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Chemical, Morphological and Thermal Characterization of Rice Husk and Sunflower Stalk as Supplementary Raw Materials for Particleboard Manufacturing

Yonga Levha İmalatında Yardımcı Hammadde Olarak Pirinç Kabuğu ve Ayçiçeği Sapının Kimyasal, Morfolojik ve Termal Karakterizasyonu

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Abstract
This study presents a comprehensive material-level characterization of rice husk and sunflower stalk as potential supplementary raw materials for particleboard manufacturing, with industrial wood chips used as a reference material. To evaluate their suitability in terms of raw material selection and process safety, proximate composition analyses (moisture, ash, protein, dietary fiber, and cellulose), elemental composition, total oil content, fatty acid profiling, self-ignition behavior, and surface morphology were systematically investigated. The results revealed that sunflower stalk exhibits properties much closer to traditional wood chips in several parameters compared to rice husk. Scanning electron microscope observations confirmed that the porous structure of sunflower stalk could offer similar advantages to wood chips in terms of adhesive penetration and mechanical interlocking during board production. Self-ignition tests further revealed distinct thermal stability profiles among the materials. Rice husk exhibited ignition at lower temperatures and shorter exposure times, whereas sunflower stalk showed no ignition under the tested conditions. Overall, the findings highlight sunflower stalk as a promising supplementary lignocellulosic resource whose chemical, morphological, and thermal characteristics approach those of conventional wood chips. This study provides a fundamental characterization framework that can support future particleboard manufacturing trials and formulation optimization involving agricultural residues.

Öz
Bu çalışma, endüstriyel odun talaşını referans malzeme olarak kullanarak, yonga levha üretiminde potansiyel ek hammadde olarak pirinç kabuğu ve ayçiçeği sapının kapsamlı bir malzeme düzeyinde karakterizasyonunu sunmaktadır. Hammadde seçimi ve süreç güvenliği açısından uygunluklarını değerlendirmek için, yaklaşık bileşim analizleri (nem, kül, protein, diyet lifi ve selüloz), elementel bileşim, toplam yağ içeriği, yağ asidi profili, kendiliğinden tutuşma davranışı ve yüzey morfolojisi sistematik olarak incelenmiştir. Elde edilen sonuçlar, ayçiçeği sapının birçok parametre bakımından pirinç kabuğuna kıyasla geleneksel odun yongalarına daha yakın özellikler sergilediğini ortaya koymuştur. Taramalı elektron mikroskobu gözlemleri, ayçiçeği sapının gözenekli yapısının levha üretimi sırasında yapıştırıcı penetrasyonu ve mekanik kenetlenme açısından odun yongalarına benzer avantajlar sağlayabileceğini doğrulamıştır. Kendiliğinden tutuşma testleri ise materyaller arasında farklı termal stabilite profillerinin bulunduğunu göstermiştir. Pirinç kabuğunda daha düşük sıcaklıklarda ve daha kısa maruziyet sürelerinde tutuşma gözlenirken, ayçiçeği sapında test edilen koşullar altında herhangi bir tutuşma meydana gelmemiştir. Genel olarak bulgular, ayçiçeği sapının kimyasal, morfolojik ve termal özellikleri bakımından geleneksel odun yongalarına yaklaşan umut vadeden tamamlayıcı bir lignoselülozik kaynak olduğunu göstermektedir. Bu çalışma, tarımsal atıkları içeren sunta üretimi denemelerini ve formülasyon optimizasyonunu destekleyebilecek temel bir karakterizasyon çerçevesi sunmaktadır.

INTRODUCTION

The particleboard industry relies heavily on wood chips as the primary raw material (Guler et al., 2016; Ayata & Çamlıbel, 2023; Aras & Kalaycıoğlu, 2023); however, increasing demand, rising costs, and sustainability concerns associated with forest resources have intensified the search for alternative lignocellulosic materials (Dukarska et al., 2025). In this context, agricultural residues have attracted significant attention due to their wide availability, low cost, and reduced environmental footprint. Utilizing such residues not only alleviates pressure on forest resources but also supports circular economy strategies by converting low-value biomass into high-value composite materials. Among various agricultural by-products, rice husk and sunflower stalk are generated in substantial quantities worldwide and are often underutilized or disposed of through open burning, leading to environmental concerns (Gupta et al., 2022, 2023; Singh et al., 2025).

Rice husk has been extensively investigated as a filler or reinforcement material in composite panels due to its high silica content and fibrous structure, which can enhance fire resistance and dimensional stability (Ndazi et al., 2007; Suhot et al., 2021; Boran et al., 2026). However, its elevated ash content and silica-rich surface often pose challenges in adhesive bonding, potentially compromising mechanical performance in particleboard applications. Sunflower stalk, on the other hand, has emerged as a promising lignocellulosic resource owing to its favorable chemical composition, porous structure, and relatively low density (Mehdikhani et al., 2019; Kindzera & Kochubei, 2025). Previous studies have demonstrated that sunflower stalk-based panels can exhibit acceptable mechanical properties when appropriately processed, although issues related to heterogeneity, mineral content, and thermal behavior remain insufficiently addressed (Bektas et al., 2005; Efe & Alma, 2014; Ghofrani et al., 2015; Güler, 2019; Bekhta et al., 2023). Notably, comparative studies that simultaneously evaluate chemical composition, elemental profile, surface morphology, lipid characteristics, and self-ignition behavior of these materials alongside conventional wood chips are still limited. Material characterization studies play a crucial role in narrowing down viable agricultural residues before time- and cost-intensive particleboard manufacturing trials are conducted (Jawaid et al., 2017).

In this study, rice husk and sunflower stalk were evaluated as potential supplementary raw materials for particleboard manufacturing through a comprehensive material characterization approach. Rather than producing laboratory-scale particleboards and performing mechanical performance tests, the present work focuses on comparing the chemical composition, elemental distribution, surface morphology, fatty acid profile, and self-ignition behavior of these agricultural residues with industrial wood chips. These material-level properties are known to critically influence raw material selection, process safety, adhesive interaction, and thermal stability during particleboard production. Accordingly, the findings of this study aim to provide a fundamental assessment that can guide future panel manufacturing studies and formulation optimization involving agricultural residues.

MATERIALS AND METHODS

Materials

Tests were performed on Wood Chips (I), Rice Husks (II), and Sunflower stalks (III). The samples used were representative samples obtained under normal operating conditions of the process. The rice husks were sourced from KANITEMİZ Gıda Tar. Hay. İnş. Nak. San. ve Tic. Ltd. Şti. in Osmancık, Çorum. Sunflower stalks were sourced from fields belonging to Çorum Municipality in the Konaklı district. Wood chips were supplied by ÇAMSAN ORDU Ağaç San. ve Tic. A.Ş., and Kolçam Ağaç San. ve Tic. A.Ş.

Method for Determining Self-Ignition Temperature

To perform the tests in compliance with the SR EN 15188:2008 standard, a laboratory oven setup was utilized. This standard outlines the procedures for analyzing and evaluating the self-ignition temperatures (TSI) of combustible dust or granular materials under hot storage conditions in ovens operating at constant temperatures. The specified method is applicable to all solid materials for which the thermal explosion theory defined in Annex A.2 is valid and is not limited solely to oxidatively unstable substances.

The test method is primarily intended for dust or granular substances that react with atmospheric oxygen. For safety reasons, it is not applicable to materials mixed with solid/liquid oxidizers (e.g., gunpowder, thermite, or wood impregnated with liquid oxygen), or to substances capable of undergoing violent non-oxidative reactions (e.g., peroxides, explosives). However, on a case-by-case basis, certain materials that may undergo non-oxidative reactions (e.g., non-violent exothermic decomposition) can be tested if additional safety precautions are implemented.

The oven temperature was monitored through a digital display located on the device, and ignition of the samples was visually inspected at specified time intervals to assess whether combustion occurred (Prodan et al., 2022).

Determination of % Moisture

Moisture determination was performed using a KERN DBS60-3 (Germany) moisture analyzer, equipped with a halogen heating system and integrated analytical balance. The halogen lamp ensured uniform heating at the present temperature until the sample was completely dried, reaching zero moisture content. Upon completion, the device displayed both the final weight and the moisture percentage. This model allows temperature settings between 50 °C and 200 °C. The analytical balance features a resolution of 0.001 g, repeatability of ±0.0001 g, and a maximum capacity of 60 g. The studies were conducted in triplicate.

Method for Total Oil Extraction

The oil content of wood chips (I), rice husks (II), and sunflower stalks samples was determined using the Soxhlet extraction method with diethyl ether as the solvent (Kabutey et al., 2022). Approximately 10 grams of each sample were used for the extraction. The solvents in the extracted oils were first removed using a rotary evaporator. To ensure complete solvent elimination, the oils were further dried in an oven until a constant weight was achieved. The oil content (%) was then calculated using the following formula (1):

$$\text{Oil content (\%)} = (\text{Weight of total oil (g) / Weight (g) of sample}) \times 100 \quad (1)$$

The oil yields were calculated, and the extracted oils were subsequently subjected to fatty acid composition analysis.

Method for Determining Fatty Acid Composition

The extracted oils were saponified following standard IUPAC procedures. Fatty acids were subsequently esterified using 10% (v/v) methanolic boron trifluoride (BF_3-MeOH) as the esterification reagent. Methylation of total lipids was performed to obtain fatty acid methyl esters (FAMEs), in accordance with the AOAC official method (Yeşilayer & Genç, 2013; Kisa et al., 2020).

Gas chromatographic (GC) analysis was carried out using a Thermo Scientific Trace 1310 GC system equipped with a flame ionization detector (FID) and operated in split mode (split ratio: 50:1). The system was fitted with an RTX-2330 apolar capillary column (30 m × 0.25 mm i.d., 0.2 µm film thickness; Restek). Helium was used as the carrier gas at a flow rate of 1.0 mL/min. The injector and detector temperatures were set at 250 °C and 260 °C, respectively.

The oven temperature program was as follows: an initial temperature of 70 °C was raised to 120 °C at a rate of 4 °C/min. Without holding, the temperature was further increased to 180 °C at a rate of 2 °C/min and held for 3 minutes. Subsequently, the temperature increased to 200 °C at 4 °C/min and held for another 3 minutes, followed by a final increase to 230 °C at 7 °C/min, with a hold time of 5.21 minutes.

Fatty acid components were identified by comparing their retention times with those of an authentic standard mixture (Supelco 37 Component FAME Mix, Catalog No. 18919). The relative composition of fatty acids was expressed as the percentage of total identified fatty acids, based on peak areas obtained from FID chromatograms.

Protein Determination

Protein determination of samples was performed according to AOAC Standard Method No: 945.18-B (AOAC, 1945). A measured sample of a precise mass was heated and digested in a concentrated sulfuric acid solution using a Kjeldahl flask. To enhance the decomposition rate, the digestion was carried out in the presence of an appropriate catalyst. During the combustion process, organic compounds were oxidatively broken down, while nitrogen was reduced and converted to ammonium sulfate ($(NH_4)_2SO_4$). Following the addition of a sodium hydroxide (NaOH) solution, the released ammonia was distilled via steam distillation and captured in a receiving flask. The protein content was then quantified by titrating the distillate with standardized sulfuric acid (H_2SO_4) solution. The studies were conducted in triplicate.

Determination of Dry Matter

The dry matter content of the samples was determined following the AOAC 925.10 method (AOAC, 1925). Approximately 5–10 g of solid food material was accurately weighed (precision ±0.1 mg) into pre-dried, tared moisture dishes. Samples were oven-dried at 105°C until constant weight was attained. After drying, the dishes were transferred to a desiccator for cooling and reweighed with high precision. The studies were conducted in triplicate.

The percentage of dry matter (g/100 g) was calculated using the following formula (2):

$$\%Dry\ matter\ (g/100\ g) = (T2 - T1)\ /\ S \times 100 \tag{2}$$

T_1 = Tare weight of the container (g)
T_2 = Tare weight of the container (g) + dry matter weight (g)
S = Sample weight (g)

Ash Determination

Ash content determination was performed according to AACC Standard Method No: 08-01.01 (AACC, 1999a). The method involved weighing a specified sample quantity into a pre-ashed porcelain crucible, followed by combustion in a muffle furnace at 600-900°C until complete oxidation of organic matter. The studies were conducted in triplicate.

The total ash percentage (g/100g) was calculated using the formula (3):

$$\%\ \mathrm{Total\ ash\ (g/100g)} = (100(\mathrm{a} - \mathrm{b})/\mathrm{S}) \times (100/(100 - \mathrm{N})) \tag{3}$$

a = Weight of ash + porcelain crucible (g)
b = Weight of porcelain crucible (g)
S = Sample weight (g)
N = Moisture content of sample (%)

Total Dietary Fiber Determination

The total dietary fiber content was analyzed following AOAC Method 991.43 (AOAC, 1991). Samples underwent sequential enzymatic hydrolysis with α-amylase, protease, and amyloglucosidase in a controlled digestion system to eliminate starch and protein components. After enzymatic treatment, soluble dietary fiber was precipitated using ethanol, followed by successive washes with water and acetone. The remaining residue was oven-dried and precisely weighed to determine the total dietary fiber content. The studies were conducted in triplicate.

Determination of Crude Cellulose

Cellulose content was determined according to AACC Standard Method No: 32-10 (AACC, 1999b). Samples were boiled with sulfuric acid and sodium hydroxide, filtered, and washed with acetone. The obtained residue was dried and subsequently ashed. The resulting weight after combustion represents the crude cellulose content of the sample. The studies were conducted in triplicate.

Determination of Elemental Composition

The elemental composition of the samples was determined using inductively coupled plasma optical emission spectrometry (ICP-OES). All chemicals used throughout the analysis were of analytical grade and employed without further purification. For sample digestion, concentrated nitric acid (HNO_3, 65% v/v; Sigma-Aldrich, St. Louis, MO, USA) and hydrogen peroxide (H_2O_2, 30% m/v; Merck, Darmstadt, Germany) were utilized. Calibration standards for elements including Al, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, and Zn were prepared from a commercially available multi-element standard solution (Merck, Item No. 1.11355, Darmstadt, Germany). Approximately 0.4 g of each homogenized powdered sample was accurately weighed into Teflon digestion vessels. A mixture of 7 mL HNO_3 and 1 mL H_2O_2 was added to each sample prior to digestion. The microwave assisted digestion was carried out using a closed vessel system (Speedwave, Berghof Instruments, Germany), following a three-stage temperature protocol recommended by the manufacturer: initial heating at 145 °C for 5 minutes, followed by 200 °C for 10 minutes, and then cooling at 50 °C for 10 minutes. After digestion, the resulting clear solutions were transferred to 25 mL volumetric flasks and brought to volume with ultrapure deionized water.

Elemental concentrations were measured using an ICP-OES instrument (iCAP 6000 Dual View, Thermo Scientific, Cambridge, UK). Quantification was achieved using external calibration curves established with appropriate standard solutions. All measurements were performed in triplicate to ensure analytical accuracy and reproducibility (Sezer et al., 2018).

SEM Imaging Method

Scanning electron microscopy (SEM) analysis was performed to examine the surface morphologies of the raw materials (rice husk, sunflower stalk, and wood chips) used in the study. SEM imaging was performed using a Quanta FEG 450 microscope located at the Hitit University Scientific and Technical Application and Research Center (HÜBTUAM). The samples were prepared by drying and grinding before analysis; a thin layer of gold (Au) coating was applied to the samples to increase surface conductivity. The coating process was carried out using the sputter coating method under low vacuum conditions. Imaging was performed under a 5 kV accelerator voltage and in high vacuum mode, and randomly selected surface regions from each sample were examined at different magnification levels (e.g., ×500, ×1.000, ×5.000). Morphological parameters such as surface roughness, fibrous structure, porosity, and microstructural regularity were evaluated from the obtained images, and the materials were interpreted comparatively.

RESULTS AND DISCUSSION

Proximate Composition Analyses

Dry Matter (%)

Among the tested materials, wood chips exhibit the lowest dry matter content (99.34%), whereas sunflower stalks (99.81%) and rice husks (99.36%) present higher values as shown in Table 1. Dry matter content reflects the proportion of non-water components in biomass and is inversely related to moisture content. Thus, materials with higher dry matter content contain less moisture and exhibit a drier composition. The elevated dry matter levels observed in sunflower stalks and rice husks indicate these agricultural residues have reduced moisture retention capacity compared to wood chips. This difference arises from their inherent structural properties; the fibrous and porous nature of lignocellulosic agricultural byproducts results in lower moisture adsorption than denser wood-based materials, such as wood chips (Anand et al., 2023)

Ash (%)

Among the analyzed biomass samples (wood chips, sunflower stalks, and rice husks) wood chips showed the lowest inorganic content with an ash content of 1.14%. Sunflower stalks (8.67%) and rice husks (15.01%), however, exhibited substantially higher mineral content. Ash content reflects the inorganic fraction of biomass, representing the non-combustible residue remaining after complete combustion. The particularly high ash content in rice husks is mainly due to their elevated silica (SiO_2) concentration, which can account for up to 90% of their inorganic composition, leading to significant residual ash (Surahmanto & Harnowo, 2020). Likewise, sunflower stalks display considerable ash content, which can be attributed to agricultural factors, such as soil contamination during harvesting and the inherent inorganic components within their cell wall structure (Isemin et al., 2022).

Protein (%)

Among the analyzed biomass samples, wood chips contained the lowest protein content (0.80%), while sunflower stalks (2.23%) and rice husks (2.55%) demonstrated higher protein levels as shown in Table 1. Although protein content is widely studied within the context of biomass conversion processes, particularly anaerobic digestion and bioenergy production, studies on its direct effect on particleboard performance have not been encountred in the literature. This is thought to stem from the general acceptance that the contribution of proteins to plate properties is more limited compared to the main lignocellulosic components: cellulose, hemicellulose, and lignin.

Protein content is a key indicator of biochemical quality in lignocellulosic biomass, significantly affecting fermentation efficiency and biodegradability (Surahmanto & Harnowo, 2020; Lymperatou et al., 2023). The observed differences in protein content likely arise from variations in biomass composition, structural properties, and agronomic factors, including cultivation practices and harvest timing.

Dietary Fiber (%)

The wood chips exhibited an intermediate dietary fiber content of 27.05%, falling between sunflower stalks (23.61%) and rice husks (35.79%). Dietary fiber in lignocellulosic biomass mainly consists of cellulose, hemicellulose, and lignin, which are the principal structural components responsible for the performance of biomass-based composite materials. The higher fiber content observed in rice husks can be attributed to their cell wall composition, which contains abundant lignocellulosic fibers and inorganic constituents such as silica (Fadaei & Salehifar, 2012). Sunflower stalks, despite their agricultural origin, showed lower fiber content than wood chips, likely due to their less dense fibrous structure and greater porosity. The moderate fiber content of wood chips reflects their woody composition, which provides a more compact and uniform fiber distribution.

With the increasing global demand for wood-based products, the depletion of forest resources, and growing environmental concerns, lignocellulosic agricultural residues have attracted considerable attention as alternative raw materials for particleboard production (Borysiuk et al., 2019). The suitability of these materials is largely associated with their fiber content and composition. Cellulose-rich fibers contribute to the formation of a strong reinforcing network within the board structure, resulting in improved mechanical strength, stiffness, and dimensional stability, whereas lignin can soften during hot pressing and act as a natural binding component, thereby enhancing inter-particle adhesion and resistance to moisture-related deterioration (Alharbi et al., 2020) Therefore, the relatively high fiber contents observed in rice husks and wood chips suggest their potential to provide adequate structural performance in particleboard applications.

Nevertheless, the successful utilization of agricultural residues depends not only on fiber content but also on their physicochemical characteristics. High water absorption capacity, excessive extractive substances, and elevated ash or silica contents may negatively affect adhesive bonding and panel performance. Consequently, these materials are frequently blended with industrial wood particles or subjected to chemical and physical surface modifications, including alkaline, silane, or plasma treatments, to improve compatibility and enhance board properties (Alharbi et al., 2020). Such approaches support the development of sustainable particleboards and biocomposites with reduced dependence on virgin wood resources and petrochemical-based materials, thereby contributing to circular economy principles and environmentally friendly panel production (Pędzik et al., 2021). Overall, the dietary fiber results obtained in the present study are particularly important because they provide an indirect indication of the lignocellulosic constituents responsible for the mechanical performance, dimensional stability, and durability of particleboards.

Crude Cellulose (%)

Analysis of crude cellulose content revealed rice husks had the highest concentration at 50.39%, followed by wood chips (47.64%), while sunflower stalks contained the least (41.55%). As the primary structural polysaccharide in lignocellulosic biomass, cellulose plays a crucial role in biocomposite production, paper manufacturing, and bioplastic synthesis. The high cellulose content in rice husks results from their fibrous tissue architecture and silica-reinforced cell walls, enhancing resistance to thermal and mechanical processing. Wood chips, derived from arboreal sources, feature densely packed, highly organized cellulose microfibrils that make them particularly suitable for cellulose-based industrial applications. Sunflower stalks' relatively lower cellulose content reflects both reduced cellulose deposition in their stem structure and less compact tissue structure. (Rudi et al., 2016).

Table 1. Basic composition of wood chips, sunflower stalks, and rice husks

Sample Type	Dry Matter (%)	Ash (%)	Protein (%)	Dietary fiber (%)	Crude Cellulose (%)
Wood Chips	99.34±0.30	1.14±0.01	0.80±0.02	27.05±0.50	47.64±0.45
Sunflower Stalks	99.81±0.08	8.67±0.13	2.23±0.02	23.61±0.51	41.55±0.20
Rice Husks	99.36±0.13	15.01±0.01	2.55±0.46	35.79±0.15	50.39±0.26

Result of Total Oil Content

Soxhlet extraction was performed to determine the oil content of three different samples, and the results are presented in Figure 1. According to these findings, the oil percentages in sunflower stalks (0.597%) and wood chips (0.656%) were like each other, being approximately three times higher than the percentage found in rice husks (0.214%).

The oil content of sunflower stalks (*Helianthus annuus* L. stalk) significantly differs from that of the seeds, which are known for their high oil content (ranging from 22% to 50%). While sunflower seeds are rich in oil, the stalks primarily consist of a lignocellulosic structure and are commonly considered as a source of biomass fuel or fiber. Due to the extremely low oil content of the stalks, relevant studies on this subject are scarce in the literature. This has generally been addressed in the context of using the stalks as green biomass or as roughage in animal feed. (Marechal & Rigal, 1999).

In the literature, the oil content of wood and consequently of screened wood chips is generally reported to be very low, typically below 1%. Some sources indicate that the 'ether extract', which includes oils, waxes, resins, and pigments, can range from 0.4% to 2.0% of the wood's dry weight. However, it has been reported that a significant portion of this extract consists of non-lipid organic compounds. (Miranda et al., 2017).

The oil content of rice husk, which constitutes the outermost layer of the rice grain, differs significantly from that of rice bran and is generally very low. While rice bran contains approximately 15–25% oil, the oil content of rice husk is typically reported to be around 0.2–0.9%, with its main components identified as cellulose, lignin, and a high proportion of silica (Korotkova et al., 2016; Scaglioni & Badiale-Furlong, 2016; Edrisi et al., 2018).

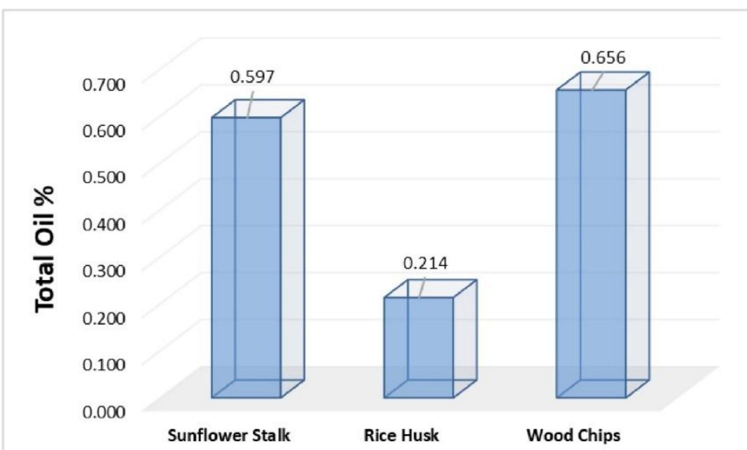

Figure 1. Total oil of samples

Fatty Acid Composition Results

When comparing the fatty acid profiles of the three different oil samples (sunflower stalk, rice husk, and wood chips), significant differences were observed in both saturated and unsaturated fatty acid contents. These differences may influence their potential applications in various industrial fields.

Examining the fatty acid composition of oil obtained from sunflower stalks (as shown in Table 2) reveals results that are compatible with those of sunflower oil (Akkaya, 2018; Baydar & Erbaş, 2005). Sunflower stalk oil is notable for its high unsaturated fatty acid content (77.71%), which gives it a liquid consistency, relatively low oxidative stability and makes it suitable for use as a fuel. Notably, it contains high levels of monounsaturated and polyunsaturated fatty acids (MUFA and PUFA), including oleic acid (42.30%) and linoleic acid (23.37 %). The saturated fatty acid (SFA) content is relatively low at 21.61%, and the SFA/UFA ratio is the lowest of all the samples at 0.28. This indicates favourable properties such as good fluidity and a low freezing point (Hoekman et al., 2012).

Table 2. Fatty acid profile of sunflower stalk sample

Fatty acid methyl ester (FAME)	Content (%)
C4:0 (Butyric Acid Methyl Ester)	0.54
C15:0 (Pentadecanoic Acid Methyl Ester)	0.42
C16:0 (Palmitic Acid Methyl Ester)	8.24
C16:1 (Palmitoleic Acid Methyl Ester)	0.52
C17:0 (Heptadecanoic Acid Methyl Ester)	0.39
C17:1 (cis-10-Heptadecenoic Acid Methyl Ester)	0.35
C18:0 (Stearic Acid Methyl Ester)	5.49
C18:1n9c (Oleic Acid Methyl Ester)	42.30
C18:2n6c (Linoleic Acid Methyl Ester)	23.37
C20:0 (Arachidic Acid Methyl Ester)	2.96
C18:3n3 (α-Linolenic Acid Methyl Ester)	2.88
C21:0 (Heneicosanoic Acid Methyl Ester)	0.33
C20:3n6 (cis-8, 11, 14-Eicosatrienoic Acid Methyl Ester)	7.54
C24:0 (Lignoceric Acid Methyl Ester)	3.24
C22:6n3 (cis-4, 7, 10, 13, 16, 19-Docosahexaenoic Acid Methyl Ester)	0.75
Saturated Fatty Acids (SFA) %	***21.61***
Unsaturated Fatty Acids (UFA) %	***77.71***
Saturated/Unsaturated Fatty Acid Ratio (SFA/UFA) %	***0.28***
Monounsaturated Fatty Acid (MUFA) %	***43.17***
Polyunsaturated Fatty Acid (PUFA) %	***34.54***

The fatty acid composition of rice husk oil determined by GC–FID analysis is presented in Table 3. The results indicate that rice husk oil is characterized by a predominance of unsaturated fatty acids (54.49%), with saturated fatty acids accounting for 45.50% of the total fatty acid content. The calculated SFA/UFA ratio (0.84) suggests a relatively balanced fatty acid profile, with a slight dominance of unsaturated components.

Oleic acid (C18:1n9c) was identified as the major fatty acid, representing 35.05% of the total fatty acids, followed by palmitic acid (C16:0, 26.70%) and linoleic acid (C18:2n6c, 8.18%). These findings are consistent with previous reports on rice husk and rice bran oils, where oleic and palmitic acids were reported as the dominant fatty acids, typically ranging between 30–40% and 20–30%, respectively (Ghazani & Marangoni, 2016; Sahu et al., 2018; Dunford, 2019). The observed linoleic acid content is also in agreement with literature values, which generally fall within the range of 7–12%, depending on rice variety, cultivation conditions, and extraction method.

The presence of monounsaturated fatty acids (MUFA) at a relatively high level (38.97%) is mainly attributed to oleic acid, while polyunsaturated fatty acids (PUFA) constituted 15.52% of the total fatty acids. Similar MUFA-dominant profiles have been reported for rice-derived oils, highlighting their favorable oxidative stability compared to oils rich in PUFA.

Table 3. Fatty acid profile of oils in rice husk sample

Fatty acid methyl ester (FAME)	Content (%)	Fatty acid methyl ester (FAME)	Content (%)
C8:0 (Caprylic Acid Methyl Ester)	0.10	C18:2n6c (Linoleic Acid Methyl Ester)	8.18
C10:0 (Capric Acid Methyl Ester)	0.23	C18:3n3 (α-Linolenic Acid Methyl Ester)	1.32
C11:0 (Undecanoic Acid)	0.29	C21:0 (Heneicosanoic Acid Methyl Ester)	2.52
C12:0 (Lauric Acid Methyl Ester)	0.85	C20:3n6 (cis-8, 11, 14-Eicosatrienoic Acid Methyl Ester)	2.85
C13:0 (Tridecanoic Acid Methyl Ester)	0.34	C22:2 (cis-13, 16-Docosadienoic Acid Methyl Ester)	1.73
C14:0 (Myristic Acid Methyl Ester)	2.18	C20:5n3 (cis-5, 8, 11, 14, 17-Eicosapentaenoic Acid Methyl Ester)	1.44
C15:0 (Pentadecanoic Acid Methyl Ester)	0.97	C24:0 (Lignoceric Acid Methyl Ester)	4.44
C15:1 (cis-10-Pentadecanoic Acid Methyl Ester)	0.50	***Saturated Fatty Acids (SFA) %***	***45.50***
C16:0 (Palmitic Acid Methyl Ester)	26.70	***Unsaturated Fatty Acids (UFA) %***	***54.49***
C16:1 (Palmitoleic Acid Methyl Ester)	3.42	***Saturated/Unsaturated Fatty Acid Ratio (SFA/UFA) %***	***0.84***
C17:0 (Heptadecanoic Acid Methyl Ester)	2.31	***Monounsaturated Fatty Acid (MUFA) %***	***38.97***
C18:0 (Stearic Acid Methyl Ester)	4.59	***Polyunsaturated Fatty Acid (PUFA) %***	***15.52***
C18:1n9c (Oleic Acid Methyl Ester)	35.05		

The fatty acid composition of screened wood chips oil determined by GC–FID analysis is presented in Table 4. The results reveal that this oil exhibits the highest proportion of saturated fatty acids (SFA, 44.98%) among the samples analyzed, indicating a relatively rigid and thermally stable lipid structure. The unsaturated fatty acid (UFA) content was determined as 55.01%, resulting in an SFA/UFA ratio of 0.82, which is the highest value observed within the studied group. This elevated ratio suggests that screened wood chips oil is likely to exhibit higher viscosity and a higher flash point compared to oils with lower SFA/UFA ratios (Knothe, 2005; Ramos et al., 2009).

Table 4. Fatty acid profile of wood chips sample

Fatty acid methyl ester (FAME)	Content (%)	Fatty acid methyl ester (FAME)	Content (%)
C6:0 (Caproic Acid Methyl Ester)	0.18	C21:0 (Heneicosanoic Acid Methyl Ester)	0.64
C8:0 (Caprylic Acid Methyl Ester)	0.25	C20:3n3 (cis-11, 14, 17-Eicosatrienoic Acid Methyl Ester)	1.65
C10:0 (Capric Acid Methyl Ester)	0.25	C20:3n6 (cis-8, 11, 14-Eicosatrienoic Acid Methyl Ester)	7.61
C12:0 (Lauric Acid Methyl Ester)	0.82	C22:2 (cis-13, 16-Docosadienoic Acid Methyl Ester)	0.60
C14:0 (Myristic Acid Methyl Ester)	0.99	C20:5n3 (cis-5, 8, 11, 14, 17-Eicosapentaenoic Acid Methyl Ester)	3.15
C15:0 (Pentadecanoic Acid Methyl Ester)	0.48	C24:0 (Lignoceric Acid Methyl Ester)	20.90
C16:0 (Palmitic Acid Methyl Ester)	14.18	C22:6n3 (cis-4, 7, 10, 13, 16, 19-Docosahexaenoic Acid Methyl Ester)	3.48
C18:0 (Stearic Acid Methyl Ester)	4.15	***Saturated Fatty Acids (SFA) %***	***44.98***
C18:1n9c (Oleic Acid Methyl Ester)	12.74	***Unsaturated Fatty Acids (UFA) %***	***55.01***
C18:2n6c (Linoleic Acid Methyl Ester)	21.56	***Saturated/Unsaturated Fatty Acid Ratio (SFA/UFA) %***	***0.82***
C20:0 (Arachidic Acid Methyl Ester)	2.14	***Monounsaturated Fatty Acid (MUFA) %***	***13.22***
C18:3n3 (α-Linolenic Acid Methyl Ester)	3.73	***Polyunsaturated Fatty Acid (PUFA) %***	***41.79***
C20:1n9 (cis-11-Eicosenoic Acid Methyl Ester)	0.48		

Among the unsaturated fatty acids, polyunsaturated fatty acids (PUFA) constituted the major fraction (41.79%), whereas monounsaturated fatty acids (MUFA) were present at a relatively low level (13.22%), the lowest MUFA content among the examined samples. The presence of these highly unsaturated fatty acids contributes to the nutritional and functional complexity of the oil but also renders it more susceptible to oxidative degradation (Islam et al., 2023; Machado et al., 2023).

The relatively low MUFA content, primarily represented by oleic acid (C18:1n9c, 12.74%), further accentuates the oxidative sensitivity of screened wood chips oil. MUFAs are generally associated with improved oxidative stability compared to PUFAs; thus, the limited MUFA fraction in this oil suggests reduced resistance to oxidation despite its high SFA content (Frankel, 1987). This dual nature high thermal stability due to long chain SFAs and increased oxidative sensitivity due to elevated PUFA levels highlights the distinctive compositional characteristics of screened wood chips oil. Overall, the fatty acid profile indicates that screened wood chips oil offers high thermal stability and potential applicability in high-temperature or industrial processes such as particleboard where oxidation can be controlled.

The fatty acid profiles of rice husk, sunflower stalk, and wood chips oils exhibited distinct compositional characteristics, which may influence their suitability for different industrial applications. Among the studied samples, wood chips oil showed a high saturated fatty acid (SFA) content and an elevated SFA/UFA ratio, indicating enhanced thermal stability and rigidity. These properties are advantageous in particleboard (chipboard) production, where thermal resistance and dimensional stability during hot pressing are critical.

In contrast, rice husk oil showed a more balanced fatty acid distribution, with moderate saturated and unsaturated fractions, suggesting intermediate behavior between sunflower stalks and wood chips. Although rice husk presents potential for various applications, the fatty acid profile of sunflower stalks appears more comparable to that of wood chips in terms of suitability for particleboard production, supporting their potential use as a lignocellulosic substitute in wood-based panel industries.

Evaluation of Elemental Composition Results

In this study, the elemental compositions of sunflower stalks, rice husk, and industrial wood chip samples were analyzed using ICP-OES. Among all three materials, calcium (Ca) and potassium (K) emerged as the predominant macro elements as Table 5. The sunflower stalk sample exhibited the highest concentrations, with approximately 5873.43 ppm Ca and 5027.1 ppm K. These findings are consistent with reports in the literature, which highlight the high Ca and especially K content of sunflower residue ash (Vamvuka et al., 2009).

For instance, one study reported that potassium oxide accounted for as much as 47.2% of the ash content in sunflower residues. In contrast, the rice husk sample demonstrated significantly lower levels of Ca (1418.07 ppm) and K (1682.8 ppm), a result attributable to its high silica content. Although silicon (Si) was not directly quantified in this study, previous research indicates that rice husks contain approximately 14% silica, while the CaO content remains around 0.2%. This composition contributes to the fire resistant nature of rice husks and their rich amorphous silica content (Sawasdee & Pisutpaisal, 2022).

The industrial wood chip sample, with 4278.57 ppm Ca and 3104.22 ppm K, displayed a mineral profile comparable to sunflower stalks and significantly higher than rice husks. These results align with the known characteristics of woody biomass, which typically contains less than 1% ash primarily composed of Ca and K (Vamvuka et al., 2009; Sawasdee & Pisutpaisal, 2022).

Table 5. Elemental composition (ppm) of wood chips, sunflower stalks, and rice husks

Element	Sunflower Stalk	Rice Husk	Wood Chips
Ag	ND	ND	ND
Ca	5873.43	1418.07	4278.57
Cd	ND	ND	ND
Co	ND	ND	ND
Cr	1.96	0.75	1.99
Cu	5.98	74.19	27.79
Fe	104.26	120.08	104.5
K	5027.1	1682.8	3104.22
Li	ND	ND	ND
Mg	1516.88	1112.56	1070.14
Mn	9.33	41.95	15.31
Na	ND	ND	ND
Ni	ND	ND	ND
Pb	ND	ND	ND
Sr	143.19	10.35	82.22
Zn	21.06	31.36	22.55

Magnesium (Mg) and iron (Fe) concentrations were also found to be relatively similar across the samples, with Mg levels ranging from 1070.14 to 1516.88 ppm and Fe around 104.26 to 120.08 ppm. The Mg content in wood chips (1070.14 ppm) was comparable to sunflower stalks (1516.88 ppm) and slightly lower than rice husks (1112.56 ppm). This pattern is consistent with literature findings reporting considerable MgO levels in the ash of sunflower residues (Gül, 2019). Likewise, Fe concentrations showed little variation across the samples, suggesting that this element does not significantly impact structural differentiation between materials. The strontium (Sr) concentration was highest in sunflower stalks (143.19 ppm), followed by wood chips (82.22 ppm) and rice husks (10.35 ppm). Since Sr exhibits chemical behavior similar to Ca, its elevated level in sunflower stalks may be attributed to the corresponding high Ca content. Although limited, existing literature on Sr in plant ashes supports this interpretation.

Trace element analysis revealed marked differences in copper (Cu), manganese (Mn), and zinc (Zn) concentrations. Rice husk presented a notably high Cu level (74.19 ppm), which was approximately 12 times higher than in sunflower stalks (5.98 ppm) and 2.5 times higher than in wood chips (27.79 ppm). Mn concentrations followed a similar trend, with rice husk (41.95 ppm) exhibiting significantly higher levels than sunflower stalks (9.33 ppm) and wood chips (15.31 ppm). These disparities may be attributed to agrochemical use or irrigation water influencing trace element accumulation in rice plants (Gaima et al., 2022). In contrast, Zn concentrations were more consistent across the materials, ranging between 21.06 and 31.36 ppm. These values correspond well with literature reports that plant-based ashes typically contain Zn at several tens of ppm. For instance, ZnO has been identified in rice husk ash at approximately 0.02%, supporting the Zn levels observed in raw husk samples (Sawasdee & Pisutpaisal, 2022). Chromium (Cr) was found at low and comparable concentrations (1–2 ppm) across all samples, indicating minimal Cr related environmental risk. Notably, none of the materials contain detectable levels of toxic or environmentally hazardous elements such as Ag, Cd, Co, Li, Na, Ni, or Pb. This indicates that the materials assessed are within safe limits in terms of heavy metal contamination, corroborating previous findings that clean agricultural residues generally exhibit negligible levels of toxic elements (Gül, 2019).

The implications of these elemental profiles for particleboard production are multifaceted. In terms of fire resistance, inorganic constituents play a pivotal role (Lou et al., 2013). Alkali and alkaline earth metals, particularly potassium and calcium, are known to catalyze the pyrolytic decomposition of lignocellulosic biomass, promoting char formation over the release of volatiles. Agblevor & Besler, (1996) demonstrated that demineralized biomass favors volatile production, whereas mineral rich biomass leads to enhanced solid residue formation (Agblevor & Besler, 1996). High ash content biomass, such as stalks and husks, tends to produce more charm than softwoods under combustion. Accordingly, the elevated K and Ca levels in sunflower stalks and wood chips suggest a higher potential for thermal stability through char layer formation. Although low in Ca and K, rice husk offers a separate advantage due to its high silica content, which forms a protective, glassy layer during combustion, limiting heat transfer and flame propagation.

Studies have shown that rice husk acts as a synergistic flame retardant when incorporated into polymer matrices due to this silica rich composition (Glushankova et al., 2018). Thus, the natural mineral compositions of the biomass materials investigated may contribute passively to fire resistance in composite boards, especially in sunflower stalks and wood chips due to their Ca and K richness. Additionally, Mg and Sr may contribute to the formation of mineral matrices in the ash phase. For instance, K and Ca compounds in biomass can form fairchildite and calcite at 450–600 °C, providing structural reinforcement to the char layer (Huang et al., 2024).

However, the influence of high mineral content on mechanical properties should also be considered. In lignocellulosic materials, increased ash content can interfere with adhesive bonding, reducing the internal bond (IB) strength of composites (Li et al., 2010). In rice straw-based boards, for example, high silica and ash content have been shown to compromise bonding efficiency. Zhang et al. (2003) reported difficulties in achieving acceptable mechanical performance in rice straw panels using urea formaldehyde resins due to silica enriched particle surfaces (Zhang et al., 2003). Findings suggest that rice husk, despite its thermal benefits, may face similar challenges as a raw material for particleboard unless pre-treatment or resin modification is applied. In sunflower stalks, the presence of a pithy core, a low density and mineral rich region could form weak points within the board (Li et al., 2010). A classical study, found that removing the pith from sunflower stalks significantly enhanced internal bond and bending strength (Khristova et al., 1996).

This emphasizes the need to exclude structurally inferior or ash rich components to preserve mechanical performance. Strategies such as screening out mineral dense fractions, limiting their blend ratios, or increasing resin loading may be necessary. Indeed, previous studies have shown that increasing resin content in stalk or straw based panels can help restore IB strength to acceptable levels. The wood chip sample examined here, with its moderate ash content (~0.8–1.2%) and high fiber density, presents a balanced profile for both adhesive compatibility and structural reliability (Zhang et al., 2003; Li et al., 2010). Its Ca and K richness, coupled with low overall ash content, may facilitate effective bonding while still contributing to thermal resistance.

In conclusion, the elemental profiles of sunflower stalks, rice husks, and industrial wood chips are broadly consistent with literature values. Sunflower stalks and wood chips offer high levels of structural minerals such as Ca and K, whereas rice husk is distinctive for its high silica and trace metal content. These differences bear significant implications for particleboard production. On one hand, natural mineral content can enhance fire resistance via char or barrier formation (Zhao et al., 2009; Lou et al., 2013). On the other hand, excessive ash or silica may inhibit adhesive bonding and degrade mechanical strength (Li et al., 2010). Therefore, optimizing raw material formulation is a crucial parameter in particleboard production. Among the materials evaluated, industrial wood chips, with their balanced mineral content and absence of toxic elements, appear to be technically and environmentally suitable alternative raw material. When appropriately blended with agricultural residues such as sunflower stalks or rice husks, it may be possible to develop environmentally friendly composite panels that offer both adequate mechanical performance and improved fire resistance. This study contributes to the growing body of knowledge on sustainable biomass valorization and underscores the dual roles of elemental composition in functional composite material design.

Examination of SEM Imaging

Scanning electron microscopy (SEM) imaging of unprocessed raw materials (rice husk, sunflower stalk, wood chips) allowed for detailed examination of the morphological structures, pore conditions, and surface properties of the materials. This type of analysis is a very common approach, especially in understanding the physical characteristics of bio-based and fibrous materials (Battegazzore et al., 2014).

Scanning Electron Microscopy (SEM) analysis of the surface morphology of rice husk reveals rough, fibrous, and layered structures (Battegazzore et al., 2014). In the low-magnification general view (Figure 2A), its layered texture is clearly visible, and in its raw state, no prominent open external pore structure is observed. However, it is reported that porosity exists in certain internal regions due to the microfibrillar structure originating from the material's cellulosic and hemicellulosic content (Andalia et al., 2020). The regular distribution of fine fibrous and layered structures across the surface indicates a high level of internal integrity and suggests that surface micro-roughness remains within controlled limits (Arjmandi et al., 2015).

When compared to sunflower stalks and wood chips, rice husk emerges as the smootest, most homogeneous, and most compact surface characteristics, which is confirmed in the high-magnification detailed image (Figure 2B) (Arjmandi et al., 2015). Nevertheless, this highly smooth and compact structure may restrict adhesive penetration, potentially present a challenge when use for particleboard manufacturing. While the outer bark section displays a linear formation depending on the alignment of external fibers, the low-magnification SEM image (Figure 2C) clearly captures that the internal pith tissue possesses a honeycomb-like meshing texture consisting of well-interconnected cells. High-magnification SEM images (Figure 2D) identify grain and fiber structures oriented in various directions, along with porous areas randomly distributed at the micron level (Fang et al., 2020). Although untreated sunflower stalk fibers generally maintain an undamaged organization, detailed examination reveals significant surface irregularities, crack-like microstructures, and particle accumulations (Özuyar & Hoşgün, 2025).

While this high porosity and heterogeneous framework suggest that the standalone structural integrity of the material may be relatively weaker, this specific morphology makes sunflower stalks exceptionally suitable for particleboard and composite panel manufacturing. The highly porous network architecture allows for adhesive penetration and promotes strong mechanical interlocking during the board pressing process, favoring interfacial interaction and making it an ideal supplementary raw material. Wood chips generally possess a dense texture and an integrated, smooth surface (Mopoung & Dejang, 2021; Qu et al., 2024). Low-magnification SEM micrographs (Figure 2E) show massive, aggregated structures formed by the clustering of fibers; however, as seen in the high-magnification details (Figure 2F), unlike sunflower stalks, they lack distinct and widespread porous networks. The surface structure is moderately ordered. Depending on the fragmentation method and natural resin content, wood chips contain compact regions as well as localized agglomerations and material buildup. This indicates that while the material maintains internal integrity in specific areas, there is a lack of total homogeneity in its overall distribution (Rowell, 2005).

Overall, the rice husk sample stood out as having the smoothest and most compact structure, while the other samples were found to contain porosity, surface roughness, and microstructural irregularities. These findings are important for evaluating the suitability of the materials for advanced applications.

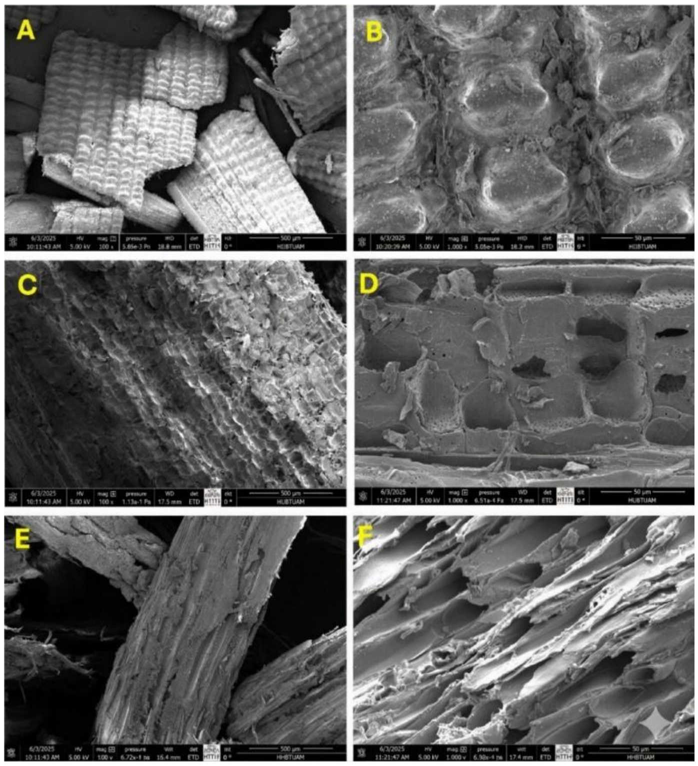

Figure 2. SEM images of A-B) Rice Husks, C-D) Sunflower Stalks, and E-F) Wood Chips (X100-1000)

Evaluation of Self Ignition Results

The self ignition/combustion behavior of different biomass samples (Wood Chips, Rice Husk and Sunflower Stalk) at specific temperatures and durations was investigated and the findings are presented in Table 6. Tests have shown that rice husk ignites at its lowest temperature of 140 °C in just 20 minutes. As stated in the literature, rice husk dust residues are considered one of the most hazardous materials due to their low activation energy and high carbon content (Osibuamhe et al., 2024). This early ignition reaction of rice husk proves that the material begins to react exothermically with air even at low furnace temperatures, and the rate of heat production rapidly exceeds the rate of heat loss (Osibuamhe et al., 2024).

Table 6. Self ignition temperature parameters and results

Set Temperature	Time (minutes)	Rice husk	Wood chips	Sunflower stalk
140-150 °C	20 min.	Combustion/ignition occurred at 140 °C.	No ignition	No ignition
170 °C	45 min.	-	No ignition	No ignition
190 °C	45 min.	-	No ignition	No ignition
190 °C	After 75 min.	-	Combustion/ignition occurred at 190 °C after 75 min.	No ignition

In the wood chips samples, it was observed that ignition was directly dependent not only on temperature but also on exposure time. While ignition did not occur after 45 minutes at 190 °C, it did occur after 75 minutes at the same temperature. This situation is explained by the concept of "induction time" as defined in the literature (Skrizovska et al., 2020; Osibuamhe et al., 2024). Induction time is the delay between the moment the material reaches its storage temperature and the moment the runaway reaction begins (Osibuamhe et al., 2024). The 75-minute period provided sufficient time for the accumulation of exothermic oxidation reactions in the internal structure of the wood chips and for reaching the critical heat threshold.

Within the tested temperature and time limits (190 °C/75 minutes), no combustion or ignition was observed in the sunflower stalk sample. This finding indicates that sunflower stalks have higher thermal stability than rice husk and wood chips, given the sample volume and exposure time used. Although sources state that the ignition temperature (TSI) of sunflower waste can drop to 62 °C depending on the volume, this laboratory-scale result reveals that the specific volume tested did not reach its critical ignition temperature during this time period (as shown in Figure 3) (Prodan et al., 2022).

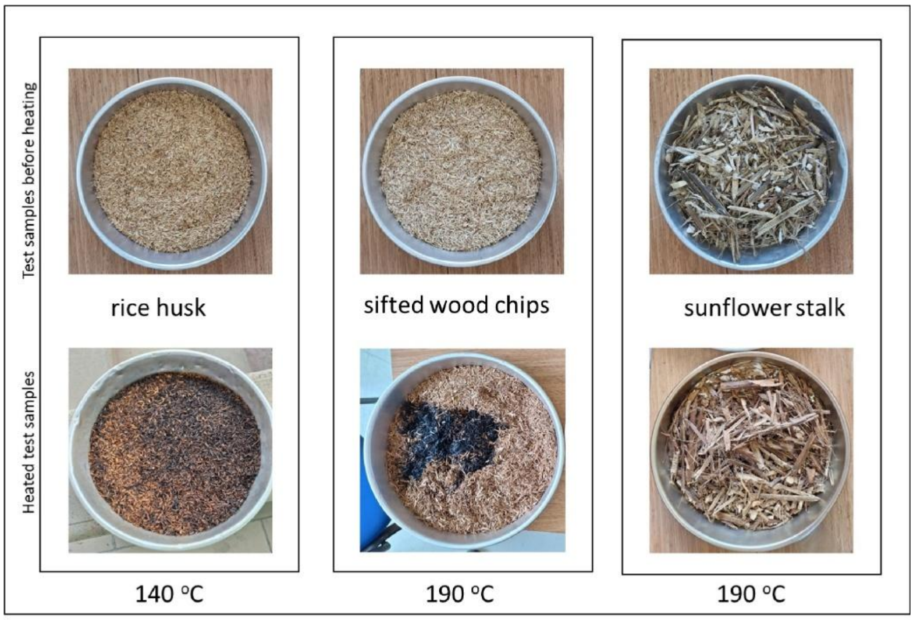

Figure 3. Visual appearance of wood chips, sunflower stalks, and rice husks before and after self-ignition

The results confirm that temperature, time, and material type are inseparable factors in determining the fire risk during the storage and processing of biomass materials. According to the principle of thermal balance, heat generation exceeds heat loss even at low temperatures in materials with a high surface area, such as rice husk; however, in wood chips, this balance is only disrupted by prolonged thermal exposure (Prodan et al., 2022). These data indicate that much stricter temperature controls are needed for rice husk in industrial storage processes, and that long storage periods (time factor) should be included in the risk analysis for chip-type biomass (Skrizovska et al., 2020; Osibuamhe et al., 2024).

Current trends in sustainable civil engineering and building materials technologies encourage the use of agricultural wastes (sunflower stalks, corn cobs, etc.) as an alternative to traditional wood chips due to their environmentally friendly and economical nature (Prodan et al., 2022). The data obtained in this study reveal that using sunflower stalk samples instead of wood chips particleboard production can offer significant advantages, especially in terms of thermal safety in production processes**.**

According to the experimental results, wood chips samples showed spontaneous combustion after 75 minutes of exposure at a furnace temperature of 190 °C; while sunflower stalks maintained their thermal stability under the same temperature and time conditions and showed no signs of combustion. This demonstrates that the critical ignition temperature (TSI) of sunflower stalks is higher than that of traditional wood chips within the tested volume and time limits. In production processes requiring pressing under high temperature and pressure, such as particleboard, raw material stability is a critical parameter to minimize fire risk (Skrizovska et al., 2020; Osibuamhe et al., 2024).

As stated in the literature, the self-heating mechanism is triggered when the rate of heat production of exothermic oxidation reactions within the material exceeds the heat loss to the environment. While a period of 75 minutes in wood chips provides a sufficient induction time for a "runaway" reaction, the fact that sunflower stalks remain stable during this time indicates that the material has higher oxidation resistance. This property suggests that the use of sunflower stalks offers a wider "safe operating range," especially when unexpected stoppages or process extensions occur during the drying and hot-pressing stages (Prodan et al., 2022; Osibuamhe et al., 2024).

Consequently, sunflower stalks can be suitable for use as a raw material in particleboard production in place of sifted wood chips in terms of thermal safety. Furthermore, the fact that sunflower stalks exhibit longer resistance at higher temperatures suggests that they may reduce the fire risk in the production line to lower levels compared to pine wood chips, thus increasing the safety margin in industrial use.

CONCLUSION

This study provided a comprehensive material-level characterization of rice husk and sunflower stalk as supplementary lignocellulosic resources for particleboard manufacturing, using industrial wood chips as a benchmark material. By integrating proximate composition, elemental analysis, fatty acid profiling, surface morphology, and self-ignition behavior, the work aimed to assess critical raw material properties that influence process safety, thermal stability, and material compatibility during particleboard production.

The results demonstrated that sunflower stalk exhibits physicochemical and thermal characteristics that are generally closer to those of conventional wood chips than rice husk. In particular, sunflower stalk showed a more balanced mineral composition, with elevated calcium and potassium contents, moderate ash levels, and a porous surface morphology that may favor adhesive penetration and interfacial interaction. In contrast, rice husk was characterized by a significantly higher ash content and lower thermal stability, as evidenced by its early ignition behavior, which may pose challenges during high-temperature processing unless appropriate pretreatment or formulation strategies are applied.

Self-ignition experiments further highlighted the importance of exposure time and material composition in assessing fire risk during biomass handling and processing. Under the tested conditions, sunflower stalk exhibited superior thermal resistance compared to both rice husk and wood chips, suggesting a wider safety margin during drying and hot-pressing operations. These findings emphasize that thermal behavior, in addition to chemical composition, could be considered as a key criterion in raw material selection for particleboard manufacturing.

Overall, this study demonstrates that sunflower stalk can be a promising supplementary raw material whose material-level properties approach those of conventional wood chips, while rice husk may be more suitable for limited or modified applications due to its high ash content and lower ignition threshold. The results presented here are considered to be a fundamental reference for future studies focusing on particleboard production, where mechanical performance, resin optimization, and mixing ratios need to be systematically evaluated and the advantages at this material level translated into practical particleboard performance.

A potential shortcoming of the present study is that the particleboards were not manufactured, which means that their physical and mechanical properties could not be evaluated. Consequently, future studies should concentrate on the production of particleboards using these raw materials, investigating resin optimisation, suitable blending ratios, mechanical properties, water absorption and thickness swelling behaviour.

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