УДК 662.638 **DOI**: 10.31521/2313-092X/2021-1(109)-11

QUALITY OF PELLETS PRODUCED FROM AGRICULTURAL WOOD RESIDUES SPECIFIC TO THE PRUT RIVER BASIN

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This paper presents an overview of the prospects for the use of agricultural wood residues, specific to the climatic zone adjacent to the Prut River and the qualitative characteristics of densified solid biofuels in the form of pellets produced from the main types of the agricultural wood biomass, taken from agricultural plantations in the Republic of Moldova and Botosani, Iasi, Vaslui and Galați counties in Romania. The aim of the paper is to establish the energy potential of the main indigenous agricultural wood residues and to analyze the quality of the pellets produced from these residues.

The research results showed that the pellets produced from the studied agricultural residues mainly meet ENPlus 3 requirements for most qualitative parameters, except for those produced from blackberry and currant residues. Residues from the prunning of some types of fruit shrubs can be used to produce pellets by creating mixtures of different proportions, and their qualitative characteristics can be significantly improved by thermo-chemical pre-treatment of the raw material.

Keywords: *plant biomass, densified solid biofuels, pellets, biofuel, energy potential, agricultural wood residues.*

Relevance. The sustainable development of energy systems in the Republic of Moldova and Romania cannot be conceived without a continuous development of energy production based on renewable resources. Biomass energy presents the most viable and promising prospects for the conditions of the Republic of Moldova and the related regions of Romania (Botosani, Iasi, Vaslui and Galati counties) [1 - 3].

For the areas metioned above, the main sources suitable to be used as raw material for the production of densified solid biofuels (DSBF) are agricultural wood residues, in particular those of apple, plum, cherry, sweet cherry and pear trees, walnut bushes, as well as vines [4; 5].

During the last decade there has been a growing interest of economic agents for the cultivation of different species of shrubs, in particular sea buckthorn [6], blackberry, raspberry, blackcurrant, etc. [7]. in these areas. These crops also generate large volumes of plant residues, suitable to be used as raw material for the production of DSBF [8].

The use of agricultural waste as a raw material is argued, both because it helps to reduce dependence on fossil fuels and emissions of harmful gases into the atmosphere, and because it is a stimulus to establish some new small and medium-sized enterprises in rural areas.

DSBF are produced in the form of briquettes and pellets. This paper focuses on the study of DSBF produced from pellet-shaped agricultural residues, although some results can be adopted for all types of DSBF.

Pellets are prepared from shredded biomass, with or without additives, by dehydration and compression to double energy density of green wood. It is an environmentally friendly fuel, which, when beeing burnt, eliminates the same amount of CO_2 that is absorbed during the plant growth [9, pp. 96-98]. Moreover, the use of pellets significantly reduces the generation of dust, allows the use of various mixtures and mixtures of raw materials – the process that allows to manage certain qualitative characteristics of the finished product [10].

The management of agricultural residues for the pellet production involves several specific technological operations, the realization of which is influenced by a number of factors with a significant share of ensuring the quality of the finished product.

Although, the analysis of the factors that influence the DSBF quality is quite complete in the literature [11-14], the problem of influencing factors that occur during the production of pellets from indigenous agricultural residues, requires a specific approach for each type of biomass used as raw material. In addition, there is practically no data on the use of residues derived from different species of shrubs for energy purposes in the literature.

Thus, the study of the quality of pellets produced from indigenous agricultural residues is relevant and requires a detailed analysis of the factors that influence it.

The research problem has been structured based on the findings and it consists in ensuring the quality of fire pellets, produced from various agricultural wood residues, by identifying and studying the influencing factors distributed throughout the production process.

Agricultural wood residues collected on both banks of the Prut River served as the object of research.

Analysis of the recent research. Topics related to the quality of fire pellets have always been an important study topic. The EN ISO 17225 standard specifies two classes of pellets: the first one is for residential and household uses, and the second one is fors industrial uses. Quality requirements for pellets differ from class to class, however, there are mandatory quality characteristics for both groups of pellets that give them the ability to satisfy consumer requirements to a greater or lesser extent.

The SE ISO 17225 standard regulates several qualitative characteristics of fire pellets, the most important of which are: moisture content, ash content, bulk density, fine fraction content, durability, lower calorific value at reception, S, N and Cl content.

The quality of pellets is influenced by several factors that can be grouped as follows: raw material variables and manufacturing process variables [9, p. 39-46; 155-162; 15; 16].

The raw material variables, which show the maximum influence on the quality of pellets, refer to the origin of the biomass, moisture content, impurity content, storage time and particle sizes [17-19].

According to the classification of solid biofuels by origin, the research object of this paper is classified in group 1.1.7 „Sorted wood from gardens, parks, road maintenance, vineyards, orchards and floating wood material from fresh water", and according to the classification of biomass for energy purposes it can be found in the category – residues, wastes and agricultural plant by-products [9, p. 35].

Our earlier research has shown that the quantity of the plant wood biomass derived from agricultural wastes makes up approximately 9 % of the total amount of agricultural residues [4], and this is exactly the type of the plant biomass that can ensure the production of the above-mentioned quality characteristics in accordance with the requirements of EN Plus 3 international standards [17].

The data presented by several researchers [20; 21] show the influence that the *moisture content* of the undensified raw material has on the quality of DSBF densification. For example, Tumularu experimentally demonstrated that the best conditions for the formation of adhesion and cohesion bonds between biomass particles are formed when the moisture content initiates optimal conditions for the growth of contact surfaces due to van der Waals forces that occur under certain densification conditions [22; 23]. Other authors provide similar explanations [11; 24; 17; 25], they consider that optimum conditions of particle agglomeration upon pelletizing shall be ensured by the moisture content equal to 10±2%.

Several researchers have shown that the mechanism of forming cohesion bonds when densifying pellets produced from the biomass of different origin differs from case to case. Thus, Stelte and others explain the peculiarities of cohesion and adhesion bonds formation between biomass particles by the amount of extractives present in the biomass and lignin diffusion, which depends on the processing temperature and moisture content in the biomass before it is pressed. They concluded this, having studied the adhesion mechanism between biomass particles and the evolution of structural failures in pellets produced from hard, soft and straw biomass types (Beech, spruce and wheat straw) [26-28; 22].

Production variables also demonstrate an important influence on the structure and properties of pellets. Thus, they include: technological regimes (compression pressure, grain formation temperature; roller speed); constructive parameters of the mold (diameter and length of the channels, the gap between the roller and the mold), etc.

Some of the most important properties influenced by the production variables of pellets include: mechanical durability, bulk density and fine fraction content.

It is obvious that production variables influence the mechanism of bond formation between biomass particles. However, up to now there is no single theory of this mechanism. The existing data are in most cases limited to experimental treatments for certain biomass types [29; 30; 12].

There are some proposals regarding the calculation of the pelletizing pressure depending on the sample plasticity, the Poisson ratio, the friction coefficient and the compression ratio [31], though the values calculated according to these recommendations are approximate and need to be specified for certain conditions [17].

Dependence of the pellet mechanical properties and energy consumption on the temperature and moisture content, fiber orientation [30], extractive substance content and storage time [32] – also refers to certain types of biomass.

Therefore, raw material and production variables are provided in the literature largely enough, which is why the analysis of SDBF qualitative parameters produced from indigenous agricultural residues is argued.

The aim of the work is to establish the energy potential of the main indigenous agricultural wood residues and to analyze the quality of pellets produced from these residues.

To achieve the proposed aim, the following objectives have been put forward:

– quantitative and qualitative analysis of agricultural wood residues specific to the climatic zone of the Prut River;

– analysis of the influence of production factors on the quality of SDBF produced in the form of pellets from indigenous agricultural residues;

– qualitative analysis of pellets produced from agricultural wood residues collected in the Republic of Moldova and Botosani, Iasi, Vaslui and Galati counties of Romania.

Materials and research methods. The research implied several distinct stages.

At the first stage, plant biomass was collected from different development areas of the Republic of Moldova and from the counties adjacent to the Prut River in Romania. All residues were coarsely shredded right on the field and transported to the Laboratory of Solid Biofuels, SAUM. Before processing, the biomass was dried by the natural conversion method in the dryer provided by the laboratory to M=10±2%, then grinded at the SV 7 hammer mill with a 6 mm mesh size of the sieve.

At the second stage, there was carried out a quantitative analysis of wood residues collected on the territory of the Republic of Moldova that can be used as raw material. There was determined the energy potential of the agricultural wood residues generated from one hectare of plantations. Thus, there were identified the theoretical energy potential (PTR_M=10%) and the sustainable one (PSI_M=10%). The calculation was made for the moisture content of the biomass equal to 10%, which correspondson average, to the moisture content of the finished product at reception.

The *theoretical potential* is the maximum amount of energy that can be obtained from the residues generated from one hectare with the condition it is fully used for energy purposes. It is determined by means of the following relationship:

$$\mathrm{PTR}_{M=10\%} = \mathrm{m}_{\mathrm{p.b.rec.}}\left(1-\frac{\mathrm{M_{rec}}-10}{100}\right)\cdot \cdot \mathrm{K}_{\mathrm{rez.\ rec}}\cdot \mathrm{q}_{p,net.M=10\%}, \text{MJ/an},$$

where $m_{p.b.rec}$. represents the basic production mass at harvest from one hectare, kg/ha; $K_{rez.rec.}$– unit conversion factor for that crop at harvest; M – moisture content of the biomass at harvest, %; $q_{p,net.\ M=10\%}$ - lower calorific value of the biomass with moisture content equal to 10%.

The *sustainable implementation potential* represents the amount of energy calculated considering the technical, economic and sustainability availability of the residues generated by the corresponding crop and was calculated by means of the following relationship:

$$PSI_{M=10\%} = \mathrm{PTR}_{M-10\%} k_{d.t-e} \cdot \cdot \left(1-k_{per}\right), MJ/an,$$

where $k_{d.t-e}$ is the factor of sustainable technical and economic availability for energy purposes of the residues with reference to the corresponding crop, k_{per}. is the coefficient of unavoidable residue losses.

At the third stage there were produced pellets at the mini semi-automatic pellet production line MGL 200 within the Laboratory of solid biofuels, SAUM. A horizontal mold with two rotating rollers and the mesh size of the sieve of 6 mm was used as a working body.

The *fourth stage* was devoted to determining the properties of pellets made from the studied agricultural residues.

The *higher calorific value* was obtained using the LEGO isoperibolic calorimetric pump (model MC 10) in accordance with the procedures described in the EN ISO 18125 standard. The lower calorific value was determined for humidity equal to 10% using the following relationship:

$$q_{p,net,M=10} = \{q_{v,gr,d} - 212{,}2w(H)_d - -0{,}8[w(O)_d + w(N)_d]\}(1 - 0{,}01M) - 24{,}43M,$$

where: $q_{p,net,d}$ is the lower calorific value in the dry base at constant pressure, J/g; $q_{v,gr,d}$ is the higher calorific value at constant volume, J/g; $w(H)_d$ – the mass content of hydrogen, %; $w(O)_d$ – the mass content of oxygen in the dry base, %; $w(N)_d$ – the mass content of nitrogen in the dry base, %; M – the moisture content at which the lower calorific value was determined (M= 10%).

The ash content was determined for samples of crushed pellets in advance at a German mill SM 100 by passing through the sieve with the mesh screen of 1 mm. The samples were calcined according to the EN ISO 18122 standard by keeping them for 6 hours at a temperature of 550°C in the LH 05/13 chamber furnace.

The content of *N, S* and *Cl* was established as the result of the chemical analysis performed at the elemental analyzer Vario MACRO cube CHNS & Cl.

The bulk density was determined in accordance with the EN ISO 17828 standard for pellets with a moisture content of (10±2)%.

The mechanical durability was established by determining the ability of the pellets to resist shocks and wear being subjected to controlled blows in accordance with the EN ISO 17831 standard. The test was carried out for pre-screened pellet samples with a mass of 500±10 g. the samples were taken and sampled in accordance with the requirements of the EN ISO 14780 and EN ISO 18135:2017 standards.

The samples were rotated in the plant to determine durability with a frequency of 50±2 m for 10 min-1. The durability value was calculated with the ratio of the pellet mass before and after the test and sifted through a sieve with a 3.15 mm mesh screen.

The *content of the fine fraction* was determined as the ratio percentage of the mass of the particle fraction, formed after sifting a certain amount of pellets through a vibrating sieve with mesh screen dimensions of 3.15mm and the initial amount of the tested pellet sample.

The energy density was determined as the amount of energy stored per unit of volume as follows:

$$E_{density} = BD\mathrm{q}_{\mathrm{p,net,M=10}}.$$

RESEARCH RESULTS AND DISCUSSIONS

The raw material analysis. In order to justify the use of different types of residues as raw material for the production of SDBF, it is necessary to know the potential available for different types of residues and their quality. Table 1 shows the estimate of the theoretical and sustainable energy potential of agricultural wood residues calculated on the basis of the average harvest obtained during the years 2017-2019.

Table 1

The energy potential of plant biomass generated by agricultural wood residues in the Republic Of Moldova

Crops	$m_{p.b.i.}$, kg/ha				$K_{rez.rec.\ max.}$	$k_{d.t-e}$	k_{per}	$q_{p,\ net}$, MJ/kg		$PTR_{M=10\%}$ in MJ/ha	$PSI_{M=10\%}$, in MJ/ha
	2017	2018	2019	Average				In the dry base	moisture content 10%		
Seed fruit, and namely:											
Apples	10710.0	14760.0	16030.0	13833.3	0.29	0.80	0.10	19.0	16.8	57.1	41.1
Pears	2060.0	2060.0	320.0	1480.0	0.22	0.80	0.10	19.6	17.4	3.9	2.8
Stone fruit, and namely:											
cherries	3010.0	5910.0	5960.0	4960.0	0.16	0.80	0.10	19.4	17.2	11.5	8.3
sweet cherries	4640.0	5320.0	3930.0	4630.0	0.24	0.80	0.10	20.8	18.5	16.9	12.2
apricots	2850.0	2330.0	5510.0	3563.3	0.31	0.80	0.10	19.5	17.3	16.4	11.8
peaches and nectarines	1950.0	1870.0	1340.0	1720.0	0.26	0.80	0.10	20.0	17.8	6.7	4.8
plums	5640.0	8170.0	8390.0	7400.0	0.30	0.80	0.10	20.1	17.8	29.7	21.4
Nuts, almonds, etc.	340.0	610.0	540.0	496.7	0.10	0.80	0.10	16.9	14.4	*0.5*	*0.4*
Fruit shrubs	850.0	3320.0	3910.0	2693.3	0.70	0.80	0.10	19.9	16.8	*23.5*	*16.9*
Vines, and namely:											
table varieties	7190.0	7480.0	7640.0	7436.7	0.6	0.7	0.1	19.0	16.9	54.8	34.5
technical variables	4480.0	5490.0	4370.0	4780.0	0.4	0.7	0.1	18.3	16.3	20.5	12.9

Note: conventional ratings are provided according to formulas 1 and 2.

The results presented in Table 1 show that practically all the studied agricultural residues, as calorific value, can be used as raw material for the production of pellets for residential and similar uses having a calorific value at 10% humidity greater than 16.5 MJ/kg, with the exception of nuts and residues of vines, technical varieties.

The highest energy potential can be obtained from the emondation of apple trees (41.1 GJ/ha), followed by that of vines, table varieties (34.5 GJ/ha) and the one received from the emondation of plums (21.4 GJ/kg). Thus, it can be concluded that the studied residues are an important source of raw material for SDBF production, in particular pellets.

The influence of production factors on the quality of pellets. The properties of pellets, regulated by the EN ISO 17225-2 standard, are grouped into physical and chemical properties. Physical properties influence the combustion efficiency and logistics of pellets; chemical properties are responsible for the environmental impact, durability and smooth operation of thermal power plants [17].

The quality analysis results of the pellets produced from different types of agricultural wood biomass are presented in Table 2.

The first thing that interests the beneficiary is the amount of heat obtained from the combustion of a unit mass of pellets that is expressed in the upper (gross) calorific value, the lower (net) calorific value and the energy density.

Table 2

Qualitative parameters of pellets produced from agricultural wood residues

Name of residues	$q_{p.net.r.}$, MJ/kg	A,%	DU,%	DB, kg/m³	FF,%	E, GJ/m³	N,%	S,%	Cl,%
Apples	17.72	0.9	98.25	680	0.42	12.05	0.25	0.03	0.02
Pears	17.31	1.47	97.9	674	0.44	11.67	0.26	0.03	0.03
Cherries	17.10	1.11	98.1	682	0.51	11.66	0.27	0.03	0.03
Sweet cherries	18.00	1.42	98	680	0.52	12.24	0.3	0.03	0.03
Apricots	17.04	1.08	98.3	654	0.48	11.14	0.3	0.03	0.03
Peaches and nectarines	17.07	1.38	97.9	658	0.54	11.23	0.28	0.03	0.03
Plums	17.70	0.74	98.2	684	0.41	12.11	0.3	0.03	0.03
Sea buckthorn	17.05	1.3	98.1	685	0.38	11.68	0.98	0.05	0.04
Blackberries	15.7	1.62	97.4	656	0.66	10.30	0.88	0.06	0.04
Black currants	15.3	2.53	97.2	654	0.72	10.01	0.87	0.05	0.03
Vines, table variables	16.8	2.6	98.10	702	0.66	11.79			
Vines, technical varieties	16.5	2.5	97.9	696	0.67	11.48			

The lower calorific value, calculated for moisture equal to 10% for all pellet samples, except those of blackberries and black currants, falls within the limits stipulated by the ENPlus 3 norms, i.e. exceeds 16.5 Mj/kg.

Energy density, derived from the lower calorific value and bulk density, is important for transporting and storing pellets.

The obtained results show that the energy density of pellets, produced from agricultural wood residues is quite high. The lowest energy density was reported in black currant and blackberry pellets with the following values of 10.01 GJ/m³ and 10.30 GJ/m3 respectively; the highest energy density was noticed in sweet cherry pellets (12.24 GJ/m³) followed by those produced from plums (12.11 GJ/m³) and apples (12.05 GJ/m³).

The lower density of blackberry and black currant pellets can be explained by their lower calorific value as well as by their low bulk density in relation to the other pellet samples.

The bulk density of the studied pellets does not vary greatly from one biomass type to another, ranging from 654 kg/ m³-for the black currant pellet sample to 702 kg/ m³ for the pellet sample produced from vine residues.

The indicative limits for wood pellets are specified by En Plus 3 with the range of $600 \leq BD \geq 750$ kg/m³. Thus, all the studied pellets fall under the ENPlus 3 regulations.

The ash content is one of the most important qualitative characteristics of pellets, which influences, above all, the calorific value; the combustion process and the corrosion degree of boilers. It is for these reasons that the ENPlus rules have become more demanding, reducing the allowed amount of ash from 1.5 to 1.2% for Class ENPlus A2 and from 3 to 2% for Class En-B (9 p. 171).

The obtained results demonstrate that the ash content of pellets produced from black currant and vine plant residues exceeds the allowed norms for residential pellets, however, this qualitative parameter allows their application for industrial uses. The least amount of ash results from burning plum and apple pellets.

The *content of N, S and Cl* have a negative impact on the environment and the functioning of thermal power plants. Thus, nitrogen, when being burnt, forms nitrogen oxides, which leads to the formation of acid rain and smog.

The ENPlus 3 rules limit the nitrogen content for residential pellets up to 0.3% for Class A1 pellets, up to 0.5% for Class A2 and up to 1% for Class EN-B.

The requirements for nitrogen content in the pellets for industrial uses are more severe, having the following restrictions: 0.3% – for classes I1 and I2 and 0.6% - for Class I3.

Looking at the data, provided in Table 2, we can state that all pellet samples scored a percentage of N less than 1% and can be classified into different classes of pellets for residential uses. At the same time, blackberry, sea buckthorn and black currant pellets can not be used for industrial uses.

The *sulphur content* for residential pellets is limited by ENPlus 3 up to 0.04% for Class A2 and up to 0.05% for classes A2 and EN-B. The sulphur content must not exceed 0.05% in the case of all classes of pellets for industrial uses.

All analyzed samples had an S content of less than or equal to 0.05%, with the exception of those of blackberries which exceeded the maximum allowed limit insignificantly.

Chlorine content participates in the formation of various compounds, in particular HCl and dionines / furans. CL compounds strengthened by condensation processes cause intense corrosive effects of metal components of heating systems; such effects significantly reduce their reliability. Therefore, the ENPlus 3 regulations limit the CL content in pellets up to 0.02% for classes A1 and A2 and up to 0.03% for Class EN-B.

The CL content allowed by ENPlus 3 is higher for industrial pellets: Class I1 ≤ 0.03%; I2 ≤ 0.05 and I3 ≤ 1%. Thus, all pellet samples analyzed at this parameter correspond to the requirements of ENPlus3 for different quality classes.

Improving the quality of pellets by creating biomass mixtures from agricultural residues. The following research refers to the quality assessment of pellets produced from mixtures that consist of vegetable agricultural residues, have lower calorific value and are less studied. Since the energy potential of agricultural residues from shrubs is the highest and the quality properties are lower than those of other agricultural residues from trees (see Table 1), one has studied the pellets produced from mixtures of blackberry and sea buckthorn residues.

Table 2 shows that murine residues have registered the following parameters: the calorific value (qp, net, M=10% = 15.7 MJ/kg), ash 1.62%, nitrogen 0.88% and sulfur content 0.06%, and pellets from sea buckthorn residues have a calorific value (qp, net, M=10% = 17.05 MJ/kg), ash content 1.3%, nitrogen 0,98% and sulphur 0,05%. These indicators proves the possibility to use these two types of biomass in the mixture.

Ten samples of mixtures with a different content and a step of 5% were studied. The results are presented in Table 3.

Table 3

Quality parameters of pellets produced from mixtures of murine residues (RM) and sea buckthorn residues (RCA)

Nr. of sample	BBR, w%	SBR, w%	$q_{p,\ net,\ M=10\%}$, MJ/kg	A, %	DU,%	DB, kg/m^3	FF,%	N,%	S,%	Cl, %
1	0	100	17.05	1.3 (±0.021)	98.03 (±0.15)	685 (±2.5)	0.42 (±0.022)	0.98	0.05	0.04
2	10	90	17.64	1.3 (±0.015)	98.03 (±0.1)	682 (±1.5)	0.42 (±0.018)	0.98	0.05	0.04
3	15	85	17.214	1.35 (±0.01)	98 (±0.21)	680 (±3)	0.42 (±0.01)	0.96	0.05	0.04
4	20	80	16.84	1.36 (±0.016)	97.98 (±0.14)	680 (±2.8)	0.44 (±0.019)	0.96	0.05	0.04
5	25	75	16.54	1.4 (±0.012)	97.93 (±0.17)	677 (±3.2)	0.45 (±0.009)	0.97	0.05	0.04
6	30	70	16.52	1.39(±0.01)	97.9 (±0.21)	676 (±1.8)	0.44 (±0.02)	0.95	0.4	0.04
7	35	65	16.52	1.41(±0.011)	97.86 (±0.18)	674 (±1.5)	0.46 (±0.01)	0.94	0.05	0.04
8	40	60	16.5	1.43(±0.01)	97.82 (±0.14)	674 (±2.1)	0.48 (±0.017)	0.94	0.04	0.04
9	45	55	16.5	1.45(±0.018)	97.75 (±0.21)	673 (±2.1)	0.52 (±0.022)	0.93	0.04	0.04
10	50	50	16.1	1.46(±0.012)	97.75 (±0.22)	670 (±1.5)	0.52 (±0.016)	0.93	0.04	0.04

The obtained results demonstrate the efficiency of biomass mixtures produced from bush prunning. All qualitative parameters of samples 1 ... 9 fall within the limits stated by MS EN ISO 17225-3:2016 standard.

Improving the quality of pellets produced from agricultural residues by torrefaction. The research results presented in Table 3 show that as to the calorific value, a part of the studied biomass samples has a net calorific value of less than 16.5 MJ/kg or is close to this value.

One of the effective methods to improve the quality of SDBF produced from the biomass with lower characteristics, is the heat pre-treatment of the raw material with the absence of oxygen. The process, called torrefaction, consists of slowly heating the biomass or the finished product in an inert environment at relatively low temperatures (200 ... 300)°C under the atmospheric pressure and at the speed that does not exceed 50 °C/min.

The torified biomass is more easily ground, so the bulk density of the biomass before densification is low, therefore the densification expenditure is reduced and the particle density of the finished product is changed. At the same time, the chemical composition of the biomass changes too because a significant amount of moisture and volatile matter is removed, which leads to dehydration, dehydrooxylation and decarboxylation reactions.

Due to the degradation of hemicellulosis during torrefaction, caused by the interaction of the drying phenomenon with incomplete pyrolysis, the content of lignin that has more carbon is increased, which leads to an increase in the calorific value of the product.

Obviously, since it is a thermochemical process, torrefaction is influenced by several factors, in particular torrefaction temperature and time.

In order to estimate the effect of torrefaction, one studied the biomass mixture, which consisted of 50% of the sea buckthorn and 50% of the blackberry shrubs.

The torrefaction experiment was carried out according to a polyfactor program with two influence factors (see Table 4). A laboratory facility was used to simulate the torrefaction process in an oxygen-free environment by creating a vacuum atmosphere in a closed space (Figure 1).

Table 4

Experimental plan to study the effect of torrefaction

Coded coordinates		Natural coordinates	
T_t, °C	σ_t, min	T_t, °C	σ_t, min
1	1	1	1
-1	-1	-1	-1
0	0	0	0
0	0	0	0
1	1	1	1
-1	-1	-1	-1
0	0	0	0
1	1	1	1
-1	-1	-1	-1

A vacuum drying furnace was used as a reactor to torrefact biomass samples under laboratory conditions (see Figure 1). The air from the furnace is discharged by a vacuum pump that provides a depression of 0.08 MPa. The temperature inside the furnace was monitored and controlled with a thermocouple at the predetermined temperature within the range of +35 – + 350°C with a sensitivity of ±2°C

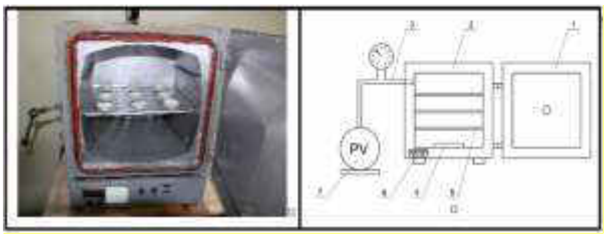
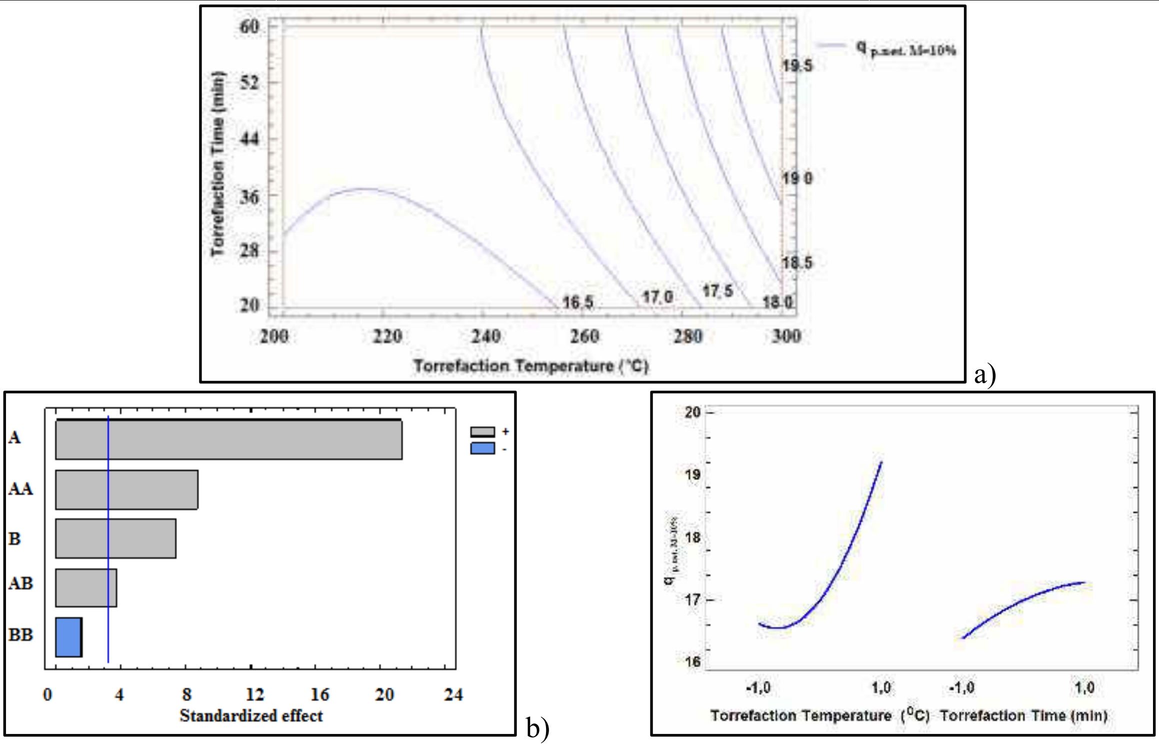


Figure 1. **The laboratory installation used to torrefact biomass samples in vacuum:**

1 – the sealed furnace door; 2 – the furnace frame; 3 – the air outlet with a vacuum meter; 4 – the thermostat support; 5 – shelves; 6 – the control panel and the control of thermal regimes; 7 – the vacuum pump.

The obtained results are shown in Figure 2. Exemplified by the contours of the response surfaces, the Pareto diagram and dominated effects.

As you may see in the figure, the torrefaction temperature influences the calorific value most of all. Basically, the maximum point is outside the aim of the experiment, but this area is limited by the maximum temperature that can be used at torrefaction, and namely 300 °C. The duration of torrefaction also has an increasing trend of influence, though it is slower in the case of temperature.



a) b) c)

Figure 2. **Calorific value of the biomass mixture that includes 50% of blackberry, 50% of sea buckthorn according to torrefaction temperature and time:**

a) Contours of Estimated Response Surface; b) Standardized Pareto Chart for q p. net M=10% (A – Torrefaction temperature, oC; B – Torrefaction Time, min); c) Main Effect Plot for q p. net M=10%

The obtained results demonstrate that the calorific value of the mixtures consisting of 50% of blackberry residues and 50% of sea buckthorn residues can be increased by up to about 20% using heat treatment and torrefaction. In order to get this performance it is necessary to re-establish torrefaction at a temperature, which is as close to 300 ºC as possible and maintain this temperature for at least 40 minutes. The longer the torrefaction time, the better the expected result.

Conclusion and prospects for use. As to the quality and the possibility of the use of agricultural wood residues for the production of solid biofuels in the form of pellets, it has been found out that the existing data in the literature refer to particular types of plant biomass, and does not sufficiently reflect the integrity of the situation with regard to the quality of solid biofuels in the form of pellets made from agricultural wood residues, collected in the specific climate of the Prut river. This conclusion is based on the knowledge accumulated at both national and international levels.

The results of the quantitative study of the agricultural wood residues, suitable to be used as raw material for the production of solid biofuels in the form of pellets under the conditions of the Republic of Moldova and the counties of Botosani, Iasi, Vaslui and Galati, Romania, have shown that the potential energy that is sustainable for the implementation of agricultural residues, which is estimated from a hectare of plantation, is an important source of raw material for the production of solid biofuels. It has been stated that plantations of apples (41.1 GJ/ha), vines (34.5 GJ/ha), plums (21.4 GJ/ha), sweet cherries (12.2 GJ/ha) and apricots (11.8 GJ/kg) show higher energy potentials.

The estimation of the qualitative parameters of pellets produced from agricultural wood residues collected in the areas adjacent to the Prut river have shown that they largely correspond to ENPlus 3 requirements for most qualitative parameters except for those produced from blackberry and black currant residues.

The highest net calorific value is recorded in the case of sweet cherry (11.8 MJ/kg), plum (17.7 MJ/kg), apple (17.72 MJ/kg) and pear (17.31 MJ/kg) pellets.

The obtained results can be applied by pellet producers to argue the use of different types of agricultural wood residues in the production of pellets. At the same time the results of this study can be used for further research in the field of quality management of the finished product by forming mixtures of different types of plant biomass and by improving the technological process of processing pellets and other types of densified solid biofuels. It is also interesting to study the way the moisture content, processing temperature, origin and particle size affect the flow properties of polymers in agricultural wood biomass during pelletizing.

Experimentally it has been shown that the arboreal residues, received from prunning some types of fruit shrubs, can be used to produce pellets by creating mixtures with different proportions, and their qualitative characteristics can be significantly improved by thermo-chemical pre-treatment of the raw material.

Acknowledgements. This study was made possible thanks to the funding of the cross-border grant project 2SOFT/1.2/44 "*Improving the Quality of Solid Biofuels are Produced from the Raw Material Collected From Both Sides of the Prut River*" within the Joint Operational Programme Romania – Republic of Moldova 2014-2020, financed by the ENI CBC and fruitful collaboration of the staff of the Laboratory of Solid Biofuels from the Sate Agrarian University of Moldova, and the Mechanical Faculty, Gh. Asachi Technical University of Iasi, Romania.

The research related to the analysis of plant biomass mixtures resulted from prunning shrubs was possible due to the support of project 20.80009.5107.13 no. 50-PS within the State Programme of the Republic of Moldova.

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Г. Мариан, И. Гелу, А. Гудыма, Б. Назар, Б. Истрат, А. Павленко, А. Банари, Н. Дарадуда. **Качество пеллет, изготовленных из сельскохозяйственных древесных отходов, характерных для бассейна реки Прут**

В статье представлены перспективы использования древесных сельскохозяйственных отходов, характерных для климатической зоны, прилегающей к реке Прут, а также качественные характеристики уплотненного твердого биотоплива в виде пеллет, полученных из основных видов древесной сельскохозяйственной биомассы, характерной для Республики Молдова и уездов Ботошаны, Яссы, Васлуй и Галац из Румынии. Целью статьи является определение энергетического потенциала основных местных сельскохозяйственных древесных отходов и анализ качества пеллет, производимых из этих отходов.

Результаты исследования показали, что пеллеты, полученные из изученных сельскохозяйственных отходов, в значительной степени соответствуют требованиям ENPlus 3 по большинству качественных показателей, за исключением пеллет, полученных из отходов ежевики и смородины. Отходы, полученные от обрезки определенных типов плодовых кустарников, могут быть использованы для производства пеллет путем формирования смесей различных пропорций, а их качественные характеристики могут быть значительно улучшены путем предварительной термохимической обработки сырья.

***Ключевые слова**: растительная биомасса, уплотненное твердое биотопливо, пеллеты, биотопливо, энергетический потенциал, древесные сельскохозяйственные отходы.*

Г. Маріан, Й. Гелу, А. Гудима, Б. Назар, Б. Істрат, А. Павленко, А. Банарі, Н. Дарадуда. **Якість пелет, виготовлених з сільськогосподарських деревних відходів, характерних для басейна річки Прут**

У статті представлено перспективи використання деревних сільськогосподарських відходів, характерних для кліматичної зони, прилеглої до річки Прут, а також якісні характеристики ущільненого твердого біопалива у вигляді пелет, отриманих з основних видів деревної сільськогосподарської біомаси, характерної для Республіки Молдова і повітів Ботошани, Яссі, Васлуй і Галац з Румунії. Метою статті є визначення енергетичного потенціалу основних місцевих сільськогосподарських деревних відходів і аналіз якості пелет, вироблених з цих відходів.

Результати дослідження показали, що пелети, отримані з вивчених сільськогосподарських відходів, значною мірою відповідають вимогам ENPlus 3 за більшістю якісних показників, за винятком пелет, отриманих з відходів ожини та смородини. Відходи, отримані від обрізки певних типів плодових чагарників, можуть бути використані для виробництва пелет шляхом формування сумішей різних пропорцій, а їх якісні характеристики можуть бути значно поліпшені шляхом попередньої термохімічної обробки сировини.

***Ключові слова:** рослинна біомаса, ущільнене тверде біопаливо , пелети, біопаливо, енергетичний потенціал, деревні сільськогосподарські відходи.*