Advances in Science and Technology Research Journal

Advances in Science and Technology Research Journal 2023, 17(5), 236–247
https://doi.org/10.12913/22998624/172534
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Received: 2023.07.05
Accepted: 2023.09.15
Published: 2023.10.20

Characterizing Sawdust Fractional Composition from Oak Parquet Woodworking for Briquette and Pellet Production

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ABSTRACT

The particle size distribution of woodworking residues influences the quality of the biofuels made of these materials. Hence, it is essential to investigate the fractional composition of raw materials for pellet production. Tested materials originated from ten parquet manufacturing facilities located in western Poland. The research material consisted of uncontaminated oak (*Quercus* spp.) wood particles. The tested material had a moisture content ranging from 8.8% to 11.4% and a density of 210.7 ± 1.79 kg/m^3. A sieve analysis method segregated the tested material into four distinct size fractions (<1.0 mm, 1.0–2.5 mm, 2.5–5.0 mm, and >5 mm). The average mass shares in these fractions were 53.72 ±0.51%, 35.14 ±0.27%, 9.59 ±0.36%, and 1.55% ±0.11%, respectively. The particle size distributions of wood particles generated in all the facilities demonstrate remarkable similarity. No substantial differences were observed in terms of tilt angle and calorific value. Factors such as variations in raw material species, geographical origins, density, humidity, and technological processes appear to have minimal influence on the sieve-size distributions of the generated sawdust. All these solid wood processing residues can undergo processing into high-quality solid biofuel production.

Keywords: by-produscts, production waste, biofuel, wood particles, quercus petraea, sieve analysis, size fractions, fractional composition.

INTRODUCTION

Mechanical wood processing generates particles of different sizes [1], from pieces of many mm in length to finely shredded wood powder. All these by-products can be used as fuel directly or after compaction if not contaminated. Wood particle dimensions are classified into commercial categories depending on their industrial destination. Based on their particle size, wood particles can be categorized as fuel powder, sawdust, and shavings [2]. Fuel powder typically has a particle size of less than 1 mm and is generated from processes such as sanding and milling. Sawdust has a particle size ranging from 1 to 5 mm and is produced during sawing and milling. Shavings, with a particle size of 1 to 30 mm, are obtained from planing wood using sharp tools. These wood-based materials can undergo mechanical compression to form briquettes, which typically have a diameter larger than 25 mm, or they can be compressed into pellets with a diameter equal to or less than 25 mm. Briquettes and pellets are convenient forms of solid biofuels that facilitate handling, storage, and efficient combustion [3]. Like any other fuel product, wood fuels have typical quality elements, including moisture content (MC), energy density, low ash content, mechanical durability, consistent size and shape, low impurities, and low-emissions sourcing compared to other fuels.

The granulometric composition of the raw material influences the quality of briquettes and pellets. Bergström et al. in 2008 showed that the particle size distribution of pine wood in pellets affects the energy consumption and the compressive strength but has no apparent effect on bulk density, moisture content, moisture absorption during storage, and abrasion resistance. The differences in combustion were less than 5%, and, according to the authors, they were insignificant. Furthermore, the authors propose that reducing wood particle size to less than 8 mm during the preparation for pelletization is not advisable. This practice, they argue, fails to yield any measurable benefits and instead results in elevated energy costs [4]. Relova et al. in 2009 studied the influence of the size distribution of the mixture of pine wood particles with bark (proportion of bark approximately 18%), originating from the sawing and milling processes (circular and band saw, as well as milling). The study aimed to determine the influence of pressure (15.9, 23.9, 31.8, and 39.9 MPa), moisture content (6, 9.5, 13, and 20%), and wood particle size (<0.63, in the range of 0.63-1.0, and 1-2 mm), finding that compaction pressure and moisture content had the most significant influence on the pellets produced. At the same time, the impact of granulometric composition ranked only third [5]. Zepeda-Cepeda et al., in 2021, also studied the effect of the granulometric composition of pine wood particles (in the range up to 2.36 mm) on the mechanical properties of pellets. They showed that a high proportion of small particles lends higher density and impact resistance to pellets, while pellets made from larger particles have a higher calorific value [6]. Pellets prepared from the medium fraction among those tested had the highest abrasion resistance. The authors also indicate that the selection of different particle sizes for the mixtures increases the quality of the briquettes. The study on the influence of the granulometric composition and other additives on the properties of briquettes and pellets of various nature is a current research topic, e.g., the additive cocoa pod husks [7], rice husks [8], etc. The literature points out that increasing the lignin content and achieving an optimal moisture content, along with higher pelletizing temperatures, positively enhance the durability of biomass pellets. On the other hand, larger particle sizes, elevated levels of extractives, and higher moisture contents harm durability by decreasing friction and disrupting the binding process [9]. Despite the high energy demand [10], briquetting of various materials is still a current scientific topic [11–13]. Additionally, the intensive development of electricity generators originating, for example, from the sun, wind or the combustion of alternative fossil fuels (compressed natural gas, liquefied petroleum gas) in energy cogenerators with combustion engines [14,15] will contribute to the increase in the use of brikirting processes.

Research has been conducted on the physical properties of wood shredded into wood particles in the processing operations, taking into account the influence of different processing types [16], including milling [17, 18], turning [19], sawing [20,21], sanding [18–21] or the influence of wood type during different wood processing methods, e.g., sanding [24,25], CNC milling [26–28]. Kminiak et al. in 2020 analyzed the effect of prior heat treatment of wood on the size of particles generated in the sawing and milling processes, showing that thermal modification of birch wood with saturated steam did not affect the mass share of the size fractions produced [29]. In contrast, Dzurenda et al. in 2010 showed that thermally modified oak particles are finer, with a significantly higher share of size fraction ranging from 125 to 500 μm and a slight increase for fractions ranging from 32 to 125 μm [30]. The analysis of wood dust granulometric composition is mainly conducted for human respiratory safety [31] and fire protection purposes [32], but can also be carried out to improve the brittleness of wood dust for pellet production [33].

The oak parquet production consists of several stages that transform raw wood material into refined flooring. The initial phase involves debarking oak logs and later cutting them into lumber of suitable dimensions. The next step consists of kiln drying to lower the lumber elements' moisture content, which are then sawn into uniform thin planks. These sawn planks undergo planing and sanding to achieve the desired thickness and a smooth surface. Planks can be modeled into various profiles or shapes to accommodate diverse parquet designs, including tongue and groove patterns, ensuring secure interlocking. The final production stage is surface refinement, which involves applying and processing multilayer coatings. The described woodworking processes generate by-products that remain uncontaminated by varnishes and adhesives and may be transformed into biofuel as briquettes or pellets. However, the knowledge of the fractional composition of this by-product, currently missing, is crucial to achieving high-quality solid biofuel production. The present study aims to determine the particle-size composition of wood particles manufactured during oak parquet production in wood flooring plants in western Poland.

MATERIALS AND METHODS

Samples were collected from ten parquet production plants situated in western Poland. The wood processed in these facilities was sourced from various Forest Districts within the Polish State Forests system, as detailed in Table 1. Figure 1 shows the sampling and testing procedure.

The raw material used to produce parquet in analyzed facilities was oak wood (*Quercus* spp.), predominantly comprising pedunculate oak (*Quercus robur* L.) (80–85%), along with approximately 15% of sessile oak (*Quercus petraea* (Matt.) Liebl.). There may be a slight admixture of other oak species, such as northern red oak (*Quercus rubra* L.) and potentially pin oak (*Quercus palustris* Münchh.). The surveyed enterprises utilized raw wood materials with diverse species compositions. Table 2 summarises the variety of wood species compositions and the average raw-material densities employed in the parquet production process during the wood sample collection phase.

Table 1. Geographical area of origin of wood from the Polish National Forest Holding "State Forests"

Description	Production facility				
	1	2	3	4	5
Origin of wood logs (Forest District)	Łopuchówko	Wronki	Karczma Borowa	Grodziec	Szczecinek
	Production facility				
	6	7	8	9	10
Origin of wood logs (Forest District)	Choszczno	Lubniewice	Nowa sól	Legnica	Oława

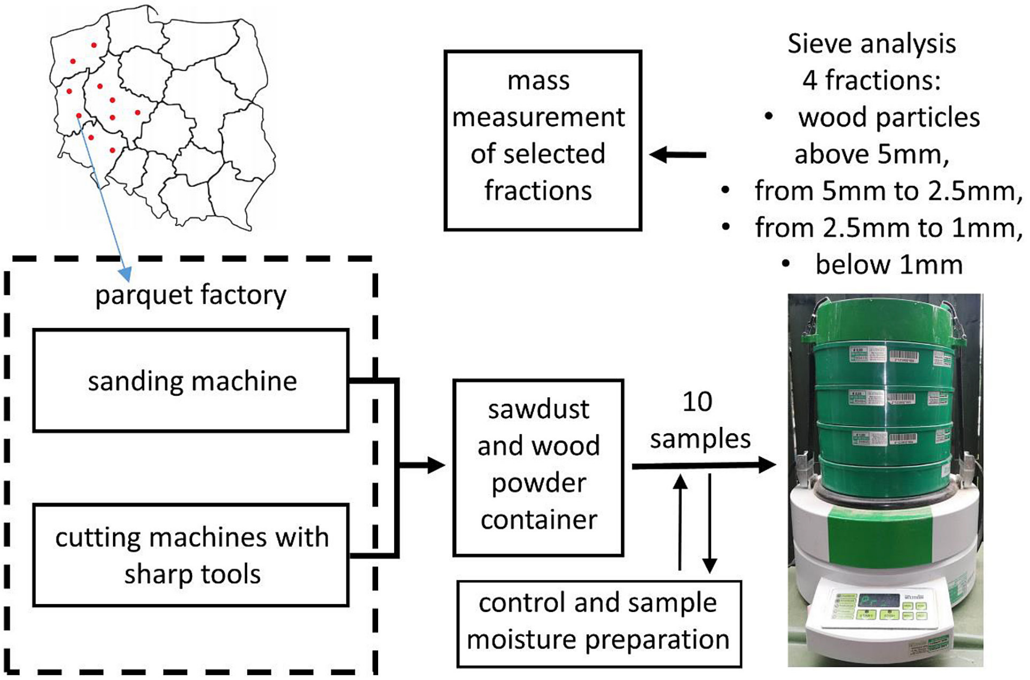

Fig. 1. Scheme of the measurement methodology

Table 2. Oak species composition and average density of the raw material used to produce parquet during sawdust sampling

Description	No. of the production facility				
	1	2	3	4	5
Species composition	Pedunculate oak 80% Sessile oak 19% Red oak 1%	Pedunculate oak 90% Sessile oak 6% Red oak 4%	Pedunculate oak 90% Sessile oak 10% Red oak 0%	Pedunculate oak 100% Sessile oak 0% Red oak 0%	Pedunculate oak 95% Sessile oak 5% Red oak 0%
Average density	0.80 ±0.1 kg/m^3	0.65 ±0.1 kg/m^3	0.75 ±0.1 kg/m^3	0.81 ±0.1 kg/m^3	0.62 ±0.1 kg/m^3
	No. of the production facility				
	6	7	8	9	10
Species composition	Pedunculate oak 99% Sessile oak 1% Red oak 0%	Pedunculate oak 100% Sessile oak 0% Red oak 0%	Pedunculate oak 85% Sessile oak 15% Red oak 0%	Pedunculate oak 94% Sessile oak 4% Red oak 2%	Pedunculate oak 95% Sessile oak 4% Red oak 1%
Average density	0.70 ±0.1 kg/m^3	0.77 ±0.1 kg/m^3	0.80 ±0.1 kg/m^3	0.75 ±0.1 kg/m^3	0.74 ±0.1 kg/m^3

Figure 2 presents the overall processing scheme, standard for all the production plants. Manufacturing oak parquet in the production plants can be divided into three main stages. The first stage involves sawmill processing, while the second stage encompasses surface leveling, the creation of installation grooves, and preliminary sanding. Sawdust was gathered from the first and second stages, which include sawing, planing, and milling of raw wood, as well as the initial sanding process. Thanks to this approach, dust contaminated with varnishes and adhesives was not collected. Thus, the sawdust came from different woodworking processes with varying process parameters. We collected research material aggregated from many processes and manufacturers who use processing parameters that can change over time.

Samples for testing were taken only from stages I and II, shown in Figure 2. Sawdust from stage III was not accepted due to its contamination with varnish, which constitutes hazardous waste [34, 35] and is subject to special restrictions during its disposal [36, 37]. As mentioned in the introduction, the granulometric composition of sawdust is influenced by the technological processes of woodworking and the parameters used in these processes. Table 3 presents machine

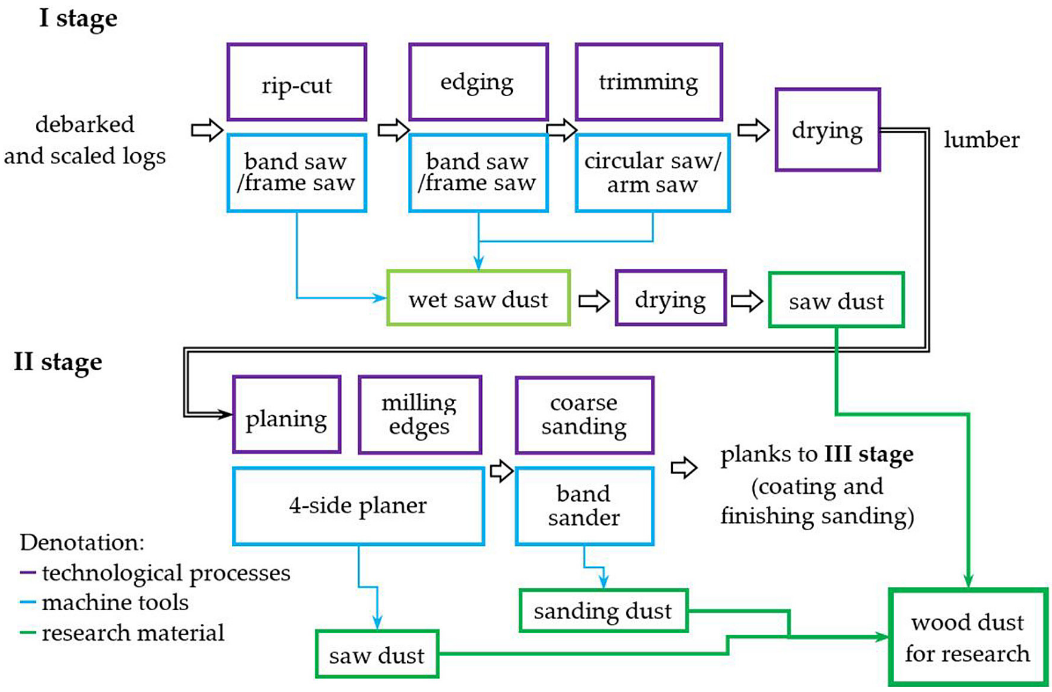

Fig. 2. The process through which the examined sawdust was generated

Table 3. Machine tools in the facilities and standard parameters of their settings (v_f – fed rate, v_c – cutting speed, P60 – sandpaper grit size)

Production facility				
1	2	3	4	5
Band saw (v_c = 40 m/s; v_f = 50 m/min) Band saw (v_c = 50 m/s; v_f = 50 m/min) Circular saw (v_c = 2500 m/min; v_f = 8 m/min) 4-side planer (v_c = 35 m/s; v_f = 20 m/min) Band sander (P60; v_c = 20 m/s)	Frame saw (v_c = 40 mm/rpm; v_f = 7 m/s) Band saw (v_c = 30 m/s; v_f = 40 m/min) Arm saw (v_c = 2800m/min; v_f = 7 m/min) 4-side planer (v_c = 55 m/s; v_f = 30 m/min) Band sander P60 (v_c = 24 m/s)	Band saw (v_c = 40 m/s; v_f = 30 m/min) Frame saw (v_c = 35 mm/rpm; v_f = 5 m/s) Circular saw (v_c = 3000m/min; v_f = 10 m/min) 4-side planer (v_c = 25 m/s; v_f = 10 m/min) Band sander (P60; v_c = 20 m/s)	4-side planer (v_c = 45 m/s; v_f = 20 m/min) Band sander (P60; v_c = 15 m/s)	Band saw (v_c = 45 m/s; v_f = 45 m/min) Band saw (v_c = 50 m/s; v_f = 60 m/min) Circular saw (v_c = 2000m/min; v_f = 5 m/min) 4-side planer (v_c = 35 m/s; v_f = 25 m/min) Band sander (P60; v_c = 11 m/s)
Production facility				
6	7	8	9	10
4-side planer (v_c = 25 m/s; v_f = 15 m/min) Band sander P60 (v_c = 20 m/s)	Band saw (v_c = 40 m/s; v_f = 30 m/min) Band saw (v_c = 50 m/s; v_f = 50 m/min) Arm saw (v_c = 3000m/min; v_f = 8 m/min) 4-side planer (v_c = 40 m/s; v_f = 30 m/min) Band sander (P60; v_c = 22 m/s)	Band saw (v_c = 40 m/s; v_f = 45 m/min) Band saw (v_c = 45 m/s; v_f = 35 m/min) Circular saw (v_c = 2500m/min; v_f = 10 m/min) 4-side planer (v_c = 35 m/s; v_f = 35 m/min) Band sander (P60; v_c = 18 m/s)	Band saw (v_c = 40 m/s; v_f = 40 m/min) Frame saw (v_c = 30 mm/rpm; 6 m/s) Arm saw (v_c = 2500m/min; v_f = 6 m/min) 4-side planer (v_c = 35 m/s; v_f = 20 m/min) Band sander (P60; v_c = 20 m/s)	4-side planer (v_c = 40 m/s; v_f = 25 m/min) Band sander (P60; v_c = 24 m/s)

tools used in woodworking and the standard parameters of their settings. The required moisture content of oak planks headed for wood floor production typically falls within the 10 ± 2% range. The moisture content of sawdust may differ from these values; therefore, the moisture content of the samples was tested with a halogen moisture analyzer (mod. HE73, mfg. Mettler-Toledo International Inc., Zurich, Switzerland). Every measurement was replicated three times, and the median value was chosen from each set of measurements. All test samples were taken from central dust collecting installations equipped with waste containers with a cover to protect against atmospheric conditions. To ensure consistent moisture content (MC) across all test samples, they underwent a one-month air-conditioning MC normalization process in a controlled environment with forced air circulation, maintaining a relative humidity of 60 ± 1% and a temperature of 20 ± 1°C (Table 4).

Granulometric composition analysis was performed using a laboratory sieve shaker (mod. LPzE-2e, mfg. Multiserw-Morek, Brzeźnica, Poland). Initially, a one-liter container was loaded with sawdust, and its mass was measured with a precision laboratory balance accurate to 0.01 g (mod. 572-35, mfg. Kern & Sohn GmbH, Frankfurt am Main, Germany). Then, the material was screened for ten minutes through three different mesh sizes to obtain wood particles distributed in four size fractions. Finally, the resulting fractions were weighted with a precision scale.

When analyzing measurement errors, the estimator of the desired value was determined using the arithmetic mean. Subsequently, a confidence interval was calculated for a confidence level of p = 0.05. The statistical analysis was conducted following procedures suitable for the normal distribution of the measured data points. In addition to the sawdust's characteristics, we assessed the sawdust tilt angle following the methodology outlined by Ockajova et al. [38] and determined its calorific value based on the research methodology recommended by the Laboratory of Measurements and Measurement Systems at Wrocław University of Science and Technology. It's important to note that, for calorific analysis, sawdust particles larger than 0.2 mm were crushed, as the recommended size for fuel particles in the calorific analysis should not exceed 0.2 mm [39].

Table 4. The moisture content of wood dust samples immediately after collection and after moisture content normalization

No. of facility	1	2	3	4	5	6	7	8	9	10
Initial MC (%)	9.1	11.0	12.3	9.8	9.1	12.1	9.8	13.1	12.3	12.6
Normalized MC (%)	9.3	9.9	11.1	8.8	8.5	10.9	8.8	11.4	11.1	11.3

RESULTS AND DISCUSSION

The sawdust's particle size distribution, gathered from ten different parquet plants, is presented in Figures 3 and 4. Notably, one liter of the analyzed wood particles weighs 210 g ± 1.7 g. Limited variations are recorded among the different production facilities, ranging from 209 g ± 11 g to 217 g ± 4 g. The recorded average moisture content of the sawdust samples is set at 9 ± 0.5%.

On average, particles measuring 5 mm or more weigh approximately 3.3 ± 0.2 g, while those ranging from smaller than 5 mm but equal to or greater than 2.5 mm weigh around 20.2 ± 0.8 g. The most prevalent fractions are comprised of particles smaller than 2.5 mm and equal to or larger than 1 mm, constituting approximately 74 ± 0.8 g, whereas particles smaller than 1 mm collectively weigh around 113 ± 1.3 g.

The collected wood particles, due to their size, can be classified according to EN ISO 17225-1:2021 [2] as fuel powder (consisting of wood particles below 1 mm), sawdust (wood particles from 1 mm to 5 mm), and shavings (wood particles from 1 mm to 30 mm). The results show a mean of 53.7% of fuel powder, 46.3% of shavings, or 44.8% of sawdust (fig. 5). In a study conducted by Relova et al. in 2009, the analyzed wood scrap (including bark) taken from a sawmill in Cuba, showing a similar fractionation, where about 47.8% was powder, 46.2% was shavings, while particles larger than 2 mm accounted for about 6% [5]. Zepeda-Cepeda et al. showed that waste from lumber production in Mexico provided mainly wood particles sized up to 1.41 mm (about 48%). In this study, wood particles below 0.85 mm represented about 26%, which is nearly half the amount found by other researchers, while almost half the amount of particles was above 2.36 mm (about 8%) [6]. A study carried out by Očkajová et al. in 2006 on circular saws [40], showed that, irrespective of the type of blade geometry, wood particles below 1 mm could account for between 31% and 59%, which is consistent with the results presented in the present study (mean 53%).

The literature review presented in the introduction showed that wood particle size is influenced by the machines used during their processing (tool geometries and process settings) and by the properties of the wood. Concerning the quality of the briquettes and pellets produced, it is vital to determine what fraction of wood particles will predominate in the material that will be further transformed. Accordingly, developing a productive process adapted to the material under study is necessary to ensure the highest quality of the solid biofuel produced [41].

Figure 4 presents the comparison of woodworking residues in all tested facilities. This indicates similar processing processes and facilitates briquette or pellet production design. The differences in wood processing parameters during parquet production in the ten analyzed companies do not significantly affect the quality and type of sawdust generated. This is due to the homogeneous raw material for production and the similarity of technological processes and groups of machines used in these processes.

The supplementary measurements, specifically concerning the tilt angle of sawdust (Table 5) and the calorific value (Table 6), reveal no substantial variations among the examined samples. Regarding tilt angles, the average value aligns with literature findings for oak sawdust (44°). Očkajová et al. in 2023 reported results in the range of 42° to 44° [38]. The material tested in our study has comparable granulometric composition to the material in cited studies; therefore, the outcomes for the angle of repose are consistent.

During the calorific value tests, the particle size distribution of the test samples became irrelevant, as all test samples underwent grinding to eliminate any fractions exceeding a sieve size of 0.2 mm. Consequently, the calorific value results are uniform across all test samples due to their nearly identical test material composition. These outcomes are also consistent with findings from other researchers. For instance, Quiroga et al. in 2010 reported a calorific value of approximately 19,119 ± 920 kJ/kg for oak wood waste particles [42]. At the same time, Lunguleasa et al. in 2022

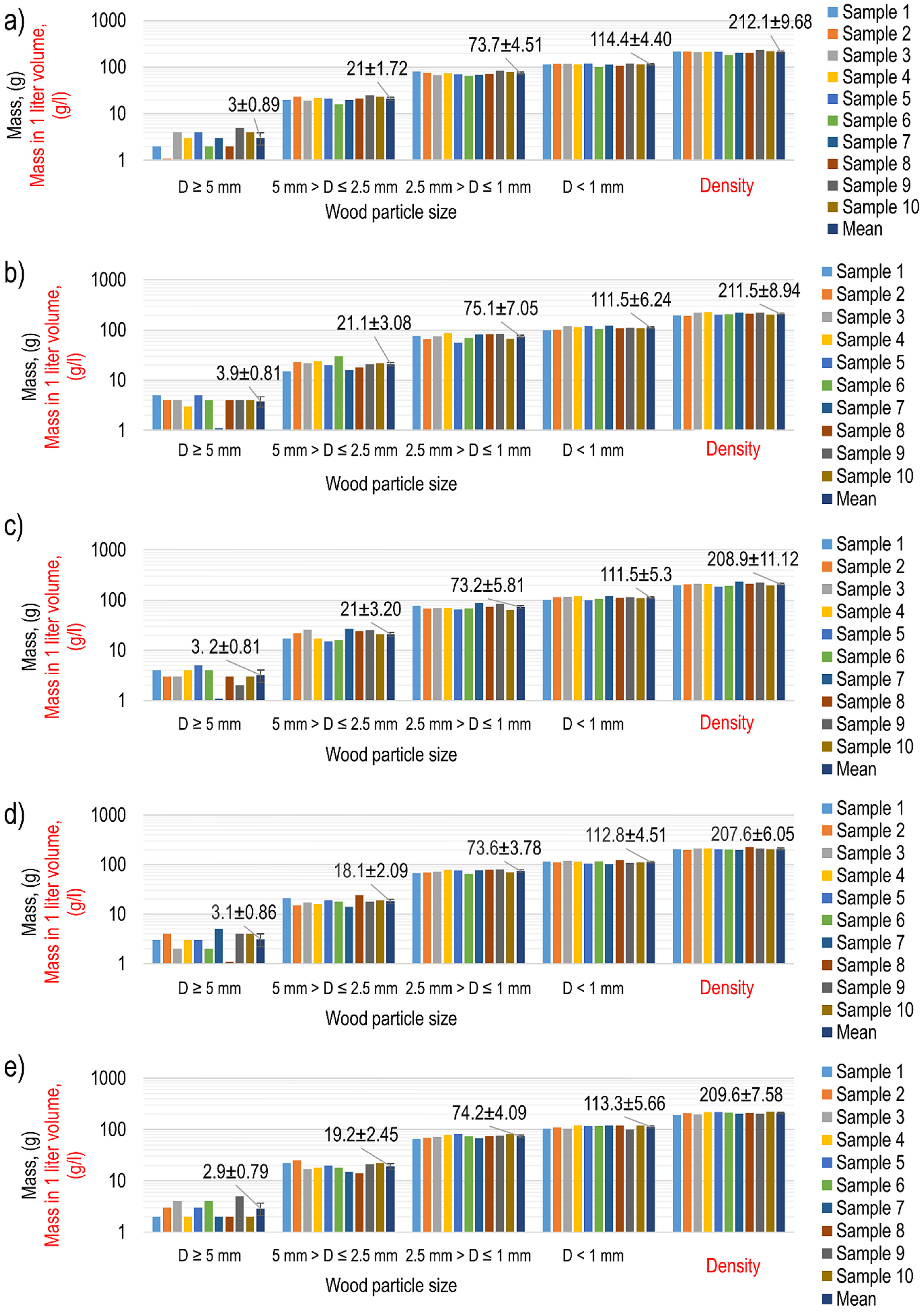

Fig. 3. Characteristics of the granulometric composition of wood by-products from parquet production plants in western Poland, where: D – wood particle size, (a) production plant 1, (b) production plant 2, (c) production plant 3, (d) production plant 4, production plant 5. All mean values were determined at a 95% confidence interval (p = 0.05)

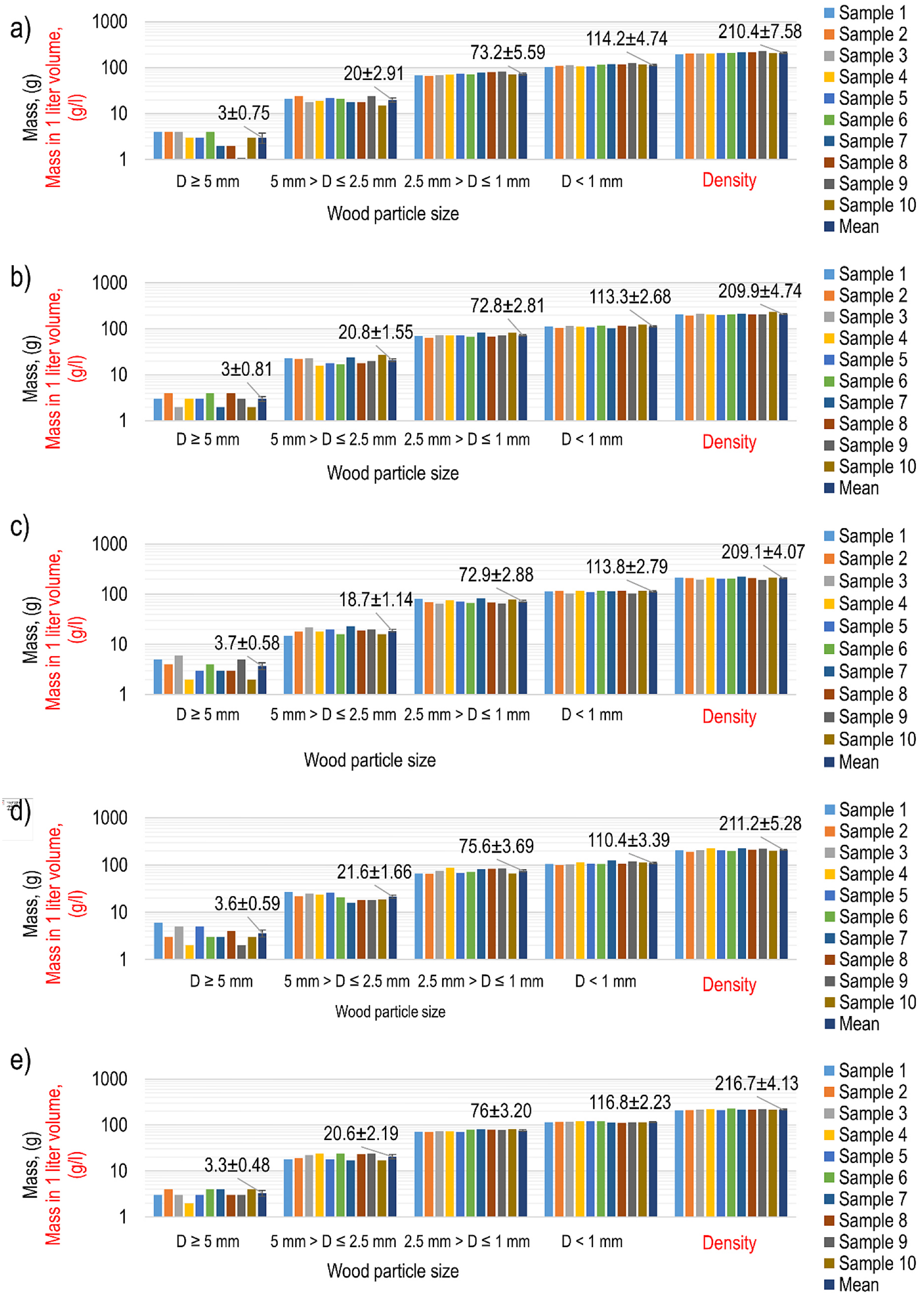

Fig. 4. Characteristics of the granulometric composition of wood by-products from parquet production plants in western Poland, where: D – wood particle size, (a) production plant 6, (b) production plant 7, (c) production plant 8, (d) production plant 9, production plant 10. All mean values were determined at a 95% confidence interval (p = 0.05)

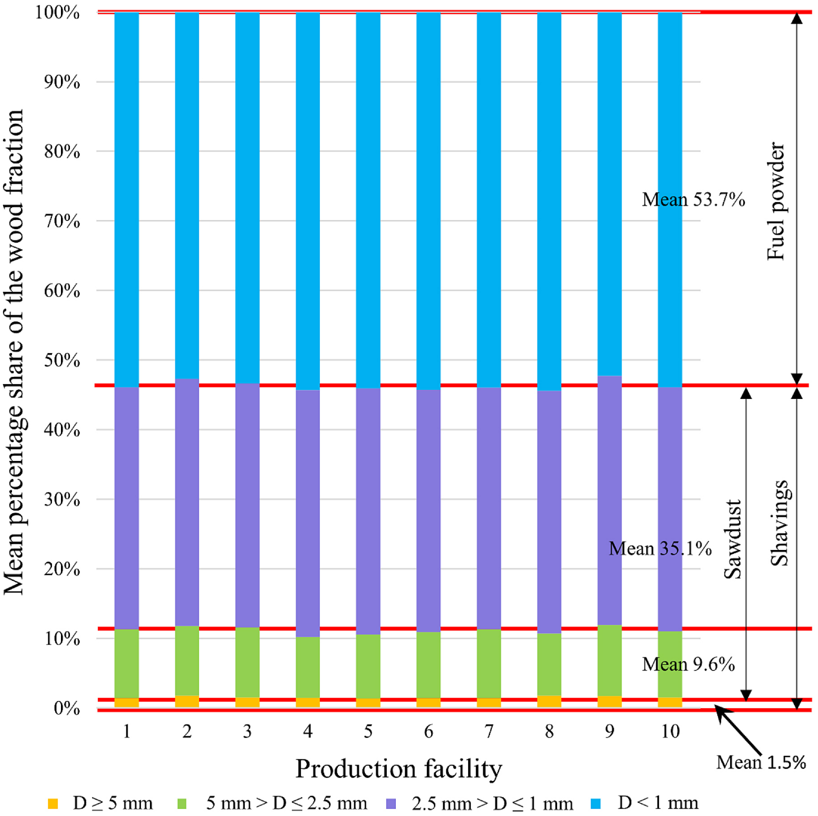

Fig. 5. Comparison of woodworking residues in all tested facilities

Table 5. Tilt angles of tested sawdust samples

Production facility				
1	2	3	4	5
44±1°	44±2°	43±2°	44±1°	45±2°
Production facility				
6	7	8	9	10
44±2°	42±2°	43±3°	44±2°	44±1°

Table 6. Calorific values of tested sawdust samples

Production facility				
1	2	3	4	5
18,750±1050 kJ/kg	20,900±950 kJ/kg	19,900±980 kJ/kg	18,800±830 kJ/kg	19,800±920 kJ/kg
Production facility				
6	7	8	9	10
21,050±1010 kJ/kg	20,545±1050 kJ/kg	19,675±850 kJ/kg	18,530±950 kJ/kg	19,920±1110 kJ/kg

measured the calorific value of oak sawdust at around 21,040 kJ/kg [43].”

There are many methods for measuring fraction size, and the appropriate one depends on the type of sample, the accuracy required by the test, and the tools and technologies available. There are many methods for measuring the particle size distribution, and the most appropriate depends on the type of sample, the accuracy required by the test, and the tools and technologies available. The sieving method reported here is well-suited for analyzing the fraction of shredded wood. Several complementary methodologies offer valuable insights when delving into the fractionation of sawdust. These include granulometric analysis, which can be further categorized into techniques like sieving, laser light diffraction, and image analysis. Additionally, microscopic approaches and flow particle size analysis hold promise. The optimal choice of fraction size measurement method hinges on factors such as the nature of the sample, the range of particle sizes, desired measurement precision, and the technological resources at hand. Frequently, a synergistic application of diverse methods is employed to achieve a more holistic and precise understanding of the subject matter [44].

CONCLUSIONS

This study aimed to analyze the fractional composition of waste generated during the production of oak parquet across ten manufacturing facilities in western Poland, offering a general overview of the attributes of the wood particles that can constitute the raw material for pellet production. Unlike existing scientific literature focusing solely on outcomes for wood particles generated during the pre-processing of wood (sawing of logs or planning of boards), this study broadens the scope by analyzing parameters of aggregated sawdust mixture from various subsequent wood machining stages, including shaping and routing, primary sanding, and sanding during finishing surfaces. While the study doesn't delve into the influences of specific wood machining processes, it offers valuable knowledge for pellet production from actual production waste. Based on the analysis of the research results, the following was concluded. The wood particles obtained during the production of oak parquet in ten production plants in western Poland are characterized by a mean wood particle size distribution in the range of 53.72 ± 0.51% (<1.0 mm fraction), 35.14 ± 0.27% (1.0-2.5 mm), 9.59 ± 0.36% (2.5-5.0 mm), and 1.55% ± 0.11% (>5 mm).

The particle size distributions of wood particles generated in all the examined plants exhibit remarkable similarity. Various factors, including variations in raw material species, geographical origins, density, humidity, and technological processes, do not exert significant influence on the granulometric size of the sawdust produced. The findings of this study offer insights for optimizing the utilization of sawdust generated during oak parquet production. Knowing its particle size distribution makes it feasible to anticipate the quality of end products, such as briquettes and pellets, supporting the production of high-quality solid biofuels. Further research should be carried out to determine the technological processes that treat the studied wastes to develop briquettes and pellets with the best exploitation properties or to look for another industrial application.

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