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Research Article

Consumer preferences for solid biomass fuels for energy purposes

Penka Zlateva[a], Krastin Yordanov[a], Mariana Murzova[b], Angel Terziev[c,*]

[a]*Department of Thermal Engineering, Technical University of Varna, 9010 Varna, Bulgaria*

[b]*Department of Industrial Design, Technical University of Varna, 9010 Varna, Bulgaria*

[c]*Faculty of Power Engineering and Power Machines, Technical University of Sofia, 1000 Sofia, Bulgaria*

Abstract. A specialized marketing survey was conducted across wholesale markets, manufacturing enterprises, online platforms and retail stores in Bulgarian market to analyze consumer preferences for various types of pellets. The study aims to identify key factors influencing consumer choices, with a particular focus on pellet qualities like ash content and the impact of additives on the combustion process. Statistical analysis of the survey results reveals that manufacturing enterprises are the most preferred purchase channels due to the superior quality of their products, while pellets from online platforms often receive negative feedback due to quality issues. Based on the findings, four types of pellets with and without additives are selected for further analysis: 100% coniferous; a mix of 80% coniferous and 20% deciduous; a mix of 80% coniferous and 20% sunflower and 100% sunflower pellets. To confirm the combustion characteristics of these pellet types, thermogravimetry (TG) and differential scanning calorimetry (DSC) analyses are conducted at heating rates of 5°C/min and 10°C/min up to 600°C. The analysis of variance (ANOVA) on the TG data shows significant differences in mass loss during thermal treatment between the various pellet types, demonstrating differences in efficiency and quality. The results indicate that sunflower pellets produce more ash, while wood pellets have superior combustion properties with lower ash generation. These findings highlight the need for improved consumer awareness, especially regarding the impact of pellet composition and additives on ash production. The correlation analysis of the DSC data reveals that some pellet types exhibit a high degree of similarity, suggesting they could be used interchangeably in combustion systems, while other types show significant differences due to varying raw material compositions. The study concludes that improving combustion processes requires careful selection of pellet fuels tailored to specific system needs and emphasizes the importance of better labeling and clearer information on pellet composition to enhance consumer knowledge and promote best practices in biomass fuel usage.

Keywords: Marketing study; consumers; pellets; thermogravimetry; differential scanning calorimetry; statistical analyses

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1. Introduction

The daily provision of energy for both household and industrial needs is a fundamental factor for the stable development of any country. Energy is at the core of many aspects of modern life, as it provides heat and light in our homes and powers the production of goods essential to society (Samokhvalov *et al.*, 2024). With each passing day, the reliance on fossil fuels like natural gas, coal and oil increases, as these resources are depleting rapidly (Halkos *et al.*, 2023; Ray *et al.*, 2023). This makes traditional methods of energy extraction and consumption unsustainable in the long term (Cieśliński *et al.*, 2024; Nunes 2023). The harmful emissions from the use of fossil fuels contribute significantly to climate change, leading to serious environmental, social and economic consequences (Alsarhan *et al.*, 2021; Bougma *et al.*, 2023; Abakumov *et al.*, 2024). In response to these issues, the demand for environmentally friendly and sustainable alternatives has increased significantly (Hassan *et al.*, 2023; Rupasinghe *et al.*, 2024). Accordingly, the energy policies of the European Union (EU) and Bulgaria focus on several key goals: ensuring supply reliability, supporting sustainable development and creating a unified internal market for energy biomass (Chlebnikovas *et al.*, 2021; Öztürk *et al.*, 2023).

Solid biomass, composed of various plant and wood waste materials, is one of the effective methods for producing energy with lower carbon emissions (Holechek *et al.*, 2022; Kalak *et al.*, 2023). It offers an alternative to fossil fuels and contributes to achieving goals for reducing the carbon footprint, combining energy efficiency with environmental responsibility (Ilari *et al.*, 2021; Hassan *et al.*, 2023).

In Bulgaria, biomass is a renewable energy source that offers significant economic and environmental advantages (Pavlov *et al.*, 2023; Terziev *et al.*, 2024). The country possesses a wide range of natural resources and agricultural products that can be used to produce various types of biomass fuels (IEA 2021; Rozhina *et al.*, 2023). These resources include agricultural waste materials, such as straw from different crops (wheat, rapeseed, lavender, etc.), corn stalks, as well as waste from various industries (Bochniak *et al.*, 2021; Kogabayev *et al.*, 2023). In addition to these, biomass encompasses wood waste from forestry and the logging industry (Butler *et al.*, 2023; Rubinos *et al.*, 2022). These diverse raw materials represent a valuable energy source that can be efficiently used to produce biofuels

* Corresponding author
Email: aterziev@tu-sofia.bg (A. Terziev)

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while also helping reduce waste and protect the environment (Božič *et al*., 2024; Anukam *et al*., 2019; Civitarese et *al*., 2023).

Pellets are one of the products derived from solid biomass. They are produced by compressing and processing plant and wood waste, making them easy to store and transport (Giannini *et al*., 2022; Mohan *et al*., 2023). Pellets are widely used for both residential and industrial heating (Mašán *et al*., 2023; Matasyoh *et al*., 2024; Mufandaedza *et al*., 2023). Pellet heating offers households and businesses the opportunity to significantly reduce fuel costs (Ochoa *et al*., 2024; Nizamutdinov *et al*., 2023). To meet the growing demand, manufacturers are introducing new technologies to optimize the production process and improve pellet quality (Osnaya-Maldonado *et al*., 2024; Morais *et al*., 2023). This contributes to the expansion of the market and offers a variety of biomass fuels with high energy efficiency (Jia 2021; Sokolova *et al*., 2023).

With the growth of the solid biofuels market, meeting consumer needs and preferences for efficient fuels has become increasingly important (Janiszewska *et al*., 2022). Marketing research plays a key role in identifying the specific requirements of various consumer groups, allowing companies to develop products that not only meet demand but also emphasize the environmental and economic benefits of biofuels (Rybak *et al*., 2021). These efforts not only promote sustainable and energy-efficient solutions but also facilitate the adaptation of marketing strategies to specific consumer requirements (Kline *et al*., 2021; Karkania *et al*., 2012).

Customer feedback on important fuel characteristics, such as moisture content, residual ash and calorific value, provides valuable insights for product improvement (Kamperidou *et al*., 2022; Islamova *et al*., 2020; Rupasinghe *et al*., 2024; Wibowo *et al*., 2022). By utilizing this information, companies can enhance their production processes by conducting studies on the physico-chemical properties of solid biofuels using thermal analysis methods and improve pellet labeling, thus ensuring high quality and efficiency (Almusafir *et al*., 2024; Fraga *et al*., 2020). As a result, customer satisfaction increases and brand loyalty strengthens in the long term.

Careful examination of consumer concerns regarding pellet quality is also crucial for complying with regulatory standards and requirements, which is essential for maintaining market competitiveness. Based on the gathered information, businesses can better position their products and highlight their unique advantages (Oluoch *et al*., 2024).

The growing consumer interest in environmentally friendly products motivates companies to seek sustainable solutions that contribute to the preservation of natural resources (Karkania *et al*., 2012). The biofuel market is evolving dynamically, responding to the demand for energy sources with low environmental impact. Pellets and other biomass fuels have established themselves as a key component of the global energy system, offering sustainable solutions for the future (Drobniak *et al*., 2024; Szulejko *et al*., 2023).

The choice of solid biofuel, produced from waste materials, depends on several key factors. The first is the efficiency of different types of biomass, which determines the amount of energy extracted from a unit of fuel, influencing its economic viability. Energy characteristics, including the physico-chemical properties of biofuels, are crucial for the performance of combustion systems, which directly improves the thermal comfort for consumers (Peralta et al., 2024; El-Sayed *et al*., 2024; Nazir *et al*., 2023, Ivanov 2019). The residual ash content is also an important parameter, as high levels can lead to deposit buildup in combustion systems, increasing maintenance costs (Dong *et al*., 2023). Additives are a factor that plays a role in the quality and performance of the fuel (Zhang *et al*., 2023; Ujvári *et al*., 2022). They can improve the combustion process and reduce harmful emissions, which is important for meeting environmental standards. The distribution channels for biofuels are another key factor, as they affect product accessibility for end users (Jonsson *et al*., 2017). Easy access to high-quality biofuels is essential for promoting their wider use and integration into the energy sector. Based on these factors, the choice of solid biofuel can be not only economically advantageous but also energy-efficient and environmentally sustainable, while simultaneously enhancing energy independence and household comfort.

This study focuses on analyzing consumer preferences for solid biomass fuels in Bulgaria through a comprehensive marketing survey that covers various distribution channels – wholesale, manufacturing enterprises, online stores and retail stores. The aim of the research is to identify the key factors that most strongly influence consumer choices regarding solid biomass fuels. A statistical analysis of consumer opinions was conducted to gain a deeper understanding of customer preferences and needs. The results of this analysis will provide potential insights for the future development of the biofuel market in the country.

In addition to the marketing analysis, an in-depth statistical analysis of the physico-chemical properties of various types of pellets was conducted using thermogravimetric analysis (TGA) and differential scanning calorimetry. These methods were used to examine the thermal behavior of the pellets, including their decomposition, thermal stability and their fuel energy potential.

The results gained from the physico-chemical analysis provide important data on the efficiency of different biomass types, aiding in the evaluation of their suitability for various applications, ranging from household heating to industrial processes. This information is valuable not only for consumers seeking better efficiency and lower costs, but also for producers and distributors, who can optimize their production and distribution practices based on scientific data about fuel quality.

2. Methods

2.1 Marketing Study on Consumer Preferences Regarding Pellet Biomass Fuels

Questionnaires have been prepared in which the wording of the questions is short and clear in order to ensure the convenience of the participants and to avoid unnecessary strain.

The questions included in the survey are as follows:

1. Where do you usually buy pellets? - This question aims to identify the preferred purchasing channels and understand consumer habits when selecting a supplier;
2. How important is the information written on the labels regarding the characteristics of the pellets? - Here, the significance of label information is evaluated and how it influences consumer decisions;
3. What type of pellets do you prefer to use in your heating device - pure or with additives? - This question explores consumer preferences regarding types of pellets and desired characteristics;
4. Which of the pellets that you use leave more ash after burning in the heating device? - This question provides information about the performance of different pellets and their impact on the maintenance of the heating devices;
5. Which of the pellets you use are more calorific? - This evaluates how consumers recognize and assess the calorific value of the pellets, which is essential for the efficiency of the combustion process;
6. Is the moisture content in the pellets important in the combustion process? - This question examines

consumers' understanding of the impact of moisture on combustion efficiency.

The specialized marketing survey was conducted across various distribution channels of biomass pellets in the Bulgarian market, including wholesale markets, manufacturing enterprises, online platforms and retail stores. The goal of the survey is to identify the key factors influencing consumer choices, focusing on pellet characteristics such as ash and moisture content, as well as the impact of additives on the quality of the combustion process.

By conducting a statistical analysis of the data gathered from 125 surveys, this study seeks to deliver a comprehensive examination of consumer preferences and pinpoint the key factors that influence the selection of biomass pellets. The findings provide important insights not only for manufacturers and sellers but also for end consumers, ultimately enhancing market orientation for pellet fuels in Bulgaria.

2.2 Preparation of the Investigated Types of Pellets for TG and DSC Analysis

The preparation of pellets for TG and DSC analyses involves several key steps that ensure reliable and valid results, which are as follows:

Sample Selection: The study focuses on four types of pellets, both with and without additives (P1-P5), sourced from different manufacturers. To ensure the accuracy of the analyses, the pellets are stored in closed plastic bags of 1 kg to prevent moisture ingress.

Sample Preparation: The pellets are crushed into small, homogeneous particles measuring less than 1 mm. This procedure is crucial because a uniform particle size ensures even heating during the analysis.

Weighing of Samples: After the preparation, each sample is weighed using a precise laboratory analytical balance. The weight of the crushed pellet samples is up to 30 mg. Recording the exact weight values is essential for obtaining accurate results from the study.

Placement in the Analyzer: The samples are examined using the Linseis STA PT 1600 apparatus. The prepared samples are placed in the specialized containers of the analyzer, ensuring optimal conditions for measuring and accurately recording the thermal properties of the crushed pellet samples.

Setting Up the Equipment: The parameters of the apparatus are configured according to the requirements of the analysis. Two different heating rates are set: 5°C/min and 10°C/min, allowing observation of the thermal reaction of the pellets. The temperature range is established from room temperature up to 600°C.

Conducting the Analysis: After the setup, the heating process begins. The thermogravimetric analysis monitors the weight loss of the pellets, while the differential scanning calorimetry measures the heat flow associated with phase changes and thermal reactions.

Recording the Results: All data obtained during the analysis of the pellets are recorded and analyzed using specialized computer software. The results from the TG and DSC analyses provide information on the thermal stability, calorific value and quality of the pellets.

After completing the preparation and the analysis, the study provides results that clarify the thermal properties of the pellets and their suitability for various combustion devices.

The obtained data will contribute to the assessment of the pellets effectiveness when burned in heating systems, which is essential for their application as a reliable energy resource. This information will be valuable both for consumers and for

Fig. 1 View of the samples (raw material) used

producers and distributors seeking to optimize their products in accordance with environmental standards and requirements.

2.3. Biomass materials

PAfter conducting a statistical analysis of the data from the marketing study focused on consumer preferences for pellets made from solid biomass waste materials, four types of pellets with and without additives were selected (see Figure 1), produced by different manufacturers. Below are the selected types of pellets, which reflect the variety of products on the market and consumer preferences regarding packaging, quality, and efficiency:

- 100% Coniferous Wood Pellets (P1) – made from white pine, these pellets have high calorific value and low ash content, according to the study;
- Mixed Pellets (P2) – comprising 80% coniferous wood (white pine) and 20% deciduous wood (beech), these pellets are reported to be more calorific due to the combination of different wood types;
- Mixed Pellets (P3) – produced from 80% coniferous wood (white pine) and 20% sunflower husks, these pellets provide a mix of energy qualities and utilize agricultural waste materials, which is important for ecological sustainability;
- 100% Sunflower Pellets (P4) – made entirely from sunflower husks, these pellets are noted by consumers to have a higher ash content, which is significant for the buildup of deposits in combustion systems.

3. Results

Based on the conducted marketing research among consumers, various types of pellets representing current interest for the consumer market were selected and studied. TG and DSC analyses were performed on the pellets, providing important information regarding their thermal properties and behavior during heating. The results obtained from the studies are presented below to enhance the understanding of the characteristics, combustion efficiency and practical application of the different types of pellets.

3.1 Results of the Marketing Research of Customer Preferences for the Studied Pellet Biofuels

The results from the statistical analysis of the data from the first question indicate that 31% of the respondents prefer to purchase pellets from wholesale markets, likely due to the economic advantages and lower prices associated with buying in bulk. A similar proportion (29%) opt for direct supply from manufacturers, which can be attributed to expectations of higher quality and assurance of product origin. Approximately 25% of the surveyed consumers prefer shopping at retail stores, where easy access and in-person service are important factors. The low preference for online purchases of pellets (only 15%) highlights the need to enhance trust and convenience in this channel to attract more consumers.

The results from the analysis of responses to question 2 demonstrate the significant impact of label information on the purchasing decision – 61% of the respondents consider this information important, while 39% do not attach much significance to it. These results reveal that the majority of the consumers view labels as an important source of information regarding the composition, quality and origin of the pellets, which directly affects their trust in the product and their satisfaction with it.

The results from the statistical analysis presented in Figure 2, Figure 3 and Figure 4 indicate that:

With the highest proportion of 20% positive responses, manufacturing companies are perceived as the most reliable channel for purchasing pellets, suggesting a high degree of consumer trust. Key factors contributing to this perception include competitive prices and guaranteed quality offered by these companies. Direct purchasing from the manufacturer provides greater transparency regarding the origin and characteristics of the pellets, facilitating informed consumer choices. Additionally, access to manufacturers allows for personalized orders or selection of specific types of pellets, significantly enhancing customer satisfaction.

Wholesale markets also play a significant role in pellet purchases with 17% positive and 14% negative responses. The positive responses indicate that a considerable number of consumers appreciate the advantages of bulk buying, particularly regarding lower prices and savings with larger quantities, making it a preferred choice for consumers with higher demand. However, the substantial share of negative

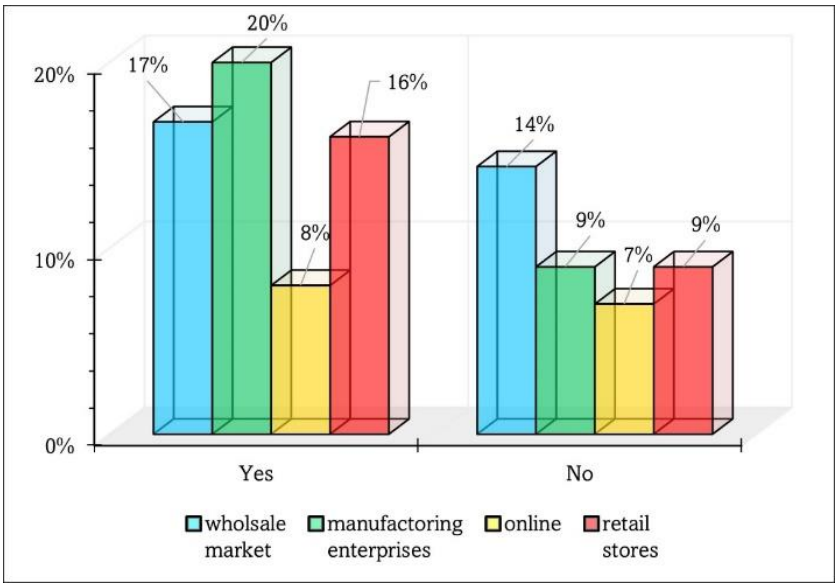

Fig. 2 Comparison of consumer opinions on questions 1 and 2

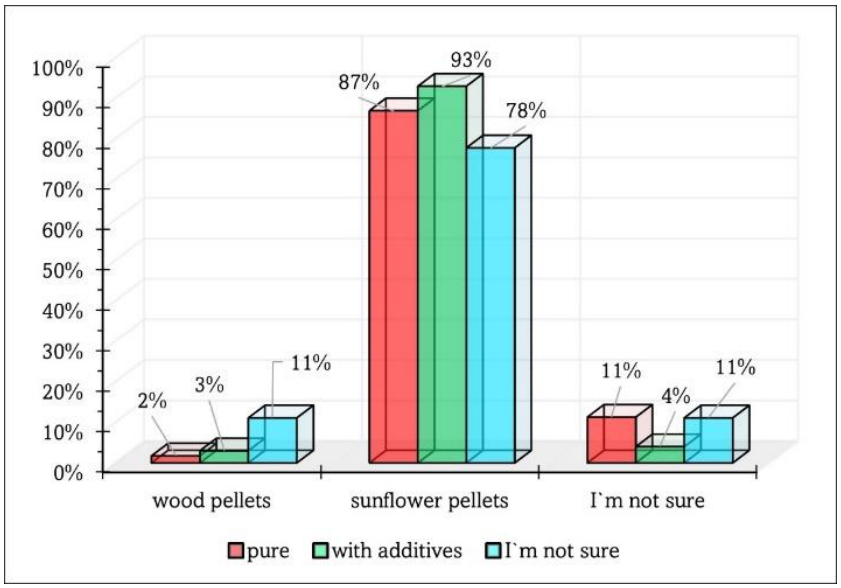

Fig. 3 Comparison of consumer opinions on questions 3 and 4

responses suggests that this channel may be inconvenient for some consumers due to the physical distance of wholesale markets and may be less practical for smaller orders.

Online platforms, with 8% positive and 7% negative responses, represent the newest yet steadily growing channel for purchasing pellets. They are regarded as a convenient and quick way to shop, especially for smaller quantities or for those who prefer to buy from home. Online shopping allows easy price comparisons and reviews of consumer feedback, increasing buyer awareness. The low percentage of negative responses indicates high satisfaction, but for some, the lack of an option to physically inspect the product may be a drawback.

Retail stores receive 16% positive and 9% negative responses, indicating that for some consumers this channel does not offer sufficient advantages. Limited availability and relatively higher prices likely diminish their appeal compared to other channels. However, retail stores provide convenient and quick access to the product and the option for immediate purchase make them a suitable choice for consumers who do not have access to manufacturing facilities or wholesale markets.

The results from the survey indicate how consumers perceive different types of pellet biofuels regarding the amount of ash residue after combustion in residential boilers. The survey covers two main types of pellets – wood and sunflower – with respondents' answers divided into three categories for their preferences: pure, with additives and I'm not sure.

The findings show that wood pellets are perceived as a source of minimal residual ash after burning. Only 2% of the respondents believe that pure wood pellets leave a significant amount of ash, confirming the general consensus that this type of fuel generates minimal waste and is suitable for clean burning. When it comes to wood pellets with additives, only 3% of the respondents think these additives contribute to increased residues. This low percentage may suggest that consumers either do not view additives as a significant factor in wood pellets or lack sufficient information regarding their impact. Additionally, 11% of respondents remain uncertain about the effect of wood pellets on the amount of ash, which may reflect a lack of experience or insufficient awareness of the characteristics of this type of biomass.

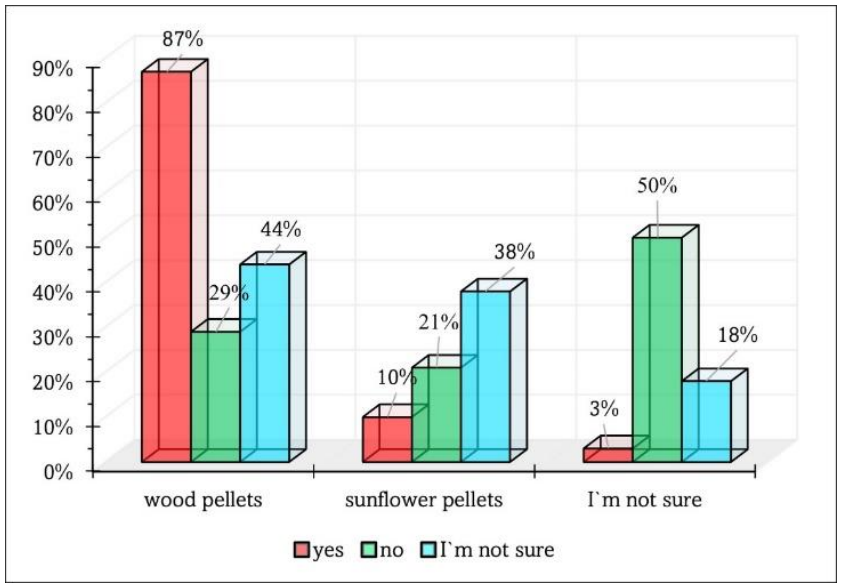

Fig. 4 Comparison of consumer opinions on questions 5 and 6

In contrast, sunflower pellets are perceived as a source of a significantly greater amount of residual ash. A substantial 87% of the respondents believe that pure sunflower pellets lead to increased ash content after burning. This is likely due to their specific composition, which suggests more mineral residues. Also 93% of the consumers believe that sunflower pellets with additives further enhance this effect. This indicates that additives play a role in increasing the residual ash, potentially leading to a significant amount of waste when used as fuel in domestic boilers. Despite these definitive results, 78% of the respondents express uncertainty about the influence of additives in sunflower pellets on the ash quantity. This uncertainty likely reflects a lack of accurate information about the composition of sunflower pellets and the specific characteristics of the additives used in them.

The comparison between the two types of pellets shows that sunflower pellets, especially the pure ones, are perceived as a primary source of ash when burned in domestic settings, in contrast to wood pellets, which are considered cleaner and more environmentally preferable. For wood pellets additives are not regarded as a significant factor concerning residues, while for sunflower pellets the additives evidently enhance the perceived amount of ash, which accounts for the high levels of residues according to consumer opinion. The high rate of uncertainty in sunflower pellets, especially regarding additives, suggests a need for clearer labeling and consumer awareness of the composition and impact of these biomass fuels.

The results of the marketing survey provide information about consumer preferences regarding the calorific value and moisture influence of different types of pellets used for heating. They reveal significant differences in the evaluations of wood and sunflower pellets, highlighting the key factors that determine fuel choice among consumers.

Wood pellets are highly rated in terms of calorific value, with 87% of the respondents identifying them as more effective and suitable for the combustion process. This predominant positive assessment demonstrates that consumers perceive wood pellets as a reliable energy source that offers a good balance between heating value and combustion cleanliness. However, 29% of the participants do not share this opinion, with 44% of them expressing uncertainty. These results emphasize the need for more detailed information about wood pellets and their benefits. Some consumers appear to have different expectations or may

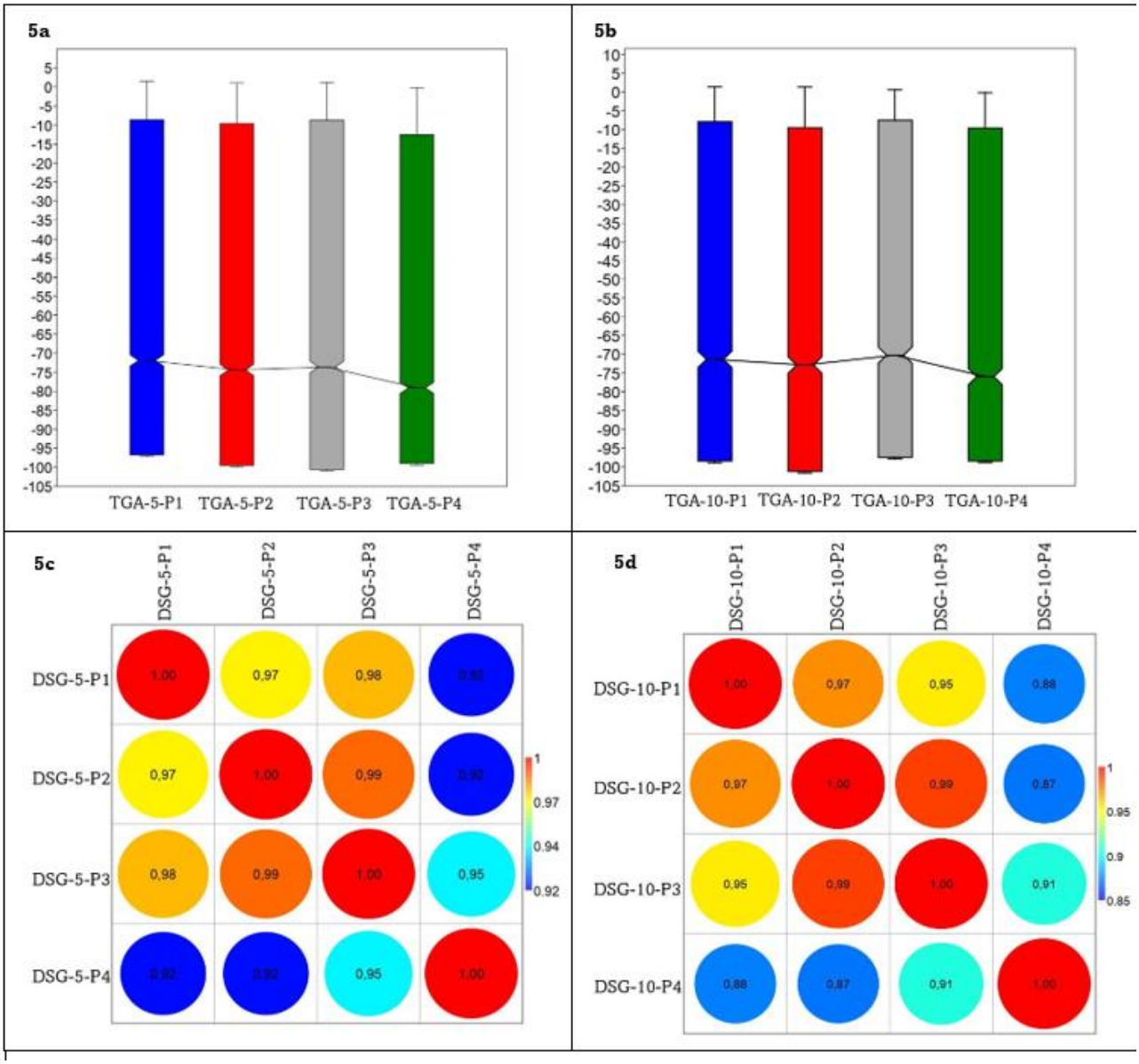

Fig. 5 Statistical analysis of TG and DSC for samples P1–P4 at heating rates of 5°C/min and 10°C/min

not be thoroughly familiar with the characteristics of this type of fuel.

Regarding sunflower pellets, only 10% of the respondents perceive them as high-calorific. Unlike wood pellets, sunflower pellets are not considered as effective a source of energy. The level of uncertainty among consumers is significantly higher for sunflower pellets, with 38% expressing doubts about their calorific value. This may be due to the specific composition of sunflower pellets, which results in a higher mineral residue content and lower energy value. Consumers may require more information about their characteristics and benefits to make a more informed choice.

The survey also examines consumers' attitudes towards moisture in pellets, which plays a crucial role in the combustion process. Half of the respondents (50%) express confidence that moisture is an important factor in combustion efficiency. This indicates that consumers are aware that higher moisture content reduces calorific value and combustion quality, leading to greater energy losses and lower efficiency. The lower moisture content in wood pellets is likely one of the reasons they are perceived as a better choice. However, a significant percentage (18%) of the respondents express uncertainty about the importance of moisture, highlighting the need for more educational information in this area. Consumers should be informed about the impact of moisture on calorific value to make better decisions when purchasing pellets.

3.2 Results of TG and DSC of the Studied Pellet Biofuels

The results of the analysis of the TG data when heating at a rate of 5°C/min shows the behavior of different types of pellets (P1, P2, P3 and P4) in terms of mass loss depending on the temperature. The graph reveals the temperature stability and the thermal profile of the pellets, which allows better understanding of their properties and potential applications (see Figure 5a).

The samples P1 and P2, which consist mainly of coniferous wood (100% for P1 and 80% for P2, respectively), demonstrate similar mass loss values. This suggests high thermal stability during heating and indicates that the addition of 20% deciduous wood in P2 does not significantly affect the thermal profile. This stability makes them suitable for applications where a predictable thermal profile is required.

In sample P3, containing 20% sunflower waste in its composition, stability in mass loss was also observed and the differences compared to P1 and P2 were minimal. This suggests that the addition of small amounts of sunflower husks does not significantly impair the stability of the coniferous wood pellets and allows a predictable thermal profile to be maintained.

Sample P4, composed entirely of sunflower husks, shows a different thermal profile with higher and uneven mass loss at lower temperatures. This can be attributed to the higher content of oils and minerals in sunflower husks, which decompose earlier upon heating. Due to these differences, P4 requires specific conditions for optimal combustion and minimization of residual ash.

These results indicate that pellets made from coniferous wood (P1, P2 and P3) are more suitable for applications requiring a stable and predictable thermal profile, while P4, due to its different reaction when heated, may be appropriate for specific combustion conditions where high mass loss is less of a concern and optimizing residual ash is a priority.

The results of the statistical analysis of TG when heating at a rate of 10°C/min reveals how the different types of pellets (P1, P2, P3 and P4) lose mass at this heating intensity. The vertical axis reflects the percentage loss of mass, while the horizontal axis represents the different types of pellets, providing clarity on the thermal stability of each (see Figure 5b).

Samples P1 and P2, primarily composed of coniferous wood (100% for P1 and 80% for P2), demonstrate similar thermal characteristics. The close values of mass loss indicate that thermal degradation is stable and predictable for these pellets at this heating rate. This reflects their suitable resilience and stability, making them appropriate for applications where the stability of the combustion process is critical.

Sample P3, which includes 20% sunflower waste and 80% coniferous wood, shows a slightly wider range of mass loss, but the difference is not significant compared to P1 and P2. This suggests that the addition of a small percentage of sunflower husks does not substantially affect the stability of thermal degradation of the pellets primarily made of coniferous wood, even at a higher heating rate. Maintaining a relatively stable thermal profile for P3 supports its application in conditions requiring more consistent combustion.

Sample P4, entirely composed of sunflower husks, displays a different thermal profile characterized by a larger range of mass loss and dispersion of values. This is a result from the specific chemical composition of sunflower husks, which contain higher amounts of oils and minerals that decompose at lower temperatures, leading to greater mass loss in the early stages of heating. Such high reactivity necessitates specific combustion conditions for the effective and controlled burning of this type of pellets.

In conclusion, at a heating rate of 10°C/min, coniferous wood pellets (P1, P2 and P3) demonstrate greater thermal stability compared to sunflower husk pellets (P4). The coniferous wood variants are suitable for applications where predictable resilience at elevated temperatures is required, while the sunflower waste pellets may require careful regulation of the combustion process to optimize their burning and minimize residual ash.

The results of the correlation analysis at a heating rate of 5°C/min focus on the differences in the composition of the pellets and are presented in Figure 5c. Samples P1, P2 and P3 show a high degree of correlation, ranging from 0.97 to 0.99, indicating similar thermal properties. This strong correlation can be attributed to the predominant content of coniferous wood in their composition, which dominates their thermal behavior. Coniferous wood is characterized by a relatively homogeneous composition of cellulose and lignin, resulting in a similar thermal profile during heating. The high correlation between P1, P2 and P3 demonstrates that the addition of deciduous wood and sunflower husks in P2 and P3 does not significantly influence the primary thermal profile of these samples, which is determined by the coniferous wood fraction.

Deciduous wood has a slightly different composition, but at a 20% content, it does not significantly alter the heating behavior of the sample, resulting in a high correlation between P2 and P1. Sunflower husks also have a different composition compared to wood, containing higher amounts of mineral substances (ash) and oils. However, with a 20% addition, coniferous wood still dominates the thermal profile of P3, which explains the high correlation of P3 with both P1 and P2.

Sample P4 has the lowest correlation with the other samples, with values ranging from 0.92 to 0.95, which is noticeably lower than the correlations among the coniferous wood containing samples. This difference in correlation can be explained by the significant differences in composition and structure between sunflower husks and wood. Sunflower pellets have a higher content of minerals and oils compared to wood. This leads to a distinct thermal profile during heating, as the oils burn at lower temperatures, and the minerals result in a higher residual ash

content. This explains the weaker correlation of P4 with the other samples, which are dominated by wood composition.

While coniferous wood pellets exhibit a relatively stable thermal profile and lower ash content, sunflower waste tends to decompose earlier and produce more ash at the same temperatures. This also leads to a weaker correlation for sample P4 with the other samples, as its thermal characteristics differ significantly.

The correlation matrix confirms that coniferous wood pellets have similar thermal properties, which do not change substantially when small amounts of deciduous wood or sunflower husks are added. This is a key finding for pellet manufacturers, as it indicates that small additives from other materials will not compromise the quality and thermal properties of coniferous wood pellets.

The difference in the thermal profile of P4, composed entirely of sunflower husks, highlights that consumers who prefer sunflower pellets should be aware that their combustion and thermal properties differ significantly from those of wood pellets. This can affect combustion efficiency and ash formation.

The analysis of the correlation matrix at a heating rate of 10°C/min reveals interesting dependencies among the thermal properties of different types of pellets with varying compositions, as shown in Figure 5d.

The samples with a high content of coniferous wood (P1, P2 and P3) exhibit a strong correlation with each other, with values between 0.95 and 0.99. This indicates thermal stability even at faster heating rates. These results are consistent with those observed at a lower heating rate (5°C/min), highlighting that the coniferous wood content dominates the thermal profile and contributes to the stability of the samples. The addition of 20% deciduous wood in P2 and 20% sunflower husks in P3 also does not result in significant changes in the correlations. This suggests that incorporating small amounts of alternative materials does not disrupt the thermal stability and manufacturers can include these materials without significant deviation in thermal properties.

On the other hand, sample P4, consisting entirely of sunflower husks, shows a noticeably lower correlation with the other samples, with values between 0.87 and 0.91. The correlation further decreases at faster heating rates compared to the results at 5°C/min, indicating that sunflower husks exhibit a significantly different thermal profile under higher temperature conditions. This difference is attributed to the specific chemical composition of sunflower husks, which contain more minerals and oils that decompose more quickly and form more residual ash during the heating process. The absence of cellulose and lignin, present in the wood, also leads to lower stability when heating P4.

These results confirm that coniferous wood pellets retain the stability of their thermal properties even at higher heating temperatures and with the addition of up to 20% alternative materials. This is valuable information for manufacturers, as it emphasizes that such additives do not cause significant changes in the quality and predictability of the thermal profile of coniferous wood pellets. At the same time, pellets composed entirely of sunflower husks exhibit a specific thermal behavior, requiring special settings in combustion systems to ensure optimal performance and control over ash formation.

4. Discussion

The marketing study of consumer preferences regarding fuel pellets reveals several important factors influencing their market behavior, including purchase channels, the significance of labeling, and perceptions of calorific value and moisture content in pellets. The data show that consumers place greater trust in manufacturing companies and wholesale markets as their primary purchasing channels, largely due to perceived quality and competitive prices. This trend suggests that increasing transparency and availability of information about product quality, as well as expanding the presence of wholesale markets and direct sales from manufacturers, could meet demand and increase consumer trust.

In comparison to other studies, the research by (Johnson *et al.*, 2020) notes that a significant portion of consumers in the EU also prefer direct purchases from manufacturers, motivated by a sense of better quality control and fewer intermediaries, which aligns with the findings of the current study.

Labels are critically important to consumers, with over 60% of the respondents stating that the information they provide influences their choice. This mirrors trends noted in studies by (Drobniak *et al.*, 2024), which emphasize that consumers tend to select products with clearly marked attributes, such as calorific value and moisture content. The current study also found a notable difference in consumer attitudes toward wood and sunflower pellets – while wood pellets are highly valued for their calorific content (87%), sunflower pellets are viewed as less effective fuel sources (only 10% rated them highly). This highlights the need for better consumer education on the composition and benefits of pellets, especially those with mixed origins.

The analysis of DSC and TG of the pellets at different heating rates is also revealing. At a heating rate of 5°C/min, the observed thermal stability of wood pellets is significantly better than that of sunflower pellets and this trend becomes even more pronounced at a rate of 10°C/min. These results align with the findings of (Rupasinghe *et al.*, 2024), who noted that wood pellets exhibit higher resistance during thermal treatment, making them more suitable for high-temperature applications. However, the addition of materials like sunflower residues to wood pellets does not significantly impact thermal stability, suggesting the potential for material blending without substantial loss in efficiency.

These data demonstrate that wood pellets have an advantage in terms of efficiency and stability during thermal processing, while sunflower pellets require improvements in label recognition and informational transparency. In the future, manufacturers could expand labeling practices and targeted informational campaigns to raise awareness about the differences in calorific value and moisture content across different pellet types.

5. Conclusion

The study highlights the important differences in the thermal properties and consumer attitudes towards wood and mixed pellets, with this data being essential for optimizing production and improving market awareness. Labels prove to be critically important for consumers, as over 60% of the respondents state that the information on the labels influences their purchasing decisions.

The marketing survey reveals that consumers prefer to buy pellets directly from manufacturers or through wholesale markets, indicating the need for reliable and transparent distribution channels that consumers trust. 31% of the respondents express a preference for wholesale markets, while 29% choose direct purchases from manufacturers, as these channels offer greater confidence in quality and pricing advantages. Additionally, labeling is a key factor in purchasing decisions – 61% of the respondents consider the information on labels important. The lack of clear data regarding the composition and origin of sunflower pellets, especially in terms of additives and moisture content, may raise concerns among

consumers. Therefore, producers should aim for better transparency and consumer awareness.

The analysis of the DSC and TGA results shows that pure wood pellets (P1) and those with a high wood content (P2) exhibit superior calorific and thermal properties compared to pellets that include sunflower husks (P3 and P4). These thermal characteristics are also reflected in consumer attitudes: wood pellets are perceived as more efficient for heating, while sunflower pellets are rated as having lower calorific value, higher moisture content and a greater ash residue.

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