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Green energy from bio-waste – study on the properties of olive stones for use as fuel in small-scale heating systems

Abstract: This study explores the potential of olive stones as a renewable biofuel for small-scale heating systems. Olive oil production generates approximately 4 million tonnes of olive stones annually, often classified as waste. By analyzing their elemental and physical properties, this research evaluates the energy potential of olive stones, offering a sustainable alternative to traditional fuels. A sample from Spain underwent elemental, technical, and thermogravimetric analyses. The results revealed a high calorific value of 18.26 MJ/kg, which can be attributed to the considerable carbon (47.4%) and hydrogen (6.1%) content, along with minimal sulfur levels. This composition makes olive stones a promising low-emission fuel. Thermogravimetric analysis showed that pyrolysis occurs in four phases, with 65% of the mass lost between 170 and 866°C, indicating the material's

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suitability for thermal energy applications. The findings suggest that olive stones hold significant potential for use in renewable energy systems. Their utilization aligns with circular economy principles, transforming waste into energy and reducing environmental impact. Olive stones have low ash and moisture content, improving their efficiency as a fuel. Their high volatile matter content also supports energy-efficient gasification processes, further enhancing their energy potential.
In conclusion, this study confirms that olive stones are a viable alternative to fossil fuels, particularly for small-scale heating applications. With their high energy value, low emissions, and minimal residual waste, olive stones offer a sustainable and efficient energy solution. Their use not only supports green energy production but also contributes to reducing the carbon footprint and promoting sustainability.

Keywords: olive stones, biofuel, renewable energy, pyrolysis, circular economy

Introduction

Climate change is one of the most significant challenges of our time, affecting everyone's quality of life. Inefficient management of local and industrial waste exacerbates the environmental impacts related to degradation and harmful emissions into the atmosphere (Cifuentes-Faura 2022; European Environment Agency (EEA) 2024). To reduce these adverse effects, effective waste management strategies must be implemented aimed at reducing waste at its source, promoting recycling, reuse, and safe disposal (Najar et al. 2024). The new circular economy concept is replacing the previously used linear economy, becoming central to sustainable development strategies. The circular economy is based on the efficient, cascading use of resources, playing a key role in maximizing the potential of raw materials (Ghisellini et al. 2016; Kalmykova et al. 2018; Yang et al. 2023).

To combat environmental changes, the European Union has introduced the „Fit for 55" policy package, aiming to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels, as part of the EU's path towards climate neutrality (Boitier et al. 2023; Ovaere and Proost 2022). These ambitious EU targets are focused on increasing the share of renewable energy, leading to intensive searches for new energy sources. These sources not only need to meet the demands of the professional energy sector but also to replace scattered conventional energy sources in various industries and for communal users who use heating systems with capacities of up to 500 kW. Utilizing waste from plant processing replaces the need for its disposal, bringing several economic and environmental benefits (Mirowski et al. 2020). These include reduced waste volumes, leading to lower disposal costs, reduced environmental impact by avoiding landfilling, and the possibility of using the waste as biofuel to produce green energy.

Lignocellulosic biomass of forest and agricultural origin is a promising energy source that can replace fossil fuels (Tzelepi et al. 2020). It is estimated that the global potential for bioenergy will reach 60 to 120 EJ annually in primary energy by 2050, which could account for about 10–20% of global energy consumption (Lacombe et al. 2024). Biomass is one of the leading renewable energy sources in Poland, and its share in heat and electricity production is continuously increasing. According to reports from the International Energy Agency (IEA) (International Energy Agency 2021), the demand for bioenergy will continue to grow, and the profile of its acquisition will change. In the future, we will move away from the traditional use of biomass in outdated heating devices in favor of utilizing organic waste, forestry residues, and short-rotation crops, as well as modern boilers adapted for their combustion.

Around 20 million tonnes of olives are produced worldwide every year. During the processing of these fruits, including pitting and oil pressing, significant amounts of waste are generated. The processes of producing olive oil generate about 4 million tonnes of pits, which are often treated as waste. This considerable amount of residual material poses both an environmental challenge and a potential opportunity for reuse (Awad 2024; García Martín et al. 2020; Rodríguez et al. 2008). Given the characteristics of the energy mix in countries such as Portugal, France, or Italy, where demand for additional bioenergy sources is relatively low, research teams from these countries have primarily focused on non-energy applications of olive stones. Examples include polymer production (Valvez et al. 2021) and projects like VALOstones – Valorization of olive stone by-products as a green source of innovative and healthy value-added products in the context of a circular bioeconomy and sustainability. Aside from these alternative uses, olive stones are commonly disposed of or stored as waste rather than being utilized effectively.

Small-scale heating devices (up to 500 kW) in Poland are subject to regulations aimed at minimizing pollutant emissions and improving energy efficiency. These requirements are specified in the Ecodesign Directive and the PN-EN 303-5+A1:2023-05 standard.

The Ecodesign regulations, effective in 2020, introduced requirements regarding the seasonal energy efficiency of heating devices. Devices up to 20 kW must have a minimum efficiency of at least 75%, while boilers with higher capacities must reach 77%. Additionally, boilers must meet nitrogen oxide emission limits, not exceeding 200 mg/m^3. To comply with these standards, boilers need to be tailored to combust specific types of biomass, necessitating appropriate fuel-feeding systems and combustion control.

According to the PN-EN 303-5+A1:2023-05 standard, emission limits for solid fuel boilers with nominal capacities up to 500 kW, including biomass boilers, have been established. For class 5 boilers, the maximum permissible emission values are 500 mg/m^3 carbon monoxide (CO), 40 mg/m^3 particulate matter (PM), 200 mg/m^3 nitrogen oxides (NO_x), and 20 mg/m^3 organic gaseous compounds (OGC). Moreover, boilers that comply with this standard must exhibit high thermal efficiency exceeding 88.4%.

In Poland, regulations governing the use of renewable energy sources, including biomass as heating fuel, are also in place. The key legislative act in this area is the Renewable Energy Sources Act of 2015 (Act on Renewable Energy Sources ((“RES Act,” Dz.U. 2015, poz. 478) 2015), which outlines support mechanisms for green energy and defines biomass as renewable fuel.

EU and national regulations significantly influence fuel selection, tightening emission standards and affecting fuel availability. Nevertheless, green fuels have significant potential in Poland, and their effective utilization requires further regulatory adjustments, technological advancements, and increased availability of alternative energy resources.

The aim of the article is to analyze the parameters of the combustion and pyrolysis processes of olive pits for potential energy use in small-scale heating devices in Poland. This study presents a comprehensive laboratory analysis of olive stone biomass as a potential fuel source. Given the current lack of commercially available burner technologies in Poland that are suitable for this type of fuel, The findings are intended to encourage further exploration of technological solutions for the energy recovery of plant-based industrial waste materials in the context of renewable energy and circular economy strategies.

1. Materials and methods

The material analyzed in this study comes from Spain, one of the largest olive producers in the world, responsible for cultivating over 35% of the global production of these fruits (European Commission 2024). The received material – olive stones – mainly consisted of fractions between 3 and 6 mm (Figs 1 and 2A). To homogenize the sample, the olive stones were ground in Testchem LMN 100 and 240 knife mills to fractions smaller than 2 mm (Fig. 2B).

Fig. 1. Olive stones from Spain obtained for analysis. The material mainly consists of fractions between 3–6 mm in size. Scale shown in centimetres

Rys. 1. Pestki oliwek z Hiszpanii pozyskane do analizy. Materiał składa się głównie z frakcji o rozmiarze 3–6 mm. Skala przedstawiona jest w centymetrach

The homogenized material underwent elemental, technical, and thermogravimetric analysis. The elemental analysis included determining the carbon, hydrogen, nitrogen, and sulfur content using CHN828 and S832 analyzers (LECO USA). The technical analysis involved determining moisture content, ash content, volatile matter, and the calorific value of the sample using an MA50-1X2A moisture analyzer (Radwag Poland), an FCF1/160M muffle furnace (Czylok

Fig. 2. A) Olive stones received for analysis. B) Olive stones after grinding in a knife mill to fractions smaller than 2 mm

Rys. 2. A) Pestki oliwek otrzymane do analizy. B) Pestki oliwek po rozdrobnieniu w młynie nożowym do frakcji poniżej niż 2 mm

Poland), and an AC600 droperidol calorimeter (LECO USA). Thermogravimetric analysis, conducted on an STA 449 F3 Jupiter apparatus (NETZSCH Germany) coupled with an Alpha II FTIR (Bruker Germany), provided detailed information on the pyrolysis characteristics of the olive stones. Fourier-transform infrared spectroscopy (FTIR) was used to analyze the volatile compounds released during pyrolysis, allowing for an assessment of potential emissions and their environmental impact. The obtained results allowed for the assessment of the physicochemical properties of the studied sample to understand its energy potential and industrial application. During the technical and elemental analyses, the samples were analyzed at least three times.

2. Results

This section presents the results of the physicochemical analysis and the combustion and pyrolysis process studies of olive stones. First, the results of the elemental analysis, presented in Table 1, show that the studied material contains 47.4% carbon, 6.1% hydrogen, and 0.1% nitrogen, while the sulfur content is below the detection limit. The moisture and ash content, known as ballast, account for 10.63% and 0.72%, respectively. The volatile matter content is 49.85%, and the sample has a calorific value of 18.26 MJ/kg.

Table 1. Results of the olive stone analysis

Tabela 1. Wyniki analizy fizykochemicznej pestek oliwek

Parameter	Content
C [%]	47,4 ± 0,101
H [%]	6,1 ± 0,008
N [%]	0,1 ± 0,036
S [%]	b.d.l.
Moisture [%]	10,63 ± 0,119
$VOC_{260°C}$ [%]	49,85 ± 0,331
Ash [%]	0,72 ± 0,032
HHV [MJ/kg]	18,26 ± 0,041

b.d.l. – below detection limit.
Source: own research.

Subsequently, the results of thermogravimetric analysis are examined, providing insights into the thermal decomposition behavior and the characteristics of pyrolysis and combustion processes. Special attention is given to identifying the main degradation stages, onset temperatures, and thermal stability of the sample.

Figure 3 shows the pyrolysis of the sample, occurring in four phases. In the first phase, lasting up to about 170°C, moisture and volatile components evaporate, leading to an initial 2.9% weight loss. In the second phase, between approximately 170 and 320°C, there is intense thermal decomposition of hemicellulose, with a maximum occurring at 284°C, which results in rapid weight loss and creates the first peak on the dTG (Derivative Thermogravimetry) curve shown in Figure 3.

With increasing temperature, the third phase begins, during which the rapid decomposition of cellulose occurs, reaching its maximum at around 350°C. The final process occurs in the fourth phase, between 452 and 866°C, leading to a further 6.5% weight loss. Lignin is characterized by a wide range of decomposition temperatures, passing through the second, third, and fourth phases. Volatile compounds consist of a wide range of chemicals with varied physicochemical properties that decompose at different temperature ranges. Therefore, the thermal decomposition of volatile compounds occurs throughout all four phases of the pyrolysis process.

In the temperature range from 170 to 866°C, the decomposition of hemicellulose, cellulose, lignin, and other compounds (e.g., oils) in the material accounts for 65% of the total weight loss.

Figure 4 shows four curves divided into two graphs. The graph at the top illustrates the thermogravimetric (TG) analysis. The graph at the bottom presents the first-order derivative (DTG). After the pyrolysis process, 30% of the carbonate remained, and 8% of the ash after the combustion process. The graphs in the lower part represent the first derivatives of the TG curves, indicating the mass loss maxima for the pyrolysis and combustion processes at a given temperature.

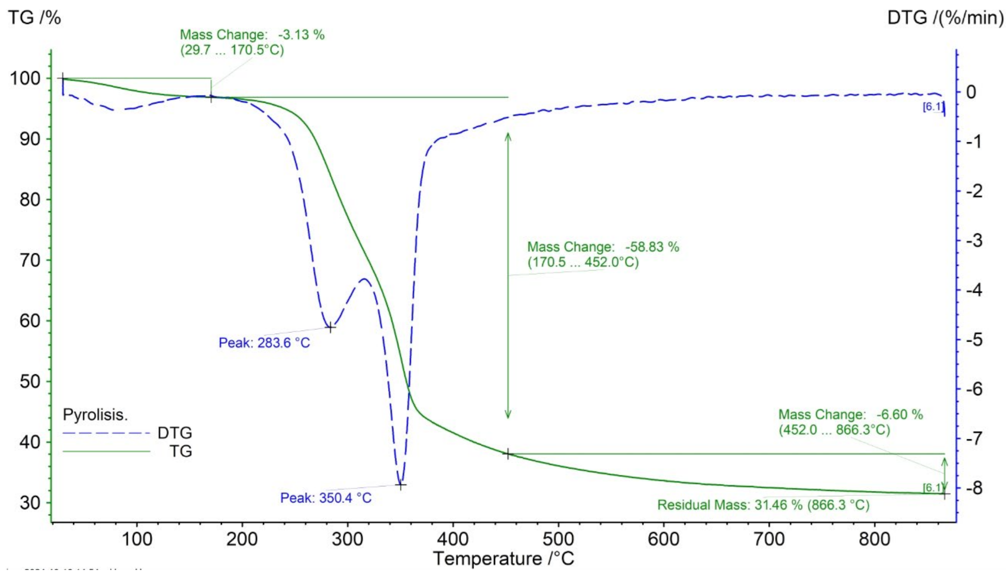

Fig. 3. Pyrolysis of olive stones: mass change graph (green line) and its first-order derivative (blue line)

Rys. 3. Piroliza pestek oliwek: wykres zmiany masy (linia zielona) oraz jej pochodna pierwszego rzędu (linia niebieska)

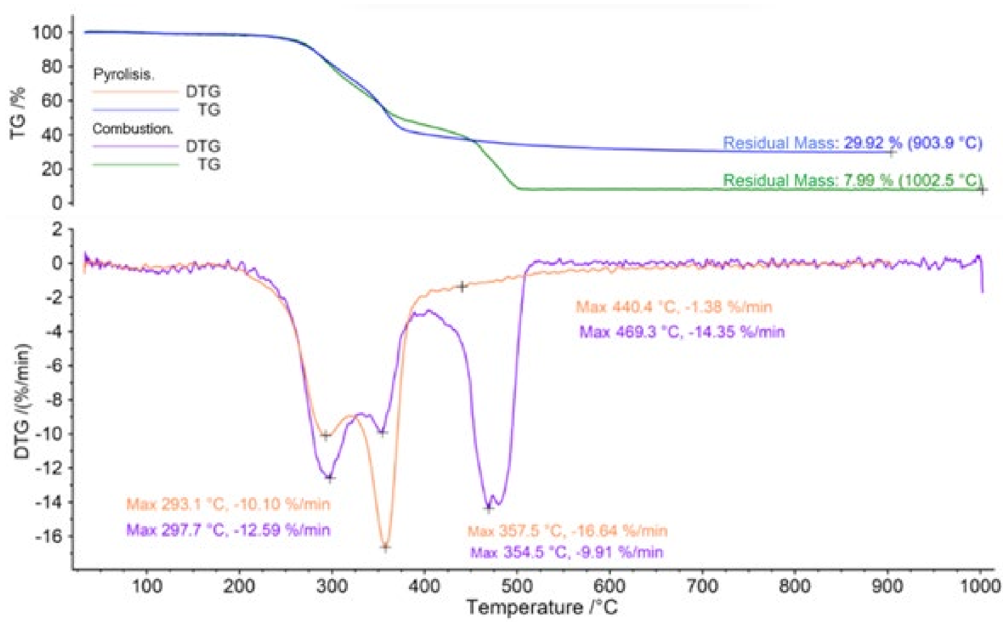

Fig. 4. Results of TG DTG analysis of olive stones
(combustion process – green/purple, pyrolysis process – blue/yellow)

Rys. 4. Wyniki analizy TG-DTG pestek oliwek (proces spalania – zielony/fioletowy, proces pirolizy – niebieski/żółty)

The highest mass loss for the pyrolysis process is observed at temperatures 293 and 358°C. In combustion, the maximum occurs at 300, 355 and 470°C. In both pyrolysis and combustion, the maxima correspond to the thermal decomposition of hemicellulose, cellulose, and lignin, respectively.

Figure 5 shows the relationship between energy effect and temperature. Pyrolysis is an endo-energetic process, which means that energy is absorbed by the process of releasing, among other volatile compounds – evaporation. The greatest amount of energy released for the combustion process can be observed at 490°C.

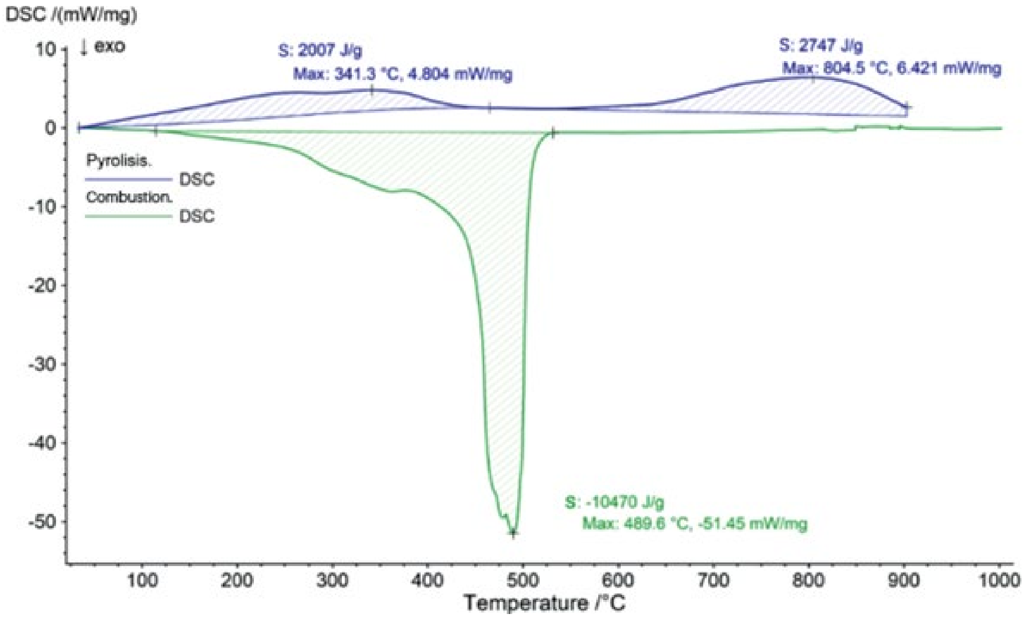

Fig. 5. Results of DSC analysis of olive stones (combustion process – green, pyrolysis process – blue)

Rys. 5. Wyniki analizy DSC pestek oliwek (proces spalania – zielony, proces pirolizy – niebieski)

Figure 6 shows the FTIR spectrums of the combustion and pyrolysis processes of olive stones recorded at 488°C.

The signal with the highest intensity in both processes came from carbon dioxide evolution, band 2,344 cm^{-1}. In addition, a signal in the band 600 cm^{-1} can be observed in the processes, confirming the presence of carbon dioxide. The bands from 1,250–2,000 cm^{-1} and 3,500–4,000 cm^{-1}, particularly visible on the pyrolysis spectrum, indicate the presence of water, while the signal around 3,000 cm^{-1} at 488°C suggests the release of volatile compounds from the olive.

Unambiguous identification of specific chemical compounds based solely on FTIR spectra requires the use of additional supporting data. The peaks observed in FTIR spectra correspond primarily to the presence of functional groups rather than entire chemical compounds. For example, the FTIR spectrum of H_2O contains several characteristic peaks within a specific wavenumber range (cm^{-1}), which collectively enable compound identification through comparison with a reference spectrum available in the NIST database (Linstorm and Mallard 2023). The occurrence of other chemicals produced or released during the pyrolysis process is expected. For example, the range 3300–3600 cm^{-1}, which corresponds to the stretching vibration of the (O–H) group, might be related to acids, alcohols, and phenols. In the range 3000–2800 cm^{-1}, absorbance bands are assigned to the (C–H) bonds, suggesting the presence of alkanes (Fadhil and Kareem 2021). Other publications show that the range from 3000–2730 cm^{-1} corresponds to CH_4, while a peak at ~3,015 cm^{-1} indicates the presence of a (C–H) vinyl group (Wzorek et al. 2021). Additional chemical compounds can be released during the thermal decomposition of

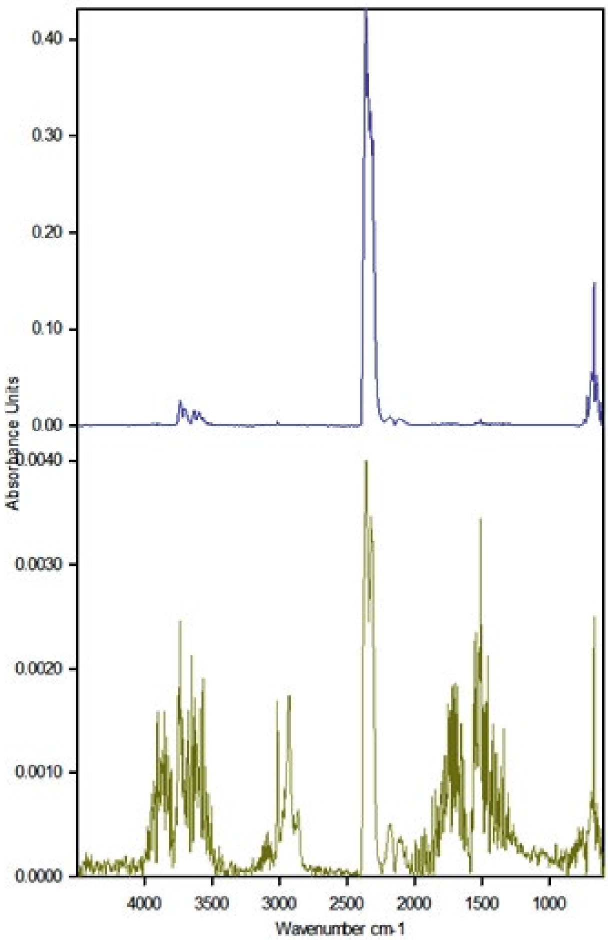

Fig. 6. FTIR spectrums of olive stones at 488°C
(combustion process – blue spectrum, pyrolysis process – green spectrum)

Rys. 6. Widma FTIR pestek oliwek w temperaturze 488°C
(proces spalania – widmo niebieskie, proces pirolizy – widmo zielone)

cellulose, hemicellulose, and lignin, such as propionic acid or acetic acid (Mumbach et al. 2022). In this study, the identification of specific compounds is hindered by the applied methodology due to intense bands from water and carbon dioxide, which make it impossible to confirm which compounds are present in the spectrum within the range of 3300–2700 cm^{-1}.

3. Discussion

The analysis of the chemical and physical parameters of the studied material provides valuable information that may be crucial when considering its use in energy processes. Relatively high carbon and hydrogen content, along with low moisture content, translate into a high calorific value. To further optimize the energy efficiency of the sample, additional drying of the material may be necessary. The low sulfur content, below the detection limit, is a positive property of the material, ensuring low emissions of harmful compounds, including sulfur oxides and hydrogen sulfide. Additionally, sulfur is a precursor for particulate matter production during combustion processes, further highlighting the environmental benefits of using this material. Olive stones have a low ash content, which results in relatively small amounts of waste remaining after energy recovery processes. The high volatile matter content of 49.85% in the studied material favors the process of autothermal gasification.

Thermal analysis of the biomass sample showed that the weight loss occurs in four phases. The first phase corresponds to moisture evaporation and the beginning of the decomposition of volatile compounds, causing an initial weight loss. The second phase involves the intensive decomposition of hemicellulose, leading to rapid weight loss and the first peak on the dTG curve. In the third phase, rapid cellulose decomposition occurs, reaching a maximum of 350°C. Lignin decomposes over a wide temperature range, covering the second, third, and fourth phases. In total, the sample loses about 68% of its weight in an argon atmosphere, illustrating significant changes resulting from thermal transformations. The thermal decomposition process of olive pits occurs in four stages, similar to commercially available pellets. However, the percentage distribution of these stages differs, indicating a distinct combustion and pyrolysis dynamic.

The results of this study's elemental analysis of olive stones align well with findings from other research but show slight variations in some parameters. These differences are likely due to variations in the source of olive stones, processing methods, and experimental conditions.

The carbon content in our study (47.4%) is consistent with the findings of Rasam et al. (2022) (46.4%) and Trubetskaya et al. (2023) (47.2%). However, it is slightly lower than that of Lacombe et al. (2024) (50.5%) and Bartocci et al. (2015) (50%). The higher carbon content reported by Lacombe et al. (2024) and Bartocci et al. (2015) might be attributed to the torrefaction and pyrolysis processes at different temperatures, which concentrate carbon in the material by reducing the oxygen content.

In terms of hydrogen, our study (6.1%) is in close agreement with Trubetskaya et al. (2023) (6.1%) and Bartocci et al. (2015) (6.17%), but significantly lower than the unusual figure reported by Rasam et al. (2022) (6.2%), which seems to be an outlier or potentially a typographical error. Lacombe et al. (2024) reported a slightly higher hydrogen content (7%), likely due to the differences in the degree of torrefaction, which concentrates both carbon and hydrogen.

Our study shows a nitrogen content of 0.1%, which is identical to the value found in Trubetskaya et al. (2023). Both Lacombe et al. (2024) (0.5%) and Bartocci et al. (2015) (0.42%) reported slightly higher nitrogen levels. The higher nitrogen levels in these studies could indicate differences in biomass origin or processing methods. High nitrogen content in biomass is typically undesirable as it leads to higher NO_x emissions during combustion.

While our study did not report sulfur content, Rasam et al. (2022) found a relatively high sulfur content of 0.39%, compared to the very low level (0.02%) reported by Trubetskaya et al. (2023). Sulfur in biomass is a key concern for emissions, as it leads to the formation of SO_2 during combustion, which can contribute to acid rain. Lower sulfur content, as reported by Trubetskaya et al. (2023), is favorable from an environmental standpoint.

The higher heating value (HHV) reported in our study (18.26 MJ/kg) is lower than those reported by Bartocci et al. (2015) (19.21 MJ/kg) and Trubetskaya et al. (2023) (19.5 MJ/kg). The slight variation could be due to differences in moisture content and the specifics of the pyrolysis process. The Lacombe et al. (2024) study reported an LHV of 19.2 MJ/kg, which is consistent with the findings of Trubetskaya et al. (2023), though our study does not provide the LHV.

Torrefaction notably enhances the properties of olive stones for energy production. As indicated by Trubetskaya et al. (2023), torrefied olive stones (TOS) have a carbon content of 51.9%, which is significantly higher than untreated olive stones (47.2%). Additionally, the moisture content drops to 2.5% after torrefaction, improving fuel stability and reducing transportation costs. The lower heating value (LHV) increases to 18.2 MJ/kg, further highlighting the improved energy density. This makes torrefied olive stones more suitable for high-efficiency combustion. Comparing this study with literature data, it can be observed that most olive stones have low sulfur and nitrogen content (0.02% and 0.1%, respectively), which minimizes harmful emissions and contributes to cleaner energy production. However, olive stones from Iran have significantly higher sulfur and nitrogen contents, at 0.4% and 1.8%, respectively.

Two additional materials were used to compare the chemical properties of the material: sunflower husks from Ukraine, whose properties were reported by (Wojtko et al. 2021), and pine sawdust (Mirowski et al. 2024). Both studies show a similar carbon content, around 47.5%. The hydrogen content in the sawdust is about 0.5 percentage points higher than in the olive stones and sunflower husk. On the other hand, the Ukrainian material has a higher nitrogen content than the studied olive stones. Sunflower husk has a similar HHV to olive stones, around 18.3 MJ/kg, while pine sawdust has an HHV of 19.5 MJ/kg.

Torrefaction significantly improves the fuel properties, primarily by removing moisture, which leads to an increase in its energy density and higher calorific value. Although Trubetskaya's studies showed slightly higher calorific values, torrefaction generally enhances

Table 2. Comparison of results with other studies

Tabela 2. Porównanie wyników z innymi badaniami

Element	Our Study	Rasam et al. 2022	Trubetskaya et al. 2023	Lacombe et al. 2024b	Bartocci et al. 2015	Wojtko et al. 2021	Own study	Own study
Material	OS	OS	OS	OS	OS	SH	SH	PS
Origin	Spain	Iran	Tunisia	Spain	Italy	Ukraine	Ukraine	Poland
Carbon [%]	47.4	46.4	47.2	50.5	50.0	48	45.7	47.0
Hydrogen [%]	6.10	6.20	6.10	7.00	6.17	6.2	6.4	6.7
Nitrogen [%]	0.1	1.8	0.1	0.5	0.42	0.76	0.21	b.d.l
Sulfur [%]	b.d.l.	0.39	0.02	N/A	N/A	0.09	0.10	0.04
Higher Heating Value [MJ/kg]	18.26	N/A	19.50	N/A	19.21	18.35	18.3	19.5
Lower Heating Value [MJ/kg]	N/A	N/A	18.0	19.2	N/A	16.73	16.7	17.9

Values marked as N/A (Not Available) indicate that the data was not provided in the respective studies.
b.d.l. – below detection limit; OS – olive stone; SH – sunflower huks; PS – pine sawdust.

the fuel's efficiency, making it more energy-efficient. Additionally, this process increases the fuel's stability, both physically and biologically, which translates into easier storage and usage. Torrefied fuels are less sensitive to moisture changes, which is crucial in the context of their use in home heating systems.

The removal of some volatile compounds with a low ignition temperature makes combustion more controlled and efficient. As a result, the chemical energy contained in the fuel can be better converted into thermal energy, improving efficiency and safety when using the fuel in small heating devices. Consequently, torrefaction not only improves the fuel's energy properties but also facilitates its use in everyday household applications, ensuring better efficiency and convenience in heating systems.

In summary, the elemental composition of olive stones in this study aligns well with those reported in the literature, with only slight variations in carbon and nitrogen content. The consistently high calorific values and low nitrogen and sulfur content across all studies reaffirm the suitability of olive stones as a clean and efficient biofuel. The findings from the literature also demonstrate that torrefaction significantly enhances the energy potential of olive stones, further supporting their use in sustainable energy production.

This comparison confirms that olive stones are a promising bioenergy resource, with high carbon content and reasonable hydrogen levels across all studies. Differences in nitrogen and sulfur content highlight the importance of sourcing and processing methods for minimizing harmful emissions. The calorific value of olive stones further supports their potential as a renewable energy source, though careful attention must be given to pre-treatment and process optimization to maximize energy output.

The results of the elemental and technical analyses indicate that the studied material has high energy potential. The energetic utilization of olive stones as waste can significantly improve the efficiency of the technological processes in which they are involved, thereby increasing the share of renewable energy and minimizing the carbon footprint of the process.

Conclusions

This paper presents a comprehensive analysis of the thermal properties of olive stones sourced from a Spanish facility that processes this biomaterial. Combustion and pyrolysis processes were analyzed using thermogravimetry coupled with FTIR spectroscopy. The analysis of both processes allowed verification of this commercially available material for its intended application in small-scale heating devices with capacities of up to 500 kW, simultaneously contributing to broader knowledge regarding biofuel applications in Poland.

This study demonstrates that olive stones possess strong potential as a renewable biofuel for small-scale heating applications. Their high calorific value and low sulfur and ash content make them both efficient and environmentally friendly. Thermogravimetric analysis revealed a multi-stage decomposition during pyrolysis, with substantial energy release and minimal residual waste. Additionally, their high volatile matter content supports energy-efficient thermochemical processes, such as gasification. Although moisture content could be optimized through drying, olive stones remain a promising alternative to conventional fossil fuels.

To fully harness this potential, further research should focus on testing dedicated burner technologies, followed by pilot- or full-scale studies to evaluate the feasibility of large-scale implementation, including economic and logistical aspects, is necessary. Nevertheless, olive stones represent a valuable resource that aligns with the principles of a circular economy, offering a sustainable pathway for renewable energy production.

Comparing the obtained research results with available literature data allowed for an assessment of their consistency and evaluation of the potential of olive stones as fuel, considering regulations on emissions and solid fuel quality, particularly emphasizing their application in Poland.

Despite the lack of technology specifically adapted to burning this raw material in small-scale devices in Poland, the analysis provided crucial information that can support future technological developments and feasibility assessments for integrating this fuel into energy--systems. It is worth noting that developing technology for using olive stones in Polish installations is not a matter of creating new technology but instead adapting existing equipment to accommodate this material.

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The Authors have no conflicts of interest to declare.

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Zielona energia z bioodpadów – badanie właściwości pestek oliwek do wykorzystania jako paliwa w małych systemach grzewczych

Streszczenie

Niniejsze badanie analizuje potencjał pestek oliwek jako odnawialnego biopaliwa do małoskalowych systemów grzewczych. Produkcja produktów pochodnych z oliwek, takich jak oliwa z oliwek, generuje znaczne ilości produktów ubocznych, rocznie powstaje około 4 milionów ton pestek oliwek, które często są traktowane jako odpady. Analiza właściwości fizykochemicznych pestek oliwek zapewnia informacje na temat możliwości wykorzystania ich jako źródła energii. Próbka, pochodząca z Hiszpanii, została poddana analizie elementarnej, technicznej oraz termograwimetrycznej. Wyniki wykazały, że pestki oliwek charakteryzują się wysoką wartością opałową (18,26 MJ/kg), co wynika z ich znacznej zawartości węgla (47,4%) i wodoru (6,1%) oraz niskiej zawartości siarki, czyniąc je obiecującym paliwem niskoemisyjnym. Analiza termograwimetryczna ujawniła, że piroliza przebiega w czterech wyraźnych fazach, z utratą 65% masy w zakresie temperatur od 170 do 866°C, co potwierdza przydatność materiału w procesach wytwarzania energii cieplnej. Wnioski z badania wskazują, że pestki oliwek, jako łatwo dostępny produkt uboczny, mają znaczący potencjał do wykorzystania w systemach energii odnawialnej, wspierając tym samym cele zrównoważonego rozwoju i gospodarki obiegu zamkniętego.

Słowa kluczowe: pestki oliwek, biopaliwo, energia odnawialna, piroliza, gospodarka o obiegu zamkniętym