



Study of application of coconut coir fiber-based wood-based panels: A literature review

Nugroho Mamayu Hayuning Bawono^a, Baju Bawono^b, Paulus Wisnu Anggoro^{b,*}, Jamari Jamari^c

^a Student of Master Program of Industrial Engineering, Universitas Atma Jaya Yogyakarta, Jl. Babarsari 43, Yogyakarta, 58111 Indonesia

^b Department of Industrial Engineering, Universitas Atma Jaya Yogyakarta, Jl. Babarsari 43, Yogyakarta, 58111 Indonesia

^c Department of Mechanical Engineering, University of Diponegoro, Jl Prof Soedharto, SH., Tembalang, Semarang, Indonesia

ARTICLE INFO

Keywords:

Coir fiber
Coconut husk
Wood-based panels
Medium density fiberboard
Renewable adhesive

ABSTRACT

Wood-based panels (WBPs) like medium-density fiberboard (MDF) rely heavily on wood resources, contributing to deforestation and sustainability challenges. Coconut coir fiber, an abundant agricultural byproduct, offers a promising alternative due to its high lignin content, mechanical strength, and environmental benefits. However, its commercial adoption in WBPs remains limited by insufficient research on bio-based adhesives and optimized processing methods. This review synthesizes current knowledge on coir fiber's properties, pre-treatment techniques (alkali, silane, enzyme), and adhesive systems (urea-formaldehyde, tannin, lignin) for WBPs. Coir's mechanical performance (tensile strength: 13.51 MPa) and density (0.63 g/cm³) are comparable to wood, but its high water absorption (90.79 % in 2H) necessitates targeted treatments. While formaldehyde-based adhesives dominate the industry, bio-alternatives like tannin and lignin show potential but require functionalization to match synthetic adhesives' strength and durability. Critical gaps include the lack of standardized production protocols and scalable bio-adhesive formulations. Future research should prioritize hybrid adhesive development, coir-wood composite optimization, and product differentiation compare to regular WBPs. This review highlights coir's viability as a wood substitute while underscoring the need for interdisciplinary innovation to overcome technical and economic barriers.

1. Introduction

Wood remains the primary raw material in the manufacturing of various wood-based panels (WBPs) such as plywood, medium-density fiberboard (MDF), and particleboard. These materials are produced from different wood types, including sawdust, excess furniture production, and recycled wood [59]. The production of fiberboard and particleboard using wood is one of the oldest and most widely used composite methods, contributing to the growing global market. However, due to increasing concerns over the sustainability of using wood resources, there has been a rising interest in finding suitable alternatives to wood for producing these composite materials. Deforestation, climate change, and resource depletion have driven this shift, alongside growing consumer awareness about the environmental impacts of excessive wood use.

Natural fibers have emerged as a promising substitute for wood in the production of WBPs. Several agricultural wastes have been used in

particleboard production due to their abundance and increased sustainability value of the product. These wastes are rice and wheat husks [72–74,118], sugarcane bagasse [46,64], fruit pond [62,81], jute [126], and cocopeat [50,98]. The addition of agricultural waste has reduced water absorption and thickness swelling if the additives are treated appropriately.

Coir fiber as seen on Fig. 1, derived from the husk of coconuts, is one of the most studied alternatives due to its availability, strength, and sustainability advantages. It is abundant, inexpensive, and possesses mechanical properties that make it comparable to wood in terms of strength, thanks to its high lignin content [92]. Finished products using coir fiber have a high sustainability value and mechanical strength that is not inferior to wood due to the lignin content that can strengthen the coir. Coconut fiber is an environmentally friendly material that can help reduce wood dependence and deforestation, and climate change. It also tends to be readily available as it is widely used in people's daily lives (markets, coconut processing plants).

* Corresponding author.

E-mail address: p.wisnuanggoro@gmail.com (P.W. Anggoro).

<https://doi.org/10.1016/j.jcomc.2025.100588>

Available online 12 April 2025

2666-6820/© 2025 The Author(s). Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

While the potential of coir fiber as a wood substitute in WBPs is well-established, the widespread use of coir fiber in commercial panel production remains limited [58]. Traditional applications of coir fiber, such as mats, ropes, and brooms, do not fully capitalize on its potential to replace wood in engineered composites. This literature review seeks to explore the feasibility of coir fiber-based WBPs and investigate the possibility of replacing or supplementing wood with this fiber through proper treatment methods and the application of environmentally friendly adhesives.

The production of WBPs using coir fiber can contribute significantly to reducing dependence on wood and promoting sustainability. Coir is readily available in regions with large coconut industries, such as Indonesia, where coconut processing largely focuses on food products like copra and coconut oil, leaving coir fiber largely untapped [52]. Coir fiber, after being processed, can be used in a variety of industrial products, including higher-value derivatives such as coir-based mats, textiles, and even biocomposites [26,67]. The environmental benefits of utilizing coir in WBPs extend beyond the reduction of deforestation; they also align with the growing push for eco-friendly and renewable materials in the construction and manufacturing industries [92].

Several studies have indicated that coir fiber can be used in the production of fiberboard and particleboard without significantly compromising mechanical strength [44]. The fiber naturally contains tannin, a fungicide, making it safe against fungi and insects such as termites. In addition, coconut fiber also contains lignin (wood substance) which is positively correlated with thermal stability at high temperatures, so it can be produced without excess chemicals [114]. When combined with appropriate treatment and adhesives, coir-based composites can perform similarly to traditional wood-based panels, offering a potential solution to the global demand for sustainable materials. The existing research has primarily focused on the mechanical

properties and treatment of coir fiber, but further studies are needed to optimize production methods, explore adhesive alternatives, and improve product performance.

One area that requires more attention is the development of sustainable adhesives for coir-based WBPs. Current adhesives used in the industry, such as urea-formaldehyde (UF) and phenol-formaldehyde (PF), are often derived from petroleum-based products and emit harmful formaldehyde during the manufacturing process [59]. The shift toward renewable and environmentally friendly adhesives, such as tannin- and lignin-based adhesives, is crucial for ensuring the full sustainability of coir-based WBPs [30,32]. While tannin and lignin are abundant in natural sources like trees and agricultural residues, their use in adhesives for coir-based WBPs remains underexplored. This review identifies the need for further investigation into bio-based adhesives that can replace formaldehyde-based ones and improve the environmental profile of coir-based products.

The review will explore the physical and mechanical properties of coir fiber, the treatment processes that enhance its compatibility with adhesives, and the potential of using renewable adhesives in WBPs production. By addressing the challenges associated with material processing, adhesive formulation, and production techniques, this study seeks to contribute to the development of environmentally friendly, high-performance coir-based panels that could help reduce global wood consumption and promote a circular economy.

2. Coir material

Coconut (*Cocos nucifera* L.) is a tropical crop commonly found in coastal and low-mountain areas. A coconut tree can yield between 50 and 100 fruits annually [36]. Based on Fig. 2. Generally, the coconut fruit consists of several parts: the exocarp (outer skin), mesocarp

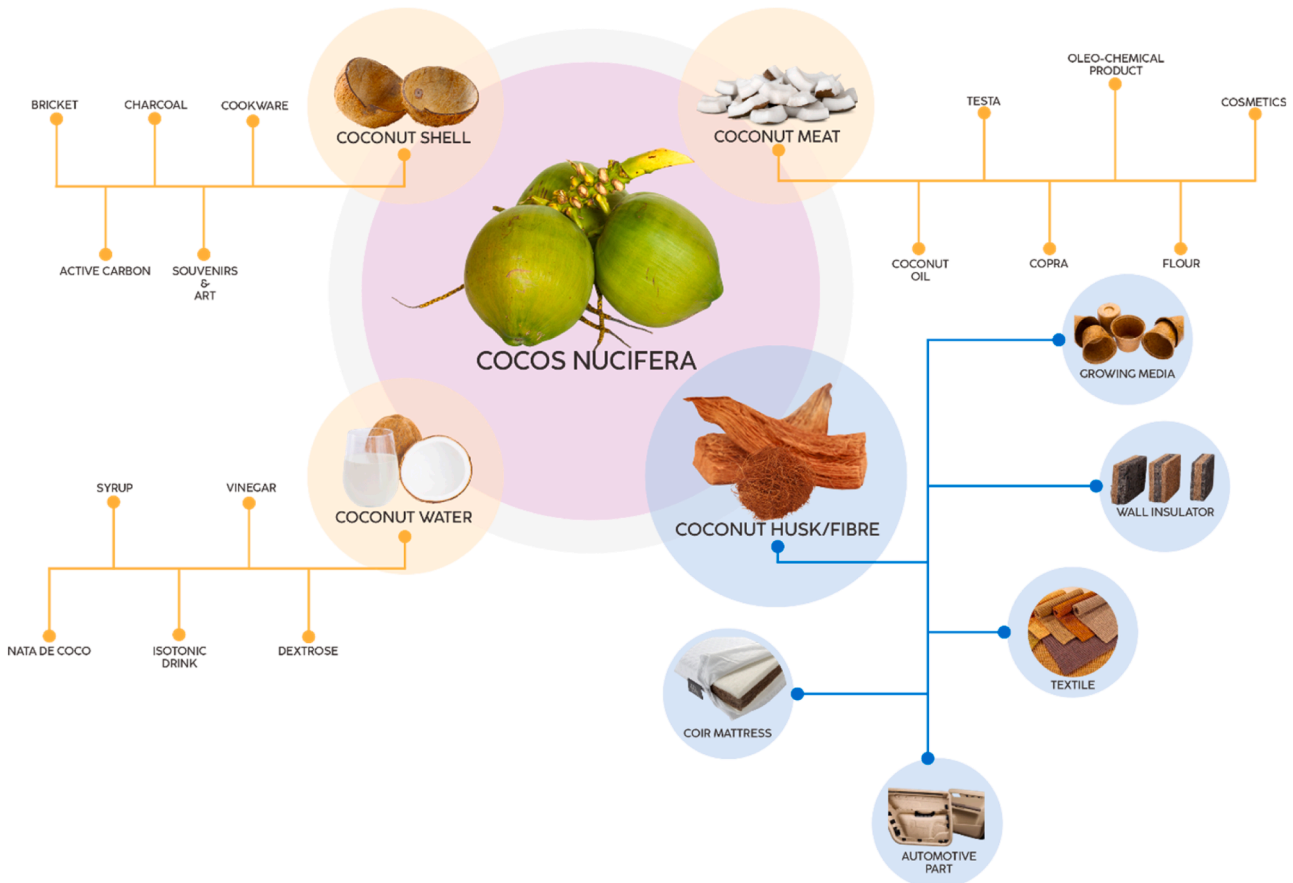


Fig. 1. Coconut derivative products.

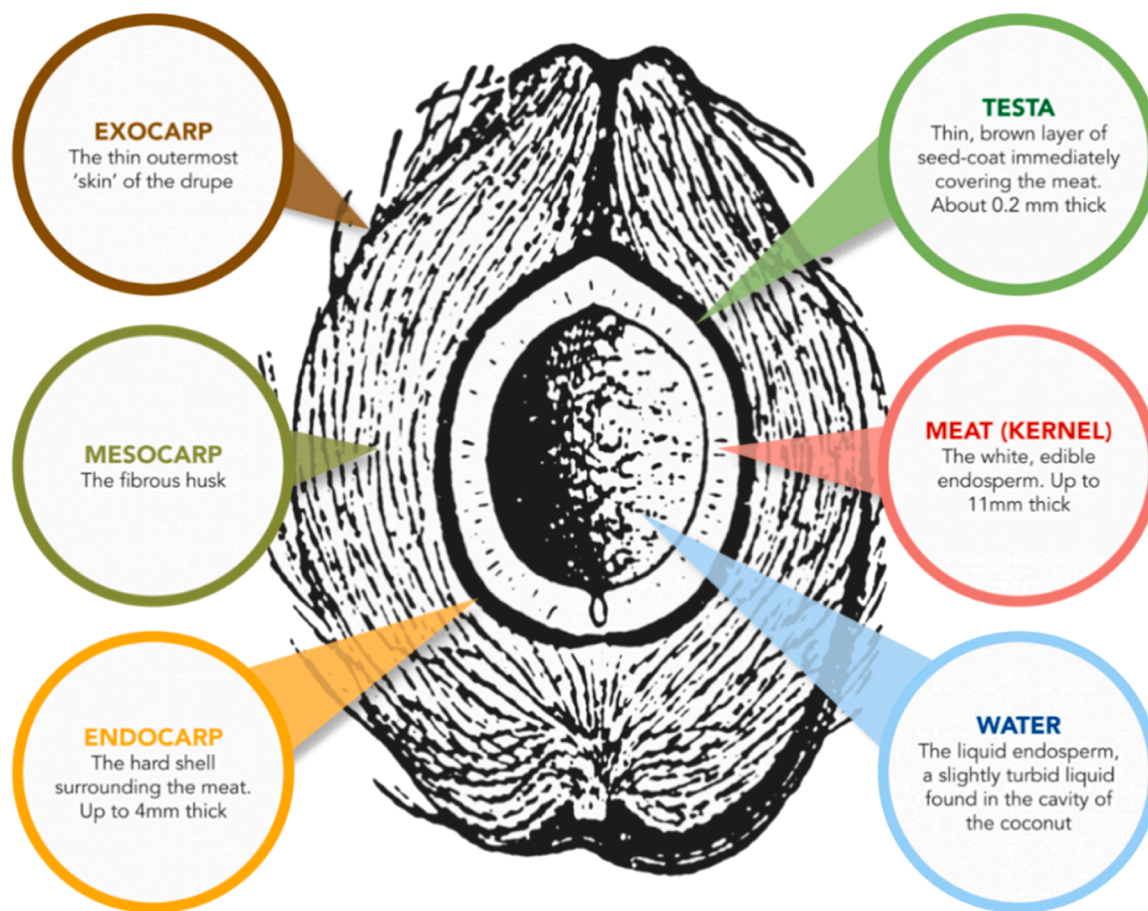


Fig. 2. Morphological Chart of Cocos Nucifera. Source: Asia Pacific Coconut Community.

(fibrous layer), endocarp (hard shell), testa (seed coat), pulp, and water. Of these, the mesocarp, or coir, is particularly relevant for industrial uses due to its fibrous nature. It is commonly processed into products like mats, ropes, and brooms. The coconut meat and water are the primary consumable components, while the coir and shell are often underutilized, despite their potential for various industrial applications.

The main composition of coconut fiber is cellulose, lignin, and hemicellulose [74]. These are the main constituents of natural plant fibers, cellulose and hemicellulose are crystalline polysaccharides. At the same time, lignin is a three-dimensional (3D) amorphous polyphenol macromolecule composed of several different phenylpropane species [16]. Specifically, coir contains 40–50 % lignin, 27–45 % cellulose, and 15–20 % hemicellulose, along with small amounts of ash and water [63]. The lignin content contributes to the fiber's rigidity and durability, while cellulose and hemicellulose provide structural support and flexibility. Coir fiber also contains tannins, which offer some resistance to fungi and pests such as termites [26].

The higher lignin content in coir, compared to other natural fibers, enhances its mechanical strength and resistance to environmental factors such as moisture and decay, making it a viable option for long-lasting materials [100].

Table 1 below compares the properties of coir fiber with other natural fibers commonly used in particleboard production. Coir fiber has a density of 1.1–1.6 g/cm³, which is comparable to other natural fibers and meets the density range required for medium-density fiberboard (MDF) production [42]. Coir fiber also exhibits favorable tensile strength and water absorption characteristics. However, its water absorption rate is higher than that of other fibers, which may require treatment to improve its performance in certain applications [105].

Table 1
Natural fiber characteristics.

Fiber Source	Density (g/cm ³)	Tensile Strength (MPa)	Young Modulus (GPa)	Elongation at break (%)
Coir	1.1–1.6	106–563	1.3–6	14.21–60.5
Bamboo	0.6–1.1	140–230	11–17	–
Bagasse	1.2–1.5	20–290	17–27	1.1
Jute	1.3–1.5	385–850	10–55	1.16–8
Kenaf	0.6–1.5	215.4–1191	2.86–6.0	1.6–6.9
Sisal	1.3–1.5	80–840	9–38	2–2.5
Hemp	1.4–1.6	310–900	30–80	1.6–6
Rice Husk	1.4	19–135	0.3–2.6	–
Cotton	1.5–1.6	45.5–1000	5.5–12.6	3–10
Sugar Palm	1.29	156.96	–	7.98
Ramie	1.45–1.5	348–938	24.5–128	1.2–8
Flax	0.6–1.5	20–290	17–27.1	1.1

Source: [22].

2.1. Coir extraction

The extraction of coir fiber from the coconut husk is an essential step in utilizing it for various industrial applications, including bio-composites and wood-based panels (WBPs) as shown in Fig. 3. Coir is primarily obtained through a mechanical process that separates the fiber from the other parts of the coconut husk. The process begins with the removal of the coconut fruit from the tree, followed by the separation of the exocarp (outer skin), mesocarp (fibrous layer), and endocarp (shell) [74]. The mesocarp, or coir, is the part used in industrial applications.

Once the coconut husk is separated, the coir fiber is extracted by

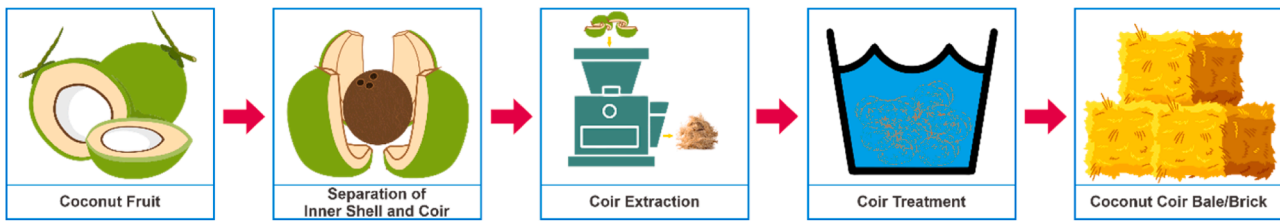


Fig. 3. Extraction Process of Coconut Husk Adapted from Faridul Hasan et al. [36].

mechanically separating the fiber from the surrounding materials. A common method involves soaking the husks in water for several hours to soften the fibers and facilitate extraction [37]. After soaking, the coir is mechanically processed to remove impurities, including dirt, sand, and other residues, using specialized machinery. This cleaning process is crucial to ensure that the fiber is free of contaminants, which could affect its performance in final products.

2.2. Wood-Based panels (WBPs) potential

Wood-based panels (WBPs), such as plywood, medium-density fiberboard (MDF), particleboard, and oriented strand board (OSB), are widely used in construction, furniture, and other industrial applications. These panels are made by binding wood particles or fibers together with adhesives under pressure and heat. The resulting products are characterized by improved mechanical strength, durability, and stability compared to raw wood, making them suitable for a variety of uses. The demand for WBPs has steadily increased due to their cost-effectiveness, availability, and versatility [42]. The mechanical specifications of these products can be seen in Fig. 4.

The potential of coir fiber as a wood substitute has been investigated in previous research by [44,68,106]. These studies demonstrated the feasibility of using coir fiber as a raw material in wood-based product (WBP) manufacturing. The incorporation of this material does not compromise the mechanical strength of existing market products. Moreover, utilizing coir fiber as a raw material contributes to the development of environmentally friendly materials by repurposing industrial waste that would otherwise be discarded or incinerated. Further research is necessary to optimize material homogenization and develop environmentally compatible adhesive applications.

Additional investigations [76,115] explored coir fiber’s potential as a wood substitute in fiberboard and particleboard production. Their findings revealed the material’s promising applications while highlighting critical performance parameters. Water absorption and tensile strength exhibited notable variations compared to traditional wood, indicating that targeted additives may be required to enhance material properties. These characteristics necessitate careful consideration to maximize coir fiber’s potential as a sustainable alternative material.

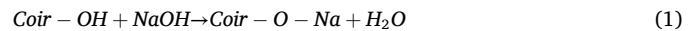
3. Coconut fiber pre-treatment

Pre-treatment is the immersion of natural fibers in a chemical liquid

before entering the manufacturing process. The pre-treatment process is designed to improve the fiber’s compatibility with adhesives, increase its mechanical strength, and reduce any impurities or components that could interfere with the bonding process [88]. In addition, chemical bonding can affect the surface quality and smoothness of the product. Previous studies listed in Table 2 have examined the pre-treatment results on the mechanical strength of natural and coir fibers.

3.1. Alkali treatment

Alkali treatment is one of the most commonly used methods for pre-treating coconut fiber. This process typically involves immersing the coir in a sodium hydroxide (NaOH) solution. Alkali treatment serves several purposes: it helps remove impurities such as waxes, oils, and lignin, and it also breaks down the hemicellulose content in the fiber [31]. As a result, the fiber becomes more open and its surface area increases, improving its ability to bond with adhesives. The chemical reaction of this method is as follows:



The chemical reaction is that the alkaline reagent liquid NaOH will assist the coconut fiber in ionizing the -OH chain into alkoxides [3]. The alkali treatment process can be adjusted in terms of the concentration of sodium hydroxide, treatment time, and temperature to achieve the desired results. Studies have shown that an optimal concentration of NaOH and treatment duration can significantly improve the mechanical properties of coir, including tensile strength and flexibility. However, excessive exposure to alkaline solutions may lead to the degradation of cellulose, which could compromise the fiber’s integrity.

3.2. Acid treatment

Acid treatment is another method used to improve the properties of coconut fiber, although it is less commonly employed than alkali treatment. Acid treatment removes minerals and impurities from coconut fibers, which is crucial for applications requiring clean and reactive surfaces. For instance, the use of HCl and H₂SO₄ in oxidative chloro-sulfonation processes has been shown to delignify and bleach coconut fibers, enhancing their suitability as substrates for functional polymers [89]. The treatment can also modify the fiber’s surface roughness, which is beneficial for improving adhesion in composite materials. This is particularly important in applications where strong bonding with adhesives is required [128].

The application of acid treatment is generally milder than alkali treatment, and the process involves soaking the coir in an acid solution for a specified period, followed by washing and neutralizing. Despite the benefits, acid treatment can lead to the degradation of fiber structure if not carefully controlled. For example, excessive acid exposure can compromise the integrity of the fibers, limiting their use in certain applications [83]. Furthermore, the environmental impact of acid use and disposal must be considered, as improper handling can lead to ecological harm. Therefore, balancing the benefits of acid treatment with its potential drawbacks is essential for sustainable application [69].

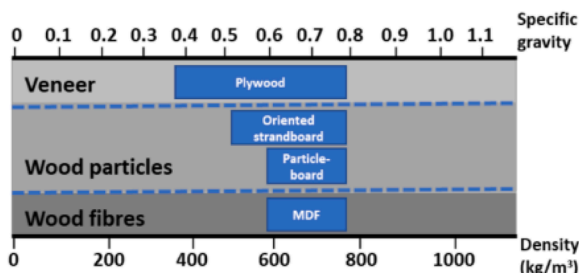


Fig. 4. Wood-Based Panels Classification. Source: [32].

Table 2
Mechanical Component of Natural Fiber After Pre-Treatment Process.

Journal	Object	Modulus of Elasticity (Gpa)	Tensile (Mpa)	Density (g/cm3)	Elongation (%)
[33]	Sisal Fiber	8.92±3.38	347±122.50	–	4.16±1.35
[65]	Pineapple	19.85	586.00	–	–
[2]	Banana	0.25	4.00	–	3.10
[105]	Coir	5.00	159.00	1.34–1.48	21.00
[105]	Ramie	86.00	715.00	1.45–1.65	4.00
[105]	Coco Frond	12.00	287.00	1.28–1.43	6.00
[112]	Coir	4.90	250.00	1.30	–
K. M.Faridul [35]	Bamboo	40.00	575.00	1.20–1.50	3.20
K. M.Faridul [35]	Sugarcane Bagasse	6.20	350.00	1.10–1.60	7.90
[63]	Abaca	12.00	760.00	1.50	10.00

3.3. Silane treatment

Silane treatment is another approach that can enhance the bond between coconut fiber and the adhesive matrix. Silane is a coupling agent that forms a chemical bond between the fiber and the adhesive, improving the interface between the two. Silane treatment significantly improves the mechanical properties of composites by enhancing interfacial adhesion. For instance, the tensile strength and interlaminar shear strength of composites are notably increased, as demonstrated in studies involving silane-treated fibers and matrices [41,53]. The use of specific silane coupling agents, such as glycidylxypropyltrimethoxysilane, has been shown to result in higher tensile strength and better interfacial adhesion in composites, compared to other agents [9]. Silane treatment is typically used when coconut fiber is combined with hydrophobic adhesives such as polyurethane or epoxy, which are commonly used in WBPs.

The silane treatment process involves immersing the coir in a silane solution, followed by drying to allow the silane to chemically bond to the surface of the fiber. This method increases the compatibility of the fiber with adhesives, leading to improved mechanical properties and stability of the final composite material. Silane treatment enhances the water resistance of composites, reducing water absorption and thickness swelling [107]. Because chemical reactions facilitated by silane coupling agents contribute to the enhanced compatibility and interfacial adhesion between the composite constituents, leading to improved overall performance [95]. This is particularly beneficial for applications where the composite is exposed to moisture or water immersion.

While silane treatment offers significant benefits in enhancing the properties of fiber-reinforced composites, it is important to consider the type and concentration of silane agents used. Different silane agents can have varying effects on the mechanical and thermal properties of the composites, and the optimal choice depends on the specific application requirements [8,123]. Additionally, while silane treatment improves many aspects of composite performance, it may not always enhance bond strength in all contexts, such as in certain repair applications where other factors may play a more significant role [70].

3.4. Enzyme treatment

Enzyme treatment is a newer approach that has been investigated for its potential to modify the surface of coconut fiber or wood based panels (WBPs). The treatment typically involves using cellulase, pectinase, or other enzymes to break down the cellulose and hemicellulose in the coir. Enzymatic treatments, such as those using pectinase, have been shown to improve the mechanical properties of composites by enhancing the interaction between fibers and the polymer matrix. For instance, pectinase treatment of plant fibers significantly increased the strength of starch/PBAT composites, demonstrating a 65 % improvement in bending strength with bamboo fibers [124].

Enzyme treatment can improve the fiber's surface properties by making it more hydrophilic and increasing its bonding potential with adhesives. In the context of coconut fibers, enzyme treatments have

been explored for their potential to enhance the properties of biopolymers derived from coconut coir. The incorporation of enzymes in the synthesis of cellulose-based products has shown promising results in terms of mechanical properties and environmental compatibility [43].

The effectiveness of enzyme treatments can vary depending on the specific type of enzyme used and the conditions under which the treatment is applied. Additionally, the cost and scalability of enzyme production and application may pose challenges for widespread adoption. However, ongoing research and development in this field continue to explore ways to optimize enzyme treatments for various applications, potentially overcoming these limitations and further establishing enzyme treatment as a viable alternative to traditional methods.

4. Potential adhesive

The selection of suitable adhesives is a critical step in ensuring the effective binding of coir fibers in wood-based panels (WBPs). The adhesive not only provides structural integrity but also influences the environmental sustainability of the product [84]. The adhesive selection process must account for various factors such as coir's lignin and cellulose content, its water retention, and the strength required for various applications according to consumer needs.

Most of the adhesives in the WBPs industry are formaldehyde-type adhesives with phenol or urea-based resins [59]. This type of adhesive is famous for its good bonding ability and weather resistance. In addition, it is competitively priced when compared to other types of adhesives, so WBPs manufacturers use it as the main adhesive material in their products.

4.1. Synthetic adhesive

Formaldehyde is a chemical liquid that, when combined with monomers such as urea, phenol, melamine, and resorcinol, functions as a crosslinker to produce phenoplast and aminoplast resins. Formalin is a carcinogenic substance with potential human health risks [42]. This adhesive type generates by-products, including emissions and unused adhesive waste, which can contaminate environmental systems through soil and water pollution.

Phenol-formaldehyde (PF) adhesives emerge as the most extensively utilized formalin-based adhesive in the wood-based products manufacturing sector. This adhesive system is characterized by several distinctive properties and manufacturing considerations. Its primary advantages include exceptional water resistance and superior weather durability, which make it particularly suitable for exterior and high-moisture applications [27]. However, these benefits are accompanied by substantial production challenges, notably the requirement for higher temperature and pressure conditions during the manufacturing process, which can be energy-intensive and costly [122].

The unique chemical composition of PF adhesives, derived from petroleum-based phenol produced through synthetic processes, contributes to distinctive product characteristics. Wood-based products manufactured using PF adhesives typically exhibit a distinctive dark

coloration, complemented by a glossy and exceptionally smooth surface texture [91]. These aesthetic and functional attributes make PF adhesives particularly attractive for specific industrial and architectural applications.

Urea-formaldehyde (UF) adhesives represent an alternative formaldehyde-based resin system, created through the chemical combination of formalin with urea. This adhesive variant presents a unique physical profile, characterized by a white to transparent appearance. UF adhesives provide excellent dimensional uniformity and surface refinement, which are critical for applications requiring precise manufacturing standards [56].

When compared to phenol-formaldehyde adhesives, urea-formaldehyde systems offer several distinctive manufacturing advantages. These include lower fabrication temperatures and enhanced fire-resistant properties, which can provide economic and safety benefits during the production process. A significant drawback of UF adhesives is the emission of formaldehyde, a volatile organic compound with health and environmental concerns [78]. To reduce this impact some research trying to find solution, one of them is to use of sepiolite. A clay mineral, as a filler in UF resins has been demonstrated to improve the mechanical properties of plywood and significantly reduce formaldehyde emissions by accelerating its release before product use [57].

4.2. Bio-Based adhesive

Natural material-based adhesives have emerged as promising alternatives to traditional formaldehyde adhesives, driven by growing health and environmental concerns. The accelerating research in this domain is primarily motivated by the abundance, relatively straightforward production processes, and renewable nature of these alternative adhesive sources. Comparative studies have consistently demonstrated that plant-derived materials show more potential than their animal-derived counterparts in developing sustainable adhesive technologies. A research by [96] in which integrating eco-friendly additives, such as beech bark in urea-formaldehyde adhesives, has been shown to reduce formaldehyde emissions while maintaining the mechanical properties of molded plywood, offering a sustainable solution for industrial applications

Tannin represents a particularly intriguing substance in the development of wood-based products (WBPs) adhesives. Characterized as a water-soluble organic compound, tannin has historically found extensive application in leather processing [32]. The utilization of tannin as an adhesive for WBPs traditionally requires the incorporation of additional resins, such as formaldehyde, to enhance its binding capabilities. Studies have shown that tannin-based adhesives can achieve satisfactory internal bond strengths for particleboards when combined with specific hardeners like furfural, meeting international standards for interior grade panels [17]. Other studies that using hybrid tannin-based resins, which incorporate other biobased materials such as starch and lignin, have been explored to enhance adhesive performance [85]. These formulations aim to balance the mechanical strength and environmental benefits.

Tannin-based adhesives eliminate formaldehyde emissions, addressing significant health and environmental concerns associated with traditional adhesives [129]. This makes them a viable option for sustainable adhesive development. The extraction and use of tannins from renewable sources like tree bark and chestnut shells further enhance the environmental benefits of these adhesives [93].

These research efforts, while innovative, face significant technical challenges. Tannin-based adhesives consistently demonstrate reduced mechanical strength and inferior weather resistance compared to established phenol-formaldehyde (PF) and urea-formaldehyde (UF) adhesives. This limitation represents a critical barrier to widespread adoption, necessitating continued research and development to improve the performance characteristics of natural material-based adhesives.

Lignin emerges as another promising natural substance with

significant potential in adhesive technology. Abundant in lignocellulosic materials, particularly wood, lignin demonstrates remarkable versatility when combined with appropriate polymers [110]. The exploration of fully biobased adhesives using Kraft lignin and 5-HMF by [20] as substitutes for phenol-formaldehyde resins represents a significant step towards reducing the reliance on petroleum-based adhesives, although further improvements in adhesive reactivity and strength are needed for industrial viability

Innovative studies have investigated multiple approaches to enhancing lignin's adhesive potential. Carbohydrate-based polymers have shown particular promise, with researchers experimenting with materials such as potato starch and tapioca starch [87]. These investigations aim to leverage the natural chemical properties of lignin, creating adhesive systems that can potentially replace synthetic alternatives. Lignin-phenol-formaldehyde resins have been explored as alternatives to petroleum-based phenol resins, although cost and appearance remain challenges [121]. Another research study organosolv lignin has shown potential in pressure-sensitive adhesive applications, demonstrating the versatility of lignin in different adhesive formulations [104]. Despite its potential, lignin's structural heterogeneity and poor processability pose challenges for its widespread application in high-performance materials, continuing research into chemical modifications and blending strategies is essential to fully realize lignin's potential as a sustainable adhesive component [103]

The ongoing research into natural material-based adhesives represents a critical intersection of environmental sustainability, material science, and industrial innovation. While challenges remain in achieving performance levels comparable to traditional formaldehyde-based adhesives, the potential environmental and health benefits continue to drive significant scientific interest and investment in these alternative technologies.

The comprehensive approach to developing natural material-based adhesives underscores the increasing importance of sustainable solutions in industrial material production. Researchers and manufacturers are progressively recognizing the need to balance performance requirements with environmental considerations, positioning natural material-based adhesives as a crucial area of technological development.

4.3. Previous research

Previous research was mostly conducted on UF and PF-based adhesives, but over time research using tannin and lignin as adhesive bases began to emerge. Research using UF and PF-based adhesives uses alternative materials as wood substitutes [37,92]. Meanwhile, research examining alternative environmentally friendly adhesives uses wood as the object of research [15,30,84]. In addition, other adhesives such as castor oil, citric acid, latex, or readily available in finished form have been used before.

Bibliometric analysis and meta-analysis are analytical methods that use mathematical and statistical methods to assess bibliometric data [19]. This analysis aims to understand the relationship between the journals collected to find a research gap. Data in the form of journal citations can be obtained through SCOPUS or other indexed journal provider sites. Another method that can be used is meta-analysis. The main difference from the bibliometric analysis is the use of secondary data that can be done to achieve research objectives. Both analyses above are quantitative methods of assessing bibliometric data [108].

Bibliometric mapping was carried out using VOSviewer software. The analysis begins with exporting data from Mendeley in the form of .RIS format files which are processed further into VOSviewer. The results obtained are in the form of a map, as shown in Fig. 8. Each keyword obtained has its own color; this is a visualization of the clusters in the journals that have been collected. According to [34], The relationship formed from keywords is co-occurrence, and the strength of the relationship is determined by the number of citations from one journal to another. In addition, the occurrence of a keyword represents the number

of journals where the keyword is found.

The occurrence of each keyword is visualized by mapping in Fig. 5. There are six main clusters viz: red, blue, yellow, green, purple, and cyan. The circle size represents the number of occurrences of the keyword, while the distance and thickness of the line represent the strength of the relationship.

Cluster 1 (red). The first cluster contains adhesives and matrices used in previous research. Keyword occurrences such as Formaldehyde, wood adhesive, lignin, and tannin dominate this cluster. Based on the visualization of the mapping, it is known that Formaldehyde dominates both in terms of the number of occurrences and the strength of the relationship. The use of this substance in research related to WBPs is still widely done. The main reason is its flexibility as a crosslink so that it can be mixed with various other substances as an adhesive. In addition, using tannin and lignin as alternatives in WBPs adhesives is also starting to be widely carried out so that both keywords appear on the map. Furthermore, keywords such as polymer and eco also appear in this cluster, referring to the properties of the adhesive solution and the emergence of research emphasizing the environmentally friendly nature of wood-based panels.

Cluster 2 (blue) and Cluster 3 (purple). The second and third clusters contain the base material and mechanical strength variables of WBPs. Keywords that appear such as: coconut husk, target density, rupture, moe, mor, and physical properties. Mechanical strength is one of the success assessment variables to be achieved in this research. Almost all keywords related to mechanical testing can be found in the JIS A 5908 (2003) standardization. This standard must be met in research that includes WBPs such as medium-density fiberboard. Specimens that pass the test will have a greater chance of mass production than those that do not.

Cluster 4 (yellow). The fourth cluster contains basic materials from previous research. The keywords that appear are: fiber, coir fiber, fibrous chip, cellulose fiber, and MDF dominate the relationships of this cluster. The use of basic materials can be mapped through this software. The emergence of fiber is a necessity because fiber is an important component in the mechanical properties of WBPs products. The selection of natural raw materials that have strong fibers and high lignin

content is a requirement that must be met in WBPs products. The content of coconut fiber which has fiber and lignin similar to wood makes it one of the potential materials in this product; with the right treatment and process, this material may become the main material of WBPs.

Cluster 5 (cyan) and Cluster 6 (green). The fifth and sixth clusters contain treatments that can be used on natural fibers. Some keywords are silane, alkaline, biocomposite, sodium hydroxide, and natural fiber. As discussed in point 3, the application of treatments is necessary in the processing of coir fiber. Substances and materials not needed in production such as oils, waxes, and fats are removed from the fiber so that they do not interfere with the final product's chemical bonding and mechanical strength.

4.3.1. Previous adhesive type research

Previous research has extensively investigated potential adhesives for wood-based panels (WBPs). As illustrated in Fig. 6, experimental studies predominantly utilized lignin, tannin, and urea-formaldehyde-based adhesives, with starch and phenol-formaldehyde following as secondary options. Lignin and tannin-based adhesives have gained particular attention due to their abundant availability and inherent hydrophobic characteristics, which are crucial for wood panel manufacturing [6].

These natural materials present unique chemical properties that make them intriguing adhesive candidates. Specifically, lignin and tannin are characterized by low dispersion properties and complex aromatic structures that impart distinctive scents. However, these characteristics necessitate preliminary functionalization through polymer integration to effectively function as adhesives.

The comprehensive literature review represented in Table 3 provides a detailed overview of adhesive types explored across multiple research studies, highlighting the diversity of approaches in developing alternative adhesive technologies for wood-based products.

5. Fabrication

The fabrication process is a critical stage in producing wood-based panels (WBPs) and composite materials, ultimately determining the

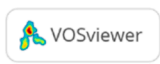
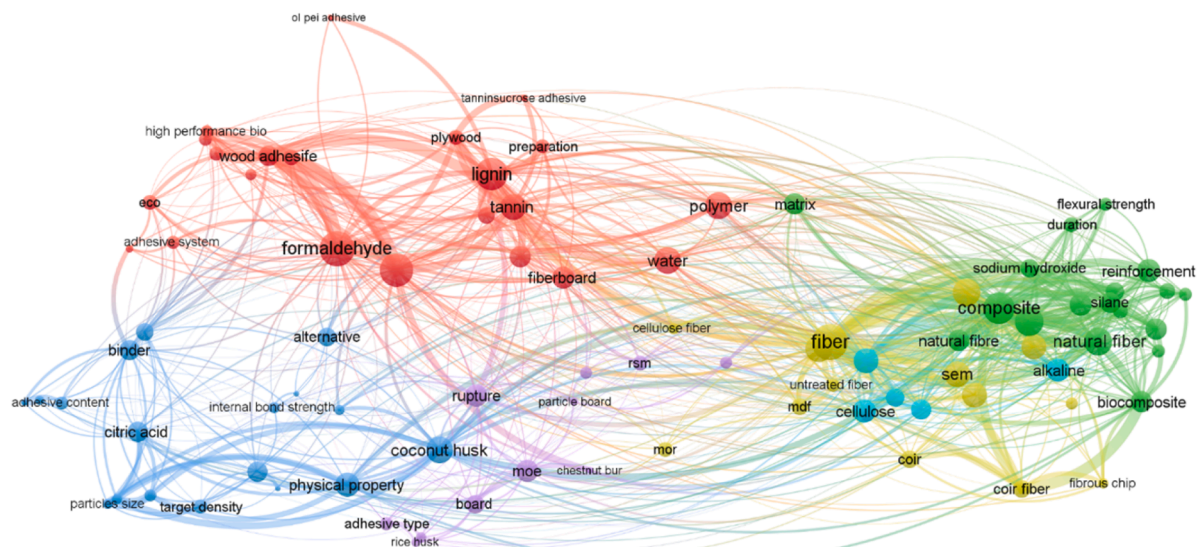


Fig. 5. Co-Occurrence keyword in this study.

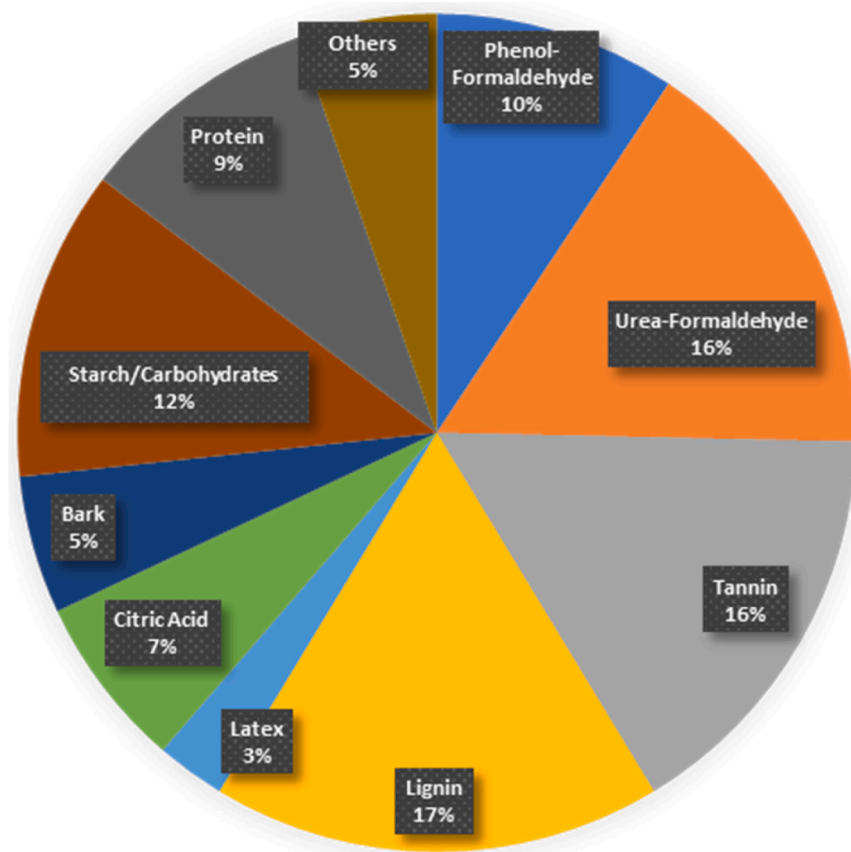


Fig. 6. Circular diagrams representing the main renewable raw materials identified for the experimental studies.

resulting product's shape, texture, and mechanical strength. For coir-based panels, the fabrication process closely follows conventional WBPs. The initial step involves soaking coir in an alkaline solution as a pre-treatment process to remove impurities and enhance fiber characteristics. Subsequently, the coir is dried in an oven until reaching approximately 10 % humidity [25].

As seen on the Fig. 7, following the drying process, the coir is cut using a cutting mill with a rotating knife to achieve the desired length and ensure homogeneous distribution throughout the material. An adhesive is then incorporated using a rotating ribbon mixer, ensuring comprehensive coverage of the coir material. The final stage involves pressing the coir-adhesive mixture using a heat press machine, with temperatures reaching up to 175 °C for 10–15 min or until the panels solidify.

Multiple fabrication methods can be applied to wood-based panels and composites derived from coir fiber, each offering unique advantages and limitations. These methods include compression molding, extrusion molding, injection molding, resin transfer molding (RTM), and open molding.

5.1. Compression molding

Compression molding represents a widely utilized method in composite and wood-based panel production, capable of processing thermoplastic, thermosetting, and cementitious materials [21,55]. This versatile process primarily employs a hydraulic press, where raw materials are initially mixed with adhesive and resin before being pressed into the desired shape. The method accommodates two primary compression types: cold and hot compression.

Both cold and hot compression techniques can produce high-quality composite panels by carefully managing critical parameters such as pressure, time, and temperature. The resulting product's physical and

surface characteristics can be precisely tailored through strategic material selection and specific production objectives.

5.2. Injection molding

The injection molding fabrication process involves applying a mixture of resin and coir fiber to create the desired product. Compared to compression molding, this method requires higher costs due to the need for complex molds and machinery. However, it offers significant advantages, including reduced impact of fiber length and pressing temperature on the final product [13,111]. A notable benefit is the shorter cycle time between processes, enabling increased production efficiency.

5.3. Extrusion molding

Extrusion molding is predominantly used in plastic polymer composite production. This method necessitates a cooling phase following the extrusion process to maintain the final product's shape. Research is ongoing regarding the application of this process to natural fibers, as suitable substitutes for plastic materials are still being investigated [38, 75,131]. Typical products created through this method include straws, cables, and other cylindrical objects.

5.4. Resin transfer molding (RTM)

Resin transfer molding (RTM) innovatively combines principles from injection and compression molding. Natural fibers are loaded into a mold and subsequently infused with polymer resin at low temperatures. Products generated through the RTM method are characterized by smooth surfaces, precise dimensional accuracy, and superior mechanical strength compared to alternative methods. The technique demonstrates

Table 3
List of Journal Represented in Fig. 7.

Journal	Adhesive									
	A	B	C	D	E	F	G	H	I	X
[36]		✓								
[92]	✓									
[59]		✓			✓	■				■
[76]		✓								
[44]						✓				■
[46]	✓									
[86]										✓
[25]							✓			
[87]						✓		✓		
[125]							✓			
[12]							✓			
[5]				✓					✓	
[49]			✓							
[62]								✓	✓	
[120]		✓	✓							
[55]	✓	✓	✓							
[79]	✓	✓								
[54]	✓									✓
[77]	✓									
[82]										✓
[58]		✓								
[106]					✓					
[84]			✓			✓		✓		
[30]			✓						✓	
[28]										✓
[24]		✓								
[119]			✓					✓		
[99]								✓		
[47]		✓								
[11]	✓									
[15]			✓							
[102]			✓			✓				
[45]		✓								
[7]			✓	✓						
[101]			✓							
[66]								✓		
[80]							✓			
[23]									✓	
[18]						✓				
[61]								✓		
[4]		✓		✓						
[109]									✓	
[130]				✓					✓	
[40]				✓						
[60]				✓						
[26]		✓								
[39]				✓				✓		
[51]				✓						
[127]				✓						
[113]				✓						
[90]				✓						
[116]				✓						
[48]								✓		
[29]				✓						
[30]			✓							✓

Legend:
 A = Phenol-Formaldehyde.
 B = Urea Formaldehyde.
 C = Tannin.
 D = Lignin.
 E = Latex.
 F = Citric Acid.
 G = Bark.
 H = Starch/Carbohydrate.
 I = Protein.
 X = Others.

particular advantages in product sustainability and technological innovation, offering enhanced mechanical properties such as improved strength and stiffness [71,94]

5.5. Open molding

Often referred to as hand lay-up, the open molding method involves applying resin directly over fibers. This technique is particularly suitable for producing large-scale items such as boat hulls, slides, and children's toys. However, it requires more resin compared to other processes and is conducted at room temperature, resulting in relatively lower mechanical strength [1].

Each fabrication method presents unique characteristics, making the selection process crucial depending on the specific requirements of the intended composite material.

6. Economical aspect and sustainability

The economic viability and sustainability of coconut coir-based materials, particularly in the production of wood-based panels (WBPs), are crucial factors in their widespread adoption. As the world faces increasing pressure to transition towards more sustainable building materials, coir-based composites have emerged as a promising alternative to conventional wood-based products. The market value of wood-based panels continues to increase every year. Based on projections, the value of WBPs will reach USD 247.23 million by 2027 with a compound annual growth rate (CAGR) increase of 6.9 % [97]. However, with increasing consumer awareness about the environment, companies have begun to look for wood substitutes as alternative materials for producing WBPs. Using alternative materials, such as coir fiber in WBPs is still uncharted as most products are still in prototype form. However, coir fiber has attracted attention from the biomedical, automotive, packaging, and construction industries [36].

Compared to other natural fibers, coir is a mature industry with a world import value of USD 719.13 million in 2021 but decrease in the next two years [14,52]. The value has almost doubled compared to the previous decade. The export value is exported in the form of semi-finished materials such as cocopeat brick and coco fiber. Product diversification efforts are carried out to expand and potential new products. With this, it is expected that in addition to exporting in the form of semi-finished products, it can also be done in the form of other derivative products such as WBPs. The economic and environmental advantages of using coir fiber in manufacturing WBPs are explored below, considering both cost-effectiveness and sustainability.

6.1. Cost-effectiveness

Coir fiber, as a by-product of the coconut industry, is relatively inexpensive and abundant in tropical regions where coconuts are cultivated [117]. This availability reduces the need for costly raw materials, contributing to a more affordable production process for coir-based WBPs. Additionally, the use of coir fibers, which are often discarded as waste, provides an economic incentive for utilizing agricultural residues, promoting a circular economy. The lignocellulosic composition of coir fibers makes them suitable for various applications, including eco-composites and polymer reinforcements, further enhancing their value in sustainable production [10].

The cost-effectiveness of coir-based wood based panels is further enhanced by the possibility of scaling up production, as the raw material is abundant and relatively inexpensive. However, additional costs are involved in processing the coir fiber and incorporating adhesives, which may increase production costs slightly, depending on the type of adhesive used. Still, the overall cost remains competitive, especially when compared to the rising costs of traditional wood products.

6.2. Sustainability benefits

The environmental sustainability of coir-based WBPs is one of the most significant advantages of using coir as a primary material. Coir is a natural fiber derived from renewable sources, making it an

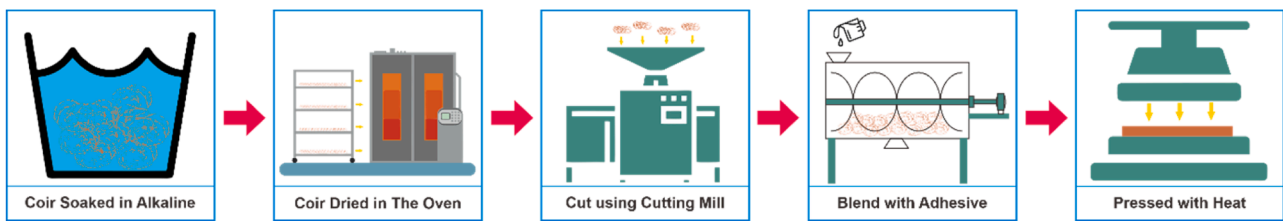


Fig. 7. Fabrication Process of Coir-based WBPs.

Coconut Coir Import Value Trends

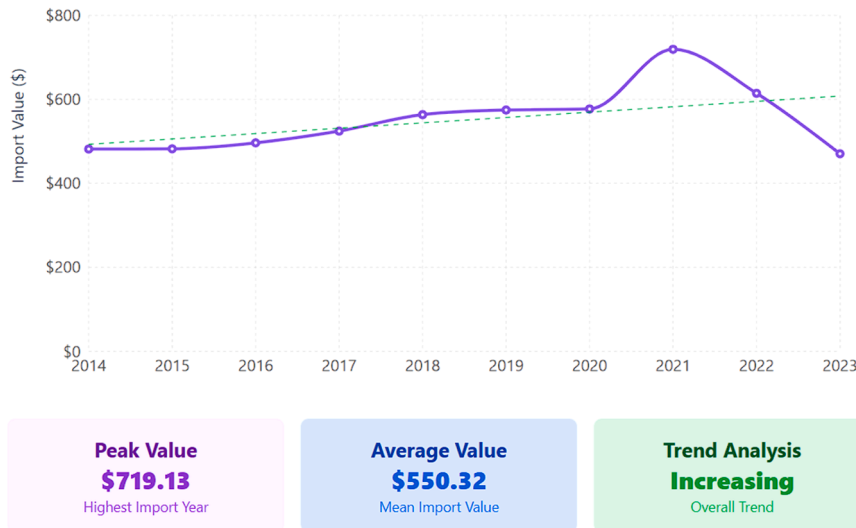


Fig. 8. World Import Value of Coconut Coir Fiber Products.

environmentally friendly alternative to wood [1]. Unlike conventional wood, which requires extensive forest resources, coir fiber is biodegradable and non-toxic, offering a less harmful environmental footprint.

Coir-based WBPs also contribute to reducing the demand for wood from forests, helping mitigate deforestation, and preserving biodiversity. Furthermore, coconut coir can be easily integrated into eco-friendly production processes with minimal energy consumption compared to more energy-intensive materials. This sustainability aspect is increasingly crucial in sectors like construction, where green building materials are in high demand due to growing concerns over climate change and resource depletion.

6.3. Challenges and future considerations

Despite the clear sustainability benefits, challenges remain in the large-scale adoption of coir-based wood-based panels (WBPs). These include issues related to the consistency of fiber quality, the need for specialized adhesives, and the processing technologies involved. The lack of standardized production processes and limited commercial infrastructure for coir-based products also poses challenges for the widespread application of these materials.

Emerging design innovations, however, are beginning to showcase the aesthetic potential of coir-based materials beyond traditional industrial applications. Contemporary designers are leveraging advanced CNC machining techniques to transform coir composites into intricate, precision-crafted tableware companions and decorative objects. These CNC-fabricated pieces not only highlight the material's versatility but also demonstrate how sustainable materials can be integrated into high-end design practices.

Ongoing research continues to improve the strength, durability, and

fire resistance of coir-based composites. Advancements in adhesives and hybridisation with other natural fibers could further enhance the properties of these materials, offering additional environmental benefits without compromising performance. The integration of digital fabrication technologies like CNC machining opens new avenues for material exploration, bridging the gap between sustainability, functionality, and aesthetic appeal.

The synergy between advanced manufacturing techniques and sustainable materials represents a promising trajectory for design innovation. By developing coir-based products that are both visually compelling and environmentally responsible, researchers and designers are creating compelling narratives around circular economy principles.

In the long term, if these challenges can be addressed, coconut coir-based WBPs are likely to become a key component in the global transition to sustainable building materials. The potential extends beyond construction, encompassing product design, furniture, and decorative arts, where the material's unique properties can be leveraged to create both functional and visually striking objects.

7. Coconut coir-based medium density fiberboard and SWOT analysis

The manufacture of medium-density fiberboard made from coconut fiber has the potential for mass production. This commercial potential is based on its lightweight, low price, and natural fire resistance [36]. Proper treatment and selection of a good adhesive are key. An environmentally friendly adhesive with low formaldehyde emission is the research objective, and the use of lignin and tannin as substitutes for Urea and phenol is possible. In addition, the JIS A 5908 (2003) standard was chosen because it is sufficient to fulfill the local and regional

feasibility in Asia.

Based on the analysis that have been done, SWOT strategy can be implemented in the development of coir-based WBPs.

1) Strengths

- i. Environmentally friendly and biodegradable product.
- ii. Lower mass compared to equivalent wood-based products.
- iii. Potential for high economic value in commercial production.
- iv. Aligns with government initiatives for product and technology downstream.
- v. Contributes to deforestation reduction.

2) Weakness

- i. Inferior interfacial bonding compared to wood-based materials.
- ii. Lack of specialized production technology processes.
- iii. Distinct surface characteristics different from traditional wood products.
- iv. Requires specialized adhesives unique to coir-based materials.

3) Opportunities

- i. High demand, particularly in biocomposite materials.
- ii. Increasing public awareness of environmentally friendly products.
- iii. Limited market competition for similar products.
- iv. Significant potential for multidisciplinary research.

4) Threats

- i. Declining prices of synthetic materials.
- ii. Potential habitat disruption due to sea-level rise affecting coastal coconut regions.
- iii. Potential customer skepticism regarding product quality.

Several strategies can be derived from this SWOT analysis. First, manufacturers can incrementally incorporate coconut fiber into WBPs while maintaining existing wood and urea-formaldehyde adhesive compositions. This approach minimizes risk and research and development expenses. Second, manufacturers may entirely replace the primary ingredient without altering the adhesive or fundamental production process, as several studies suggest that coir materials can be produced using similar technologies to wood-based products.

The most complex and high-risk strategy involves completely replacing wood and switching to bioadhesives. This approach requires substantial research and development investment, necessitating significant adjustments to supply chain management and raw material procurement, even if production machinery remains unchanged.

8. Conclusion

This literature review explores the application of coir fiber in wood-based panel (WBP) products. The research comprehensively examined coir fiber's physical properties, manufacturing processes, adhesive technologies, and economic considerations. Bonding mechanisms emerge as a critical factor in research success, with the mechanical strength, physical properties, and acoustic performance of WBPs fundamentally dependent on adhesive selection.

A notable finding is the limited exploration of nature-based adhesives such as tannin and lignin in coir fiber applications, presenting a significant research gap. The feasibility of using coir fiber as an alternative material in WBPs is contingent upon appropriate treatment processes and adhesive selection.

Continued investigation and research are essential to develop diverse coir fiber-based product applications. While utilizing existing market adhesives represents an economically viable short-term solution, the long-term research objective focuses on developing environmentally friendly, non-carcinogenic adhesives and establishing an efficient production system for coconut fiber-based WBPs.

CRediT authorship contribution statement

Nugroho Mamayu Hayuning Bawono: Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Baju Bawono:** Formal analysis, Investigation, Resources, Software, Validation. **Paulus Wisnu Anggoro:** Conceptualization, Project administration, Writing – original draft, Writing – review & editing. **Jamari Jamari:** Formal analysis, Methodology, Supervision, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The authors declare no conflicts of interest.

Data availability

No data was used for the research described in the article.

References

- [1] A.G. Adeniyi, D.V. Onifade, J.O. Ighalo, A.S. Adeoye, A review of coir fiber reinforced polymer composites, *Compos. Part B* 176 (June) (2019) 107305, <https://doi.org/10.1016/j.compositesb.2019.107305>.
- [2] A. Al-Daas, A.S. Azmi, F.B. Ali, H. Anuar, The effect of alkaline treatment to pseudo-stem banana fibers on the performance of polylactic acid/banana Fiber composite, *J. Nat. Fibers* 20 (1) (2023), <https://doi.org/10.1080/15440478.2023.2176401>.
- [3] A. Ali, K. Shaker, Y. Nawab, M. Jabbar, T. Hussain, J. Militky, V. Baheti, Hydrophobic treatment of natural fibers and their composites—A review, *J. Ind. Text.* 47 (8) (2018) 2153–2183, <https://doi.org/10.1177/1528083716654468>.
- [4] P. Antov, V. Savov, L. Krist'ák, R. Réh, G.I. Mantanis, Eco-friendly, high-density fiberboards bonded with urea-formaldehyde and ammonium lignosulfonate, *Polymers (Basel)* 13 (2) (2021) 1–13, <https://doi.org/10.3390/polym13020220>.
- [5] A. Arias, E. Entrena-barbero, G. Feijoo, M.T. Moreira, Sustainable non-isocyanate polyurethanes bio-adhesives for engineered wood panels are revealed as promising candidates to move from formaldehyde based alternative, *J. Environ. Chem. Eng.* 10 (1) (2022) 107053, <https://doi.org/10.1016/j.jece.2021.107053>.
- [6] A. Arias, S. González-Rodríguez, M. Vetróni Barros, R. Salvador, A.C. de Francisco, C. Moro Piekarski, M.T. Moreira, Recent developments in bio-based adhesives from renewable natural resources, *J. Clean. Prod.* (June) (2021) 314, <https://doi.org/10.1016/j.jclepro.2021.127892>.
- [7] M.A. Aristri, M.A.R. Lubis, S.M. Yadav, P. Antov, A.N. Papadopoulos, A. Pizzi, W. Patriasari, M. Ismayati, A.H. Iswanto, Recent developments in lignin- and tannin-based non-isocyanate polyurethane resins for wood adhesives—a review, *Appl. Sci. (Switzerland)* 11 (9) (2021) 1–29, <https://doi.org/10.3390/app11094242>.
- [8] T. Aziz, A. Ullah, H. Fan, M.I. Jamil, F.U. Khan, R. Ullah, M. Iqbal, A. Ali, B. Ullah, Recent progress in silane coupling agent with its emerging applications, *J. Polym. Environ.* 29 (11) (2021) 3427–3443, <https://doi.org/10.1007/s10924-021-02142-1>.
- [9] A.K. Balan, S. Mottakkunnu Parambil, S. Vakyath, J. Thulissery Velayudhan, S. Naduparambath, P. Etathil, Coconut shell powder reinforced thermoplastic polyurethane/natural rubber blend-composites: effect of silane coupling agents on the mechanical and thermal properties of the composites, *J. Mater. Sci.* 52 (11) (2017) 6712–6725, <https://doi.org/10.1007/s10853-017-0907-y>.
- [10] H. Bensalah, M. Raji, H. Abdellaoui, H. Essabir, R. Bouhfid, A. el kacem Quaiss, Thermo-mechanical properties of low-cost “green” phenolic resin composites reinforced with surface modified coir fiber, *Int. J. Adv. Manuf. Technol.* 112 (7–8) (2021) 1917–1930, <https://doi.org/10.1007/s00170-020-06535-9>.
- [11] J.T. Benthien, J. Sieburg-Rockel, N. Engehausen, G. Koch, J. Lüttke, Analysis of adhesive distribution over particles according to their size and potential savings from particle surface determination, *Fibers* 10 (11) (2022) 97, <https://doi.org/10.3390/fib10110097>.
- [12] R.A. Bispo, M.F. Trevisan, S.A.M. da Silva, V.B. Aquino, M. de, R.L. Saraiva, P. de, F.N. Arroyo, J.C. Molina, E. Chahud, L.A.M.N. Branco, T.H. Panzera, F.A.R. Lahr, A.L. Christoforo, Production and evaluation of particleboards made of coconut fibers, pine, and eucalyptus using bicomponent polyurethane-castor oil resin, *BioResources* 17 (3) (2022) 3944–3951, <https://doi.org/10.15376/biores.17.3.3944-3951>.
- [13] Bledzki, A.K., & Faruk, O. (2006). *Influence of processing temperature on microcellular injection-moulded wood – Polypropylene composites*. 1226–1232. <https://doi.org/10.1002/mame.200600210>.
- [14] Center, I.T. (2025). *List of imported products for the selected product product: 530500 cocunut, abaca “Manila hemp or Musa textilis Nee”, ramie, agave and other vegetable textile*. https://www.trademapp.org/Product_SelProduct_TS.aspx?nvp

- m=1 %7C %7C %7C %7C %7C530500 %7C %7C %7C6 %7C1 %7C1 %7C1 %7C2 %7C1 %7C1 %7C1 %7C1 %7C1.
- [15] E. Cesprini, V. Causin, A. De Iseppi, M. Zanetti, M. Marangon, M.C. Barbu, G. Tondi, Renewable tannin-based adhesive from Quebracho extract and furfural for particleboards, *Forests* 13 (11) (2022) 1–15, <https://doi.org/10.3390/f13111781>.
- [16] F.S. Chakar, A.J. Ragauskas, Review of current and future softwood kraft lignin process chemistry, *Ind. Crops. Prod.* 20 (2) (2004) 131–141, <https://doi.org/10.1016/j.indcrop.2004.04.016>.
- [17] I. Dababi, O. Gimello, E. Elaloui, N. Brosse, Water extraction of tannins from Aleppo pine bark and Sumac root for the production of green wood adhesives, *Mol. (Basel, Switzerland)* 25 (21) (2020), <https://doi.org/10.3390/molecules25215041>.
- [18] C. Del Menezzi, S. Amirou, A. Pizzi, X. Xi, L. Delmotte, Reactions with wood carbohydrates and lignin of citric acid as a bond promoter of wood veneer panels, *Polymers (Basel)* 10 (8) (2018), <https://doi.org/10.3390/polym10080833>.
- [19] N. Donthu, S. Kumar, D. Mukherjee, N. Pandey, W.M. Lim, How to conduct a bibliometric analysis: an overview and guidelines, *J. Bus. Res.* 133 (April) (2021) 285–296, <https://doi.org/10.1016/j.jbusres.2021.04.070>.
- [20] L. Dorn, A. Thirion, M. Ghorbani, L.M. Olaechea, I. Mayer, Exploring fully biobased adhesives: sustainable kraft lignin and 5-HMF adhesive for particleboards, *Polymers (Basel)* 15 (12) (2023), <https://doi.org/10.3390/polym15122668>.
- [21] Y.A. El-Shekeil, S.M. Sapuan, K. Abdan, E.S. Zainudin, Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites, *Mater. Des.* 40 (October 2018) (2012) 299–303, <https://doi.org/10.1016/j.matdes.2012.04.003>.
- [22] I. Elfaleh, F. Abbassi, M. Habibi, F. Ahmad, M. Guedri, M. Nasri, C. Garnier, A comprehensive review of natural fibers and their composites: an eco-friendly alternative to conventional materials, *Results Eng.* 19 (June) (2023), <https://doi.org/10.1016/j.rineng.2023.101271>.
- [23] O.D. Fagbemi, B. Sithole, Evaluation of waste chicken feather protein hydrolysate as a bio-based binder for particleboard production, *Curr. Res. Green Sustainable Chem.* 4 (June) (2021) 100168, <https://doi.org/10.1016/j.crgsc.2021.100168>.
- [24] J. Fehrmann, B. Belleville, B. Ozarska, Effects of particle dimension and constituent proportions on internal bond strength of ultra-low-density hemp hurd particleboard, *Forests* 13 (11) (2022), <https://doi.org/10.3390/f13111967>.
- [25] J. Fiorelli, S.B. Bueno, M.R. Cabral, Assessment of multilayer particleboards produced with green coconut and sugarcane bagasse fibers, *Constr. Build. Mater.* 205 (2019) 1–9, <https://doi.org/10.1016/j.conbuildmat.2019.02.024>.
- [26] A.L.F. Freire, C.P.de Araújo Júnior, M.de F. Rosa, M.C.B.de Figueiredo, J.A. de Almeida Neto, Environmental assessment of bioproducts in development stage: the case of fiberboards made from coconut residues, *J. Clean. Prod.* 153 (2017) 230–241, <https://doi.org/10.1016/j.jclepro.2017.03.100>.
- [27] C.P. Gabrielli, F.A. Kamke, Phenol-formaldehyde impregnation of densified wood for improved dimensional stability, *Wood Sci. Technol.* 44 (1) (2010) 95–104, <https://doi.org/10.1007/s00226-009-0253-6>.
- [28] V. Ganesan, V. Shanmugam, B. Kaliyamoorthy, S. Sanjeevi, S.K. Shanmugam, V. Alagumalai, Y. Krishnamoorthy, M. Först, G. Sas, S.M.J. Razavi, O. Das, Optimisation of mechanical properties in saw-dust/woven-jute fibre/polyester structural composites under liquid nitrogen environment using response surface methodology, *Polymers (Basel)* 15 (2021) 13, <https://doi.org/10.3390/polym13152471>.
- [29] J. Gendron, C. Bruel, Y. Boumghar, D. Montplaisir, Preparation and optimization of a lignin-based pressure-sensitive adhesive, *MethodsX (March)* (2023) 10, <https://doi.org/10.1016/j.mex.2023.102144>.
- [30] S. Ghahri, A. Pizzi, R. Hajihassani, A study of concept to prepare totally biosourced wood adhesives from only soy protein and tannin, *Polymers (Basel)* 6 (2022) 14, <https://doi.org/10.3390/polym14061150>.
- [31] M.S.S. Godara, Effect of chemical modification of fiber surface on natural fiber composites: a review, *Mater. Today: Proc.* 18 (2019) 3428–3434, <https://doi.org/10.1016/j.matpr.2019.07.270>.
- [32] D. Gonçalves, J.M. Bordado, A.C. Marques, R.G. Dos Santos, Non-formaldehyde, bio-based adhesives for use in wood-based panel manufacturing industry—A review, *Polymers (Basel)* 23 (2021) 13, <https://doi.org/10.3390/polym13234086>.
- [33] A.D. Gudayu, L. Steuernagel, D. Meiners, R. Gideon, Effect of surface treatment on moisture absorption, thermal, and mechanical properties of sisal fiber, *J. Ind. Text.* 51 (2) (2022) 2853S–2873S, <https://doi.org/10.1177/1528083720924774>.
- [34] Y.M. Guo, Z.L. Huang, J. Guo, H. Li, X.R. Guo, M.J. Nkeli, Bibliometric analysis on smart cities research, *Sustain. (Switzerland)* 13 (2019) 11, <https://doi.org/10.3390/su11133606>.
- [35] K.M.F. Hasan, P.G. Horváth, T. Alpár, Potential natural fiber polymeric nanobiocomposites: a review, *Polymers (Basel)* 12 (5) (2020), <https://doi.org/10.3390/POLYM12051072>.
- [36] K.M.F. Hasan, P.G. Horváth, M. Bak, T. Alpár, A state-of-the-art review on coir fiber-reinforced biocomposites, *RSC Adv.* 11 (18) (2021) 10548–10571, <https://doi.org/10.1039/d1ra00231g>.
- [37] K.M.F. Hasan, P.G. Horváth, Z. Kóczán, T. Alpár, Thermo-mechanical properties of pretreated coir fiber and fibrous chips reinforced multilayered composites, *Sci. Rep.* 11 (1) (2021) 3618, <https://doi.org/10.1038/s41598-021-83140-0>.
- [38] Hassani, F.S.A., Ouahim, W., Bensalah, M.O., Essabir, H., Rodrigue, D., Bouhfid, R., & Quais, K. (2018). *Mechanical properties prediction of polypropylene /short coir fibers composites using a self-consistent approach.* 1, 1–11. <https://doi.org/10.1002/pc.24967>.
- [39] R. Hellmayr, M. Šernek, R. Myna, S. Reichenbach, B. Kromoser, F. Liebner, R. Wimmer, Heat bonding of wood with starch-lignin mixtures creates new recycling opportunities, *Mater. Today Sustain.* 19 (2022), <https://doi.org/10.1016/j.mtsust.2022.100194>.
- [40] V. Hemmilä, S. Adamopoulos, R. Hosseinpourpia, S.A. Ahmed, Ammonium lignosulfonate adhesives for particleboards with pMDI and furfuryl alcohol as crosslinkers, *Polymers (Basel)* 11 (10) (2019), <https://doi.org/10.3390/polym11101633>.
- [41] J. Hu, F. Li, B. Wang, H. Zhang, C. Ji, S. Wang, Z. Zhou, A two-step combination strategy for significantly enhancing the interfacial adhesion of CF/PPS composites: the liquid-phase oxidation followed by grafting of silane coupling agent, *Compos. B Eng.* 191 (2020) 107966, <https://doi.org/10.1016/j.compositesb.2020.107966>.
- [42] M.H. Hussin, N.H. Abd Latif, T.S. Hamidon, N.N. Idris, R. Hashim, J.N. Appaturi, N. Brosse, I. Ziegler-Devin, L. Chrusicl, W. Fatrisari, F.A. Syamani, A.H. Iswanto, L.S. Hua, S.S.A.O. Al Edrus, W.C. Lum, P. Antov, V. Savov, M.A. Rahandi Lubis, L. Kristak, J. Sedlić, Latest advancements in high-performance bio-based wood adhesives: a critical review, *J. Mater. Res. Technol.* 21 (2022) 3909–3946, <https://doi.org/10.1016/j.jmrt.2022.10.156>.
- [43] M.H. Islam, M. Hosna Ara, M.A. Khan, J. Naime, M.L. Rahman, T.A. Ruhane, M.A. R. Khan, A Sustainable Approach For the Development of Cellulose-Based Food Container from Coconut Coir, *ACS Omega*, 2024, <https://doi.org/10.1021/acsomega.4c03031>.
- [44] Ismadi, M. Gopar, S.S. Kusumah, Sudarmanto, L. Astari, Subyaktio, F.A. Syamani, R. Marlina, K. Umemura, A. Hermawan, Investigation of optimum particles size and citric acid content for coconut husk particleboard manufacturing, in: *AIP Conference Proceedings*, 2022, <https://doi.org/10.1063/5.0078508>. 2454(June).
- [45] B. Istana, I.M.L. Batan, Sutikno, S. Khem, U. Ubaidillah, I. Yahya, Influence of particle size and bulk density on sound absorption performance of oil palm frond-reinforced composites particleboard, *Polymers (Basel)* 15 (3) (2023) 510, <https://doi.org/10.3390/polym15030510>.
- [46] A.H. Iswanto, I. Azhar, A.A. Bukit, F. Oktaviani, T. Sucipto, L. Hakim, H. Manurung, A. Darwis, Samsuri, A. Zaitunan, H. Arinah, A. Susilowati, D. Elfiati, A.B. Rangkuti, O.K.H. Syahputra, M.M. Harahap, M. Ulfa, R. Ramey, R. Hartono, The properties of particleboards made from non-wood lignocellulose materials bonded with melamine formaldehyde resin, in: *IOP Conference Series: Earth and Environmental Science*, 2021, <https://doi.org/10.1088/1755-1315/912/1/012061>. 912(1).
- [47] A.H. Iswanto, J. Sutiawan, A. Darwis, M.A.R. Lubis, M. Pędzik, T. Rogoziński, W. Fatrisari, Influence of isocyanate content and hot-pressing temperatures on the physical–Mechanical properties of particleboard bonded with a hybrid urea–Formaldehyde/isocyanate adhesive, *Forests* 14 (2) (2023) 1–13, <https://doi.org/10.3390/f14020320>.
- [48] M. Jimenez Bartolome, S.S.P. Padhi, O.G. Fichtberger, N. Schwaiger, B. Seidl, M. Kozich, G.S. Nyanhongo, G.M. Guebitz, Improving properties of starch-based adhesives with carboxylic acids and enzymatically polymerized lignosulfonates, *Int. J. Mol. Sci.* 23 (21) (2022), <https://doi.org/10.3390/ijms232113547>.
- [49] P. Jorge, G. Lopes, L. Calegari, W. Alex, D.M. Silva, D.A. Gatto, P. Nicó, D. M. Neto, R.R.De Melo, I.A. Bakke, R.D.A Delucis, Tannin - based extracts of Mimosa tenuiflora bark : features and prospecting as wood adhesives, *Appl. Adhes. Sci.* (2021), <https://doi.org/10.1186/s40563-021-00133-y>.
- [50] N.A. Karim, N.A.F.N. Lah, S.A. Rahman, W.N.A.W. Nadhari, Z.F.Z. Gaffar, Strength properties of mixed cocopeat fibres and Merawan Siput Jantan (*Hopea odorata* spp.) bonded with partial rubber latex adhesive and nano- SiO₂ in particleboard manufacturing, in: *AIP Conference Proceedings* 2454, 080008, 2022, <https://doi.org/10.1063/5.0078301>.
- [51] R. Karri, R. Lappalainen, L. Tomppo, R. Yadav, Bond quality of poplar plywood reinforced with hemp fibers and lignin-phenolic adhesives, *Compos., Part C: Open Access* 9 (July) (2022) 100299, <https://doi.org/10.1016/j.jcomc.2022.100299>.
- [52] Kementerian Perdagangan Republik Indonesia, News letter Warta Daglu. *Badan Pengkajian & Pengembangan Perdagangan Kementerian Perdagangan Republik Indonesia*, Edisi Oktober 2022 (2022) 19. [https://bkperdag.kemendag.go.id/media_content/2020/10/NL_September_2020_cover_baru_compressed_\(1\).pdf](https://bkperdag.kemendag.go.id/media_content/2020/10/NL_September_2020_cover_baru_compressed_(1).pdf).
- [53] M.K.A. Khan, M. Faisal, V.R. Arun Prakash, Effect of silane coupling grafted polyethylene terephthalate foam and areca fruit fiber reinforced chitin modified vinyl ester prosthetic composite on thermal and water accelerated aging conditions, *Polym. Compos.* 45 (6) (2024) 5111–5124, <https://doi.org/10.1002/pc.28114>.
- [54] S.S. Kusumah, K. Umemura, I. Guswenrivo, T. Yoshimura, K. Kanayama, Utilization of sweet sorghum bagasse and citric acid for manufacturing of particleboard II: influences of pressing temperature and time on particleboard properties, *J. Food Sci.* 63 (2) (2017) 161–172, <https://doi.org/10.1007/s10086-016-1605-0>.
- [55] C.-J. Lee, T.-C. Chang, M.-J. Chung, Effects of gluing conditions for formaldehyde-free tannin adhesive on the oriented bamboo scrimber board properties, *Eur. J. Wood Wood Prod.* 79 (6) (2021) 1623–1631, <https://doi.org/10.1007/s00107-021-01701-6>.
- [56] J. Li, F. Ren, X. Liu, G. Chen, X. Li, Y. Qing, Y. Wu, M. Liu, Eco-friendly fiberboards with low formaldehyde content and enhanced mechanical properties produced with activated soybean protein isolate modified urea-formaldehyde resin, *Eur. Polym. J.* 210 (2024) 113002, <https://doi.org/10.1016/j.eurpolymj.2024.113002>.
- [57] X. Li, Q. Gao, C. Xia, J. Li, X. Zhou, Urea formaldehyde resin resultant plywood with rapid formaldehyde release modified by tunnel-structured sepiolite, *Polymers (Basel)* 11 (8) (2019), <https://doi.org/10.3390/polym11081286>.

- [58] J. Liang, J. Wu, J. Xu, Low-formaldehyde emission composite particleboard manufactured from waste chestnut bur, *J. Food Sci.* 67 (1) (2021), <https://doi.org/10.1186/s10086-021-01955-x>.
- [59] J.X. Lim, T.K. Ong, C.K. Ng, I.W. Chua, Y.B. Lee, Z.Y. Yap, R.A. Bakar, Development of particleboard from green coconut waste, *J. Phys. Conf. Ser.* 2120 (1) (2021), <https://doi.org/10.1088/1742-6596/2120/1/012034>.
- [60] M.A.R. Lubis, A. Labib, Sudarmanto, F. Akbar, A. Nuryawan, P. Antov, L. Kristak, A.N. Papadopoulos, Influence of lignin content and pressing time on plywood properties bonded with cold-setting adhesive based on poly (Vinyl Alcohol), lignin, and hexamine, *Polymers (Basel)* 14 (10) (2022), <https://doi.org/10.3390/polym14102111>.
- [61] M.A.R. Lubis, S.M. Yadav, B.D. Park, Modification of oxidized starch polymer with nanoclay for enhanced adhesion and free formaldehyde emission of plywood, *J. Polym. Environ.* 29 (9) (2021) 2993–3003, <https://doi.org/10.1007/s10924-021-02101-w>.
- [62] M.R. Lubis, T. Maimun, J. Kardi, R.B. Masra, Characterizing particle board made of oil palm empty fruit bunch using Central composite design, *Makara J. Sci.* 22 (1) (2018), <https://doi.org/10.7454/mss.v22i1.6988>.
- [63] S. Mahmud, K.M.F. Hasan, M.A. Jahid, K. Mohiuddin, R. Zhang, J. Zhu, Comprehensive Review On Plant Fiber-Reinforced Polymeric Biocomposites. In *Journal of Materials Science*, Vol. 56, Springer US, 2021, <https://doi.org/10.1007/s10853-021-05774-9>.
- [64] D. Maldas, B.V. Kokta, Studies on the preparation and properties of particle boards made from bagasse and PVC: II. Influence of the addition of coupling agents, *Bioresour. Technol.* 35 (3) (1991) 251–261, [https://doi.org/10.1016/0960-8524\(91\)90122-Z](https://doi.org/10.1016/0960-8524(91)90122-Z).
- [65] C. Martínez Suárez, P. Rojas Montejo, O. Gutiérrez Junco, Effects of alkaline treatments on natural fibers, *J. Phys. Conf. Ser.* (1) (2021) 2046, <https://doi.org/10.1088/1742-6596/2046/1/012056>.
- [66] M.I. Maulana, M.A.R. Lubis, F. Friyanto, L.S. Hua, A.H. Iswanto, P. Antov, L. Kristak, E. Mardawati, R.K. Sari, L.H. Zaini, W. Hidayat, V.Lo Giudice, L. Todaro, Environmentally friendly starch-based adhesives for bonding high-performance wood composites: a review, *Forests* 13 (10) (2022) 1–24, <https://doi.org/10.3390/f13101614>.
- [67] A. Merzoug, B. Bouhamida, Z. Sereir, A. Bezazi, A. Kilic, Z. Candan, Quasi-static and dynamic mechanical thermal performance of date palm/glass fiber hybrid composites, *J. Ind. Text.* 51 (5_suppl) (2022) 7599S–7621S, <https://doi.org/10.1177/1528083720958036>.
- [68] R.G.D.A. Mesquita, J.M. Marconcini, A.R. Sanadi, A.A. Da Silva César, G.H. D. Tonoli, T.M. Venãs, L.M. Mendes, Coir and sisal fibers as fillers in the production of eucalyptus medium density particleboards - MDP, *Mater. Res.* 19 (6) (2016) 1429–1436, <https://doi.org/10.1590/1980-5373-MR-2016-0361>.
- [69] Z. Miao, F. Guo, X. Zhao, Z. Guo, Y. Guo, Y. Zhang, J. Wu, Effects of acid treatment on physicochemical properties and gasification reactivity of fine slag from Texaco gasifier, *Chem. Eng. Res. Des.* 169 (2021) 1–8, <https://doi.org/10.1016/j.cherd.2021.01.020>.
- [70] G. Michelotti, M. Niedzwiecki, D. Bidjan, P. Dieckmann, S. Deari, T. Attin, T. T. Tauböck, Silane effect of universal adhesive on the composite-composite repair bond strength after different surface pretreatments, *Polymers (Basel)* 12 (4) (2020), <https://doi.org/10.3390/POLYM12040950>.
- [71] A. Mikhilchan, T. Gspann, A. Windle, Aligned carbon nanotube – epoxy composites : the effect of nanotube organization on strength, stiffness, and toughness, *J. Mater. Sci.* 51 (22) (2016) 10005–10025, <https://doi.org/10.1007/s10853-016-0228-6>.
- [72] X. Mo, E. Cheng, D. Wang, X.S. Sun, Physical properties of medium-density wheat straw particleboard using different adhesives, *Ind. Crops. Prod.* 18 (1) (2003) 47–53, [https://doi.org/10.1016/S0926-6690\(03\)00032-3](https://doi.org/10.1016/S0926-6690(03)00032-3).
- [73] X. Mo, J. Hu, X.S. Sun, J.A. Ratto, Compression and tensile strength of low-density straw-protein particleboard, *Ind. Crops. Prod.* 14 (1) (2001) 1–9, [https://doi.org/10.1016/S0926-6690\(00\)00083-2](https://doi.org/10.1016/S0926-6690(00)00083-2).
- [74] P. Muensri, T. Kunanopparat, P. Menut, S. Siriwananayotin, Effect of lignin removal on the properties of coconut coir fiber/wheat gluten biocomposite, *Compos. Part A: Appl. Sci. Manuf.* 42 (2) (2011) 173–179, <https://doi.org/10.1016/j.compositesa.2010.11.002>.
- [75] Y.S. Munde, R.B. Ingle, I. Siva, Investigation to appraise the vibration and damping characteristics of coir fibre reinforced polypropylene composites, *Adv. Mater. Process. Technol.* 0698 (2018) 1–12, <https://doi.org/10.1080/2374068X.2018.1488798>.
- [76] C.R.P. Narciso, A.H.S. Reis, J.F. Mendes, N.D. Nogueira, R.F. Mendes, Potential for the use of coconut husk in the production of medium density particleboard, *Waste Biomass Valorization* 12 (3) (2021) 1647–1658, <https://doi.org/10.1007/s12649-020-01099-x>.
- [77] M. Nasir, R. Hashim, O. Sulaiman, A. Gupta, T.A. Khan, M. Jawaid, M. Asim, Natural Fiber improvement by laccase; optimization, characterization and application in medium density fiberboard, *J. Nat. Fibers* 14 (3) (2017) 379–389, <https://doi.org/10.1080/15440478.2016.1212759>.
- [78] C.V.L. Natarelli, A.C.C. Lemos, M.R. de Assis, G.H.D. Tonoli, P.F. Trugilho, J.M. Marconcini, J.E. de Oliveira, Sulfonated Kraft lignin addition in urea–formaldehyde resin: thermokinetic analysis, *J. Therm. Anal. Calorim.* 137 (5) (2019) 1537–1547, <https://doi.org/10.1007/s10973-019-08075-1>.
- [79] M. Nazerian, Z. Beygi, R. Mohebbi Gargari, F. Kool, Application of response surface methodology for evaluating particleboard properties made from cotton stalk particles, *Wood Mater. Sci. Eng.* 13 (2) (2018) 73–80, <https://doi.org/10.1080/17480272.2017.1307280>.
- [80] P. Ndiwe, A. Pizzi, B. Tibi, R. Danwe, N. Konai, S. Amirou, African tree bark exudate extracts as biohardeners of fully biosourced thermoset tannin adhesives for wood panels, *Ind. Crops. Prod.* 132 (February) (2019) 253–268, <https://doi.org/10.1016/j.indcrop.2019.02.023>.
- [81] G.A. Ntalos, A.H. Grigoriou, Characterization and utilisation of vine prunings as a wood substitute for particleboard production, *Ind. Crops. Prod.* 16 (1) (2002) 59–68, [https://doi.org/10.1016/S0926-6690\(02\)00008-0](https://doi.org/10.1016/S0926-6690(02)00008-0).
- [82] C.C. Nwobi-Okoye, M.K. Anyichie, C.U. Atuanya, RSM and ANN modeling for production of Newbouldia Laevis fibre and recycled high density polyethylene composite: multi objective optimization using genetic algorithm, *Fibers Polym.* 21 (4) (2020) 898–909, <https://doi.org/10.1007/s12221-020-9597-1>.
- [83] D.O. Obada, K.A. Salami, A.N. Oyediji, O.A. Osuchukwu, J. Abass, C. Ogwuche, N.D. Bansod, M.I. Ubgaja, I.U. Ibrahim, B. Abdulkareem, R.K. Olawale, L. K. Abidoye, Mechanical and frictional properties of coconut husk powder reinforced polymer immersed in a simulated acidic medium for oil/gas applications, *Heliyon* 10 (3) (2024) e25026, <https://doi.org/10.1016/j.heliyon.2024.e25026>.
- [84] S. Oktay, N. Kuzilcan, B. Bengü, Development of bio-based cornstarch - Mimoso tannin - sugar adhesive for interior particleboard production, *Ind. Crops. Prod.* 170 (May) (2021), <https://doi.org/10.1016/j.indcrop.2021.113689>.
- [85] S. Oktay, A. Pizzi, N. Köken, B. Bengü, Tannin-based wood panel adhesives, *Int. J. Adhes. Adhes.* 130 (2024) 103621, <https://doi.org/10.1016/j.ijadhadh.2024.103621>.
- [86] P.W. Olupot, E. Menya, F. Lubwama, L. Ssekaluvi, B. Nabuuma, J. Wakatuntu, Effects of sawdust and adhesive type on the properties of rice husk particleboards, *Results Eng.* 16 (November) (2022) 100775, <https://doi.org/10.1016/j.rineng.2022.100775>.
- [87] A.A. Owodunni, J. Lamaming, R. Hashim, O.F. Abdulwahab Taiwo, M.H. Hussin, M.H. Mohamad Kassim, Y. Bustami, O. Sulaiman, M.H. Mohamad Amini, S. Hiziroglu, Properties of green particleboard manufactured from coconut fiber using a potato starch based adhesive, *BioResources* 15 (2) (2020) 2279–2292, <https://doi.org/10.15376/biores.15.2.2279-2292>.
- [88] A.R. Pai, R.N. Jagtap, Surface morphology & mechanical properties of some unique natural fiber reinforced polymer composites-a review, *J. Mater. Environ. Sci.* 6 (4) (2015) 902–917.
- [89] M. Palencia, N.G. Chate, A. García-Quintero, Obtaining micrometric-scale hollow fibers from wastes aged coir by oxidative chloro-sulfonation of lignin: hClO/H₂SO₄, *Bioresour. Technol. Rep.* 25 (2024) 101812, <https://doi.org/10.1016/j.biteb.2024.101812>.
- [90] W. Peng, C. Dong, J. An, G. Zhang, P. Wang, Y. Xie, A novel formaldehyde-free wood adhesive synthesized by straw soda lignin and polyethyleneimine, *BioResources* 18 (2) (2023) 3123–3143, <https://doi.org/10.15376/biores.18.2.3123-3143>.
- [91] L. Pilato, Phenolic resins: 100Years and still going strong, *React. Funct. Polym.* 73 (2) (2013) 270–277, <https://doi.org/10.1016/j.reactfunctpolym.2012.07.008>.
- [92] N. Pugazhenthii, P. Anand, Mechanical and thermal behavior of hybrid composite medium density fiberboard reinforced with phenol formaldehyde, *Heliyon* 7 (12) (2021) e08597, <https://doi.org/10.1016/j.heliyon.2021.e08597>.
- [93] D.N. Putri, A. Santoso, R.P.B. Laksana, F. Akbar, S.S. Kusumah, E.S. Wibowo, J. Sutiawan, M.A.R. Lubis, Recent developments on ultra-low formaldehyde emitting system of tannin-based adhesive derived from tropical wood barks for wood-based products manufacturing: a review, *Int. J. Adhes. Adhes.* 132 (2024) 103727, <https://doi.org/10.1016/j.ijadhadh.2024.103727>.
- [94] D.K. Rajak, D.D. Pagar, P.L. Menezes, E. Linul, Fiber-reinforced polymer composites: manufacturing, properties, and applications, *Polymers (Basel)* (1667) (2019) 11, <https://doi.org/10.3390/polym11101667>.
- [95] J. Rao, Y. Zhou, M. Fan, Revealing the interface structure and bonding mechanism of coupling agent treated WPC, *Polymers (Basel)* 10 (3) (2018) 1–13, <https://doi.org/10.3390/polym10030266>.
- [96] R. Reh, L. Kristak, J. Sedliacik, P. Bekhta, A. Wronka, G. Kowaluk, Molded plywood with proportions of beech bark in adhesive mixtures: production on an industrial scale, *Polymers (Basel)* 16 (7) (2024) 1–12, <https://doi.org/10.3390/polym16070966>.
- [97] Research, G. V. (2022). NoWood based Panel market size, share & trends analysis report by product (Plywood, MDF, HDF, OSB, Particleboard, Hardboard), by application (Furniture, Construction), by region, and segment forecasts, 2020 - 2027 title. <https://www.grandviewresearch.com/industry-analysis/wood-based-panel-market>.
- [98] R. Rocha Almeida, C. Henrique Soares Del Menezzi, D. Eterno Teixeira, Utilization of the coconut shell of babaçu (Orbignya sp.) to produce cement-bonded particleboard, *Bioresour. Technol.* 85 (2) (2002) 159–163, [https://doi.org/10.1016/S0960-8524\(02\)00082-2](https://doi.org/10.1016/S0960-8524(02)00082-2).
- [99] C. Rosenfeld, P. Solt-Rindler, W. Sailer-Kronlachner, T. Kuncinger, J. Konnerth, A. Geyer, H.W.G. van Herwijnen, Effect of mat moisture content, adhesive amount and press time on the performance of particleboards bonded with fructose-based adhesives, *Materials (Basel)* (23) (2022) 15, <https://doi.org/10.3390/ma15238701>.
- [100] S.M. Sapuan, M. Harimi, M.A. Maleque, Mechanical properties of epoxy/coconut shell filler particle composites, *Arab. J. Sci. Eng.* 28 (2 B) (2003) 171–181.
- [101] R.A.L. Sari, M.A.R. Lubis, R.K. Sari, L. Kristak, A.H. Iswanto, E. Mardawati, W. Patriasari, S.H. Lee, R. Reh, J. Sedliacik, M.I. Maulana, L. Suryanegara, B. Subiyanto, S. Maulana, Properties of plywood bonded with formaldehyde-free adhesive based on poly(vinyl alcohol)-Tannin-Hexamine at different formulations and cold-pressing times, *J. Compos. Sci.* 7 (3) (2023) 113, <https://doi.org/10.3390/jcs7030113>.
- [102] F. Segovia, P. Blanchet, N. Auclair, G.G.E. Essoua, Thermo-mechanical properties of a wood fiber insulation board using a bio-based adhesive as a binder, *Buildings* 10 (9) (2020) 1–15, <https://doi.org/10.3390/buildings10090152>.

- [103] A. Shafiq, I. Ahmad Bhatti, N. Amjed, M. Zeshan, A. Zaheer, A. Kamal, S. Naz, T. Rasheed, Lignin derived polyurethanes: current advances and future prospects in synthesis and applications, *Eur. Polym. J.* 209 (2024) 112899, <https://doi.org/10.1016/j.eurpolymj.2024.112899>.
- [104] G. Sivasankarapillai, E. Eslami, M.-P. Laborie, Potential of Organosolv lignin based materials in pressure sensitive adhesive applications, *ACS Sustain. Chem. Eng.* 7 (15) (2019) 12817–12824, <https://doi.org/10.1021/acssuschemeng.9b01670>.
- [105] I. Suriaman, J. Hendrarsakti, Y. Mardiyati, A.D. Pasek, The effect of alkali treatment on improving the mechanical properties of ramie (*boehmeria nivea*), sugar palm (*arenga pinnata*), and coir (*cocos nucifera*) fibers, *ASEAN Eng. J.* 11 (3) (2021) 177–189, <https://doi.org/10.11113/AEJ.V11.17053>.
- [106] T.D. Sutanto, C. Banon, B. Trihadi, N.F. Damayani, Effect of grain size coconut frond powder on the strength of particle board, *J. Phys. Conf. Ser.* (1) (2021) 1940, <https://doi.org/10.1088/1742-6596/1940/1/012043>.
- [107] H.R. Taghiyari, A. Karimi, P.M. Tahir, Organo-silane compounds in medium density fiberboard: physical and mechanical properties, *J. For. Res. (Harbin, China)* 26 (2) (2015) 495–500, <https://doi.org/10.1007/s11676-015-0033-0>.
- [108] J.K. Tamala, E.I. Maramag, K.A. Simeon, J.J. Ignacio, A bibliometric analysis of sustainable oil and gas production research using VOSviewer, *Clean. Eng. Technol.* 7 (2022) 100437, <https://doi.org/10.1016/j.clet.2022.100437>.
- [109] J.L. Tene Tayo, R.J. Bettelhäuser, M. Euring, Canola meal as raw material for the development of bio-adhesive for medium density fiberboards (MDFs) and particleboards production, *Polymers (Basel)* 14 (17) (2022), <https://doi.org/10.3390/polym14173554>.
- [110] V.K. Thakur, M.K. Thakur, P. Raghavan, M.R. Kessler, Progress in green polymer composites from Lignin for multifunctional applications: a review, *ACS Sustain. Chem. Eng.* 2 (5) (2014) 1072–1092, <https://doi.org/10.1021/sc500087z>.
- [111] A. Thumm, A.R. Dickson, Composites : part A the influence of fibre length and damage on the mechanical performance of polypropylene /wood pulp composites, *Compos. Part A* 46 (2013) 45–52, <https://doi.org/10.1016/j.compositesa.2012.10.009>.
- [112] Fuentes Tran, Verpoest, Vuure. Van, Tensile behavior of unidirectional bamboo/coir Fiber hybrid composites, *Fibers* 7 (7) (2019) 62, <https://doi.org/10.3390/fib707062>.
- [113] I. Valchev, Y. Yordanov, V. Savov, P. Antov, Optimization of the hot-pressing regime in the production of eco-friendly fibreboards bonded with hydrolysis lignin, *Period. Polytech., Chem. Eng.* 66 (1) (2022) 125–134, <https://doi.org/10.3311/PPch.18284>.
- [114] J.E.G. Van Dam, M.J.A. Van Den Oever, W. Teunissen, E.R.P. Keijsers, A. G. Peralta, Process for production of high density/high performance binderless boards from whole coconut husk. Part 1: lignin as intrinsic thermosetting binder resin, *Ind. Crops. Prod.* 19 (3) (2004) 207–216, <https://doi.org/10.1016/j.indcrop.2003.10.003>.
- [115] D.C.R. Velasco, F. Perissé Duarte Lopes, D. Souza, H.A. Colorado Lopera, S. Neves Monteiro, C.M. Fontes Vieira, Evaluation of composites reinforced by processed and unprocessed coconut husk powder, *Polymers (Basel)* 15 (5) (2023) 1195, <https://doi.org/10.3390/polym15051195>.
- [116] F.R. Vieira, N. Gama, S. Magina, A. Barros-Timmons, D.V. Evtuguin, P.C.O. R. Pinto, Polyurethane adhesives based on oxyalkylated kraft lignin, *Polymers (Basel)* 14 (23) (2022), <https://doi.org/10.3390/polym14235305>.
- [117] F. Vieira, H.E.P. Santana, M. Jesus, J. Santos, P. Pires, M. Vaz-Velho, D.P. Silva, D. S. Ruzene, Coconut waste: discovering sustainable approaches to advance a circular economy, *Sustainability (Switzerland)* (7) (2024) 16, <https://doi.org/10.3390/su16073066>.
- [118] D. Wang, X.S. Sun, Low density particleboard from wheat straw and corn pith, *Ind. Crops. Prod.* 15 (1) (2002) 43–50, [https://doi.org/10.1016/S0926-6690\(01\)00094-2](https://doi.org/10.1016/S0926-6690(01)00094-2).
- [119] G. Xiao, J. Liang, D. Li, Y. Tu, B. Zhang, F. Gong, W. Gu, M. Tang, X. Ding, Z. Wu, H. Lei, Fully bio-based adhesive from tannin and Sucrose for plywood manufacturing with high performances, *Materials (Basel)* 15 (24) (2022), <https://doi.org/10.3390/ma15248725>.
- [120] G. Xu, H. Tian, X. Xi, J. Song, H. Lei, G. Du, Preparation and characterization of urea – formaldehyde adhesives modified with glyoxalated tannin, *Eur. J. Wood Wood Prod.* 80 (5) (2022) 1215–1223, <https://doi.org/10.1007/s00107-022-01819-1>.
- [121] G. Yang, Z. Gong, X. Luo, L. Chen, L. Shuai, Bonding wood with uncondensed lignins as adhesives, *Nature* 621 (7979) (2023) 511–515, <https://doi.org/10.1038/s41586-023-06507-5>.
- [122] M. Yang, K.A. Rosentrater, Life cycle assessment of urea-formaldehyde adhesive and phenol-formaldehyde adhesives, *Environ. Process.* 7 (2) (2020) 553–561, <https://doi.org/10.1007/s40710-020-00432-9>.
- [123] M. Yang, J. Su, Y. Zheng, C. Fang, W. Lei, L. Li, Effect of different silane coupling agents on properties of waste corrugated paper Fiber/polylactic acid composites, *Polymers (Basel)* 15 (17) (2023) 1–15, <https://doi.org/10.3390/polym15173525>.
- [124] X. Yang, M. Wang, Y. Li, W. Wang, Y. Liu, Improvement of mechanical and thermal expansion properties of pectinase treatment plant fiber reinforced starch/PBAT composites, *Polym Compos* 45 (9) (2024) 8016–8025, <https://doi.org/10.1002/pc.28320>.
- [125] B.B.R. Yano, S.A.M. Silva, D.H. Almeida, V.B.M. Aquino, A.L. Christoforo, E.F. C. Rodrigues, A.N.C. Junior, A.P. Silva, F.A.R. Lahr, Use of sugarcane bagasse and industrial timber residue in particleboard production, *BioResources* 15 (3) (2020) 4753–4762, <https://doi.org/10.15376/biores.15.3.4753-4762>.
- [126] M. Yildirim, T.A. Negawo, A. Kilic, Z. Candan, Development and characterization of hybrid composites from sustainable green materials, *Green Mater.* 9 (4) (2020) 182–191, <https://doi.org/10.1680/jgrma.20.00044>.
- [127] H. Younesi-Kordkheili, A. Pizzi, Improving the properties of phenol-lignin-glyoxal as a wood adhesive by lignin nanoparticles, *Eur. J. Wood Wood Prod.* 81 (2) (2023) 507–512, <https://doi.org/10.1007/s00107-022-01904-5>.
- [128] J. Zamboni Schiavon, J.J. de Oliveira Andrade, Comparison between alternative chemical treatments on coir fibers for application in cementitious materials, *J. Mater. Res. Technol.* 25 (2023) 4634–4649, <https://doi.org/10.1016/j.jmrt.2023.06.210>.
- [129] B. Zhang, X. Chen, A. Pizzi, M. Petrissans, S. Dumarcay, A. Petrissans, X. Zhou, G. Du, B. Colin, X. Xi, Highly branched tannin-Tris(2-aminoethyl)amine-urea wood adhesives, *Polymers (Basel)* 15 (4) (2023), <https://doi.org/10.3390/polym15040890>.
- [130] X. Zhu, D. Wang, N. Li, X.S. Sun, Bio-based wood adhesive from Camelina protein (a Biodiesel Residue) and depolymerized lignin with improved water resistance, *ACS Omega* 2 (11) (2017) 7996–8004, <https://doi.org/10.1021/acsomega.7b01093>.
- [131] M. Zor, F. Mengelöglü, D. Aydemir, F. Şen, E. Kocatürk, Z. Candan, O. Özcelik, Wood plastic composites (WPCs): applications of nanomaterials BT - emerging nanomaterials, in: H.R. Taghiyari, J.J. Morrell, A. Husen (Eds.), *Opportunities and Challenges in Forestry Sectors*, Springer International Publishing, 2023, pp. 97–133, https://doi.org/10.1007/978-3-031-17378-3_4.