Book Chapter

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

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Abstract

Concerns over the past decades have focused, more than ever, on finding and implementing efficient, handy, renewable sources to reduce pollution. Biomass, in general, and biomass from annual vine cuttings, are a renewable source that can be used by a large mass 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 obtain of densified material as a briquettes consisted of sampling the vine cuttings, drying them naturally, chopping and grinding and briquetting. The obtained results showed that the size of the briquettes met the requirements imposed by the standard, having a length between 185 mm ... 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 maximum of 99.14% for Fetească neagră, the bulk density having values between 658.04 kg /m^3 at Fetească albă and 756 kg/m^3 for Pinot noir. The conclusions of these experiments are promising, showing that the densification of biomass from vines cuttings qualify within the standard requirements for obtaining a valuable biofuel.

Keywords

Pollution; Renewable; Biomass; Vine; Densification

Introduction

In the last 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 of oil price, global warming; the non-renewable fuels

(coal, natural gas, coal) dependent industries have caused a dramatic increase of the greenhouse effect gases emissions and 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, agricultural wastes. These energy sources are available any ware 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 the environmental pollution; nevertheless, their full potential is yet unattained due to manipulation, transportation, storage and combustion related problems [10].

The EU directive concerning the renewable energy (2009/28/CE) has set common objectives for the EU member countries, aiming for the 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 resulted 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 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 of 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 were used in 2019 for heating, with an 1.2% increase of 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 pellets consumption continued to increase in 2019 in EU28, with a supplemental consumption of 1.8 mil. tons (representing 6.8% yearly increase), reaching 27.7 mil tons [12].

Biomass has different advantages as it is easy to find, cheap, has a neutral CO_2 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 effect 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; moreover, its use imposes supplementary precaution measures because of the high pollution potential [15].

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 briquettes have a high calorific value, do not produce smoke when burned and are advantageous from an economical 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 an uniform and compacted fuel, with a higher density and energy content and lower moisture content compared with the raw material [16-22].

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 [23].
The principle of briquettes 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 [10,24,25].

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 [19,26,27].

Briquettes differ very much in size and shape, but they are usually cylindrical, with the diameter comprised between 25 and 100 mm and the length comprised between 10 and 400 mm. Briquettes may be produced with a density of 1200 kg/m^3 and a bulk density of 100 to 200 200 kg/m^3; a higher density results in a higher calorific value (kJ/kg) and a slower combustion process compared to the raw materials. Bulk density is defined as the mass of volume unit and is measured in (kg/m^3) [28-30].

The process for producing briquettes 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 to 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±2% is considered to be the optimum value.

Briquetting is achieved through a continuous process, when the screw type press is used (Figure 1.a), or in a discontinuous process when a reciprocating piston is used (Figure 1.b).

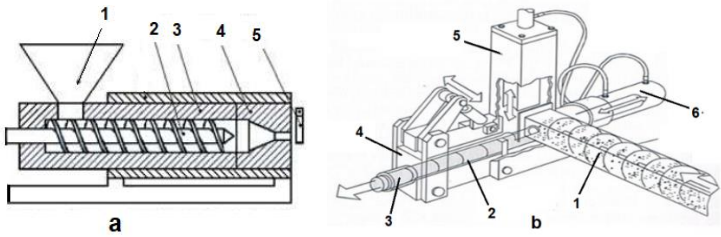


Figure 1: Briquetting procedures: a – screw type press: 1 – chopped biomass feeder; 2 – pressing screw; 3 – barrel; 4 – pressing head with calibrated orifice; 5 – cutting knife; b – piston type press: 1 – screw precompacter; 2 – pressing chamber; 3 - briquettes; 4 – pressing head with calibrated die; 5 – forced feeding device; 6 – hydraulic cylinder.

The shapes and names of the briquettes depend on the pressing process and the press manufacturer [25], 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. Figure 2 presents the diagram of the Pini-Kay pressing machine; the active parts of the machine are mechanically operated using gears and belts (the latter being also used as protection devices).

Screw extrusion briquetting machines are convenient for low scale production of briquettes. The briquettes have better combustion characteristics due to larger specific surface; the briquettes are homogenous and less prone to disintegration and superior quality of the final product [21].

Different studies [29,30] state the briquettes produced from biomass may reach a density of 1200 kg/m^3 from free biomass, with a bulk density of 100 to 200 200 kg/m^3; a higher density leads to a higher thermal value of the briquettes (kJkg), with a slower combustion in comparison with the raw materials.

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 [31,32].

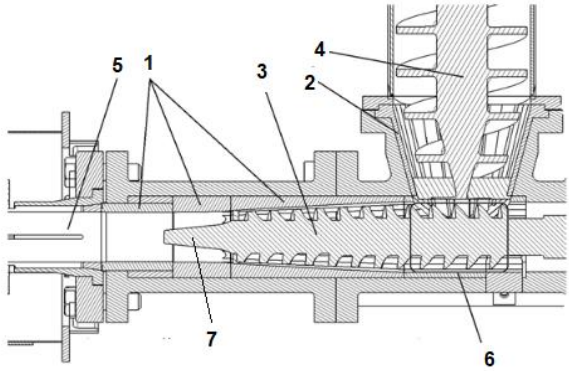


Figure 2: The Pini-Kay briquetting press: 1 – pressing chamber with calibrated dies; 2 – feeding chamber; 3 – tronconical pressing screw; 4 – feeding screw; 5 – briquettes discharge; 6 - case; 7 – conical head of the pressing screw.

The wine regions of Romania have an ideal climate for wine grapes; up-to-date there are aproximately 1300 companies which grow grapes and produce wine, esspecially in Vrancea, Bucharest, Prahova, Artad and Iaşi. Vine wastes from result form the pruning of tendrils; these are usually burned, thus contributuing to global warming thorugh the emission of greenhouse gasess [31,33,34].

The International Organization for Vine and Wine has publicly announced at a conference that took place in April, 23, 2020, that the surface of the worldwide vineyards represents 7.4 mil. hectares [35]. 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% from the overall cultivated area in Europe, with 183717 ha of vineyards and an average of 0. 2ha/farmer [35]. This data proves the tremendous potential for the use of vineyard residues as biomass.

Materials and Methods

The experiments aiming to design the technology for producing densified biomass in the form of briquettes have 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 Iaşi; the plantation is a part of the Copou Vineyards, located near the city of Iaşi.

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

The technological process for producing the briquettes has comprised the following operations (Table 1): dormant pruning of vine; tendrils collecting 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.

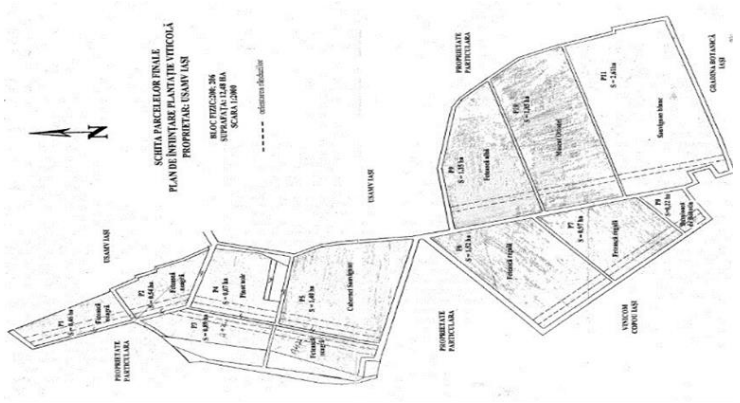
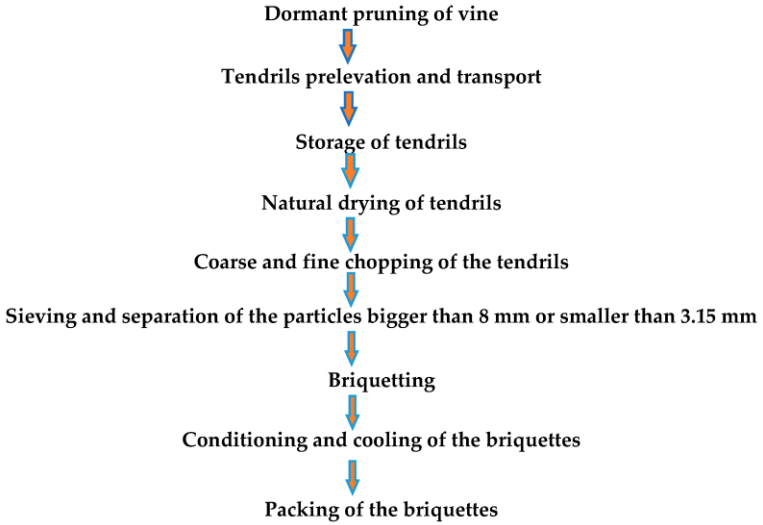


Figure 3: Cadastral map of the vineyard plantation located at the "Vasile Adamachi"farm.

Collecting the Tendrils

The biological material for producing the briquettes was collected from the tendrils belonging to eight vine varieties: *Fetească Neagră; Fetească Albă; Fetească Regală; Muscat Ottonel; Pinot Noir; Cabernet Sauvignon; Sauvignon Blanc* and *Busuioacă de Bohotin.*

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



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

Collecting and Transporting the Tendrils

The tendrils were collected from each of the twelve plots, from five vines placed on the first row, 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.

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.

Natural Drying of Biomass

Moisture is an important characteristic of biomass, representing the water content of the respective material. According to different studies, the ideal moisture content, which ensures the appropriate physical and mechanical characteristics of the solid biofuel, depends on the particle size, properties of the raw material and parameters of the densification process.

The moisture content may be expressed as dry base or wet base. Biomass may be dried following a passive process (without external energy sources) or an active process (using external heat and/or fans) [36,37].
Natural passive drying is an easy method for obtaining the adequate moisture content of biomass, does not require supplementary equipment and external energy, but is a slow process. Natural drying occurs when biomass has a higher moisture content than the surrounding environment [38].

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 fibers solubilisation during briquetting [39,40].

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 [41]. Different studies recommend a moisture content between 5-12% or 8-12%, 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 risk of explosion. Another disadvantage of the high moisture content is that it favors the reproduction of harmful microorganisms [42]. 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 [43,44].

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%.

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. After the fine grinding large variations of the dimensions of the particles were obtained, but quality briquettes only from particles with dimensions between 3.15 and 8 mm. When the particles are smaller than 3.15 mm the capacity of integrating the particles into the briquettes is diminished, and the final product has a low consistency structure of the wooden fibers. When briquettes are produces from particles bigger than 8 mm, their mechanical durability is low and combustion produces more ash because of the quick burning process. In this study the tendrils were grinded, after drying, using the CARAVAGGI BIO 90 shredder. This is a 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) 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 m^3/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 orifices 15 mm 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 4).

Figure 4: Operating the CARAVAGGI BIO 90 shredder.

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 resulted material was evaluated; in order to achieve this operation, samples were collected according to the requirements of the ISO SR EN 14778:2011 [45] standard for solid biofuels; the volume of each sample was 8 liters. In order to separate the granulometric fractions, a laboratory sieving equipment was used (Figure 5); according to the ISO SR EN 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.

Sieving and Separation of the Particles bigger than 8 mm or Smaller than 3.15 mm

After the biomass was grinded it was sieved in order to obtain only particles with dimensions between 3.155 and 8 mm. This operation was performed with a mechanical sieving machine (Figure 6), equipped with three sieves with orifices with diameters of 3.15 mm, 8 mm and 16 mm, respectively. The existing biomass was thus divided in four categories:

- Material with particles smaller than 3.15 mm, which will be later used for producing pellets;
- Material with the dimensions of the particles comprised between 3.15 and 8 mm, which was used for producing briquettes;
- Material with the dimensions of the particles comprised between 8 and 16 mm, which will be grinded again;
- Material containing particles bigger than 16 mm, which will be shredded and grinded.

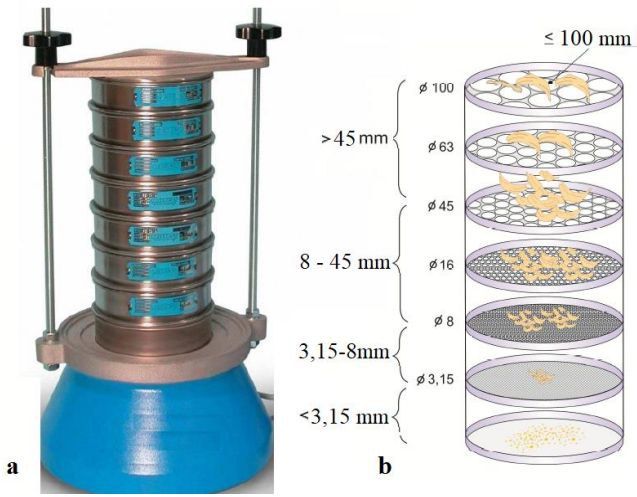


Figure 5: Equipment for the granulometric separation of grinded tendrils: **(a)** – general view; **(b)** – sieves

(a)

(b)

(c)

(d)

Figure 6: Sieving of the grinded tendrils: (a) and (b) – sieving machine; (c) – grinded tendrils before sieving; (d) – grinded tendrils ready for briquetting.

Briquetting of the Grinded Tendrils

In this research *Pini-kay* briquettes were produced, using the GCBA-1 (Figure 7) 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 tree, oak tree, birch tree, 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 elctric heater: 5 kW;
- Maximum length of the particles to be densified: 8 mm;
- Raw material density: 0.5...0.8 kg/dm^3;
- Raw material moisture content: 10...14%;
- Weight: 580 kg.

Figure 7: Briquetting machine [47]: 1 - frame; 2 – electric motor; 3 – electric pannel; 4, 5 – belt transmissions; 6, 7- bearings and main shaft; 8 – feeding shute; 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 8) is composed of a pressing chamber (b) and a tronconical screw (a), ending with a cone shaped tip.

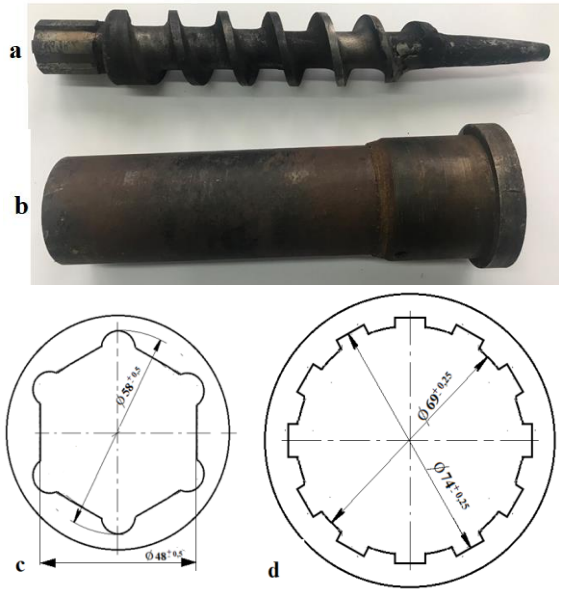


Figure 8: Active parts of the densification device: (**a)** – tronconical screw; (**b)** – pressing chamber; (**c)** – cross-section of the briquettes discharge die; (**d)** – inlet cross-section of the pressing die.

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 8d, and ending with 6 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 8c) 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 – 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 9.a) and is then split into fragments with a length of 200, 300 or 400 mm (Figure 9.b).

(a)

(b)

Figure 9: Briquettes from vine tendrils: (**a)** – manufacturing of the briquettes: 1 – briquetting machine; 2 – densification and continous discharge of the briquette; (**b)** – briquettes produced from the varieties: *Cabernet Suvignon; Fetească Regală; Pinot Noir; Muscat Ottonel; Fetească Albă; Sauvignon Blanc; Fetească Neagră*; *Busuioacă de Bohotin*.

Methods and Equipment for the Assessment of Quality Indices

After performing the densification of the grinded tendrils, the following quality indices of the briquettes were evaluated:

- Length and diameter;
- Moisture content;
- Briquetting coefficient;
- Mechanical durability;
- Bulk density;
- Volumetric density;
- Calorific value.

Dimensions of the Briquettes

Depending on the equipments, the biomass briquettes may have different shapes and dimensions. The SR EN ISO 17225-7:2014 [48] takes into account seven shapes (Figure 10 a, b, c, d, e, f , g) and provides values for the diameter (D) and length (L_1).

The SR EN ISO 17225-7/2014 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: 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, $L_1 > 400$.

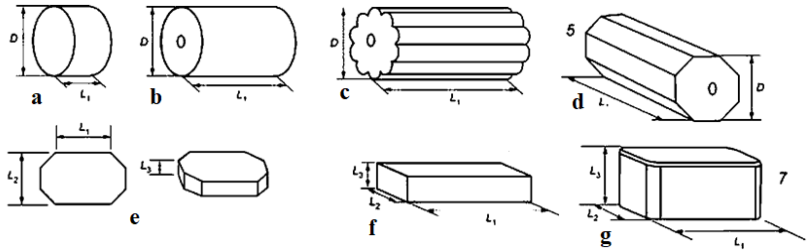


Figure 10: Dimensions of the briquettes according to SR EN ISO 17225-7:2014 standard [48].

In the present study the following dimensions were measured (Figure 11), ISO 17829 [49]:

- Maximum diameter, D;
- Diameter of the hexagon inscribed circle, d_1;
- Diameter of the orifice, d_2;
- Width, b;
- Length, L_1.

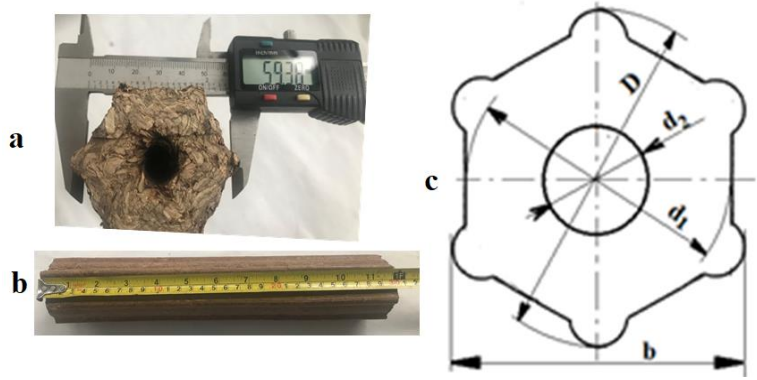


Figure 11: Dimensions of the briquettes: (a) – cross-section measurement; (b) – length measurement; (c) – cross-section dimensions.

Five briquettes from each vine variety were measured in order to evaluate the dimensions; on each briquette, the measurements (except for the length) were performed in the central area and at both ends. The mean value for each measured item was then calculated in order to obtain the final data.

Evaluation of Moisture Content

The thermal balance method was used in order to evaluate the moisture content of the raw material, grinded matter and briquettes, using the AGS 210 moisture analyzer (Figure 12). The method is based on the evaporation of water from the heated sample (105° C), under intensified air circulation; the drying process was considered to be complete when the mass of the sample remained constant. Each measurement was repeated five times and the average values were considered.

Figure 12: Measurement of moisture content

Coefficient of Briquetting

The briquetting coefficient was calculated as percentage of biomass converted into briquettes from the overall quantity of biomass grinded 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 grinded tendrils, with the dimensions of the particles comprised between 3.15 and 8 mm;

- Non-sieved grinded 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.

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 mechanical durability was evaluated according to the SR EN ISO 17831-1:2016 standard [50], using the equipment shown in Figure 13; the test drum (1) has a volume of 160 dm^3 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.

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.

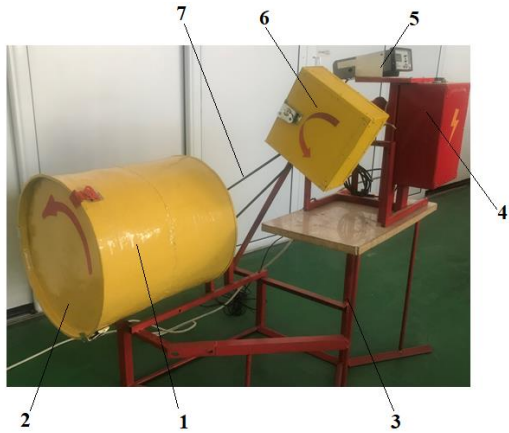


Figure 13: Mechanical durability testing equipment: 1 –rotating drum; 2 – cover; 3 – frame; 4 – electric pannel; 5 – revolutions counter; 6 – electrc engine and gear transmisssion; 7 – belt transmission.

The samples for testing were weighted with and 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 mechanical durabiliy was calculated with the formula:

$$DU = \frac{m_A}{m_E} x100 \quad [\%] \qquad (1)$$

where m_A is the initial weight of the briquette and m_E is the final weight. At least three replicates were considered for each type (variety of vine tendril) of briquette.

In order to evaluate the bulk density 20 briquettes were stacked in order to form a block (Figure 14) and its dimensions (length, width, height) were measured. The bulk density was calculatzed as the ratio between the weight and volume of the stack. Five measurements were performed for each vine variety.

Evaluation of Briquettes Density

The unit density of the briquettes was determined using a gradutated 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 distiled water was weighted (Figure 15a); them the briquette was imersed into the cylinder and the displaced water volume and weight of the cylinder were measured. The unit density was then calculated with the formula:

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

where m_a is the initial mass of the cylinder, m_b is the mas of the cylinder with the briquette inmersed into the water and V_a is the displaced volume of water. Five samples were used for each vine variety.

Figure 14: Evaluation of bulk density.

(a) (b)

Figure 15: Evaluation of unit density.

Determination of Calorific Value

The high calorific value (HCV) 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 [51]. 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 HCV was obtained by calculation, taking into account the moisture and hydrogen content of the samples.

Results and Discussion

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 2 presents the experimental results regarding the dimensions of the particles resulted in the two grinding stages (coarse and fine grinding).

The data presented in Table 2 show that fractions which are unsuitable for briquetting (particles smaller than 3.15 mm or bigger than 8 mm have resulted after coarse grinding); the fractions which are suitable for briquetting (with particle dimensions between 8 and 3.15 mm) were comprised between 45.8% for the *Muscat ottonel* variety and 52,78% for the *Fetească albă* variety.

After the fine grinding, 92% of the resulted particles were suitable for the following briquetting process (dimensions between 8 and 3.15 mm)

Table 2: Results regarding the grinding of the vine tendrils.

Nr. crt.	Vine variety	Moisture content of tendrils (%)	Grinding operation	Fractions (%)			
				> 45 (mm)	45 - 8 (mm)	8-3.15 (mm)	< 3.15 (mm)
1	Pinot noir	9.48	Coarse grinding	18.7	32.9	46.80	1.60
			Fine grinding	-	2.33	93.89	3.78
2	Muscat Ottonel	8.76	Coarse grinding	17.63	34.72	**45.78**	1.87
			Fine grinding	-	3.52	92.86	3.62
3	Fetească neagră	9.05	Coarse grinding	18.12	32.93	52.78	1.73
			Fine grinding	-	3.36	93.46	3.18
4	Fetească albă	7.99	Coarse grinding	16.92	33.69	52.73	2.12
			Fine grinding	-	2.33	94.05	3.62
5	Fetească regală	9.25	Coarse grinding	19.21	33.2	46.07	1.52
			Fine grinding	-	2.46	93.58	3.96
6	Cabernet sauvignon	8.04	Coarse grinding	17.80	34.56	46.32	1.32
			Fine grinding	-	3.21	93.82	2.97
7	Sauvignon blanc	7.54	Coarse grinding	19.29	32.13	46.5	2.08
			Fine grinding	-	3.27	93.06	3.67
8	Busuioacă de Bohotin	8.03	Coarse grinding	17.69	31.37	48.96	1.98
			Fine grinding	-	3.14	93.4	3.46

Briquetting of the Vine Tendrils

Briquetting Coefficient

The results presented in Table 3, 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 has reached values higher than 98.24% for the grinded biomass consisting of particles between 3.15 and 6 mm. For the grinded biomass with the same humidity, but which also contained particles smaller than 3.15 mm the briquetting coefficient has decreased by 4…5%. This behavior was a consequence of the fact that high local temperatures (380 °C ... 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 over 10% the briquetting coefficient has decreased significantly, especially for the non-sieved mixtures which contain vegetable dust.

In this case the high moisture content and high temperatures (180 °C ... 220 °C) caused the water in grinded tendrils to evaporate, generating high pressure steam, which was accumulate inside the material and has 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 has decreased. As for the non-sieved tendrils, the cumulated effect of vapor and of micro-explosions created by the self-ignited dust has led to a significant reduction of 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 grinded 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.

Table 3: Briquetting coefficient [%].

Nr. crt.	Vine variety	Grinded and seived tendrils, size of particles between 3.15 mm and 8.0 mm			Grinded, 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
1	Sauvignon Blanc	98.46	94.56	84.51*	93.36	94.56	76.23*
2	Pinot Noir	98.67	93.58	83.88*	92.43	93.58	75.37*
3	Fetească Albă	98.89	93.83	83.78*	92.86	93.83	75.12*
4	Fetească Regală	98.53	94.15	84.65*	93.55	94.15	76.37*
5	Fetească Neagră	98.46	94.64	85.32*	93.31	94.64	75.69*
6	Busuioacă de Bohotin	98.24	94.12	84.51*	93.21	94.12	76.62*
7	Cabernet Sauvignon	98.41	93.88	83.29*	92.98	93.88	74.93*
8	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 mechanical durability lower than the one imposed by the SR EN ISO 17225 [48] standard (94.3%).

Dimensions of the Briquettes

The measurements have shown that the briquettes produced from vine tendrils fall into the Pini-kay category (Figure 10b), third class, D 60 (according to the specifications of the SR EN ISO 17225-7:2014 standard [48]) as far as the diameter and length are concerned (Table 4).

Referring to the notations in Figure 11, the briquettes have the following dimensions:

- Maximum diameter D = 58 mm, with a maximum size variation of ±0.75 mm for the ones obtained from the variety *Busuioacă de Bohotin*;
- Diameter of the inscribed circle d_1 = 49 mm for all the varieties, with a maximum size variation of ± 0.83 mm for the ones obtained from *Sauvignon blanc* variety;
- Inner diameter d_2 = 16 mm, with a maximum size variation of ± 0.62 mm for the ones obtained from *Busuioacă de Bohotin* variety;

The length of the briquettes depends on the precision of the cutting device and was comprised between 200±1.5 mm for the tendrils from the *Muscat Ottonel* variety and 200±2.5 mm for the *Busuioacă de Bohotin* variety.

Table 4: Dimensions of the briquettes.

Nr. crt.	Variety	Dimensions (according to Figure 12)				Shape
		D (mm)	d_1 (mm)	d_2 (mm)	L (mm)	
1.	Pinot noir	58±0.32	49±0.28	16±0.28	200±2.0	3
2.	Muscat Ottonel	58±0.45	49±0.36	16±0.36	200±1.5	3
3.	Fetească neagră	58±0.32	49±0.45	16±0.42	200±1.7	3
4.	Fetească albă	58±0.54	49±0.53	16±0.21	200±1.6	3
5.	Fetească regală	58±0.36	49±0.62	16±0.18	200±1.8	3
6.	Cabernet sauvignon	58±0.37	49±0.72	16±0.41	200±1.8	3
7.	Sauvignon blanc	58±0.68	49±0.83	16±0.57	200±2.0	3
8.	Busuioacă de Bohotin	58±0.75	49±0.34	16±0.62	200±2.5	3

Table 5: Moisture content of the grinded tendrils and briquettes**.**

Nr.crt.	Vine variety	Moisture content of grinded tendrils (%)	Moisture content of briquettes (%)
1.	Pinot noir	**9.48**	**7.98**
2.	Muscat Ottonel	8.76	7.10
3.	Fetească neagră	9.05	7.25
4.	Fetească albă	7.99	5.63
5.	Fetească regală	9.25	7.39
6.	Cabernet sauvignon	8.04	5.98
7.	Sauvignon blanc	***7.54***	***5.42***
8.	Busuioacă de Bohotin	8.03	6.25

Table 6: Mechanical durability, bulk density and unit density of the briquettes.

Nr.crt.	Vine variety	Bulk density (kg/m^3)	Unit density (kg/m^3)	Mechanical durability (%)
1.	Pinot noir	682.24	1312.00	99.13
2.	Muscat Ottonel	**722.28**	**1389.00**	98.17
3.	Fetească neagră	693.68	1334.00	***97.34***
4.	Fetească albă	***658.04***	***1227.00***	**99.14**
5.	Fetească regală	681.20	1310.33	97.97
6.	Cabernet sauvignon	708.50	1362.50	99.00
7.	Sauvignon blanc	702.00	1370.33	99.02
8.	Busuioacă de Bohotin	700.26	1349.00	98.85

Moisture Content of the Grinded 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 significant impact over the quality indices of the final product (briquettes).

Table 5 presents the experimental data regarding the moisture content of the grinded tendrils and briquettes resulted from material containing particles with a diameter of 3.15 to 8 mm. The results show that the moisture content of the grinded tendrils differs from one variety of vine to another, with the lowest value (7.54%) being recorded for the *Sauvignon blanc* variety and the highest one (9.48%) for the *Pinnot noir* variety; nevertheless, these values are within the recommended limits [39,42] .

After densification, the moisture content of the resulted briquettes has decreased by aprox. 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 *Pinnot noir*.

Considering the requirements of the ISO 18134-1 [52] and ISO 18134-2 [53] it was concluded that, with a moisture content less than 12%, the briquettes obtained from vine tendrils belong to the quality class A1.

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 mechanical durability proves that the briquettes production process was properly conducted. The ISO 17225-3 [48] defines several quality classes for the briquettes, depending on their mechanical durability: class A1, for a durability higher than 97.0%; classes A2 and B, for briquettes with a mechanical durability higher than 95.0%.

The experimental results presented in Table 6 show that the mechanical durability of the briquettes made of grinded vine tendrils has exceeded 97%, which means that they belong to the quality class A1.

The highest mechanical durability (99.14%) was achieved by the briquettes obtained from the Fetească albă vine variety.

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/m^3. The results presented in Table 6 prove that all the briquettes have fulfilled the requirements regarding bulk density (values higher than 650 kg/m^3). The lowest value (658,04 kg/m^3) was recorded for the briquettes obtained from the *Fetească albă* vine variety.

Concerning the *unit density*, the values obtained for this index were higher than 1227 kg/m^3; this is proof that this type of biomass is very suited for densification as it has fulfilled the ISO 18847:2016 standard [54] requirements for the quality class A1.

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 16 presents these results, showing that the operating capacity of the briquetting machine was comprised between 234.18 kg/h and 244.03 kg/h.

Calorific Value of the Briquettes

The calorific value was expressed based on two indices: the low calorific value and the high calorific value. The high calorific value represent 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 high calorific value in order to obtain the low calorific value. Table 7 presents the results referring to the calorific value of the briquettes.

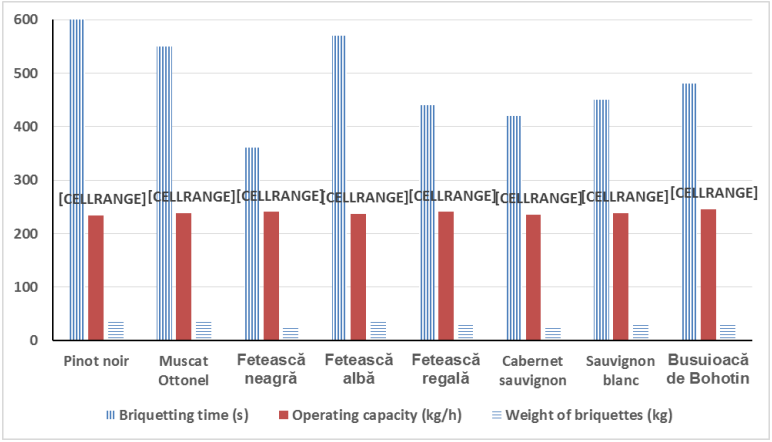


Figure 16: Briquetting time, weight of the briquettes and operating capacity of the briquetting machine.

Table 7: Calorific value.

Nr. crt.	Vine variety	High calorific value [KJ/kg]	Low calorific value [KJ/kg]
1.	Pinot noir	18,897	17,455
2.	Muscat Ottonel	***18,346***	***16,923***
3.	Fetească neagră	19,066	17,626
4.	Fetească albă	19,011	17,623
5.	Fetească regală	19,121	17,772
6.	Cabernet sauvignon	18,993	17,616
7.	Sauvignon blanc	**19,268**	**17,948**
8.	Busuioacă de Bohotin	19,041	17,712

From the experimental results shown in Table 7 it was concluded that, as far as the calorific value is concerned, there were no significant differences between the briquettes produced from different vine varieties.

Taking into account the requirements of the ISO 17225:2014 [48] standard for the low calorific value, all the tendrils correspond to the A1 quality class, with values higher than 15500 kJ/kg.

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 has evaluated the technological phases for the production of densified biomass in the form of briquettes.

Specialized equipment was design 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 have shown that the briquettes from vine tendrils satisfy the requirements of the quality class A1, according to the specifications of the SR EN ISO 17225-3:2014 standard.

One of the significant findings of this study is that the presence of particles smaller than 3.15 mm (dust-like particles especially) in the material the briquettes are made of 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 damaged structural integrity of the briquettes and lower briquetting indices. This phenomenon has occurred even when the moisture content of the tendrils was within the accepted limits. When moisture content of the tendrils was increased, the high pressure water vapor has added its negative effects and serious damage of the final product has occurred.

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