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SUSTAINABLE UTILIZATION OF AGRICULTURAL RESIDUES FROM FRUIT SHRUBS: ENERGY POTENTIAL AND PHYSICAL-CHEMICAL PROPERTIES

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Abstract

The energy crisis, population growth, and rising living standards exert significant pressure on energy resources and the environment in the Republic of Moldova. In this context, the utilization of agricultural residues, which are abundantly available in rural areas, for renewable energy production from biomass gains increasing importance. This study aims to evaluate the sustainable potential of residues generated by fruit-bearing shrubs, a crop that is expanding in the Republic of Moldova. The physical and chemical properties of biomass derived from the most widespread fruit shrub species cultivated in the country—raspberry, blackberry, gooseberry, currant, blueberry, and sea buckthorn—were analyzed. For these species, the sustainable energy potential and the prospects of using biomass as a raw material for producing densified solid biofuels have been determined. Proximate and ultimate analyses of biomass samples were conducted using standardized and validated methods at the Scientific Laboratory of Solid Biofuels of the Technical University of Moldova. The obtained data indicate that the highest sustainable energy potential is recorded for blackberry biomass (54.78±4.48 GJ/ha), followed by sea buckthorn (42.20±1.37 GJ/ha) and raspberry (40.59±3.79 GJ/ha). The lowest values were recorded for gooseberry and currant biomass, influenced by both lower biomass yields per hectare and lower calorific values.

***Keywords**: Biomas; Fruit-bearing shrubs; Sustainable energy potential; Calorific value*

Introduction

In the context of the transition of agriculture toward a circular economy and the need to reduce environmental impact, the sustainable valorization of agricultural residues is becoming increasingly important [1, 2]. Among the raw materials used in the production of densified solid biofuels (DSB), residues resulting from the care and processing of fruit shrubs play a distinct role [3, 4]. However, many aspects related to the sustainable valorization of agricultural residues from fruit shrubs remain insufficiently studied.

The main challenge in energy production from plant biomass is the efficient management of the solid biofuel supply chain (SBSC), which must consider the availability and quality of the biomass used as raw material [5]. A well-structured SBSC ensures the optimal valorization of plant biomass, accelerating the agricultural sector's transition to a circular economy [6]. This process has a significant impact on reducing negative environmental effects, increasing energy efficiency, and fostering regional economic development [1].

To ensure an efficient transition to the circular economy, the SBSC for agricultural plant biomass must include the following stages [5, 7]:

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• Collection and management of plant residues – involves identifying, estimating, collecting, transporting, and optimally storing woody materials resulting from the maintenance pruning of orchards and vineyards.

• Pretreatment and conditioning of biomass – includes operations such as chopping and drying of the raw material.

• Processing and densification of solid biofuels (SB).

• Distribution and utilization – involves developing an efficient distribution network for industrial, agricultural, or residential consumers.

The integration of biomass resulting from the cultivation of fruit shrubs into a solid biofuel supply chain (SBSC) capable of meeting the requirements of a circular economy takes on new dimensions, considering the ongoing development of this agricultural sector [8, 9]. The importance of this approach is also supported by the increasing interest in using plant biomass from various agricultural activities, particularly in recent decades. This is driven by the growing energy crisis, depletion of fossil energy resources, and environmental concerns, as well as the need to ensure more reliable and economically accessible local energy sources [10, 11].

The potential for using plant biomass to produce densified solid biofuels (DSB) depends on its local availability, the possibility of collection, transport, and storage, and the densification capacity, as well as its composition and properties [9, 12, 13]. Additionally, the characteristics of agricultural plant biomass vary depending on factors such as species, growing conditions, and harvesting technologies [14, 15].

Numerous studies show that orchard and vineyard biomass can be effectively used as a raw material for the production of densified solid biofuels (DSB) with characteristics that meet the requirements stipulated in the SM EN ISO 17225 standard series [16-22]. This finding, complemented by recent research [9, 23, 24], also provides promising prospects for using plant biomass from the maintenance of fruit shrubs as a raw material for DSB production.

Due to its geographical position and morphological characteristics, particularly in the Northern and Central regions, the Republic of Moldova has seen a significant increase in the area cultivated with fruit shrubs, from 698ha in 2021 to 908ha in 2023 [25]. The main cultivated species include raspberry (*Rubus idaeus L.*), blackcurrant (*Ribes spp*.), gooseberry (*Ribes Grossularia L.*), blackberry (*Rubus fruticosus L.*), and sea buckthorn (*Hippophae rhamnoides*). In addition to these crops, species such as dog rose (*Rosa canina*) and blackthorn (*Prunus spinosa*) are also found in Moldova, which present potential for biomass valorization.

For the efficient use of local plant residues generated by fruit shrubs, it is essential to understand their physical and chemical properties. This information serves as a key criterion that underpins all links of the SBSC and determines the feasibility and efficiency of using biomass as a raw material for DSB production, in line with consumer requirements and reference standards.

This article aims to analyze the energy potential of residues from fruit shrubs, highlighting their relevant characteristics for energy valorization. The study contributes to the foundation of sustainable technological solutions for utilizing these resources within the solid biofuel supply chain (SBSC), supporting the development of more efficient and environmentally friendly agricultural practices.

Experimental part

Materials

As the object of research, plant biomass samples from fruit shrubs were collected from various agricultural holdings in the Republic of Moldova using both manual and mechanized methods. For example, blackberry samples were taken from plantations in Teleșeu, Orhei district, while raspberry, blueberry, and blackcurrant samples were collected from family farms in

Trușeni, Chișinău municipality. Sea buckthorn samples were obtained from Pohrebea, Dubăsari district, and Clișova, Orhei district (Figs. 1 and 2).

Fig. 1. Sequences during the blackberry biomass sampling process

Fig. 2. Sequences during the harvest of sea buckthorn plant biomass in Clișova village, Orhei district, Republic of Moldova: a) manual harvesting by detaching branches with fruits; b) freezing the branches; c) sea buckthorn after threshing; d) plant biomass in the form of leaves; e) plant biomass in the form of branches after threshing

Initially, based on direct field observations, the quantity and type of representative residues were determined. All samples were taken from representative plots, and the obtained data were extrapolated to larger areas. Trees were selected using the quarter method, which was also applied by *A. Pavlenco et al.* [18] in his study on the energy potential of agricultural residues in the northern development region of the Republic of Moldova.

The mass of the sampled specimens was determined by weighing using the ACEN 50K scale, with a measurement range of 0.1-50kg and a division of 10g, calibrated internally with a 2kg reference weight (INM 2025), immediately after collection. Before weighing, the biomass was coarsely chopped directly in the field using the *Murena woodchipper*, made in the Czech Republic (Fig. 3).

Fig. 3. Sequences during the coarse chopping of sea buckthorn biomass

A portion of the samples was preserved, sealed in polyethylene bags, and transported to the Solid Biofuel Supply Chain Laboratory (LȘBCS) for moisture determination at harvest, as well as for conducting other physical and chemical analyses.

The amount of sea buckthorn biomass was estimated after freezing and threshing the fruits, as their harvest is carried out by detaching the branches along with the fruits, leaving 10-12cm of the base of the branches on the plant in the form of stumps. This method ensures the regeneration of the crown in the following year.

Figure 4 presents the plant biomass samples from fruit shrubs tested in this study. To compare the data from the literature with those obtained in this study and to approximate the actual amount of biomass, calculated at the average moisture content recommended for pellet and briquette processing, the quantitative potential of the biomass was adjusted to a moisture content of 10%. For this, the amount of biomass considered completely dry (0% moisture) was determined using the following equation:

$$\boldsymbol{m_d = \frac{m_{br}(100-M_r)}{100}}, \quad (1)$$

Where m_d is the mass of completely dry biomass (0% moisture), kg; m_b - is the biomass mass at harvest, kg; and M_r - is the moisture content at harvest, % or a moisture content of 10%, the formula becomes:

$$\boldsymbol{m_{i,10\,\%} = \frac{m_d}{0,9}}, \quad (2)$$

The validity and repeatability of the experimental data were ensured by adhering to the technical, methodological, and organizational measures outlined in the SM EN ISO 17025:2018 standard.

Methods

In the conducted study, the parameters of the biomass samples were evaluated through proximate and ultimate analyses carried out at the Solid Biofuel Supply Chain Laboratory (LȘBCS), following the standardized and validated methodologies within the laboratory. A detailed description of the methodologies used is presented in our paper [26]. The experimental results were statistically processed using Statgraphics and Excel software.

The energy potential of plant biomass from fruit shrubs was determined for three categories of potential: theoretical, available, and sustainable for implementation.

Fig. 4. Studied biomass samples

The theoretical potential represents the total amount of energy contained in the biomass that can be harvested from a specific plantation area, without considering limiting factors [22].

The available energy potential is a portion of the theoretical energy potential, influenced by factors such as the use of biomass for purposes other than energy, the efficiency of the technological process, and other constraints [27].

The sustainable energy potential for implementation (*SEPI*) represents the fraction of the available energy potential that can be profitably utilized, considering the costs associated with collecting, processing, and using the biomass, as well as technical and sustainability factors. The value of *SEPI* is influenced by economic, technological, and political aspects [28, 29].

The efficiency of using plant biomass from fruit shrub residues was analyzed through examples of pellet production from blackberry, sea buckthorn, and various mixtures composed of the components with the widest availability in the Republic of Moldova.

Results and discussion

Characterization of agricultural residues from fruit shrubs

Samples of biomass generated by 5 raspberry varieties, 4 blackberry varieties, 2 gooseberry varieties, 3 currant varieties, 3 blueberry varieties, and 4 sea buckthorn varieties were analyzed. In order to determine the energy potential of the biomass per hectare of plantation, the average quantity and limit values of the plant residues generated by the fruit shrubs analyzed in this study were determined.

Figure 5 shows the distribution of the residual biomass quantities obtained from the experiments, highlighting significant variations between the analyzed species. It is observed that these differences are influenced by the characteristics of each shrub, which determine the availability of biomass for utilization.

According to the data presented, the largest quantities of residues are generated by blackberry and raspberry, with average values of 4124±227 and 3209±297kg/ha, respectively. Sea buckthorn and blueberry produce moderate amounts, ranging between 3039±99kg/ha and 2081±207kg/ha, while the lowest quantities of residues come from gooseberry (752±84kg/ha) and currant (1197±87kg/ha). These results highlight the importance of properly selecting plant resources for efficient biomass utilization.

Thus, it can be concluded that species with high residue yields, such as blackberry, raspberry, sea buckthorn, and blueberry, have a superior potential for utilizing residual biomass for energy or industrial purposes. On the other hand, species with lower yields, such as gooseberry and currant, may require a different approach, such as combining their biomass with other sources to ensure optimal efficiency in the conversion process.

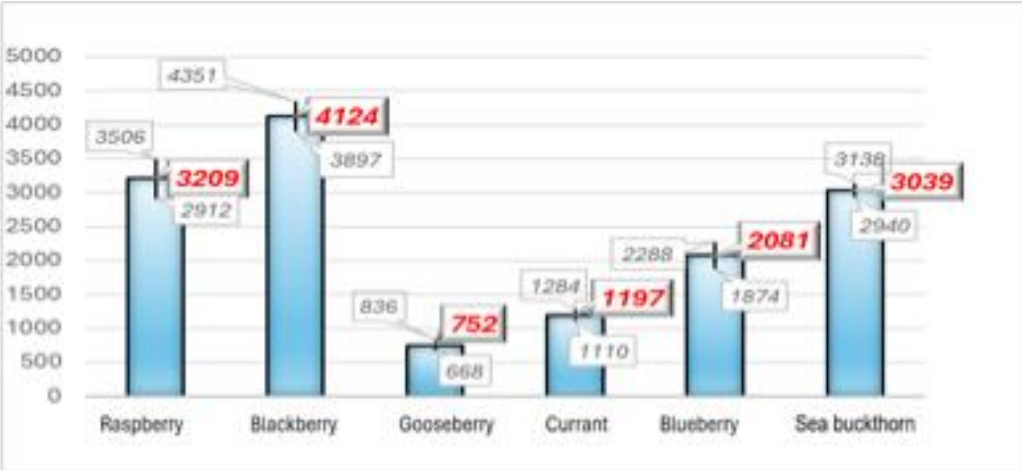

Fig. 5. The average, maximum, and minimum quantity of fruit shrub residues generated per hectare of plantation. The values are expressed in mass units and correspond to biomass with a moisture content of 10%

The variability in the quantities of residues can be influenced by several factors, including crop density, the techniques and frequency of maintenance works, as well as the pedoclimatic conditions specific to each cultivation area. These aspects must be considered for efficient management of available biomass resources.

To adequately assess the suitability of biomass generated by fruit shrubs as raw material for producing solid biofuels, a detailed characterization of its properties is required. In this regard, Table 1 summarizes the results of the proximate analysis for different species of fruit shrubs, highlighting the main characteristics of the varieties cultivated in the Republic of Moldova. This data is essential for determining the energy efficiency and the potential for integrating biomass into the solid biofuel supply chain.

The comparative analysis of the data in Table 1 shows that sea buckthorn biomass has the highest calorific value ($q_{Pnet\ M=10\%}$=17.142±0,015MJ/kg), followed by currant biomass ($q_{Pnet\ M=10\%}$=15,888±0,009MJ/kg), making them the most suitable for combustion. Blackberry biomass has the lowest calorific value ($q_{Pnet\ M=10\%}$=14.951±0,155MJ/kg), but it has the highest quantity of biomass harvested per hectare (see fig. 5).

A limiting factor for currant biomass is the high ash content (3.78±0.28%) and the small amount of residues from nectar, while gooseberry biomass has a high moisture content at harvest (47.93±0.11%), which requires additional energy for drying. Additionally, the amount of biomass harvested per hectare is very small (752±84kg/ha). Therefore, sea buckthorn and blackberry biomass are recommended for individual use or in mixtures due to their superior energy yield.

The other types of biomass can be used in mixtures but require supplementation with biomass species that have high calorific values and a specific ash content.

Table 1. Proximate analysis of plant biomass generated by different varieties of fruit shrubs cultivated in the Republic of Moldova

Berry cultivar	q_{Vd}, J/g	$q_{Vnet\ d}$, J/g	$q_{Pnet\ M=10\%}$	A, %	M_r	MV, %	CFd, %
Raspberry							
Barnaulievskaya	19.207	17.872	15.840	1.71	47.01	79.69	18.60
Scromnița	19.042	17.703	15.688	1.82	47.91	80.02	18.16
Laszka	19.019	17.663	15.652	1.63	44.7	79.54	18.83
Sugana	18.637	17.311	15.335	1.69	47.21	79.47	18.84
Glen Ample	18.872	17.558	15.558	1.69	46.34	79.71	18.60
Mean	**18.956**	**17.621**	**15.615**	**1.71**	**46.63**	**79.69**	**18.61**
Standard Deviation	**0.214**	**0.207**	**0.186**	**0.07**	**1.22**	**0.21**	**0.28**
Confidence Interval	**0.171**	**0.166**	**0.149**	**0.06**	**0.97**	**0.17**	**0.22**
Blackberry							
Loch Tay	18.325	16.885	14.952	2.64	45.58	78.32	19.04
Triple Crown	18.422	16.997	15.053	2.43	46.75	78.45	19.12
Thornfree	18.023	16.562	14.661	2.54	47.06	78.22	19.24
Arapaho	18.527	17.092	15.138	2.97	47.21	78.39	18.64
Mean	**18.324**	**16.884**	**14.951**	**2.65**	**46.65**	**78.35**	**19.01**
Standard Deviation	**0.217**	**0.231**	**0.208**	**0.23**	**0.74**	**0.10**	**0.26**
Confidence Interval	**0.174**	**0.185**	**0.166**	**0.19**	**0.59**	**0.08**	**0.21**
Gooseberry							
Doneţki krupnoplodnîi	19.306	17.872	15.840	2.61	48.01	79.87	17.52
Donetski perveneţ	19.307	17.919	15.883	2.51	47.84	79.55	17.94
Mean	**19.307**	**17.895**	**15.862**	**2.56**	**47.93**	**79.71**	**17.73**
Standard Deviation	**0.001**	**0.033**	**0.030**	**0.07**	**0.12**	**0.22**	**0.29**
Confidence Interval	**0.001**	**0.029**	**0.026**	**0.06**	**0.11**	**0.20**	**0.26**
Currant							
Titania	19.288	17.924	15.887	3.91	41.89	78.29	17.80
Roșu de Olanda	19.289	17.943	15.905	3.41	42.24	78.32	18.27
Belorusskaia sladkaia	19.290	17.921	15.885	4.02	41.78	78.25	17.73
Mean	**19.289**	**17.929**	**15.892**	**3.78**	**41.97**	**78.29**	**17.93**
Standard Deviation	**0.001**	**0.012**	**0.011**	**0.33**	**0.24**	**0.04**	**0.29**
Confidence Interval	**0.001**	**0.010**	**0.009**	**0.28**	**0.21**	**0.03**	**0.26**
Blueberry							
Bluegold	19.342	17.931	15.894	2.44	44.55	79.18	18.38
Blue Crop	19.224	17.872	15.841	2.68	44.62	79.26	18.06
Duke	18.947	17.557	15.557	2.21	44.44	79.08	18.71
Mean	**19.171**	**17.787**	**15.764**	**2.44**	**44.54**	**79.17**	**18.38**
Standard Deviation	**0.203**	**0.201**	**0.181**	**0.24**	**0.09**	**0.09**	**0.33**
Confidence Interval	**0.178**	**0.177**	**0.159**	**0.21**	**0.08**	**0.08**	**0.28**
Sea buckthorn							
Cora	20.699	19.324	17.147	2.44	44.55	79.18	18.38
Andros	20.700	19.325	17.148	2.44	44.55	79.18	18.38
Clara	20.700	19.333	17.156	2.36	44.62	79.24	18.40
Mara	20.701	19.290	17.117	1.96	44.44	79.02	19.02
Mean	**20.700**	**19.318**	**17.142**	**2.30**	**44.54**	**79.16**	**18.55**
Standard Deviation	**0.001**	**0.019**	**0.017**	**0.23**	**0.07**	**0.09**	**0.32**
Confidence Interval	**0.001**	**0.017**	**0.015**	**0.20**	**0.07**	**0.08**	**0.28**

Note: q_{Vd} – higher calorific value measured at constant volume; $q_{Vnet\ d}$, J/g – lower calorific value at constant pressure; $q_{Pnet\ M=10\%}$ – net calorific value of the biomass estimated for a moisture content of 10%, calculated for constant pressure; A – ash content on a dry basis; CFd – carbon content on a dry basis. M_r – moisture content in biomass at harvest; MV – volatile matter content.

Analysis of the energy potential of plant residues from fruit shrubs

In order to identify the efficiency of using fruit shrub residues in the production of solid biofuels, the energy potential of the plant biomass resulting from the pruning of six species of fruit shrubs cultivated in the Republic of Moldova was determined: raspberry, blackberry, gooseberry, currant, blueberry, and sea buckthorn.

The obtained data (Table 2) provide a detailed picture regarding the biomass quantity estimated per hectare of plantation, the calorific value of the studied biomass species, and the theoretical, available, and sustainable implementation potential.

The quantitative analysis of the biomass shows that it varies significantly between the analyzed species, affecting their energy potential, suggesting differences in cultivation conditions, plant age, or harvesting techniques.

Thus, blackberry has the highest energy potential. It is worth noting that although blackberry has the highest biomass yield, its calorific value is among the lowest, while sea buckthorn, with a biomass yield lower than blackberry and raspberry, compensates with a high calorific power.

Blueberry, currant, and gooseberry have similar calorific values: blueberry (15.76MJ/kg), currant (15.89MJ/kg), and gooseberry (15.86MJ/kg), but the reduced biomass quantity limits their total energy potential.

Table 2. The energy potential of fruit shrub residues

Parameters		Raspberry	Blackberry	Gooseberry	Currant	Blueberry	Sea buckthorn
$m_{M=10\%}$, kg/ha	m	3209	4124	752	1197	2081	3039
	σ	297	227	84	87	207	99
$q_{Pnet\ M=10\%}$,	m	15.61	14.95	15.86	15.89	15.76	17.14
MJ/kg	σ	0.19	0.21	0.03	0.01	0.18	0.02
A_i		0.9	0.9	0.9	0.9	0.9	0.9
k_{il}		0.1	0.1	0.1	0.1	0.1	0.1
PET, GJ/ha		50.11	61.66	11.93	19.02	32.80	52.10
up, GJ/ha		4.68	3.50	1.33	1.37	3.28	1.69
PED, GJ/ha		45.10	55.49	10.74	17.12	29.52	46.89
up		4.21	3.15	1.19	1.24	2.95	1.52
PESI, GJ/ha		40.59	49.94	9.67	15.40	26.57	42.20
up		3.79	2.83	1.07	1.11	2.66	1.37

Note: $m_{M=10\%}$, - is the average biomass amount converted for a moisture content of 10%; $q_{Pnet\ M=10\%}$ - is the net calorific value of the biomass estimated for a moisture content of 10%, calculated for constant pressure; PET - theoretical energy potential; PED - available energy potential; PESI - sustainable energy potential for implementation; A_i – availability coefficient, equal to 0.8; k_{il} - implementation loss coefficient, equal to 0.1; up – predictive uncertainty; m – mean value, σ – standard deviation.

The analysis of the available energy potential, calculated after applying loss and technological restriction coefficients, remains high for blackberry (61.66±3.50GJ/ha), sea buckthorn (52.19±1.69GJ/ha), and raspberry (50.11±4.69GJ/ha), confirming the efficiency of these species for energy use. The lowest PED values are reported for gooseberry (10.74±1.19 GJ/ha) and currant (17.12±1.24GJ/ha), making them less efficient from an energy utilization perspective.

The sustainable energy potential for implementation confirms the same hierarchy as before, with blackberry (49.94±2.83GJ/ha), sea buckthorn (42.20±1.37GJ/ha), and raspberry (40.59±3.79GJ/ha) having the highest values of usable sustainable energy. Blueberry, with a PESI value of 26.57±2.66GJ/ha, remains a viable option, while gooseberry (9.67±1.07GJ/ha) and currant (15.40±1.11GJ/ha) have a lower energy potential. The results allow us to make the following interpretations and recommendations:

- Blackberry, sea buckthorn, and raspberry are the most promising species for energy use due to their high biomass yield and favorable calorific value.
- Blueberry, gooseberry, and currant can be used in combination with other plant resources with a higher calorific value to optimize solid biofuel production.
- Factors such as humidity, logistical costs, and technological compatibility must be considered to optimize the biomass valorization process.

The analysis provides support that can be used by solid biofuel producers in decision-making regarding biomass resource management and contributes to the development of a sustainable bioenergy sector in the Republic of Moldova.

Sustainable valorization of agricultural residues from fruit shrubs through the formation of mixtures

The achievement of objectives and policies related to the development of renewable energy sources from biomass is directly dependent on the sustainability of LABCS [30] with guaranteed quality parameters of the final product [31].

Ensuring the quality of solid biofuels through the optimization of the supply chain has been extensively studied. Research highlights the dependence of the quality of pellets and briquettes on the characteristics of the raw material and the conditioning and densification regimes of biomass, such as those from straw and their mixtures [32-34].

Wheat straw, considered a secondary product, is frequently used as an additive in the production of densified solid biofuels due to its availability in agricultural regions [34-36]. In the Republic of Moldova, it is widespread in all regions [37], but its high ash content and variations in chemical composition, dependent on soil, climate, and location, limit its use in its individual state as raw material for BCSD production [38]. Also, the presence of the cuticle complicates the densification process.

The possibility of using mixtures of wheat straw with fruit shrub residues was explored through an example of a three-component mixture: white sea buckthorn plant residues (SBPR), blackberry plant residues (BPR), and wheat straw (WS). The research was carried out using a multifactorial plan consisting of 10 mixture variants (Table 3). For each mixture, the calorific value estimated at 10% moisture, ash content in dry basis, bulk density, and mechanical strength were analyzed.

Table 3. The program for optimizing the composition of raw material mixtures for pellet production from fruit shrub residues and wheat straw

Sample numbe r	Influencing factors			Response factors				
	RVCA	RVN	PG	Q, MJ/kg	A, %	BD, kg/m³	DU, %	F, %
1	0	0	1	14,52	7,111	627,6	94,664	2,46
2	0,33	0,67	0	15,58	2,58	588,4	98,9	0,20
3	0,33	0,33	0,33	15,48	3,912	605,2	96,5	3,11
4	0,33	0	0,67	15,17	6,516	578,4	99,203	0,28
5	0,67	0	0,33	15,9	4,296	572,0	98,097	0,46
6	0	1	0	14,95	2,65	560,0	98,7	0,21
7	0	0,33	0,67	14,8	6,552	605,6	97,485	0,76
8	0,67	0,33	0	15,61	3,048	617,6	97,497	0,50
9	1	0	0	16,86	2,44	646,0	99,2	0,18
10	0	0,67	0,33	14,81	4,12	582,4	97,4	0,95

The influence of the mixture composition on the properties of the pellets produced from the studied mixtures can be observed in Figure 6.

The analysis of the images in Figure 6 shows that all the samples studied recorded a calorific value of over 14.5MJ/kg. This indicates that any proportion of the components used in the mixtures allows for the achievement of a calorific value in accordance with the requirements of the SM EN ISO 17225-6:2021 standard. A similar situation is observed with the ash content, with all samples having values below 6%, the threshold set by the same standard. Other characteristics can be ensured by adjusting the proportions of the components in the mixture. For example, a bulk density of over 600kg/m³, when the mixture does not contain PG if the proportion of RVM does not exceed 40%. In the case of mixtures consisting of PG and RVCA, most of the analyzed samples reached this density, except for those located between the lines marked in red, which recorded values below 600 kg/m³.

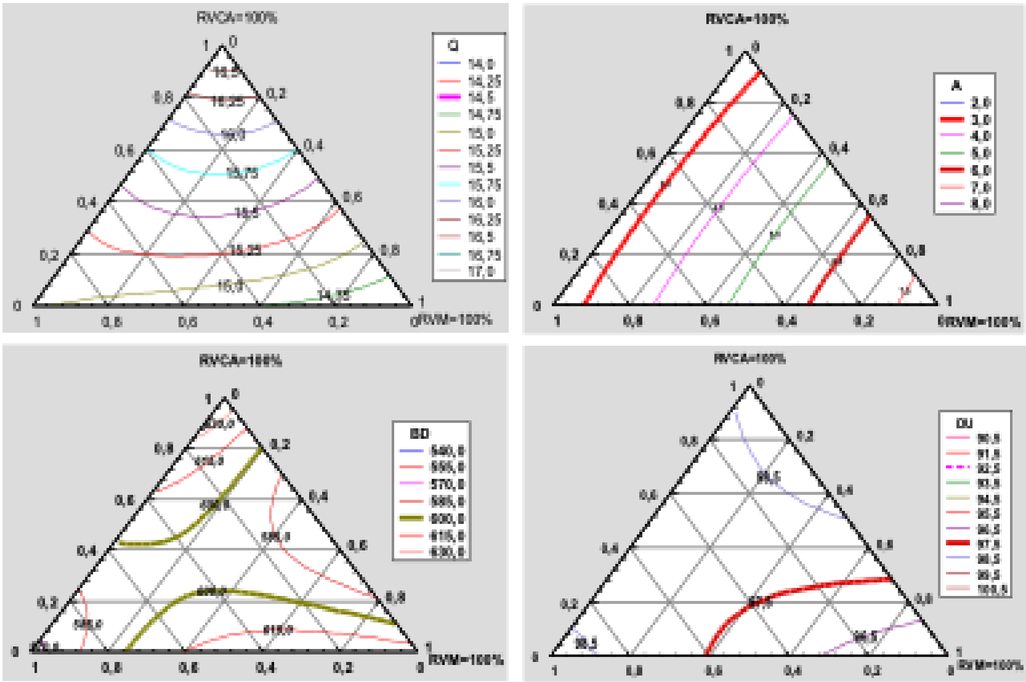

Fig. 6. The variation in the properties of the pellets produced from mixtures of white sea buckthorn plant residues (RVCA) + blackberry plant residues (RVN) + wheat straw (PG): Q - calorific value estimated at 10% moisture content, MJ/kg; A - Ash content on a dry basis, %; BD – Bulk density, kg/m^3; DU – Mechanical strength, %

Conclusions

The main results obtained in this study led to the following conclusions:

1. The analysis of the energy potential of plant biomass from fruit shrubs showed that the highest energy potential is recorded by the biomass of blackberry (PESI = 49.94±2.83GJ/ha) and white sea buckthorn (PESI = 42.20±1.37GJ/ha), followed closely by raspberry biomass (PESI = 40.59±3.79GJ/ha). The lowest values are found for the plant biomass of gooseberry (PESI = 9.67±1.07GJ/ha) and black currant (PESI = 15.40±1.11GJ/ha), a fact influenced either by a smaller amount of biomass produced per hectare or by a lower calorific value.

2. The correlation of the uncertainty in determining the energy potential of biomass generated by fruit shrubs indicates quite large and varying values for certain shrub species. This aspect highlights the need for a more precise assessment at the level of plantations and specific locations before initiating the activities of producing densified solid biofuels from the analyzed plant residues.

3. Following the examination of 10 pellet samples produced from mixtures of white sea buckthorn plant residues, blackberry plant residues, and wheat straw, ternary diagrams were constructed to allow the selection of the optimal composition of raw material mixtures based on the required quality parameters.

4. All 10 samples of mixtures based on white sea buckthorn plant residues recorded a calorific value greater than 14.5MJ/kg, meaning that any proportion of the components used in the formation of the mixtures ensures the production of pellets with a calorific value required by

SM EN ISO 17225-6:2021. The same situation applies to the ash content, as all the samples showed an ash content of less than 6%, the value required by SM EN ISO 17225-6:2021.

The other characteristics of the pellets produced from mixtures of white sea buckthorn plant residues, blackberry, and wheat straw can only be ensured by forming the mixtures with a specific percentage of constituents. For example, bulk density, with values greater than 600kg/m^3, can be ensured if no wheat straw is included in the mixture and if the content of blackberry plant residues does not exceed 40%. If the mixture consists of wheat straw and white sea buckthorn plant residues, a bulk density greater than 600 kg/m^3 is practically ensured by all the samples studied, except for those located between the lines marked in red, which have values lower than 600kg/m^3.

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