RESEARCHES REGARDING EVALUATION OF ENERGY CONSUMPTION FOR MANUFACTURING OF PELLETS FROM VINE PRUNING RESIDUES

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Abstract. Renewable energy resources represent real prospects for replacing fossil fuels. Compared to other combustible materials (coal, oil etc.), biomass is widespread and can be found in various forms (wood, woody plants, aquatic, agricultural, waste etc.). Any country on the globe has the possibility and obligation to produce green energy from biomass. Biomass contributes with 14 % to global primary energy consumption, and for three quarters of the world's population living in developing countries it is the most important source of energy. The researches of the present paper were aimed to evaluate the potential of biomass resulting from dry cutting of varieties of vines on the fruit and the energy consumed during the operations of milling, drying and manufacturing of pellets derived from it. All the operations were carried out with equipment designed and realized within the Laboratory of Mechanization of Agriculture, from the University of Agricultural Sciences and Veterinary Medicine "Ion Ionescu de Brad" from Iasi. Following the analyses performed, it was found that the higher calorific value of the vine pruning residues harvested and taken in the study was between 14.49-18.31 MJ·kg^{-1}, and the lower calorific power varies between 13.08 ... 16.88 MJ·kg^{-1}, depending on the variety. Considering the specific nature of the vineyard plantation, it turns out that the energy potential of the biomass harvested from one hectare has values between 8746.39 MJ·(kg·ha)$^{-1}$ and 13603.94 MJ·(kg·ha)$^{-1}$, equivalent to one quantity of firewood between 696.37 kg and 812.18 kg. Also, within this work, the energy requirements for conversion of vine pruning residues into densified biomass, as pellets, were evaluated. Thus, a total average electricity consumption of 0.5215-3.4959 MJ·kg^{-1} was recorded, of which, for coarse chopping 0.0236-0.0306 MJ·kg^{-1}, for grinding particles larger than 4 mm, 0.0587 MJ·kg^{-1}, for drying 2.692 MJ·kg^{-1} and for pelletizing 0.4392 MJ·kg^{-1}.

Keywords: solid biofuels, pellets, vine tendrils, energy consumption.

Introduction

Biomass is one of the most important sources of primary energy, after fossil fuels, providing approximately 14 % of the world energy consumption [1]. The main sources of biomass are agricultural and forest residues, energetic crops, different organic wastes etc.

The interest for conversion of biomass into thermal and/or electric energy is due to the fact that it is a valuable and renewable resource and because it has several advantages regarding the environmental protection [2]. In comparison with other combustible materials (coal, oil etc.), biomass is to be found all over the globe, it is present in different forms (wood, wooden crops, aqueous and agricultural crops, wastes etc.), does not increase the concentration of CO_2 in the atmosphere, reduces the global warming effect and does not produce acid rains, because it has a low sulphur content [3]. It is for these reasons that there is an increased interest in developing and improving the technologies used in order to produce green energy from biomass [4; 5]. It is an inexhaustible reserve and an important source of energy for mankind, because during the growing process of the crops, carbon dioxide in the atmosphere and water in the soil, together with the nutritive elements, are harnessed through photosynthesis and turned into carbohydrates that are constitutive elements of biomass. The solar energy is accumulated through photosynthesis into the chemical bonds of the biomass structural elements. Through the combustion of biomass, atmospheric oxygen is combined with carbon in the plants, resulting in carbon dioxide and water. Thus, the process is a cyclic one, carbon dioxide in the atmosphere is being once again absorbed by the plants [3; 4]. It should be mentioned that modern technologies achieve a complete combustion of biomass, and the main combustion products are carbon dioxide (CO_2) and water (H_2O), as the ash, particles and sulphur content is lower compared to fossil fuels and especially coal [6]. Moreover, biomass, as the lignocellulose raw material for producing densified fuels, contains large amounts of elements that promote combustion, such as carbon and hydrogen, and low amounts of elements that do not promote combustion, respectively oxygen, sulphur, nitrogen, water and ash [7].

The tendrils resulting from the dormant pruning of vines are also a combustible lignocellulose raw material. The resulted biomass is an important energy source due to the significant level of the high calorific value, which is comprised between 14.49 MJ·kg^{-1} for the Pinot noir variety and 18.31 MJ·kg^{-1} for the Feteasca regala variety [8]; from a chemical point of view, this type of biomass has high carbon content, over 43.1 % for all the studied varieties [8]. The vine tendrils contain 24-32 % lignin, 29-40 % cellulose and 17-26 % hemicellulose, depending on the variety [8-10]. The high content of lignocellulose substances is favourable for production of densified biomass in the form of briquettes and pellets.

The aim of the present paper is to present the results of experimental tests regarding the technological conditions for producing pellets from vine tendrils and the required energy consumption.

Materials and methods

In order to perform the research regarding the optimum technological conditions for production of densified biomass in the form of pellets, tendrils resulting from the dormant pruning of vine were collected. The vineyard belongs to the Didactical Station of the University of Agricultural Sciences and Veterinary Medicine in Iasi (Horticultural Farm "Vasile Adamachi"). The tendrils were collected from the following vine varieties: Sauvignon Blanc; Pinot Noir; Feteasca Alba; Feteasca Reagala; Feteasca Neagra; Busuioaca de Bohotin; Cabernet Sauvignon and Muscat Ottonel.

The densification technology for tendrils, used for obtaining pellets, comprises the following unit operations: course grinding, drying, fine grinding (in order to obtain particles smaller than 4 mm) and pelletization of the tendrils (Fig. 1 and Fig. 2).

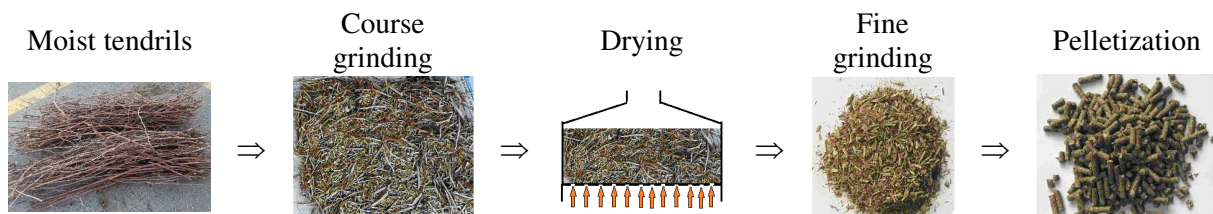Fig. 1. **Technological phases for pelletization of vine tendrils (natural drying)**

Fig. 2. **Technological phases for pelletization of vine tendrils (forced drying)**

In order to evaluate the overall energy consumption, the collected tendrils, with a humidity of 44-46 %, were dried until the humidity dropped to 12-14 %, using one of the following procedures:

- natural drying – the tendrils were deposited for 70 days in an open shed (in order to allow air circulation);
- forced drying, using hot air (70 °C, 100 °C and 120 °C) with the circulation velocity of 0.75 m·s^{-1}.

The tendrils were grinded with the BIO 90 grinder (Fig. 3), produced by Caravaggi, Italy, aimed to operate with a 30-60 HP tractor; in order to evaluate the energy consumption, the grinder was driven with a 7.5 kW electric motor. The contraption is equipped with a chopping apparatus containing two rotary blades, a counter-beater. In the first stage the sieve has 15 mm diameter orifices and the resulting particles have a diameter lower than 50 mm; in the second stage the sieve has 5 mm orifices and the diameter of the resulting particles is less than 4 mm.

In order to establish the kinetics of the drying process and the energy consumption during the forced drying of tendrils a laboratory installation (Fig. 4) was designed and constructed. The installation has the following features: the cylindrical drying shell (1) has a diameter Ø = 440 mm and

a height $h = 700$ mm; the cylindrical biomass hopper (2) has an exterior diameter $\emptyset_e = 280$ mm, an interior diameter $\emptyset_i = 110$ mm and the height $h = 540$ mm, allowing the drying of a 5-7 kg biomass charge. The drying agent is prepared in a hot-gas recycling system, equipped with the adjustable flaps (12 and 13), which are used in order to adjust the recycle air flow and the discharged air flow, respectively. In order to obtain a uniform distribution of the drying agent, the air feeding connection (19) is tangent to the drum. Electric resistance (14) is used to heat the air; the electric power of the resistance is 2500 W and it is provided with fins for better heat transfer.

Fig. 3. **BIO 90 grinder:** 1 – frame, with 3 point hitch strut; 2 – universal joints transmission; 3 – belt transmission; 4 – grinding device; 5 – grinded material chute; 6 – feeding chute
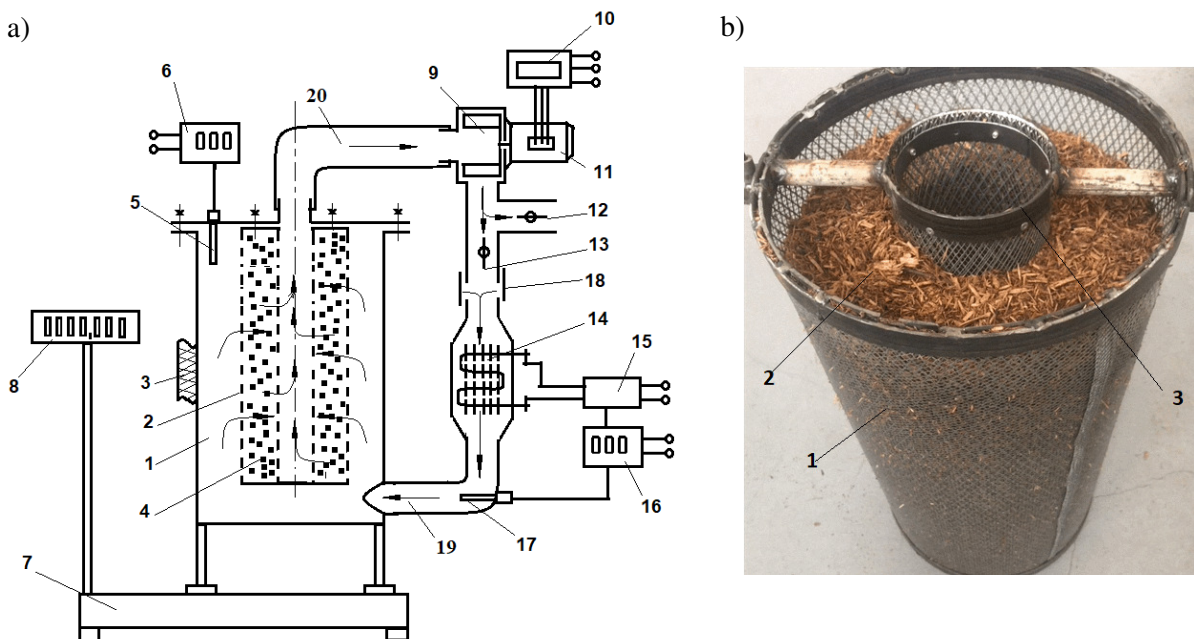

Fig. 4. **Laboratory test rig for drying of grinded tendrils**: a – general schematics (1 – drying drum; 2 – grinde biomass chute; 3 – insulation; 4 – grinded tendrils; 5 – anemometer; 6 – hot wire probe; 7 – scale; 8 – display; 9 – centrifugal fan; 10 – VFD; 11 – electric motor; 12, 13 – adjustable flaps; 14 – heating resistance; 15 – relay; 16 – thermostat; 17 – RTD probe; 18 – air intake orifices; 19 – fresh hot air feeding pipe; 20 – used hot air intake pipe); b – biomass drum (1 – outer casing; 2 – grinded tendrils; 3 – hot air central pipe)

The drying equipment is provided with automation devices, which allow adjustment of the velocity of the drying agent (by modifying the speed of the motor driving the fan) and monitoring of

the operating parameters, such as the thermostat with the RTD temperature transducer (16 and 17), anemometer and the hot wire probe (5 and 6), electronic scale for measuring the quantity of evaporated water. In order to diminish heat losses, the entire equipment is thermally insulated.

Pelletization of the grinded tendrils was performed using the pelletizing equipment (Fig. 5a) with a rotating horizontal matrix and two cylindrical rollers for the extrusion (Fig. 5b). The equipment has the following characteristics: operating capacity 80-120 kg·h⁻¹; matrix diameter 170 mm; diameter of the matrix orifices 6 mm; roller with 98 mm diameter and a width of 40 mm; power of the electric driving motor – 7.5 kW. The rollers are free mounted on a spindle, which is provided with a device allowing the adjustment of the pressure between the rollers and the matrix.
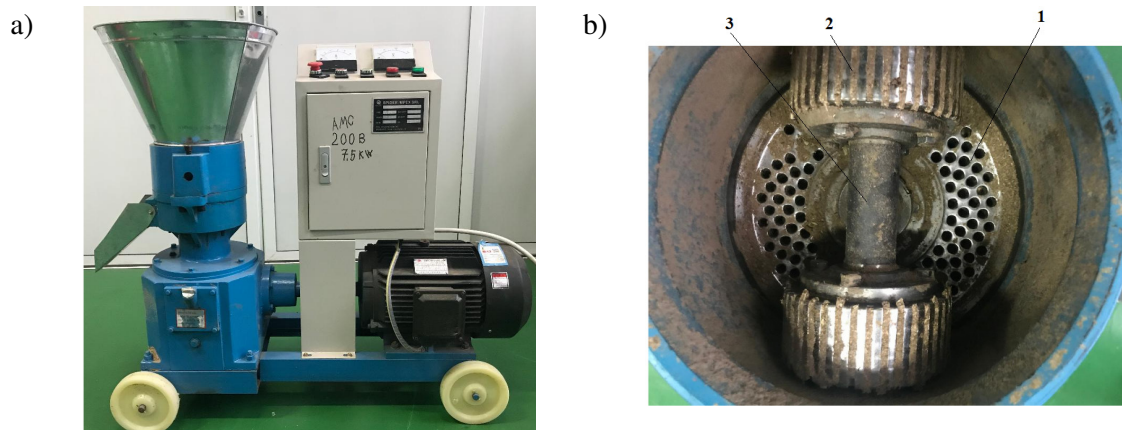

Fig. 5. **Pelletizing equipment:** a – general view; b – operating parts of the equipment
(1 – matrix; 2 – cylindrical rollers; 3 – spindle)

The water mass fraction of the grinded tendrils, ready for pelletization, was 12 ± 0.5 %. This value of the humidity was adopted after some initial tests were performed in order to achieve the pelletization ratio over 90 %. It should be noted that specialized literature indicates that, in order to obtain superior quality pellets, the water content of the grinded raw material should be comprised between 11 and 13 % [7; 11] in order to achieve the cohesion bonds among the compacted particles.

A thermobalance with the following features was used in order to measure the water content: max. drying temperature 160 ℃; precision: sample mass 0.1-5 g ± 0.3 %; sample mass 5-15 g ± 0.06 %; sample mass > 15 g ± 0.04 %. Tendrils dehydration was performed at 105 ℃ [12].

The operating parts of the matrix were heated to more than 110 ℃ before pelletization in order to achieve proper densification conditions, respectively, temperatures above 130 ℃ inside the pellet, due to friction [12-14].

After the tendrils were pelletized, the following parameters were evaluated: pelletization ratio, mechanical durability of the pellets, dimensions of the pellets (diameter and length), bulk density and unit density of the pellets.

The pelletization ratio (G_p) was evaluated by sieving the pellets through a sieve according to the SR EN ISO 17831-1 standard: cage diameter – 400 mm; round orifices with a diameter of 3.15 mm [12]. The initial sieved sample (m_{pi}), obtained through pelletization, was split into two components: pellets that remained on the sieve (m_p), larger than 3.15 mm, and fragments that passed through the orifices of the sieve. The initial sample and the pellets larger than 3.15 mm were weighted on an electronic scale (precision 0.01 g) and the pelletization ratio was calculated with the formula:

$$G_p = \frac{m_p}{m_{pi}} \times 100 \ \% \ .$$ (1)

A calibrated 1 dm³ aluminium cylinder was used in order to evaluate the bulk density; the interior diameter of the cylinder was 88 mm and its height was 164.5 mm. The same electronic scale was used in order to weight the sample [12].

Unit density was evaluated with the picnometer method for measuring the relative density [12].

Mechanical durability of the pellets was evaluated according to the method presented in SR EN ISO 17831-1:2016 standard, using the device shown in Fig. 6.
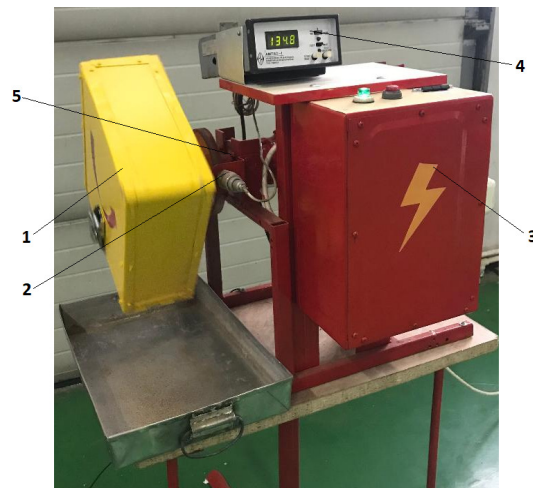

Fig. 6. **Equipment for evaluation of durability of the pellets, according to SR EN ISO 17831-1/2016:** 1 – sealed box; 2 – speed sensor; 3 – electric panel; 4 – tachometer; 5 – reduction gear [12]

The device is comprised of a sealed box ($L = 300$ mm; $W = 300$ mm; $H = 125$ mm); the box has an interior baffle and a driving mechanism. A tachometer is used to measure the number of rotations and the rotation speed of the box.

The tested sample (500 ± 10 g) is loaded into the box and the box is then rotated with 50 ± 2 rpm (500 revolutions – [12]). Then the pellets are sieved, using the same sieve as for the pelletization ratio. The sample is weighted before the test (m_i); after the test, the pellets retained by the sieve are also weighted (m_f); the mechanical durability (DU) is calculated with the formula:

$$DU = \frac{m_f}{m_i} \times 100 \ \% \, .$$
(2)

The samples which were tested were prepared according to the requirements of the SR EN ISO 17831-1/2016 standard: an amount of 2 kg of pellets was split into four equal samples. One sample was used to evaluate the water content and the other three samples were used to perform the mechanical durability test in 3 replicates [12].

In order to evaluate the energy consumption for each technological operation, the equipment and machines were powered from the electrical grid by means of a single phase power meter, type Energy Logger 4000 (Fig. 7a); for the three phase consumers, three single phase energy meters were used (Fig. 7b). This type of power meter measures and records the energy consumption on a SD card; the recorded data are then downloaded to the computer using proprietary software and then exported into a MS Excel spreadsheet.

Results and discussion

The experimental tests were performed according to the procedures presented above and were aimed to evaluate the technological conditions for densification of vine tendrils as pellets. The densification process comprised two stages: preparation of the raw material (harvesting, natural dehydration and grinding of the tendrils) and pelletization.

The *dimensions* of the pellets were in accordance with the requirements of the ISO 17829 standard: the average diameter was 6 ± 0.5 mm and the length was between 3.15 and 40 mm.

The *pelletization ratio* reveals that the pelletization process was successful; its values were between 93.13 % for Feteasca Alba variety and 94.65 % for the variety Feteasca Regala. The differences are due to the fact that different vine varieties have different contents of lignocelluloses and different textures.

Bulk density and unit density are important features of densified biofuels. The analysis of the results regarding the bulk density led to the conclusion that this item recorded values were between

682.83 kg·m^{-3} for the variety Feteasca Regala and 612.32 kg·m^{-3} for the variety Cabernet, thus exceeding the limits imposed by the ISO 17828 standard. The unit density of the pellets was between 1045.15 kg·m^{-3} for Cabernet Sauvignon and 1227.31 kg·m^{-3} for Feteasca Regala.

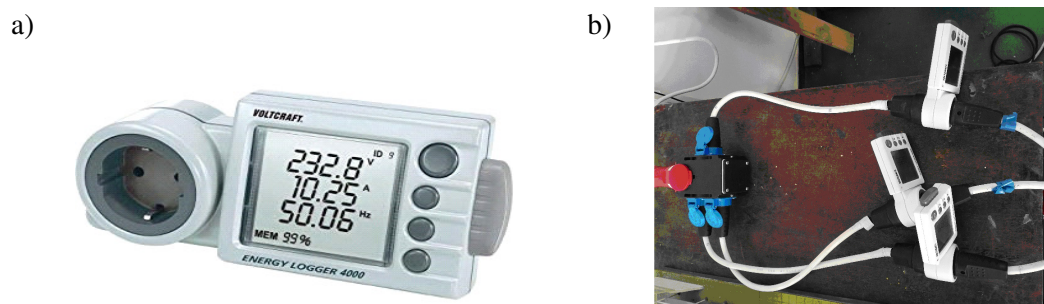a)   b)

Fig. 7. **Energy Logger 4000 type power meter**: a – single phase consumer; b – three phase consumer

The mechanical durability of the pellets defines the conservation conditions of the final product throughout the commercial chain. This parameter was evaluated performing experimental tests, which simulate the mechanical stress of the pellets throughout the storage, transportation and handling chains. The experimental results show that the values of mechanical durability of the pellets obtained from vine tendrils (Table 1) fulfil the quality requirements imposed by the ISO 17225-6/2014 standard for all vine varieties. It should be mentioned that this is true only when the temperature inside the pellets exceeds 130 ºC [12].

Table 1

Mechanical durability and water content of pellets from vine tendrils

Item	Vine variety							
	Busuioaca de Bohotin	Cabernet Sauvignon	Feteasca Alba	Feteasca Neagra	Feteasca Regala	Muscat Ottonel	Pinot Noir	Sauvignon Blanc
Durability, %	97.6	97.8	97.5	97.7	97.7	97.5	97.6	97.7
Water content, %	9.62	9.34	9.45	9.68	9.74	9.86	9.88	9.74

In order to evaluate the overall energy consumption for densification of vine tendrils all the phases of the technological process were accounted for. Thus, in order to transform biomass into raw material for pelletization, with the dimension of the particles lower than 4 mm, the grinding process of the tendrils from the variety Feteasca Regala was studied for both the tendrils with the water content of 44.24 % and for the dehydrated ones with 11.25 % water content. The results referring to the energy consumption for coarse grinding are presented in Table 2, while those for fine grinding are shown in Table 3; for each grinding stage 20 kg of material were processed.

Table 2

Fractions and energy consumption for coarse grinding of vine tendrils

Water content, %	Quantity, kg	Grinded fractions								Energy consumption, MJ·kg^{-1}
		> 50 mm		15-50 mm		4-15 mm		< 4 mm		
		kg	%	kg	%	kg	%	kg	%	
44.25	20.00	4.25	21.25	8.83	44.15	5.42	27.1	1.5	7.5	0.0306
11.25	20.00	3.15	15.73	5.47	27.33	6.93	34.67	4.45	22.27	0.0236

The size of the particles resulted from coarse grinding strongly depends on the water content of the tendrils; thus, for the dehydrated material, over 22 % of the particles were smaller than 4 mm, while the specific energy consumption decreased from 0.0306 kWh·kg^{-1} to 0.0236 kWh·kg^{-1}.

A mass of 20 kg of coarse grinded tendrils was used for fine grinding, with particles with a diameter larger than 4 mm.

In the case of fine grinding, the operating process is substantially improved for the dehydrated tendrils, both in terms of particle dimension and energy consumption; thus, the energy consumption has decreased by 30 % and the amount of material that imposes supplementary grinding has decreased by 10 %.

Table 3

Fractions and energy consumption for fine grinding of vine tendrils

Water content, %	Quantity, kg	Grinded fractions								Energy consumption, MJ·kg^{-1}
		> 10mm		6-8 mm		4-6 mm		< 4 mm		
		kg	%	kg	%	kg	%	kg	%	
44.25	20.00	1.82	9.46	2.52	12.59	4.24	21.2	11.35	56.75	0.0860
11.25	20.00	1.47	7.37	1.98	9.86	3.96	19.81	12.59	62.96	0.0587

For the same vine variety as above (Feteasca Regala), the effect of the temperature of the drying agent over the dehydration process was studied. Three temperatures of the drying agent were used (70 ºC, 100 ºC and 120 ºC) and the results are shown in Table 4.

Table 4

Dehydration kinetics and energy consumption for drying vine tendrils C

Drying agent temp. °C	Drying time to 11-12 % water content, min	Mass of the sample, g		water content, %		Amount of evaporated water, g	Dehydration velocity g H$_2$O·(h·kg biomass)$^{-1}$	Energy consumption kW	Specific energy consumption MJ·kg^{-1}
		Initial	Final	Initial	Final				
70	240	6670	4474	44.56	11.64	2196	82.31	4.79	2.585
100	180	6860	4610	44.56	11.76	2250	109.33	5.129	2.692
120	145	6842	4585	44.56	11.58	2257	136.5	5.513	2.901

The results referring to the energy consumption for production of pellets are shown in Table 5 (for 10 kg of grinded tendrils)

Table 5

Energy consumption and duration for pelletization of 10 kg of grinded tendrils, variety Feteasca Regala

Overall energy consumption, kWh	Pelletization time, min	Energy consumption per unit of biomass, kWh·kg^{-1}	Specific energy consumption, MJ·kg^{-1}
1.22	8.36	0.122	0.4392

The data in Table 6 summarize the energy consumption for densification of tendrils, based on the two drying technologies (normal dehydration and forced dehydration) for Feteasca Regala variety. The results clearly show that the energy consumption for the forced dehydration of tendrils is 6 times higher than for the normal dehydration.

Table 6

Energy consumption for producing pellets from vine tendrils

Technological variant	Energy consumption for the technological phases				Overall energy consumption, MJ·kg^{-1}
	Coarse grinding, MJ·kg^{-1}	Forced dehydration, MJ·kg^{-1}	Fine grinding, MJ·kg^{-1}	Pelletization, MJ·kg^{-1}	
Normal dehydration	0.0236	0	0.0587	0.4392	0.5215
Forced dehydration	0.0306	2.692*	0.0587	0.4392	3.4959

*air temperature: 100 ºC.

Conclusions

1. The use of renewable energy sources is a necessity for the present and future of civilization, as biomass is one of the maim raw materials for production of energy.
2. The tendrils produced as a consequence of dormant pruning of vine are also lignocellulose raw materials; they have high calorific value and are an important source of energy.
3. The research was aimed to establish the technological conditions for producing densified biomass in the form of pellets from tendrils resulted from the dormant pruning of vine. All the phases of the technological process for obtaining pellets were taken into account.
4. Specific equipment for production of pellets was designed or purchased in order to measure all the parameters that define the quality indices of the pellets and the energy consumption for their production.
5. The quality of the pellets produced from vine tendrils fulfils the requirements of the SR EN ISO 17225-6-2014 standard.
6. The results regarding the energy consumption for the production of pellets indicate that normal dehydration, due to free flow of atmospheric air, is the optimum variant with regard to the energy requirements.

Acknowledgement

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