the mechanical integrity of the briquettes is preserved during maneuvering, transport, and storage.

This study provides a model for the practical application of the circular economy concept, which is an economic model aiming to minimize waste and maximize the use of resources by promoting recycling, reusing, and regeneration [51,52]. This system, based on

the valorization of the waste from different agricultural and food industry technological processes, provides energy resources for other branches of the economy, thus eliminating the concept of waste.

3.5. Multivariate Analysis

The hierarchical clustering dendrogram (HCA) of the briquettes is presented in Figure 9. This analysis was conducted using all the variables employed to characterize the briquettes and energy consumption. The results demonstrate that the briquettes can be classified into two distinct clusters based on their quality and energetic parameters. The first cluster comprises briquettes produced from Pinot Noir and Muscat Ottonel, which share similar characteristics and energy consumption profiles. The second cluster includes briquettes produced from Fetească Neagră and Sauvignon Blanc, as well as those produced from Sauvignon Blanc and Busuioacă de Bohotin. These clusters indicate a clear distinction in the quality and energetic parameters between the two groups of briquettes.

Table 5 presents a descriptive analysis of the entire data set for all types of briquettes analyzed. The data show that the lowest diversity, expressed by the mean coefficient of variation, was observed in most of the parameters. The highest variability was observed for zinc content (35.98%), indicating a significant difference in zinc content between the different briquettes. Arsenic content also showed significant variability (16.47%) while chlorine content showed a moderate level of variability (12.36%). Chromium content had the lowest variability (0.65%), indicating consistent levels across samples, while the lower calorific value (LCV) also showed minimal variability, suggesting similar energy content between briquettes. The amount of biomass at a 12% moisture content (11.65%) showed moderate variability, which could be due to differences in moisture retention among the biomass samples. Most of the other parameters such as moisture, ash, density, and energy content parameters (e.g., E_{bcg} , E_{bd}) had coefficients of variation below 10%, indicating relatively consistent results. The relatively higher coefficients of variation for Zn, As, and Cl indicate potential outliers or significant differences between briquette samples from different vine varieties. The analysis shows that while most parameters have low to moderate variability, certain elements such as Zn, As, and Cl have higher variability, suggesting differences in source material or processing conditions. These results highlight the importance of monitoring specific parameters to ensure consistent quality and performance of briquettes.

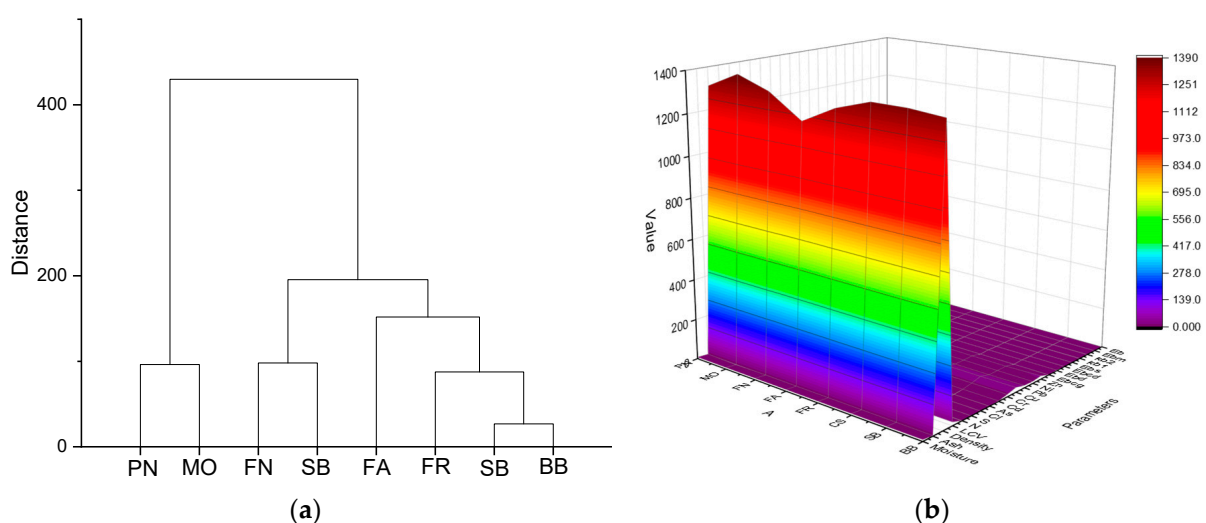


Figure 9. (a) Dendrogram of the cluster analysis on different briquette varieties; (b) 3D surface plot of variables used for dendrogram evaluation.

Table 5. Selected statistical analysis indicators for the studied features.

Feature	Mean Average	Standard Deviation	Sum	Minimum Value	Median	Maximum Value	Coefficient of Variation (%)
Average quantity of tendrils/stump (kg/stump)	0.36738	0.03959	2.939	0.327	0.357	0.433	8.10
Quantity of biomass at the initial moisture ratio (kg/ha)	1596.95	172.10932	12,775.6	1421.4	1551.85	1882.2	8.10
Initial moisture ratio of tendrils (%)	44.125	1.85159	353	41.87	44.055	47.47	4.61
Quantity of biomass at a 12% moisture ratio (kg/ha)	1061.3375	130.56427	8490.7	907	1019.75	1250.8	11.65
Moisture (%)	7.96125	0.13789	63.69	7.78	7.95	8.2	1.68
Ash (%)	2.92375	0.37811	23.39	2.09	3.05	3.27	4.62
Density (kg/cm ³)	1330.7875	49.69425	10,646.3	1227	1341.5	1389	2.79
LCV (MJ/kg)	17.53875	0.26643	140.31	16.92	17.615	17.77	0.42
N (%)	0.92875	0.10895	7.43	0.76	0.93	1.15	3.19
S (%)	0.03762	0.00283	0.301	0.033	0.037	0.042	4.01
Cl (%)	0.05875	0.00991	0.47	0.04	0.06	0.07	12.36
As (mg/kg)	0.13375	0.022	1.07	0.09	0.135	0.16	16.47
Cd (mg/kg)	2.8375	0.0512	22.7	2.78	2.845	2.89	2.35
Cr (mg/kg)	11.575	0.30589	92.6	11.3	11.5	12.3	0.65
Cu (mg/kg)	23.725	1.02783	189.8	22.3	23.6	25.2	3.77
Pb (mg/kg)	10.32875	0.70552	82.63	9.8	10	11.8	2.74
Ni (mg·kg ^{−1})	9.86375	0.12011	78.91	9.7	9.835	10	1.73
Zn (mg/kg)	15.56875	5.36157	124.55	9.6	14.525	23.6	35.98
Ebcg (MJ/kg product)	0.08456	0.00127	0.6765	0.0829	0.0845	0.0865	1.84
Ebd (MJ/kg)	2.57887	0.12967	20.631	2.421	2.5435	2.752	5.86
Ebcd (MJ/kg)	0.0638	0.00156	0.5104	0.0619	0.0635	0.0664	2.10
Ebs (MJ/kg)	0.00761	3.22656 × 10 ^{−4}	0.0609	0.0072	0.00755	0.0081	5.89
kb1	0.62538	0.01068	5.003	0.609	0.6255	0.643	1.42
kb2	0.51363	0.01186	4.109	0.49	0.515	0.526	2.45
Ebm (MJ/kg)	0.09852	0.00285	0.7882	0.0931	0.0985	0.1032	1.28
Eb (MJ/kg)	0.32425	0.00939	2.594	0.313	0.3225	0.34	2.76

4. Conclusions

The biomass resulting from the agricultural technological processes is a primary source of carbon, which may be used as raw material for producing solid biofuels with high energy value for different economic activities. Biomass is the only renewable resource that may be directly used for combustion. The combustion of biofuels releases CO₂ into the atmosphere, which is then utilized by plants to produce new quantities of biomass. The aim of the paper was to evaluate briquette production using vine tendrils resulting from vine pruning as raw material. When designing the scientific endeavor, the following aspects were considered: defining the aim and objectives of the research; design of the research algorithm; collection, preparation, and conditioning of the biomass; chemical analysis of the briquettes; evaluation of the technological characteristics of the briquettes; and evaluation of the energy consumption and energy efficiency for producing the briquettes, taking into account two drying methods (natural and artificial drying).

The analysis of the experimental data led to the following conclusions:

- The average quantity of dried biomass (12% moisture ratio) exceeded 1000 kg/ha;
- The lower calorific value of the briquettes from vine tendrils is over 17 MJ/kg;
- The unit density of the produced *Pini-kay*-type briquettes is over 1330 kg/m³;
- The dimensions of the briquettes are within the limits imposed by the international standards;
- The chemical composition of the briquettes is within the limits imposed by the ISO 17225-3 standard [26] for Class A1, A2, and B1 briquettes for most parameters; however, the values for chrome, copper, and cadmium exceed the maximum limits imposed by the standard;
- The overall energy consumption in producing briquettes is mainly affected by the drying method: forced convection requires a significantly higher energy consumption for reducing the moisture ratio from 44% to 12% in comparison with natural convection;

- Artificial drying leads to an average energy efficiency of 82.52%, while a higher average efficiency (97.45%) was obtained for the natural drying of biomass.

Although some of the chemical elements in briquettes exceed the limits imposed by the ISO 17225-3 standard [26], the biomass produced from vine tendrils may be regarded as a valuable solid biofuel, with high added energy value. Meanwhile, the valorization of biomass in the form of briquettes eliminates the need for their disposal through burning in the open air, thus eliminating the negative impact of this process on the environment.

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