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INVESTIGATION ON THE QUALITY OF BRIQUETTES MADE FROM RARELY USED WOOD SPECIES, AGRO-WASTES AND FOREST BIOMASS

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Abstract:

Characteristics of briquettes made from various biomass resources (staghorn sumac wood, vineyard and apple tree pruning biomass, pine cones, corn stalk and corn cobs) were investigated in the present paper. The moisture content of raw materials was first determined, before compacting them in a hydraulic briquetting machine. Briquettes with diameter of 40mm and various lengths were obtained. Five replicates of each briquette type were selected for the determination of density, compression strength and calorific value. The results were compared to those of beech and pine briquettes obtained under similar conditions. Based on the experimental results, mathematical correlations between density and compression strength and density and calorific value were investigated.

Key words: *briquettes; sumac; apple tree, vineyard; pruning; corn stalk and cob; compression strength, calorific value.*

INTRODUCTION

Biomass used for solid fuels as briquettes and pellets is important for several reasons. First, it is not harmful to the environment; second, the amount of carbon dioxide released to the atmosphere during its combustion is compensated by the same amount of carbon dioxide absorbed by the plants during photosynthesis. Third, heating with biomass is nowadays effective in terms of cost, because the price of biomass is competitive on the fuel market. On the other hand, the waste management (from forestry, agriculture and industry) will extend the biomass utilization in the future. Using biomass is an advantage to the environment protection, is a renewable resource for obtaining energy. More than that, wastes of food surpluses, wastes from forestry and agriculture are studied as potential recycled raw materials. The growth of biomass production in the future is connected by some researchers with the more intensive use of energy crops (van Dam *et al*. 2007). In Romania, agro-wastes are investigated as potential energy resources (Borza *et al*. 2011), Thus, the amount of corn waste collected from an area of 350 hectares is evaluated at 3150 tones, whilst the amount of biomass resulted from an area of 40 hectares of vineyard and fruit trees pruning is evaluated at 12.5 tones. In the same study, the calorific value of these resources was evaluated at 15.5MJ/kg for corn waste and 12MJ/kg for vineyard and fruit trees pruning biomass.

Biomass resources are available all over the world and from this point of view, as a renewable resource of energy, biomass is a safe one. Briquettes and pellets obtained from compacted biomass, compared to other types of biofuels, have low transportation and storage costs, uniform product quality and constant moisture content (Samuelsson *et al*. 2009, Lunguleasa 2010, Nilsson *et al*. 2011). The biomass for briquettes and pellets are mainly produced from agricultural waste materials, but the material most commonly used is a typical waste from the timber industry: sawdust. (Garivait *et al*. 2006). Briquettes and pellets made from compacted biomass require no additives since humidity and the lignin content work as natural adhesive. A study on the quality of briquettes and pellets made from biomass and offered by European market have shown that the majority of the producers do not use chemicals or additives, which increase the content of pollutants and cause problems regarding emissions, deposit formation and corrosion. (Obernberger and Thek 2004).

Previous research (Stolarski *et al*. 2013) on the properties of briquettes made from pine sawdust, straws, rape straw and rapeseed oilcake mixture, concluded that the highest net calorific value was determined for the briquettes made from pine sawdust (18144J/kg). Other determinations on calorific value (Lica *et al*.

2012) have shown higher values for briquettes made from pine sawdust (24192J/kg). Investigations on the biomass obtained from vineyard and fruit trees pruning biomass have shown various results. The heat value determined for vineyard pruning biomass varied between 16.3MJ/kg and 16.83MJ/kg on a dry ash-free basis (Hernandez *et al*. 2010, Muzikant *et al*. 2010). Other researchers (Gudima and Marian 2013) obtained as result a calorific value of 20.20MJ/kg (for dried conditions) for vineyard pruning biomass, and it was lower than the values determined for branches of fruit trees and sunflower husks, and higher than the values obtained for straw, corn stalks, sorghum, and poplar. The densities of spruce and beech briquettes from previous research had values of 835kg/m^3 and 845kg/m^3 respectively, and the compression strength of 1.30N/mm^2 and 1.40N/mm^2 respectively (Lunguleasa *et al*. 2010).

There are also wood species, not used or tested for combustion, yet. This is the case of staghorn sumac (*Rhus typhina*), a decorative tree with reddish fall foliage. It can be found in gardens, on hills, at the forest edges. Its growth needs low water requirements and all kind of soil types. It is an invasive tree, and it rapidly colonizes areas of the landscape, so it needs to be removed, producing thus a potential biomass for fuels. Staghorn sumac is a lightweight wood, having a density of 530kg/m^3 (http://www.wood-database.com/lumber-identification/hardwoods/sumac/), and the structure presented in Fig. 1.

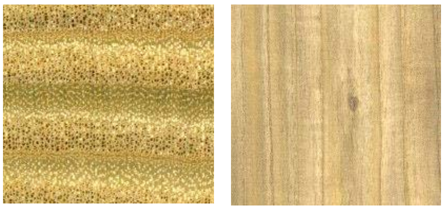

a b

Fig. 1.
Macroscopic structure of staghorn sumac wood; a – transversal section; b – longitudinal section.
(http://www.wood-database.com/lumber-identification/hardwoods/sumac/)

Agro-wastes as corn stalk, corn cobs, vineyard and fruit tree pruning biomass were found in the literature as potential raw materials for briquettes (Muzikant *et al*. 2010, Bilandzija *et al.* 2012, Brkića *et al*. 2012, Stolarski *et al*. 2013), but no unitary data regarding their compression strength, density or calorific values were found in the literature, in order to compare them. New biomass resources are continuously investigated nowadays for their energetic potential. The present paper proposes two new resources: staghorn sumac (*Rhus typhina*) and pine cones for briquetting. All biomass resources mentioned before were used to make briquettes and test them in the same conditions, so as to have comparable results. These results are a contribution to the research of the quality of the briquettes made from various biomass resources and waste, including wood sawdust.

OBJECTIVES

The present paper investigates the quality of briquettes made under laboratory conditions from six biomass resources: staghorn sumac wood, vineyard and apple tree pruning biomass, pine cones, corn stalk and corn cobs. Their quality is investigated by determining the density, calorific value and compression strength in the same laboratory conditions, the results being compared afterwards. Correlations between the experimental data of density and compression strength on one hand and the density and calorific value on the other hand will indicate the potential mathematical equations to be used in order to avoid the destructive tests. The obtained results were finally compared with those of the briquettes made from sawdust (beech and pine) obtained in the same laboratory conditions in a previous research (Lica *et al*. 2012).

METHOD, MATERIALS AND EQUIPMENT

The biomass resources presented in Fig. 2 were prepared and compacted on a hydraulic briquetting machine in order to obtain briquettes with a diameter of 40mm and various lengths.


a b c d e f

Fig. 2.
Biomass resources as raw materials for briquetting; a – corn cobs; b – corn stalk; c – staghorn sumac wood; d - apple tree pruning biomass; e – vineyard pruning biomass; f – pine cones.

The biomass was collected on October and air dried for three months. The moisture content was determined according to SR EN 322-1996. The samples (20g) were initially weighed with an accuracy of 0.01g, and then dried at a temperature of 103±2ºC, until the constant mass was noticed. The moisture content was calculated in %, using Eq. 1.

$$u = \frac{m_i - m_0}{m_0} \cdot 100\% \tag{1}$$

where m_i is the initial mass, in g;
m_0 – oven dry mass, in g.
The obtained results are presented in Table 1.

Table 1

Moisture content of the biomass used as raw materials for briquetting

No.	Raw material	Moisture content, %
1	Corn stalk	6.02
2	Corn cobs	4.88
3	Staghorn sumac	7.13
4	Apple tree pruning biomass	18.5
5	Vineyard pruning biomass	9.6
6	Pine cones	9.8

The briquettes were obtained in the laboratory conditions by means of a hydraulic Goldmark MB-4 briquetting machine. The process of obtaining the briquettes is presented in Fig. 3.

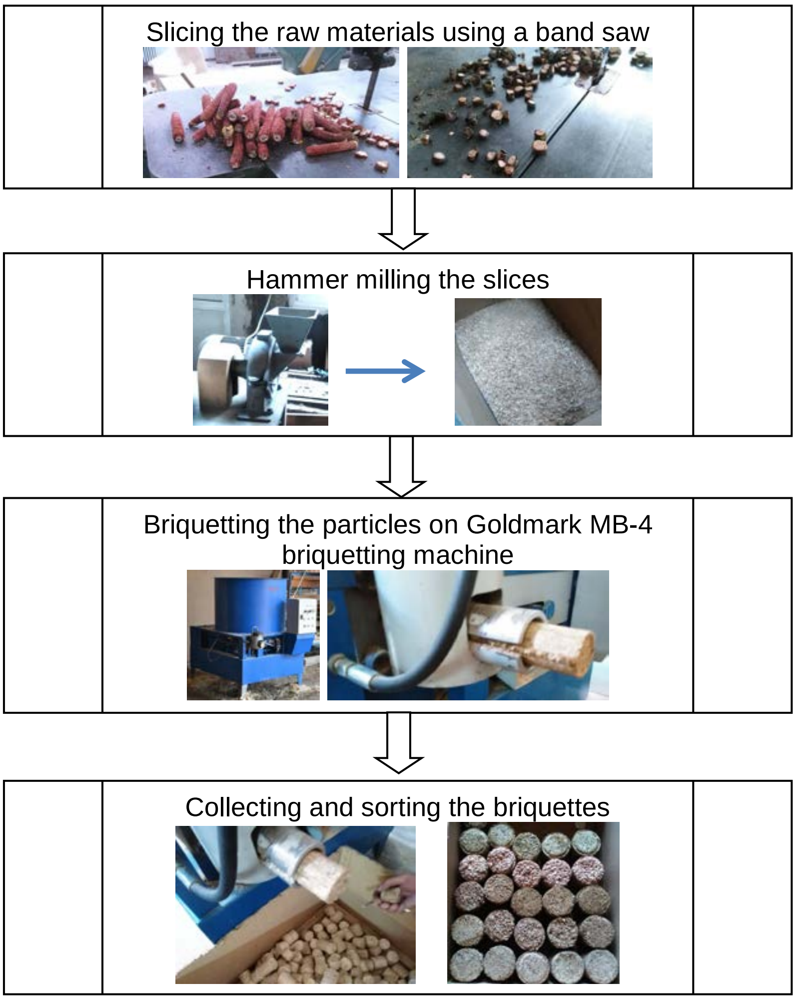


Fig. 3.
The process of obtaining the briquettes in the laboratory conditions.

Five replicates of each briquette type with a diameter of 40mm and variable lengths (from 38mm to 41mm) were selected for further testing. First, the density of the briquettes was calculated as the ratio between the weight and the volume of the briquettes resulted after briquetting the particles. They were weighed on the electronic balance TP KERN EW 1500-24 type, with an accuracy of 0.01g and measured by an electronic caliper with an accuracy of 0.01mm. The code numbers, sizes and mass of the briquettes selected for testing are shown in Table 2.

Table 2

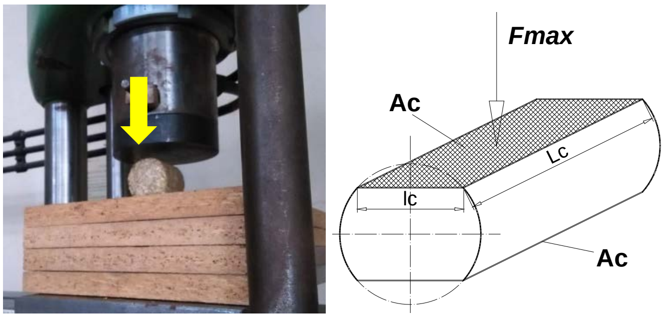
Sizes and masses of briquettes selected for further investigations

Type of briquette	Symbol	No.	Length L, in mm	Radius R, in mm	Volume V, in cm^3	Mass m, in g	Density ρ, in kg/m^3
Corn stalk	CT1	1	38.92	20.44	51.0580	42.85	839
	CT2	2	36.90	20.44	48.4080	41.70	861
	CT3	3	39.23	20.38	51.1630	38.60	754
	CT4	4	37.70	20.81	51.2643	41.26	805
	CT5	5	38.90	20.63	51.9849	41.37	796
Corn cobs	CS1	1	40.11	20.83	54.6463	47.72	873
	CS2	2	41.00	20.41	53.6289	41.90	781
	CS3	3	40.80	20.62	54.4712	47.50	872
	CS4	4	39.79	20.51	52.5575	47.06	895
	CS5	5	40.74	20.71	54.8669	41.62	758
Staghorn sumac	O1	1	40.87	20.84	55.7352	51.82	929
	O2	2	41.76	20.31	54.0891	52.87	977
	O3	3	40.55	20.65	54.2951	49.38	909
	O4	4	40.66	20.42	53.2363	51.00	957
	O5	5	40.80	20.5	53.8390	52.86	981
Apple tree pruning	M1	1	41.00	20.53	54.2614	45.03	829
	M2	2	39.90	20.27	51.4766	38.29	743
	M3	3	41.00	20.31	53.1047	42.53	800
	M4	4	39.90	19.96	49.9141	39.94	800
	M5	5	40.60	20.37	52.8978	52.02	983
Vineyard pruning	V1	1	40.11	20.33	52.0543	47.70	916
	V2	2	40.22	20.34	52.2484	47.52	909
	V3	3	40.51	20.52	53.5607	47.74	891
	V4	4	38.90	20.33	50.4840	45.76	906
	V5	5	41.90	20.6	55.8313	51.96	930
Pine cones	P1	1	39.71	20.21	50.9286	49.22	966
	P2	2	40.11	20.56	53.2388	50.94	956
	P3	3	41.33	20.42	54.1136	52.34	967
	P4	4	39.93	20.53	52.8453	51.89	981
	P5	5	40.88	20.51	53.9972	52.16	965

In order to test the compression strength of the briquettes, 5 briquettes of each type were tested on the universal testing machine under the load of a compression force. The maximum compression force (F_{max}) was recorded before the briquettes got disintegrated. The compression strength was calculated using Eq. 2:

$$\sigma_c = \frac{F_{max}}{2\cdot A_c} = \frac{F_{max}}{2\cdot L_c\cdot l_c} \qquad (2)$$

where: A_c is the compression area, calculated by multiplying the length (L_c) and width (l_c) of the area of the deformed briquettes under the load of the maximum compression force (F_{max}), as presented in Fig. 4. The sizes L_c and l_c were measured with an electronic caliper.



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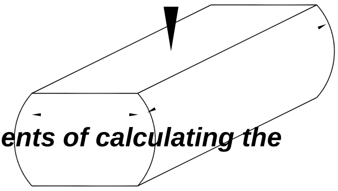


Fig. 4.
Compression test on the universal testing machine (a) and the geometric elements of calculating the area of compression strength (b).

The further testing was conducted for the determination of the calorific value of the briquettes, which represents the amount of heat released when burning a unitary mass of fuel. The equipment used for this determination is a calorimetric bomb XRY 1C type. The samples had an initial temperature of 20°C. Two characteristics were determined: the gross calorific value (specific to the phase of condensation of the water steams, when the evaporation heat is released) and the net calorific value (when a part of the released heat is used to vaporize the water). The gross calorific value (Q_s) represents the amount of heat released for a perfect combustion of 1kg of fuel, and the net calorific value (Q_i) results after subtracting from the previous one the amount of heat used to vaporize the water from burning gases. This is the reason the net calorific values (Q_i) were finally compared. The gross calorific value and the net calorific value are automatically calculated by the software of the calorimetric bomb according to Eq. 3 and 4.

$$Q_s = \frac{k \cdot (t_f - t_i + t_c) - q_s}{m}, \text{ in J/kg} \qquad (3)$$

where: k is the calorimetric factor, depending on the calorimeter type and it is determined by the calibration with benzoic acid, in J/ °C;
t_f – final temperature value, in °C;
t_i – the initial temperature value, in °C;
q_s – the heat consumed to burn the ignition initiation wire, in J;
m – the mass of the wood sample, in kg;

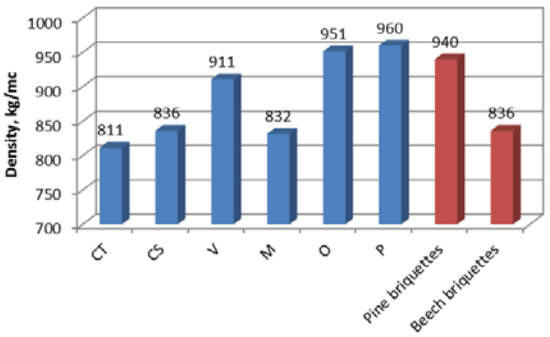
The net calorific value can be calculated using the following equation (4):

$$Q_i = Q_s - 6 \cdot (u + 9 \cdot h), \text{ in J/kg} \qquad (4)$$

where: u is the sample's moisture content, in %;
h – the sample's hydrogen content, in %.

RESULTS AND DISCUSSIONS

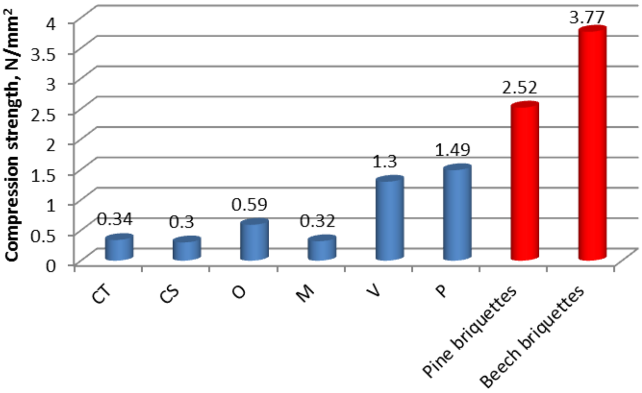
The mean values of the briquette densities are presented in Fig. 5.



Legend:
CT – briquettes made from corn stalk;
CS – briquettes made from corn cobs;
V- briquettes made from vineyard pruning biomass;
M – briquettes made from apple tree pruning biomass;
O – briquettes made from staghorn sumac;
P – briquettes made from pine cones.

Fig. 5.
Comparison of the densities of the briquettes made from biomass and pine and beech sawdust.

The briquettes made from pine and beech sawdust were manufactured in the same conditions as the investigated briquettes, and the values of densities and compacting strengths are the results of previous research (Lica *et al*. 2012, Lunguleasa *et al*. 2010). As shown in Fig. 5, high densities were obtained for the briquettes made from pine cones, staghorn sumac and vineyard pruning biomass. Instead, good results for compression strengths were obtained only for briquettes made from pine cones and vineyard pruning biomass. Bad results were obtained for the briquettes made from corn biomass and apple tree pruning biomass (Fig. 6). After completing the compression testing, the briquettes disintegrated, as seen in Fig. 7.



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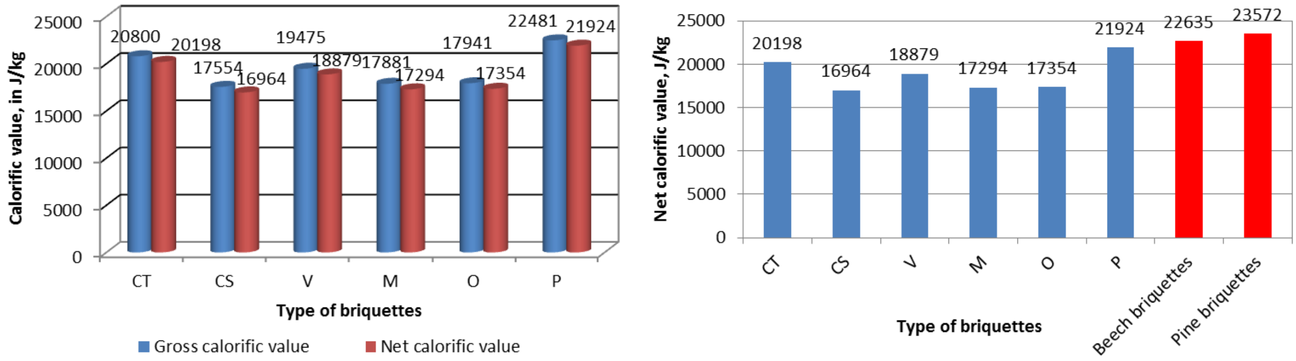
V- briquettes made from vineyard pruning biomass;
M – briquettes made from apple tree pruning biomass;
O – briquettes made from staghorn sumac;
P – briquettes made from pine cones.

Fig. 6.
Comparison of the compression strengths of the briquettes made from biomass and pine and beech sawdust; results of the experimental research.

Fig. 7.
Briquettes made from biomass, which were disintegrated after completing the compression testing.

The results of the experimentally determined calorific value are presented in Fig. 8.



a **b**

Fig. 8.
Calorific value experimentally determined: a – gross and net calorific values of the briquettes made from biomass; b – comparison of the net calorific values of the briquettes made from biomass and sawdust (beech and pine).

In order to calculate the oven-dry calorific value (NCV_0) of briquettes as function of moisture content (u) presented in Table 1, Eq. (5) was used (Wood Fuels Handbook 2008):

$$NCV_u = \frac{NCV_0 \cdot (100-u) - 2.44 \cdot u}{100}, \text{ in J/kg} \tag{5}$$

Using the calorific values experimentally determined ($Q_i = NCV_u$) and the moisture content of each biomass type, the oven-dry calorific values (NCV_0) were calculated in order to create a unitary base of comparison. The results are shown in Fig. 9. In this case, the briquettes made from pine cones have very close value of NCV_0 to that of briquettes made from beech sawdust. Similar results were obtained for briquettes made from corn stalk, vine cane and apple tree pruning biomass. Low values were obtained for briquettes made from corn cobs and staghorn sumac.

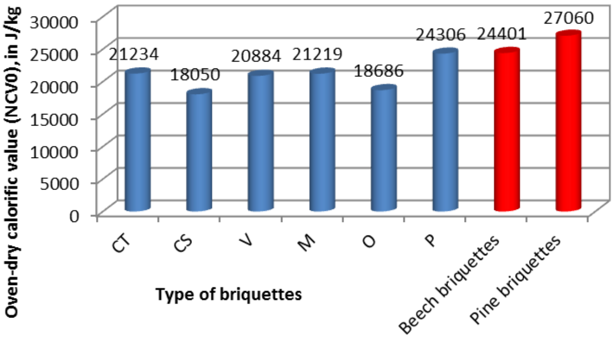


Fig. 9.
Oven-dry calorific values calculated as function of moisture content for all types of briquettes.

The next step of the research objective was to investigate the correlation between the density and the compression strength on one hand, and the density and the calorific value on the other hand. The results of the experimental determinations were used to find the mathematical correlations between the density and the other two mentioned characteristics. As seen in Fig. 10, it was found that there is a mathematical correlation only between the density and the compression strength, expressed by the polynomial function in the diagram from Fig. 10b (where $R^2 = 0.9945$), and no mathematical correlation was found between the density and the calorific value (Fig. 10c and Fig. 10d).

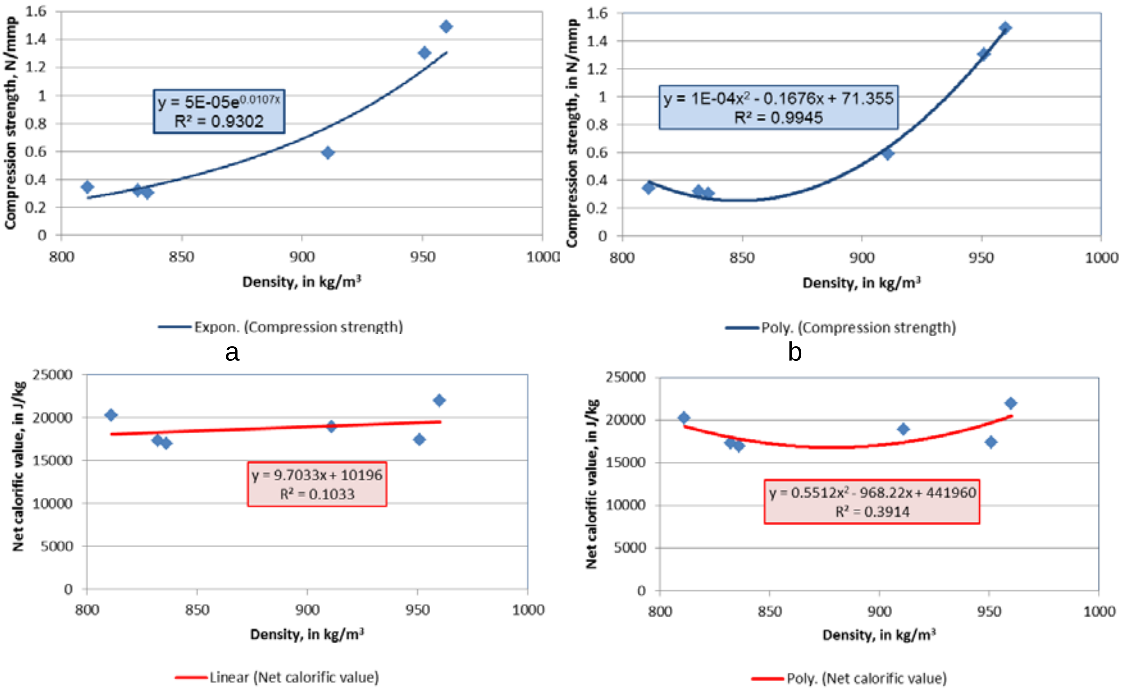


Fig. 9.
Mathematical correlations; a, b – between density and compression strength; c, d – between density and calorific value.

CONCLUSIONS

The briquettes made from corn stalk, corn cobs, staghorn sumac, apple tree and vineyard pruning and finally pine cones resulted as stable and compact structures. The weakest structures, proved by the compression testing results, were obtained for the briquettes made from corn biomass (especially the case of corn cobs) and apple tree pruning biomass. The results show that these types of briquettes will disintegrate easier during transportation and storage. A first conclusion is then noticed: corn cobs can be burned as they are, without transforming them in briquettes. For apple tree pruning biomass, a good net calorific value was obtained (in the dry state), instead. That means that the briquettes made from this resource have a good energetic potential when the moisture content is low, but methods of improving their compression strength have to be applied. Very good results were obtained for briquettes made from vineyard pruning biomass and pine cones. Thus, the obtained briquettes had high densities, high compression strength values and also high calorific values. They can be added on the list of valuable renewable resources to be used for briquetting. Staghorn sumac, unfortunately, is not recommended for briquetting. Low density, low compression strength and small values of the calorific value were experimentally obtained for these kinds of briquettes. The polynomial function of correlation between the density and the compression strength is an advantage in assessing the behavior of the briquettes during transportation without destructive compression tests. Further research can be conducted on pellets made from the same biomass resources and also on methods of improving the compression strength and calorific value of the briquettes with bad results in the present research.

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