QUALITY ASSURANCE OF DENSIFIED BIOFUELS FROM VINEYARD RESIDUES: CASE STUDY FOR "CABERNET" AND "MOLDOVA" VARIETIES CULTIVATED IN THE REPUBLIC OF MOLDOVA

ASIGURAREA CALITĂȚII BIOCOMBUSTIBILILOR DENSIFICAȚI DIN REZIDUURI DE VIȚĂ-DE-VIE: STUDIU DE CAZ PENTRU SOIURILE „CABERNET” ȘI „MOLDOVA” CULTIVATE ÎN REPUBLICA MOLDOVA

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Abstract.
In the context of efficiently utilizing available biomass resources, this study explores the possibility of ensuring the quality of pellets and briquettes produced from biomass obtained from vineyard residues, through a case study of the most widespread grape varieties in the Republic of Moldova – "Cabernet" and "Moldova." The aim of the study is to validate the proposed hypothesis, which focuses on the feasibility of producing densified solid biofuels made of biomass resulting from vineyard care, in all aspects covered by the ENplus certification system. The adopted methodology includes both statistical analyses based on data from the scientific literature and experimental investigations carried out in the Scientific Laboratory of Solid Biofuels at the Technical University of Moldova. The results indicated a promising potential of using vineyard residues for biofuel production, while adhering to ENplus quality standards. Additionally, the study highlights the need for implementing specific technological procedures to maximize yield and minimize losses throughout the entire production process. The conclusions emphasize the multiple benefits of utilizing vineyard residues, both from an economic and ecological perspective, contributing to the sustainable development of the viticulture industry and environmental protection.
Key words: Biomass, vine residues, densified solid biofuels, pellets, briquettes

Rezumat.
În contextul valorificării eficiente a resurselor disponibile de biomasă, studiul de față explorează posibilitatea asigurării calității peleților produși din biomasă provenită din reziduuri de viță-de-vie, printr-un

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studiu de caz pentru cele mai răspândite soiuri de struguri din Republica Moldova – „Cabernet" și „Moldova". Scopul studiului este validarea ipotezei propuse, care se concentrează pe posibilitatea obținerii biocombustibililor solizi densificați din biomasă rezultată din îngrijirea viței-de-vie, în toate aspectele prevăzute de sistemul de certificare ENplus. Metodologia adoptată include atât analize statistice bazate pe date din literatura de specialitate, cât și investigații experimentale efectuate în cadrul Laboratorului Științific de Biocombustibili Solizi al Universității Tehnice din Moldova. Rezultatele indică posibilitatea utilizării reziduurilor de viță-de-vie pentru producția de biocombustibili, cu respectarea standardelor de calitate ENplus. În plus, studiul evidențiază necesitatea implementării unor proceduri tehnologice specifice pentru a maximiza randamentul și a minimiza pierderile pe parcursul întregului proces de producție. Concluziile subliniază beneficiile multiple ale valorificării reziduurilor de viță-de-vie, atât din perspectivă economică, cât și ecologică, contribuind la dezvoltarea durabilă a industriei vitivinicole și la protejarea mediului.

Cuvinte cheie: Biomasă, reziduuri de viță-de-vie, biocombustibili solizi densificați, peleți, brichete

INTRODUCTION

The use of densified solid biofuels (DSBFs), in the form of pellets and briquettes, is continuously increasing worldwide, including in the Republic of Moldova. This has become a popular solution due to its renewable nature and numerous advantages, such as energy efficiency, reduction of harmful gas emissions, economic feasibility, and wide availability [Marian *et al*., 2021; Rupasinghe *et al*., 2024; Ţenu *et al*., 2024].

In the context of using DSBFs as renewable energy in the Republic of Moldova, briquettes and pellets play an essential role in providing sustainable fuel alternatives [Marian, 2016]. Both forms of DSBFs are produced from lignocellulosic biomass, offering economic solutions to reduce energy imports [Marian *et al*., 2021].

Although briquettes and pellets have similar origin, they differ significantly in terms of size and shape, physical and mechanical characteristics, production processes, applications, and prices. For this reason, to make DSBFs competitive in the market and accessible to consumers, it is important to ensure an optimal balance between quality and price, which depends on several factors in the production value chain [Cesprini *et al*., 2021; Ene and Ranca, 2023].

DSBFs are considered high quality if they meet the requirements stipulated by ENplus standards, which indicate consistent quality for pellets and briquettes [Schön *et al*., 2019; Cesprini *et al*., 2021; Marian *et al*., 2022]. Producing DSBFs with properties compliant with ENplus standards not only provides renewable energy solutions that are environmentally friendly but also contributes to new income streams for agricultural producers [Pavlenco, 2018; Kpalo *et al*., 2020; Ţenu *et al*., 2021].

In the Republic of Moldova, the main sources of raw materials for DSBFs production are agroforestry residues. However, their use remains inefficient, partly due to limited information on the feasibility of raw material supply chains. Also, data regarding the energy potential of different types of biomass and methods for ensuring the quality of biomass-based final products are scarce. This situation, exacerbated by recent energy shortages in the Republic of Moldova, has served as a catalyst for seeking affordable methods to increase the available and sustainable biomass energy for producing DSBFs with properties satisfying the international quality standards [Marian *et al*., 2021, 2022; Ciolacu *et al.*, 2022].

At the same time, several studies on the use of biomass generated from agroforestry activities for DSBFs production in the Republic of Moldova have highlighted that, although there is a significant amount of biomass suitable for DSBFs production, only a portion can be directly used for producing pellets and briquettes with ENplus characteristics [Gudîma, 2017; Pavlenco *et al*., 2018].

An important source of agricultural residues that can be used as a feedstock for producing pellets and briquettes with properties close to ENplus standards is the residual biomass from vineyard pruning [Senila *et al*., 2020, 2022; Kovacs *et al.*, 2022].

Based on these findings, the study hypothesis focuses on the potential of producing DSBFs with ENplus characteristics from waste biomass from vineyard care. To confirm this hypothesis, it is of interest to conduct a detailed study of the major components of the quality assurance chain for pellets and briquettes produced from vineyard residues, throughout the entire life cycle of the final product.

This study aims to demonstrate the feasibility of using vineyard pruning residues by evaluating the biomass potential obtained per hectare of plantation and assessing the quality of this biomass, as well as the pellets and briquettes produced from it. Moreover, the study highlights the main methods for ensuring the quality of the final product, to be certified according to ENplus standards.

Thus, the goal of the study is to validate the hypothesis that utilizing biomass generated from vineyard pruning residues is feasible for DSBFs production in all aspects provided by the ENplus certification system.

To achieve this goal, the following specific objectives were set:

- Identify the particularities of the value chain for DSBFs production from vineyard residues, with a focus on ensuring the quality of the final product.
- Evaluate the biomass potential from vineyard residues, estimated per unit area for grape plantations of the "Cabernet" and "Moldova" varieties.
- Conduct a qualitative analysis of vineyard residues, as well as the final pellets and briquettes produced.

MATERIAL AND METHOD

Design of Experiments and Sample Collection. The research was carried out according to an algorithm consisting of four distinct stages, as presented in Figure 1.

Following a detailed analysis of the studies published in the scientific literature on the use of agricultural plant residues, with a special focus on vine residues, and critically evaluating the presented data, we formulated the working hypothesis. This hypothesis assumes the possibility of using the residues generated from vine pruning for the production of DSBFs with characteristics that comply with ENplus standards.

Considering that ensuring the quality of DSBFs is a continuous process integrated into all stages of the value chain, a comprehensive research methodology was defined. This involves a detailed analysis of the major factors influencing the quality of the final product throughout the entire life cycle of the pellets and briquettes. The investigations are based on a case study focusing on the use of vine residues as raw material.

The studied material of this research was the biomass resulting from the vineyard pruning, as well as DSBFs produced either only from this biomass or from mixtures based on it. The biomass was sampled from five vineyards located in the villages of Geamănă, Anenii-Noi district, FCP "ASCONI" SRL; the town of Căinari, Căușeni district, SRL PI – CAFT and the communes of Trușeni and Stăuceni in the municipality of Chișinău.

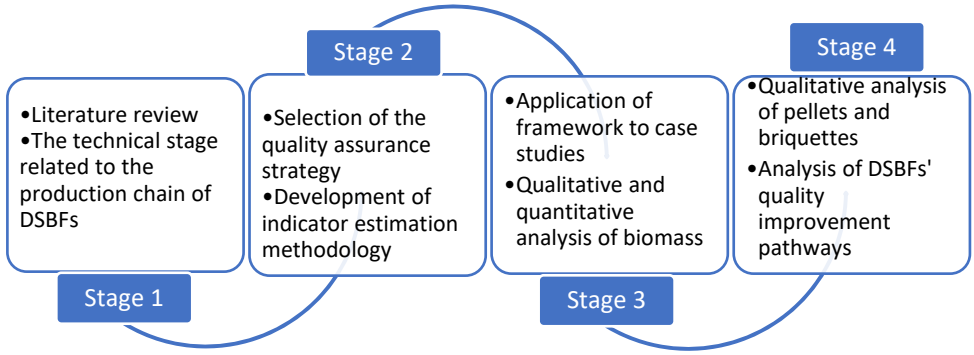

Fig. 1. Research algorithm

To determine the mass of residues generated from pruning the vines, 5 vineyard sectors were selected for each of the two grape varieties examined. The surface area of the sectors varies according to the actual conditions in the field (see Table 1).

The biomass was estimated for a predetermined number of vine stocks, selected from each field, using the quarter method for sampling. The biomass from the pruning of the selected vine stocks (approximately 2% of the total number of vine stocks in each field) was collected and shredded directly in the field by the mobile woodchipper Morena 1, available at the Scientific Laboratory of Solid Biofuels at the Technical University of Moldova (SLSBF TUM). It was then weighed using an ACEN scale of 50 kg, with a precision of 10 g.

Part of the biomass was hermetically packed in polyethylene bags to determine the moisture content at harvest, ash content, and calorific value. All selected biomass was transported on the same day to the SLSBF TUM, where it was prepared for further testing and the production of briquettes and pellets necessary for the qualitative assessment of the final product.

The average values obtained were used as a reference for calculating the mass of residues that can be harvested per hectare of vineyard for the respective grape variety.

Laboratory testing. The qualitative indicators of the biomass and the final products were estimated using the validated standard methods applied at the SLSBF. Each test was performed in five repetitions to ensure measurement accuracy. Finally, the standard deviation and confidence interval were calculated for the results obtained within each test series, corresponding to each grape variety. The methodology for tests' conduction has been described in our previous works [Ciolacu *et al.*, 2022; Marian *et al*., 2022].

Biomass densification into briquettes was carried out using two distinct methods. The first method involved multiple pressing using the Briklis hydraulic press, available at SLSBF. The second method consisted of single pressing on the specially designed device for studying the densification process of a plant biomass in the form of briquettes, protected by the patent MD 1734 Y from 2023.12.31 [Daraduda *et al.*, 2023]. Pellet manufacturing was done using the pellet production technological line Kovo Novák at SLSBF TUM.

RESULTS AND DISCUSSIONS

General aspects related to the value chain for the production of solid biofuels made of plant biomass, from the perspective of ensuring the quality of the final product

The major elements in the quality assurance chain throughout the life cycle of solid biofuels from biomass generated from the vineyard maintenance are presented in Figure 2.

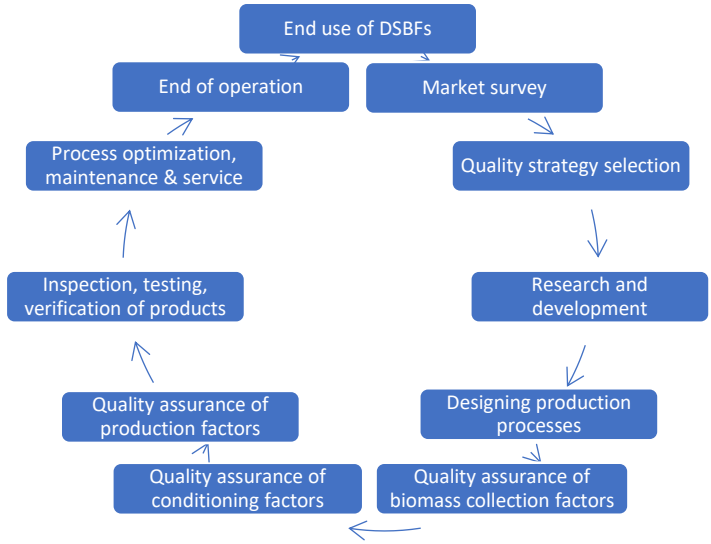

Fig. 2. Juran's quality spiral adapted for solid biofuels

The value chain for the production of solid biofuels from residues derived from agroforestry activities is characterized by the quantitative and qualitative specifics of the raw material collection process and the processing of biomass into final products with qualitative characteristics capable of meeting the requirements of beneficiaries [Cesprini *et al.*, 2021].

Quality management in the production of solid biofuels from plant biomass is a complex process that begins with a well-conducted market study and continues with the implementation of rigorous quality assurance strategies. Through continuous monitoring and optimization of production processes, companies can ensure high-quality products that comply with international standards and effectively meet market demand [Marian, 2016].

This holistic approach ensures not only the fulfillment of consumers' energy needs but also the long-term sustainability and success of businesses in this sector.

Market survey is the first important step in quality management, playing a crucial role in the value chain of quality assurance, influencing every stage from production to consumption. It is vital to understand the beneficiaries' requirements, whether they are residential or industrial consumers, and assess their consumption capacity.

The market study provides essential information about the demand and supply for biomass pellets and briquettes. It helps producers understand market trends, consumer preferences, competitive prices, and the quality standards needed to meet market demands. Through detailed analysis, companies can identify the most profitable market segments and adapt production processes to meet the specific requirements of their clients.

For example, in the case of producing solid biomass fuels from vine residues, production should be organized in vineyard areas, such as those in the Central and Southern regions of the Republic of Moldova. However, these regions are not uniform regarding the availability of biomass in different districts, which requires careful planning and knowledge of the existing potential of biomass suitable for using as a raw material in the production of solid biofuels.

Selecting a quality strategy is another essential aspect for any solid biofuel-producing enterprise. Entrepreneurs intending to bring a new product or service to the market must create viable strategies to advertise and introduce their product. Regarding DSBFs, strategies should aim to produce a final product that meets international standards like ENplus [Nunes *et al*., 2021]. To achieve this goal, the enterprise must establish, document, implement, and maintain a quality management system throughout all technological stages of the production [Pavlenco, 2018].

The effective implementation of quality assurance strategies requires accurate data based on studies conducted for each specific case. This includes the selection and preparation of raw materials, the use of appropriate production processes and equipment. Regular inspections, testing, and verification of the final

product are also essential to ensure compliance with relevant industry standards, such as ENplus or the standards from the SM EN ISO 17225 package.

An important part of the quality assurance strategy relates to process optimization. The use of sensors and control systems for real-time monitoring of the process allows for quick and efficient adjustments. Regular maintenance of equipment is also crucial to ensure the main parameters of technological equipment reliability, such as proper functioning, durability, and maintainability.

Potential and quality of biomass resulting from pruning the "Cabernet" and "Moldova" vines

The grape varieties "Cabernet" and "Moldova" cover significant areas in the Republic of Moldova. "Cabernet", a variety used for wine production, is known for its organoleptic qualities and international popularity, holding an important place in local viticulture. According to the National Office of Vine and Wine (ONVV) data, the "Cabernet" wine grape variety ranks second in terms of area covered by red grape varieties in Moldova and first in vineyards with Protected Geographical Indication [ONVV, 2024].

The "Moldova" grape variety is an indigenous table grape created in the Republic of Moldova, which is widespread and cultivated in the Central and Southern regions of the country. Since the "Moldova" vines are vigorous with good maturation of the canes, they result in a significant amount of biomass following seasonal pruning [Cuharschi *et al*., 2019], which can be utilized in the production of pellets and briquettes.

Table 1 provides a detailed estimate of the residue production resulting from pruning the "Cabernet" and "Moldova" vines, including various variables such as the average mass of residues per vine, moisture content, and calorific values of the biomass.

Table 1

The production of pruning residues from the "Cabernet" and "Moldova" grape varieties

Field	Plantation scheme, m / No of grapevines examined	S_i, ha	n_p, units/field	m_b, kg/grapevine	$m_{t.h.}$, kg	M_h,%	$m_{d.Si}$, kg	m_d, kg/ha	$m_{M=10\%}$, kg/ha	Q_{vd}, J/g	$Q_{Vnet\ d}$, J/g	$Q_{Pnet\ M=10\%}$, J/g	A, %
Cabernet													
1	1,2x2,5/24	0.41	1312	0.777	1019.42	59.41	413.8	1009.2	1121.4	18857.2	17475	15483	2.97
2	1,2x2,5/36	0.58	1856	0.711	1319.62	59.29	537.2	926.2	1029.1	18959.3	17589	15586	2.88
3	1,2x2,5/16	0.19	608	0.771	468.77	59.30	190.8	1004.2	1115.7	19157.4	17781	15759	3.07
4	1,2x2,5/8	0.14	448	0.846	379.01	59.39	153.9	1099.4	1221.5	18862.2	17480	15487	2.92
5	1,2x2,5/12	0.19	608	0.778	473.02	59.57	191.2	1006.5	1118.4	18857.0	17481	15488	3.02
Total		**1.51**	**4832**		**3659.8**		**1486.9**						
Mean				**0.777**		**59.4**		**1009.1**	**1121.2**	**18938.6**	**17561.3**	**15560.8**	**2.97**
Std. dev.		**0.19**	**599.26**		**415.0**		**169.0**	**61.3**	**68.2**	**129.8**	**132.1**	**118.9**	**0.1**
Confidence		**0.1641**	**525.27**		**363.75**		**148.2**	**53.77**	**59.74**	**113.8**	**115.8**	**104.212**	**0.067**
Moldova													
1	1,75x3/16	0.24	457	1.011	462.23	46.05	249.4	1039.1	1154.5	18827.2	17443	15454	2.77
2	1,75x3/23	0.36	686	1.038	711.86	45.85	385.5	1070.8	1189.7	18768.1	17398	15414	2.78
3	1,75x3/16	0.25	476	1.156	550.55	46.09	296.8	1187.2	1319.1	18741.1	17363	15382	2.81
4	1,75x3/8	0.12	229	1.125	257.18	46.16	138.5	1153.9	1282.1	19057.2	17653	15644	2.82
5	1,75x3/12	0.18	343	1.089	373.42	46.11	201.2	1118.0	1242.2	18827.0	17438	15450	2.72
Total		**1.2**	**2190.8**		**2355.2**		**1271.3**						
Mean				**1.1**		**46.1**		**1113.8**	**1237.5**	**18844.1**	**17459.0**	**15468.8**	**2.78**
Std. dev.		**0.09**	**170.39**		**172.96**		**93.90**	**60.10**	**66.78**	**124.87**	**113.46**	**102.12**	**0.04**
Confidence		**0.0784**	**149.35**		**151.6**		**82.31**	**52.68**	**58.53**	**109.46**	**99.46**	**89.51**	**0.035**

Note: S_i – the area of the field from which the samples were collected; n_p – the number of grapevines in the fields from which the samples were collected; m_b – the average mass of residues collected from one grapevine; $m_{t.h}$ – the total mass of residues collected from the field from which the samples were collected; M_h – moisture content at harvest; $m_{d.Si}$ – the total mass of residues collected from the field from which the samples were collected, calculated on a dry basis; m_d – the mass of residues collected per hectare of plantation, calculated on a dry basis; $m_{M=10\%}$ – the mass of residues collected per hectare of plantation, calculated for a moisture content of M=10%; Q_{Vd} – gross calorific value determined for constant volume; $Q_{Vnet\ d}$ – net calorific value calculated for constant volume; $Q_{Pnet,M=10\%}$ – net calorific value calculated for a moisture content of M=10%; A – ash content.

The analysis of the obtained results shows that the vine varieties "Cabernet" and "Moldova" generate a significant amount of residues from seasonal pruning, which can be used as a feedstock for the production of densified solid biofuels.

For the "Cabernet" variety, the average residue production, at a moisture content of 10%, was estimated at 1121±59.7 kg/ha across the five fields analyzed. In the case of the "Moldova" variety, this value is 1237.5±58.53 kg/ha, which represents an average 1.1 times higher than that of "Cabernet."

The moisture content at the time of collection was high for both varieties, which is explainable by the fact that the biomass was harvested in early spring, right after rainfall. For this reason, the biomass quantity was calculated for both 0% and 10% moisture content, with the latter being considered optimal for the production of pellets and briquettes, as well as for the estimation of densified solid biofuels upon delivery.

The high moisture content at harvest suggests that, in order to reduce drying costs, it is reasonable to leave the biomass in the field for a certain period. After natural drying, the biomass can be coarsely chopped directly in the field and then transported to the processing site.

Additionally, the biomass from the "Cabernet" variety as well as from the "Moldova" variety – both exhibit a high ash content. This indicates the need for further processing of the material or mixing it with other biomass sources with a lower ash content, especially for pellet production.

Table 2 provides an assessment of the characteristics of pellets and briquettes produced from the pruning residues of the "Cabernet" and "Moldova" vine varieties.

The results indicate that the net calorific value ($Q_{Pnet,M=10\%}$) of the pellets produced from the residues of both grapevine varieties is below 16.5 MJ/kg, meaning they do not meet ENplus quality classes. The same situation is observed with the ash content, which exceeds 2%, the required value for residential and commercial class B pellets, and 3% for industrial class I3 pellets.

The grapevine residues studied in this work can be more effectively used for producing briquettes, for which the requirements regarding calorific value and ash content are more lenient. For class B, the calorific value needs to be at least 14.4 MJ/kg, and the ash content should be no more than 5%.

Other parameters for both pellets and briquettes meet ENplus standards. This confirms that grapevine pruning biomass can be effectively used to produce briquettes with fairly high quality. The potential to produce ENplus-standard pellets is also of interest; however, this would require additional processing of the biomass or mixing with other biomass sources that have higher calorific value and lower ash content.

Table 2

Characteristics of pellets and briquettes produced from pruning residues of the "Cabernet" and "Moldova" grape varieties

No of repetitions	Q_{Vd}, J/g	$Q_{Vnet\ d}$, J/g	$Q_{Pnet\ M=10\%}$, J/g	A, %	BD kg/m³	F (<3,15), %	Vd, %	Q_{Vd}, J/g	$Q_{Vnet\ d}$, J/g	$Q_{Pnet\ M=10\%}$, J/g	A, %	DE, g/cm³
	Cabernet											
	Pellets							**Briquettes**				
1	19058.2	17676	15664	3.98	670.34	0.78	77.79	18581.8	17200	15236	3.97	1.05
2	19105.8	17736	15718	4.02	680.54	0.54	77.85	18045.8	16677	14765	4.18	1.11
3	18892.4	17516	15520	3.98	685.85	0.72	78.13	19157.4	17782	15760	3.97	1.09
4	19002.2	17620	15613	3.89	690.74	0.66	79.58	18902.2	17521	15524	4.04	1.07
5	19007.0	17631	15623	4.05	694.85	0.68	77.88	18857.0	17482	15489	4.07	1.15
Mean	**19013.1**	**17635.7**	**15627.9**	**3.98**	**684.46**	**0.68**	**78.25**	**18708.84**	**17332.35**	**15354.8**	**4.05**	**1.09**
Std. dev.	**79.6**	**80.9**	**72.8**	**0.1**	**9.5**	**0.1**	**0.8**	**423.2**	**420.4**	**378.3**	**0.1**	**0.0**
Confidence	**69.781**	**70.932**	**63.839**	**0.053**	**8.3629**	**0.078**	**0.6638**	**370.922**	**368.4788**	**331.631**	**0.076**	**0.0337**
	Moldova											
	Pellets							**Briquettes**				
1	19058.2	17674	15662	3.41	77.91	0.49	78.31	18827.2	18827	16700	3.47	77.91
2	18995.8	17626	15619	3.36	77.85	0.54	78.25	18758.1	18758	16638	3.48	77.85
3	18882.4	17504	15509	3.43	78.03	0.58	78.08	18741.1	18741	16623	3.41	78.03
4	19002.2	17598	15594	3.32	77.98	0.44	78.58	18957.2	18957	16817	3.54	77.98
5	19007.0	17618	15612	3.55	77.78	0.47	78.38	18827.0	18827	16700	3.78	77.78
Mean	**18989.12**	**17603.98**	**15599.29**	**3.41**	**77.91**	**0.50**	**78.32**	**18822.12**	**18822.12**	**16695.61**	**3.54**	**77.91**
Std. dev.	**64.61**	**62.32**	**56.09**	**0.09**	**0.10**	**0.06**	**0.18**	**85.09**	**85.09**	**76.58**	**0.14**	**0.10**
Confidence	**56.630**	**54.624**	**49.161**	**0.077**	**0.087**	**0.049**	**0.160**	**74.580**	**74.580**	**67.122**	**0.126**	**0.087**

Note: BD – bulk density; F – fine fraction content; Vd – volatile matter content; DE – particle density.

CONCLUSIONS

This study validates the feasibility of using grapevine residues from the "Cabernet" and "Moldova" varieties for the production of densified solid biofuels in the Republic of Moldova. The results indicate that one hectare of "Cabernet" grapevine plantations generates on average 1121±59.7 kg of residues, with a moisture content of 10%, suitable for use as raw material for densified solid biofuels' production. For the "Moldova" variety, the average yield is 1237.5±58.53 kg/ha.

Analysis of the final products obtained from grapevine residues showed that they can be efficiently converted into briquettes and pellets. However, for pellets, additional processing or mixing with other types of biomass is required to meet ENplus standards, due to the high ash content and lower calorific value.

The results of this study, along with the fact that utilizing vineyard residues supports the economic sustainability of vineyards and environmental protection, provide solid reasons for future research directions. Specifically, future research should focus on improving the quality of pellets produced from blends of grapevine residues with other types of biomass available in the Republic of Moldova to reduce ash content and increase calorific value, so that the final product meets ENplus standards.

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