

Sargassum-based particleboards for sustainable construction: Performance of pelagic and benthic biomass combined with agro-industrial residues

Afonso Duran

afonso.duran@usp.br

Universidade de São Paulo

Gabriela Lyra

Universidade de São Paulo

Francisco Silva

Universidade de São Paulo

Luiz Campos Filho

Universidade de São Paulo

Gabriel Held

Universidade de São Paulo

André Ferraz

Universidade de São Paulo

Maycira Costa

University of Victoria

Juliano Fiorelli

Universidade de São Paulo

João Adriano Rossignolo

Universidade de São Paulo

Research Article

Keywords: sargassum, sustainability, castor oil resin, blue economy, biomass valorization

Posted Date: September 18th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9348393/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Sargassum-based particleboards for sustainable construction: Performance of pelagic and benthic biomass combined with agro-industrial residues

Afonso José Felício Peres Duran^{a*}, Gabriela Pitolli Lyra^a, Francisco Ailton Gomes da Silva^b, Luiz Eduardo Campos Filho^b, Gabriel Affonso da Costa Held^c, André Ferraz^d, Maycira Costa^e, Juliano Fiorelli^a, João Adriano Rossignolo^a

^a *Department of Biosystems Engineering, Faculdade de Zootecnia e Engenharia de Alimentos, University of São Paulo (USP), Pirassununga, SP, Brazil.*

^{*}*Corresponding author: afonso.duran@usp.br*

^b *Post-Graduation Program in Material Sciences and Engineering, Faculdade de Zootecnia e Engenharia de Alimentos, University of São Paulo (USP), Pirassununga, SP, Brazil.*

^c *Biosystems Engineering, Faculdade de Zootecnia e Engenharia de Alimentos, University of São Paulo (USP), Pirassununga, SP, Brazil.*

^d *Wood Science Laboratory, Department of Biotechnology, Lorena School of Engineering, University of São Paulo (EEL-USP), 12602-810, Lorena, SP, Brazil.*

^e *Spectral and Remote Sensing Laboratory, Department of Geography, University of Victoria (UVic), Victoria, British Columbia, Canada*

Abstract

The use of lignocellulosic residues for particleboard production represents a sustainable strategy aligned with circular economy principles and the valorization of underutilized biomass. In this context, recurrent sargassum seaweed beaching events have been reported along the coasts of Brazil, Mexico, and the Caribbean, generating significant environmental, economic, and public health impacts due to the decomposition of accumulated biomass. Simultaneously, large volumes of agro-industrial residues such as sugarcane bagasse and coconut husk fibers remain underexploited, despite their lignocellulosic potential. This study aimed to evaluate the technical feasibility of manufacturing medium-density particleboards using biomass from different sargassum species (pelagic and cymosum) collected during beaching events, combined with sugarcane bagasse and coconut husk fibers. The experimental program assessed the physical, mechanical and thermal performance of the panels, focusing on properties relevant to non-structural applications. The results indicate that the incorporation of pelagic and benthic sargassum biomass, particularly when associated with sugarcane bagasse, enables the production of particleboards with satisfactory performance for use in furniture components and other interior applications. Beyond mitigating the environmental and socio-economic challenges associated with massive sargassum influxes, the proposed approach promotes the

integrated valorization of marine and agro-industrial residues. By converting two problematic waste streams into value-added products, this strategy contributes to resource efficiency, waste reduction, and the development of sustainable materials.

Keywords: sargassum; sustainability; castor oil resin; blue economy; biomass valorization.

Introduction

The growing production in industrial and agro-industrial sectors often conflicts with the environmental burdens generated by these chains, posing a critical challenge for sustainable development. Circular economy strategies offer pathways to reconcile economic growth with sustainability by promoting waste valorization, emission reduction, and extended product lifespans through reuse and recycling cycles. Such approaches foster recirculation, minimize environmental impacts, and substantially decrease the reliance on virgin raw materials (Carvalho Araújo et al., 2022; Gavioli et al., 2025; Le et al., 2023; Pędzik et al., 2024; Uemura Silva et al., 2021).

Wood-based panels play a strategic role in the Brazilian furniture and construction industries, generating employment and income, with the country ranking ninth worldwide and producing 8.1 million m³ in 2024 (IBÁ, 2024). However, their production relies mainly on Eucalyptus and Pinus, thus posing a challenge due to resource dependency and sustainability, and highlighting the need to diversify raw materials to reduce pressure on conventional wood resources while fostering circular and more durable production strategies (Brito et al., 2020; Carvalho Araújo et al., 2022; Fiorelli et al., 2019; Gavioli et al., 2025; Klímek et al., 2018; Lima Mesquita et al., 2018; Nogueira et al., 2022; Soares et al., 2017).

One potential strategic approach to address this challenge is the incorporation of lignocellulosic residues, particularly those derived from agro-industrial activities. Such an approach enables the utilization of low-cost and environmentally sustainable resources, thereby minimizing the extraction of virgin raw materials and mitigating the environmental impacts associated with the disposal of agricultural wastes (Cangussu et al., 2023; Gavioli et al., 2025; Lee et al., 2022; Maraveas, 2020; Martins et al., 2021; Ribeiro et al., 2020).

The manufacture of medium-density particleboards (MDP) using such alternative raw materials represents a promising pathway toward a more sustainable industrial model. In this regard, the incorporation of agro-industrial by-products, abundantly available in the Brazilian context, has been investigated for this purpose. Among these, sugarcane bagasse has gained prominence due to its favorable performance in particleboard production (Cangussu et al.,

2023; Duran et al., 2025a, 2023; Ribeiro et al., 2020; Yano et al., 2020), alongside coconut husk fibers, which also exhibit considerable potential (Bispo et al., 2020; de Souza et al., 2023; Fiorelli et al., 2019; Narciso et al., 2021).

Adhesive resin is another essential component in panel production, with petroleum-derived and formaldehyde-based resins being the most widely used. However, aligned with sustainability and circular economy principles, there is increasing emphasis on renewable rather than fossil-based resources. In this context, castor oil-based polyurethane (PU) resin demonstrates significant potential as an alternative to conventional resins. Studies have reported better physical and mechanical performance compared to formaldehyde-based adhesives, while its raw material is renewable, biobased, and less toxic, offering additional environmental impact mitigation (Bertolini et al., 2019; Buzo et al., 2020; Duran et al., 2025b, 2025a; Faria et al., 2024; Gavioli et al., 2025; Sugahara et al., 2019. Uemura Silva et al., 2021).

Seaweeds, such as sargassum, play a fundamental role in the functioning of ecosystems within their native regions, providing habitat, food resources, and substrate for associated species, while simultaneously contributing to biogeochemical cycling through the sequestration of carbon and nitrogen from the environment (Martin et al., 2021; Peres et al., 2023; Roe et al., 2022; Rossignolo et al., 2022).

Nevertheless, climate change, alterations in the pattern of sea currents, and increasing marine pollution have intensified the occurrence of sargassum beaching events in coastal areas, such as the northern and northeastern regions of Brazil, Mexico and the Caribbean. These events adversely affect key economic sectors, including fisheries and tourism, and pose risks to public health due to the release of toxic gases—such as methane, hydrogen sulfide, and ammonia—originating from biomass decomposition during strandings (Johns et al., 2020; Resiere et al., 2018; Rodríguez-Muñoz et al., 2021; Solarin et al., 2014; van Tussenbroek et al., 2017; Wang et al., 2019).

On one hand, pelagic sargassum, predominantly composed of *Sargassum fluitans* (morphotype III) and *Sargassum natans* (morphotypes I and VIII), originally inhabits the northern Atlantic Ocean. In recent years, however, environmental alterations have triggered an intense proliferation of these species and the occurrence of large-scale strandings along coastal regions (Gower and King, 2020; Rossignolo et al., 2022; Sissini et al., 2017; Wang et al., 2019). On the other hand, *Sargassum cymosum*, a benthic species commonly distributed in coastal environments, has undergone population decline. Unlike its pelagic counterparts, this reduction is primarily associated with coastal eutrophication driven by marine pollution and climate change, which also contributes to stranding events (Costa et al., 2019; Peres et al., 2023).

In 2025, the Atalaia Beach region, located in Salinópolis, Pará (Brazil), experienced a massive stranding event of pelagic sargassum, with an estimated 46,000 tons of fresh biomass accumulated along approximately 10 km of shoreline (Figure 1a). Concurrently, recurrent strandings of *Sargassum cymosum* have been observed along coastal zones of northern and northeastern Brazil, including the Trairi region in the state of Ceará (Figure 1b).

According to Amador-Castro et al. (2021), Bueno et al. (2023) and Rossignolo et al. (2022), the development of alternative applications for sargassum biomass resulting from stranding events may constitute a viable strategy for mitigating the associated environmental impacts. However, the utilization of sargassum biomass for alternative applications, such as civil construction and related sectors, remains insufficiently explored, with a need for studies that offer more comprehensive results capable of demonstrating its feasibility.

In this context, the present study investigates the production of MDP panels incorporating biomass from different sargassum species, in combination with residues from the agroindustry and a bio-based resin derived from castor oil, to explore the potential of these lignocellulosic raw materials for the development of innovative composite materials. This research aims to evaluate the technical feasibility of sustainable panels capable of mitigating the environmental impacts of pelagic and benthic sargassum beaching events while reinforcing circular-economy strategies in affected regions. By demonstrating their viability, the study addresses a growing challenge in coastal areas of Brazil, Mexico, and the Caribbean, where recurrent sargassum influxes require scalable circular-economy solutions that transform an environmental liability into materials of strategic value for local communities.



Figure 1. Sargassum beaching events. a) pelagic sargassum beaching event in Salinópolis, Pará (Brazil) - photo: Geison Mesquita. b) *Sargassum cymosum* beaching event in Trairi region in the state of Ceará (Brazil) – photo: Thiago Holanda Basílio

Materials and methods

This study employed raw materials from diverse origins for the production of lignocellulosic particles. Sugarcane bagasse was supplied by a sugar–ethanol mill, whereas coconut husk fibers were provided by a gardening substrate company, both located in the Pirassununga region, São Paulo (Brazil). Distinct types of sargassum biomass were also collected: pelagic sargassum was sampled at Atalaia Beach, Salinópolis, Pará (Brazil), while *Sargassum cymosum* was obtained from the Trairi region, Ceará (Brazil). A castor oil–based polyurethane (PU) resin was employed as a binding agent, exhibiting thermal stability with mass loss occurring only above 210 °C, solvent-free characteristics, and a solid content of 100% (Duran et al., 2025a).

Characterization of the lignocellulosic and sargassum raw materials

The chemical compositions of sugarcane bagasse and coconut husk fibers were determined using standard methods previously described by Masarin et al. (2011). Briefly, the samples were milled to pass through a 20-mesh screen and then extracted in a Soxhlet apparatus with 95% (v/v) ethanol to remove extractives. The extracted materials were subsequently hydrolyzed in a two-step acid hydrolysis, consisting of an initial treatment with 72% (w/w) sulfuric acid (30 °C, 1 h), followed by a second step with 4% (w/w) sulfuric acid (120 °C, 1 h). The residual solids obtained after filtration corresponded to the acid-insoluble lignin fraction. Soluble lignin in the aqueous phase was quantified spectrophotometrically at 205 nm, using an absorptivity value of 105 L cm⁻¹ g⁻¹. Monomeric sugars in the soluble fraction were determined by HPLC (HPX-87H column; Bio-Rad, Hercules, CA, USA) at 45 °C, using 5 mmol L⁻¹ sulfuric acid as the mobile phase at a flow rate of 0.6 mL min⁻¹. Detection was performed with a temperature-controlled refractive index detector set at 35 °C. Under these conditions, xylose, mannose, and galactose co-eluted and appeared as a single peak.

For the sargassum samples, the whole raw material was air-dried and milled to pass through a 20-mesh screen. The milled samples were successively extracted in three steps. The first extraction was carried out with fresh water using a 2-L blender. For this purpose, 10 g of the sample was mixed with 1 L of water and allowed to hydrate for 30 min., followed by blending for 5 min. The blended suspension was filtered through filter paper, and the solid residue was extracted two additional times using the blender. The liquid fractions were

combined to yield 4.3 L of fresh-water extract, which was stored at $-18\text{ }^{\circ}\text{C}$ until characterization. The washed solids were then subjected to a second extraction step with warm water. In this step, 3 g of solids were extracted with water in a Soxhlet apparatus for 8 h. The resulting dark brown extract was stored at $-18\text{ }^{\circ}\text{C}$ until characterization. The solids recovered after the warm-water extraction were finally subjected to a third extraction step with 95% (v/v) ethanol in a Soxhlet apparatus for 6 h. The water- and ethanol-insoluble residue (WAIR) was air-dried and stored at room temperature until characterization.

Fresh- and warm-water extracts were characterized for their polysaccharide content after dilute acid hydrolysis with 4% (w/w) sulfuric acid at $120\text{ }^{\circ}\text{C}$ for 1 h. The resulting monomeric sugars and organic acids were analyzed by HPLC using the chromatographic system previously described. In this analysis, uronic acids were quantified in addition to the monomeric sugars. Mannuronic, guluronic, and galacturonic acids co-eluted under these analytical conditions and were therefore quantified collectively as total uronic acids.

The WAIR solids were characterized using the same two-step acid hydrolysis procedure applied to the lignocellulosic samples. However, uronic acids from alginate present in the seaweed samples may partially decompose under these analytical conditions (Kostas et al., 2016; Wang et al., 2024). To account for this, a standard alginate sample was hydrolyzed under the same conditions to estimate the losses of uronic acid during analysis. The recovery of uronic acids from the standard alginate was limited to $39.4 \pm 0.4\%$, and the acid-insoluble residue represented $11.1 \pm 4.1\%$ of its original dry weight. These values were therefore used to correct the uronic acid and acid-insoluble residue data obtained for the sargassum samples.

For FTIR analysis, each solid sample was further milled under liquid nitrogen using a cryogenic grinder (2010 Geno/Grinder, Spex Sample Prep) for 2 min. The macerated samples were analyzed with a Cary 630 FTIR spectrometer (Agilent, USA). Spectra were baseline-corrected in absorbance mode over the range of $1800\text{--}850\text{ cm}^{-1}$.

Microscopic analysis of the seaweed samples was performed after hydrating small portions of the crudely collected materials. Stipes were excised using a razor blade, embedded in paraffin, and sectioned into $30\text{ }\mu\text{m}$ cross-sections with a SM2010R microtome (Leica, Germany). The cross-sections were examined under bright-field illumination using a BX53 microscope (Olympus, Japan).

Multilayer particleboard production

The panels in this study were produced according to the methodology proposed by Duran et al. (2025a). After collection, the lignocellulosic raw materials were dried in a greenhouse until they reached a moisture content of ~8%. The dried materials were processed in a knife mill and sieved using a mechanical shaker equipped with screens ranging from 5 to 18 mesh to obtain particles with controlled size distribution.

Castor oil-based polyurethane resin was then applied using a planetary mixer to ensure homogeneous distribution. Based on Fiorelli et al. (2019), 15% resin (by weight) was applied to the outer layers and 12% to the core. The furnish was pre-compacted in a mold and subsequently hot-pressed in a thermo-hydraulic press.

Pressing was conducted at 100 °C and 5 MPa, for 10 min., as recommended by Fiorelli et al. (2019). Three multilayer panels were produced for each formulation, with a target density of 750 kg/m³ and a particle mass ratio of 35-30-35 across the three layers (Duran et al., 2024). Four panel types were prepared: sugarcane bagasse in the outer layers with pelagic sargassum in the core (BSPP); sugarcane bagasse in the outer layers with *Sargassum cymosum* in the core (BSCP); coconut husk fibers in the outer layers with pelagic sargassum in the core (CSPP); and coconut husk fibers in the outer layers with *Sargassum cymosum* in the core (CSCP) (Figure 2).

The final panels measured 400 × 400 × 15 mm and were conditioned at 20 ± 3 °C and 65 ± 5% RH for 72 h until constant mass was achieved.

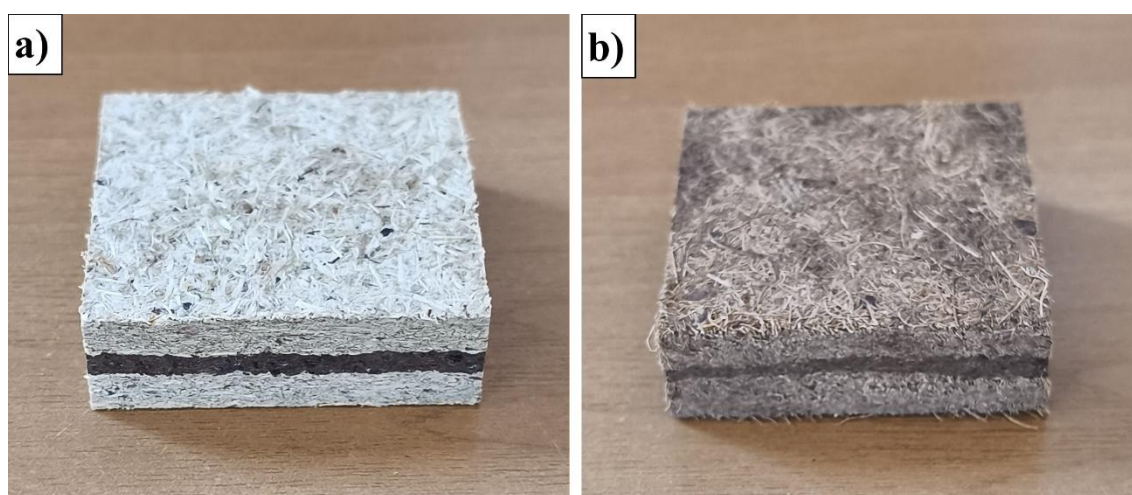


Figure 2. Images of sargassum particleboard samples. a) Image of sugarcane bagasse and sargassum particleboard. b) Image of coconut husk fiber and sargassum particleboard. Actual sizes of the samples are 50 x 50 x 15 mm.

Physical and mechanical characterization of particleboards

The physical and mechanical properties of the panels produced in this study were determined according to the procedures described in ASTM D1037-12 (2020) – Standard Test Methods for Evaluating Properties of Wood-Based Fiber and Particle Panel Materials, which was selected for presenting the highest similarity to the characteristics of the composites developed. Ten specimens were tested for each property, including: 24-hour thickness swelling (TS), water absorption (WA), static bending, including modulus of rupture (MOR) and modulus of elasticity (MOE), and perpendicular tensile strength (internal bond – IB). The specimens used for thickness swelling, water absorption, and internal bond tests measured 50 × 50 mm, while those for bending tests measured 350 × 50 mm.

Mechanical evaluations were conducted using a BioPdi universal testing machine with a capacity of 10 kN, equipped with a computerized system for monitoring and recording test variables. The loading rate was set at 8 mm/min for bending tests and 4 mm/min for perpendicular tensile strength tests. The obtained results were compared with the requirements of NBR 14810-2: Medium-density particleboard – Part 2: Requirements and test methods (in Portuguese) and ISO 16893:2016 – Wood-based panels – Particleboard.

Scanning electron microscopy and thermal conductivity analysis of the panels

Scanning electron microscopy (SEM) analysis was performed to evaluate samples of the particleboards qualitatively, focusing on pore anatomy, particle compaction, and the chemical-mechanical interactions among particles, and subsequently relating these features to the physical and mechanical properties obtained. The observations were carried out using a low-vacuum Hitachi TM-3000 scanning electron microscope.

The thermal conductivity test was performed following the methodology proposed by Fiorelli et al. (2019) and the recommendations of ASTM E1530-11 (Guarded Heat Flow Meter Technique). Measurements were carried out using a DTC-300 Thermal Conductivity Tester (Discovery). Only compositions showing the meeting physical-mechanical performance were selected for this analysis. Cylindrical specimens (50 mm diameter) were coated with thermal paste to minimize interfacial thermal resistance between the sample and the plates. A pressure of 0.28 MPa was applied, and a temperature difference of 30 °C was maintained between the plates (65 °C upper plate and 35 °C lower plate).

Statistical analysis

The physical and mechanical properties obtained for the particleboards were initially examined through descriptive statistical procedures to systematize the findings. The mean values were employed as indicators of central tendency, while the standard deviation was applied to express data dispersion.

Following this descriptive stage, the results were subjected to inferential statistical analysis to determine whether significant differences existed among the compositions under investigation. The variance structure was assessed by analysis of variance (ANOVA), and comparisons between means were performed using Tukey's post-hoc test, adopting a significance threshold of $p < 0.05$. All statistical procedures were conducted with the aid of Minitab® software, version 21.1.1.

Results and discussion

Characterization of the lignocellulosic and sargassum raw material samples

The chemical composition of sugarcane bagasse and coconut husk fibers used as the primary raw materials in the developed particleboards was consistent with values typically reported for these lignocellulosic materials (Masarin et al., 2011; van Dam et al., 2006). Both materials showed a predominance of glucan (cellulose) and hemicellulose polysaccharides, with lignin contents of 22.1% and 36.9%, respectively (Table 1). A comparison of both materials indicated that the higher lignin content in coconut husk fibers occurs at the expense of lower glucan and hemicellulose contents, thus indicating that the sugarcane bagasse samples are richer in cellulose than the coconut husk fibers.

Fiorelli et al. (2014) and Duran et al. (2024) reported that cellulose content is strongly correlated with the mechanical performance of particleboards, while lignin can function as a natural binder, enhancing particle cohesion and imparting hydrophobic characteristics that mitigate water absorption. In this regard, the lignocellulosic composition of the agro-industrial residues employed in this study closely resembles the chemical composition of Pinus wood, which is extensively used in the manufacture of MDP panels.

Table 1. Chemical composition of sugarcane bagasse and coconut husk fiber samples.

Sample	Chemical composition (g/100 g of original lignocellulosic material)						Ash
	Lignin	Glucan	Hemicellulose			Ext.*	
			Xylan**	Arabinosyl	Acetyl		
Sugarcane bagasse	22.1 ± 0.1	36.4 ± 0.2	19.8 ± 0.1	2.0 ± 0.1	3.6 ± 0.7	6.4 ± 0.2	5.6 ± 0.1
Coconut husk fiber	36.9 ± 1.1	30.4 ± 2.8	14.0 ± 1.3	1.2 ± 0.1	3.1 ± 0.3	3.1 ± 0.2	3.2 ± 0.1
<i>Pinus radiata</i> ***	27.6 ± 0.2	41.2 ± 0.4	18.7 ± 0.2	1.1 ± 0.1	1.1 ± 0.2	1.7 ± 0.2	nd

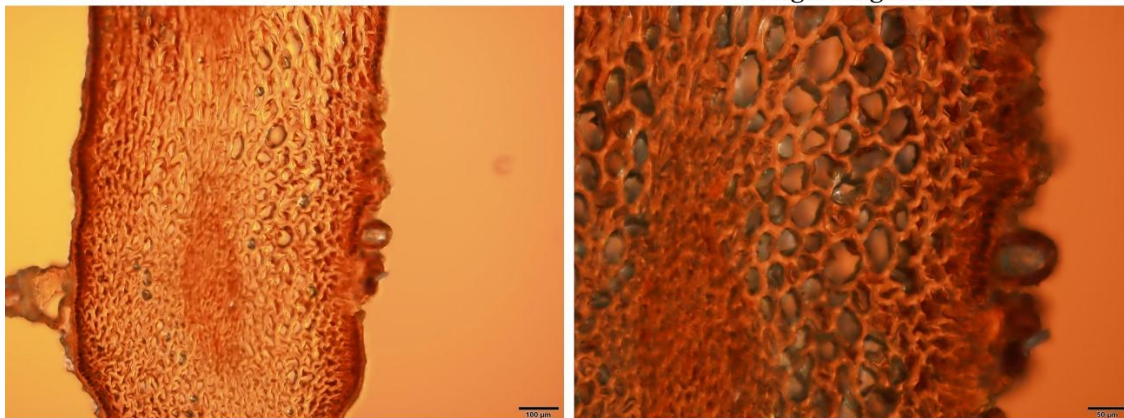
(*) Ethanol-soluble extractives; (**) in samples from *P. radiata* data includes mannan; (***) from Ferraz et al 2000; nd = not determined.

The sargassum samples used as core materials in the developed particleboards were further characterized to evaluate their anatomical features and chemical compositions. Macroscopic and microscopic digital images of hydrated samples of pelagic sargassum and *Sargassum cymosum* are shown in Figure 3. Both materials exhibited clearly distinguishable stipes and blades in the macroscopic images. Microscopic examination of the stipe cross-sections revealed variable cell diameters, ranging from 32–74 µm in pelagic sargassum and 23–50 µm in *Sargassum cymosum*, indicating high porosity and, consequently, a strong capacity for water absorption.

a)



Pelagic sargassum



b)



Sargassum cymosum

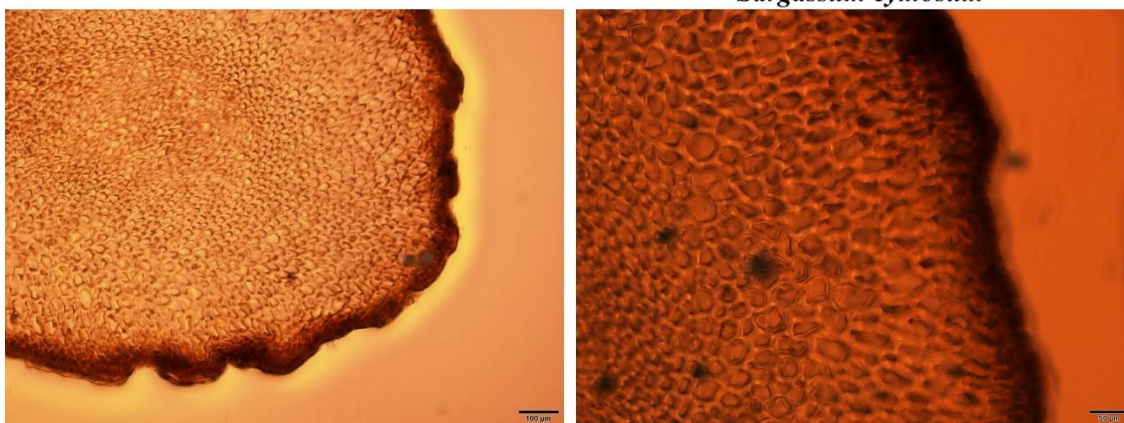


Figure 3. Digital colored images and bright-field microscopies of hydrated sargassum samples. a) Pelagic sargassum and b) *Sargassum cymosum*.

Chemical compositions of the whole sargassum samples (tallus) are indicated in Table 2. To differentiate the water-soluble components from the water-insoluble fraction, which is mainly associated with plant cell walls, the sargassum samples were subjected to successive extractions with fresh and warm water. Mass balances for all components detected in each

sample are shown in Figures 4 and 5. Extraction with fresh water dissolved 7.9% and 29.8% of the original pelagic sargassum and *Sargassum cymosum* samples, respectively.

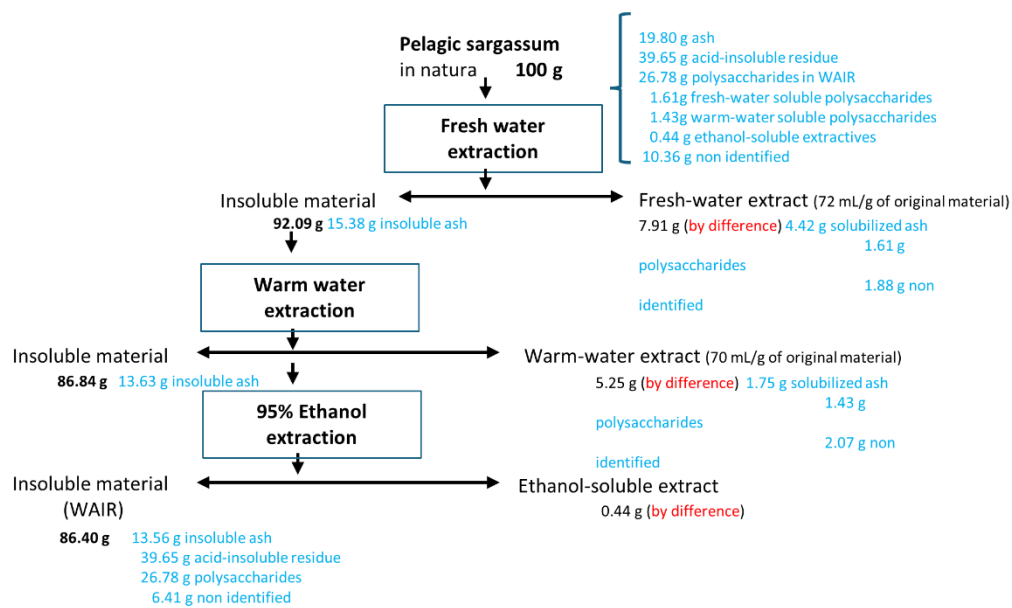


Figure 4. Mass balance for chemical compositions of pelagic sargassum

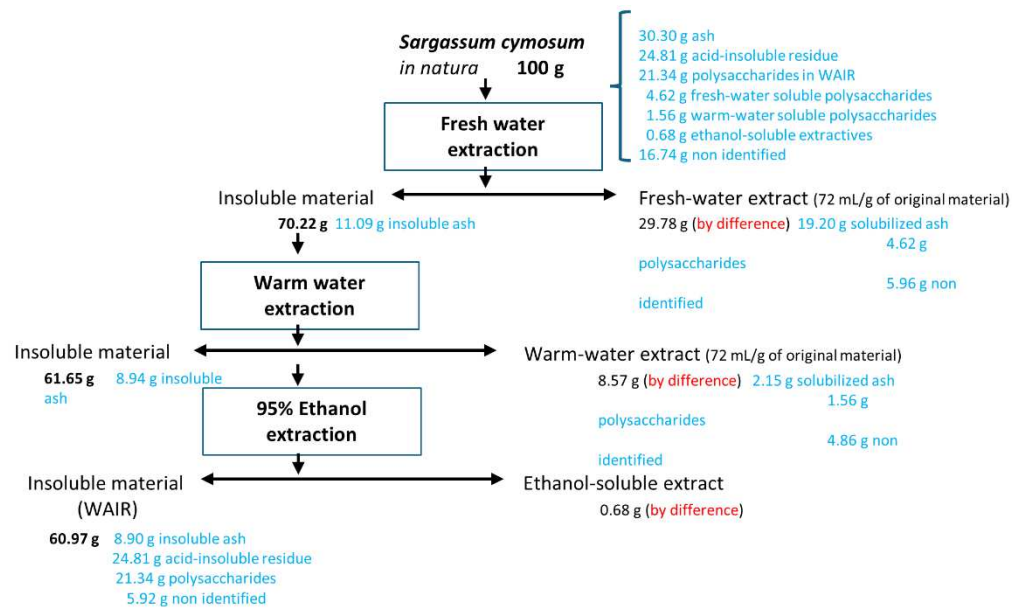


Figure 5. Mass balance for chemical compositions of *S. cymosum*

A subsequent extraction with warm water using a Soxhlet apparatus solubilized an additional 5.2% and 8.6% of the same original samples. These warm-water extracts were dark brown, suggesting the removal of significant amounts of fucoxanthin carotenoids previously reported in brown seaweeds (Cunningham et al., 2023). A final extraction of the residual solids

with 95% ethanol solubilized only 0.4% and 0.7% of the original samples. Therefore, the final water- and alcohol-insoluble residues (WAIR) from pelagic sargassum and *Sargassum cymosum* represented 86.4% and 61.0% of the original samples, respectively.

Table 2. Chemical composition of sargassum samples.

Composition of sargassum samples calculated from chemical analyses of the crude material, fresh-water extract, warm-water extract, and water- and alcohol-insoluble residue (WAIR).						
Sargassum sample	Total ash (%)	Total polysaccharides (%)	Fractions of the total polysaccharides (%)			Acid-insoluble residue (%)
			Fresh-water soluble	Warm-water soluble	WAIR	
Pelagic	18.8 ± 0.1	29.8 ± 0.3	1.6 ± 0.1	1.4 ± 0.1	26.8 ± 0.1	39.6 ± 0.2
<i>Cymosum</i>	30.3 ± 0.1	27.5 ± 0.8	4.6 ± 0.1	1.6 ± 0.1	21.3 ± 0.6	24.8 ± 1.4

Distribution of major monomeric sugars and organic acids in polysaccharides from sargassum samples						
Sargassum sample	Major monomeric sugars and organic acids detected after acid hydrolysis					
	(g/100 g of total detected sugars)					
	Uronic acids	Glucose	Xyl+Man+Gal*	Rhamnose	Fucose	Acetic acid
Pelagic polysaccharides						
Fresh-water soluble	70.0 ± 0.8	nd	15.0 ± 0.1	0.3 ± 0.3	7.6 ± 0.1	6.7 ± 0.2
Warm-water soluble	25.5 ± 2.1	11.8 ± 0.6	29.3 ± 2.5	nd	24.3 ± 0.5	9.1 ± 0.4
WAIR	29.7 ± 0.2	33.4 ± 0.1	14.7 ± 0.1	16.7 ± 0.1	4.1 ± 0.1	1.2 ± 0.1
<i>S. cymosum</i> polysaccharides						
Fresh-water soluble	20.0 ± 1.5	14.6 ± 0.1	8.5 ± 0.3	50.4 ± 1.4	4.7 ± 0.4	1.8 ± 0.1
Warm-water soluble	16.5 ± 1.2	13.0 ± 1.6	31.8 ± 2.2	4.73 ± 2.2	28.6 ± 2.3	5.3 ± 0.6
WAIR	31.0 ± 1.3	38.3 ± 1.0	13.7 ± 0.4	11.3 ± 0.3	4.6 ± 0.1	1.1 ± 0.1

(*) Xyl, Man, and Gal denotes to xylose, manose and galactose that co-eluted in the current HPLC analysis; nd denotes not detectable under the current method.

The ash content in both sargassum samples was high (Table 2). A significant fraction of the ash in *Sargassum cymosum* was soluble in water (70.6% of the total ash), whereas the water-soluble ash in pelagic sargassum accounted for only 31.5% of its total ash content (Figures 4 and 5). High ash contents in brown seaweeds have been previously reported and are associated mainly with K, Na, Ca, and Mg ions (Rodrigues et al., 2015).

The total polysaccharide content detected in the whole samples was 29.8% in pelagic sargassum and 27.5% in *Sargassum cymosum*. Pelagic sargassum also exhibited a higher

proportion of polysaccharides in the WAIR fraction, which corresponds to the cell wall component, and a lower amount of water-soluble polysaccharides that represent mainly storage nutrients in brown seaweeds (Baghel et al., 2021).

The monosaccharide composition of each polysaccharide fraction provides a clearer picture of the polysaccharide nature in each sample. Glucose and uronic acids predominated in the WAIR polysaccharides of both sargassum samples, suggesting a significant contribution of cellulose and alginate to the cell wall composition of these materials. In contrast, fucose occurred at low levels in the WAIR polysaccharides but predominated in the water-soluble fractions, consistent with the presence of soluble sulfonated fucan storage polysaccharides (Baghel et al., 2021). Uronic acids also predominated the fresh-water-soluble fraction of pelagic sargassum, indicating the occurrence of a soluble alginate fraction in this sample.

A significant fraction of both seaweed samples remained as acid-insoluble residue after the two-step acid treatment of the WAIR fraction. This two-step acid hydrolysis is commonly employed to convert polysaccharides into monosaccharides during the analysis of lignocellulosic materials. In such materials, the acid-insoluble residue is referred to as Klason lignin (Sluiter et al., 2010). However, brown seaweeds lack the metabolic pathways for monolignol and lignin biosynthesis (Wargacki et al., 2012), suggesting that their acid-insoluble residues result from incomplete polysaccharide hydrolysis and from degradation of alginate uronic acids into insoluble humins. A similar observation was previously documented in studies focused on optimizing polysaccharide analysis in seaweed samples (Kostas et al. 2016, Wang et al., 2024).

To gain further insights into the nature of the acid-insoluble residues reported in Table 2, their FTIR spectra were compared with those of the raw materials. In the 4000–2000 cm^{-1} region, all samples exhibited characteristic hydroxyl and saturated carbon–hydrogen stretching bands at approximately 3300 cm^{-1} and 2900 cm^{-1} , respectively (data not shown). The fingerprint region of the FTIR spectra is presented in Figure 6.

The raw material samples displayed the characteristic bands previously reported for brown seaweeds (Gómez-Ordóñez and Ruperez, 2011), confirming a significant presence of alginates based on the band at 1603 cm^{-1} , which is attributed to the carboxylate groups of uronic acids. The weak band at 1515 cm^{-1} , assigned to aromatic ring vibrations, indicates the presence of polyphenols, whereas the band at 1260–1220 cm^{-1} , associated with sulfate esters, suggests the presence of fucan polysaccharides. The band at 1407 cm^{-1} , attributed to C–O stretching in alcohols, along with the bands at 1083 cm^{-1} and 1024 cm^{-1} , assigned to C–O and C–C linkages, are typical of polysaccharides. Both sargassum samples exhibited similar FTIR spectra.

The FTIR spectra of the acid-insoluble residues from each sample resembled those of the corresponding raw materials. Carboxylate bands at 1603 cm^{-1} and their corresponding carboxylic acid form at 1715 cm^{-1} , typical of the uronic acids present in alginate, were still observed. A significant decrease in the band at 1407 cm^{-1} , assigned to C–O stretching in alcohols, suggests dehydration reactions during acid treatment, which are characteristic of furan formation from monomeric sugars and uronic acids (Tsilomelekis et al., 2016).

Based on the comparison of the FTIR spectra of the raw seaweed samples and their acid-insoluble residues, it is likely that the acid-insoluble residues retained portions of undigested polysaccharides as well as humins formed through the decomposition of monomeric sugars and uronic acids (Tsilomelekis et al., 2016, Kostas et al., 2016, Wang et al., 2024).

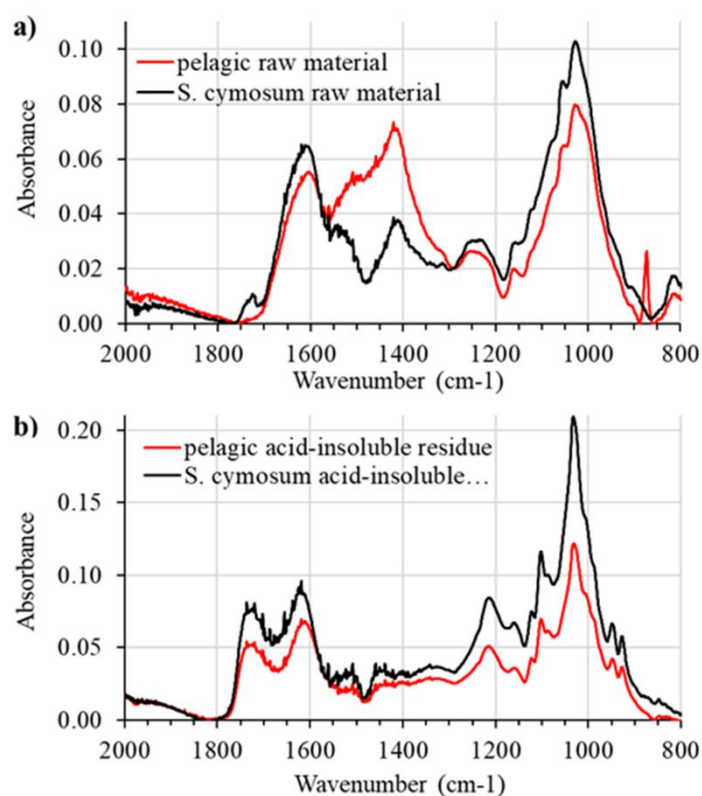


Figure 6. FTIR spectra of raw brown seaweed samples (A) and their corresponding acid-insoluble residues (B). The acid-insoluble residues were obtained after a two-step acid hydrolysis of the raw materials.

Comparison of the chemical compositions of sugarcane bagasse, coconut husk fibers, and the analyzed sargassum samples indicates that ash and non-lignocellulosic polysaccharides (alginate and fucan) predominate in sargassum. Cellulose is also detected in the WAIR fraction of sargassum, but at a lower content compared with lignocellulosic materials. The acid-insoluble residue, which corresponds to lignin in lignocellulosic samples, appears to be mainly associated with non-digested alginate and humins in the sargassum samples.

Physical, mechanical and thermal properties of particleboards

Table 3 presents the average values of the physical and mechanical properties for all panel formulations, together with a comparative analysis of the NBR 14810-2 (2024) and ISO 16893 (2016) standards, both of which apply to medium-density wood-based particleboards.

Table 3 - Average values of the physical and mechanical properties for the different particleboard formulations in relation to the applicable normative standards

Compositions	ρ (kg/m ³)	MOR (MPa)	MOE (MPa)	IB (MPa)	TS (%) 24h	WA (%)
BSPP	752 ± 33 ^a	16 ± 2 ^a	1601 ± 217 ^a	0.8 ± 0.2 ^a	20 ± 2 ^a	35 ± 7 ^a
BSCP	739 ± 19 ^a	16 ± 1 ^a	1610 ± 65 ^a	1.0 ± 0.3 ^a	22 ± 2 ^a	46 ± 4 ^b
CSPP	757 ± 26 ^a	9 ± 1 ^b	800 ± 125 ^b	0.5 ± 0.2 ^b	27 ± 3 ^b	46 ± 11 ^b
CSCP	760 ± 14 ^a	9 ± 1 ^b	751 ± 112 ^b	0.6 ± 0.2 ^b	29 ± 3 ^b	46 ± 5 ^b
NBR 14810-2:2024 - Non-structural use in dry conditions	551-750	11	1600	0.35	22	-
ISO 16893 (2016) - Furniture use in dry conditions	551-750	11	1600	0.35	-	-

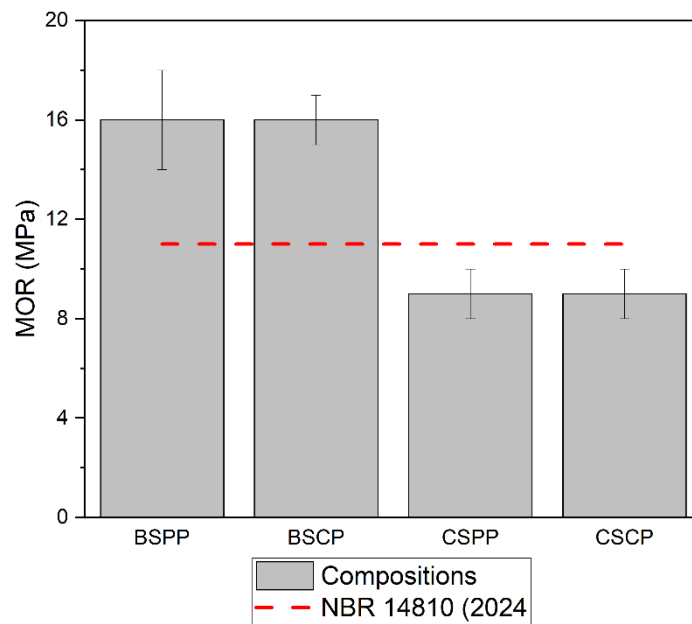
ρ : density; **MOR**: modulus of rupture; **MOE**: modulus of elasticity; **IB**: internal bond; **TS**: thickness swelling; **WA**: water absorption

* Means followed by different letters in each column differ significantly at 5 % by the Tukey's Test

The mean density results indicated that all compositions exhibited values very close to the target density (750 kg/m³), with no statistically significant differences among them according to Tukey's test ($p < 0.05$).

The mechanical properties of MOR (Figure 7) and MOE (Figure 8) revealed two statistically distinct groups. One group consisted of the BSPP and BSCP compositions, while the other included CSPP and CSCP, which did not differ from each other (Tukey's test, $p < 0.05$). Panels produced from sargassum combined with sugarcane bagasse particles exhibited superior mechanical performance compared with those made from coconut husk fibers. No significant differences were observed between panels containing pelagic and benthic sargassum particles.

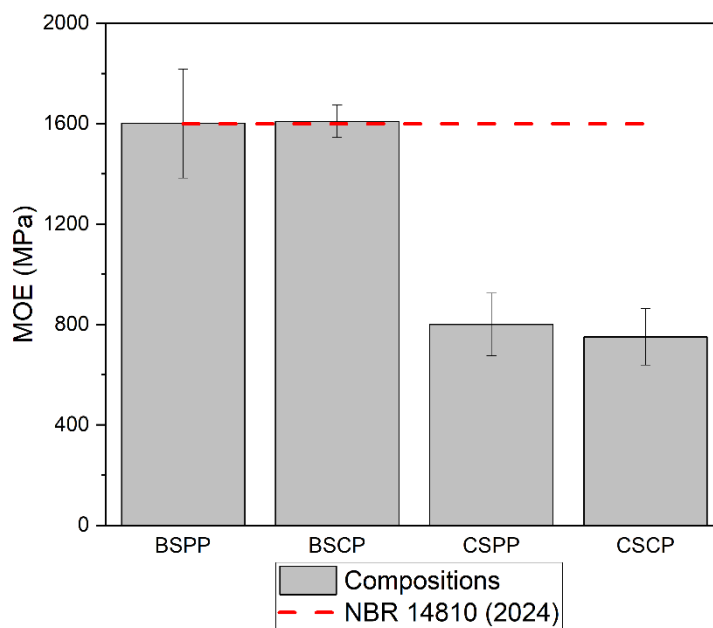
413



414

Figure 7. Mean MOR values of sargassum-based panels.

415



416

Figure 8. Mean MOE values of sargassum-based panels.

417

418

419

420

421

Stanislas et al. (2026) developed particleboards made from pelagic sargassum associated with coconut leaf sheaths, using polylactic acid (PLA) as a binder, whereas Duran et al. (2024) produced particleboards from pelagic sargassum combined with sugarcane bagasse, employing a castor oil-based polyurethane (PU) resin as an adhesive. The MOR results of the BSPP and

BSCP treatments are similar to those reported by Stanislas et al. (2026) and Duran et al. (2024), indicating comparable performance even when different species and biomasses collected from different regions are used.

The MOE results of the CSPP and CSCP treatments were similar to those reported by Stanislas et al. (2026), which did not meet the established standards, whereas BSPP and BSCP were more comparable to the findings of Duran et al. (2024), which comply with the standards (values exceeding 1600 MPa). In this context, it can be observed that the incorporation of sugarcane bagasse and the use of castor oil-based PU resin provide superior mechanical performance for sargassum-based particleboards compared to the use of coconut biomass in combination with PLA.

Similarly, the IB property (Figure 9) also showed the formation of two statistically distinct groups, again with BSPP and BSCP forming one group and CSPP and CSCP forming the other. Although panels incorporating sugarcane bagasse exhibited better statistical performance than those with coconut husk fibers, all compositions complied with both NBR 14810-2 (2024) and ISO 16893 (2016) standards for this property. The results demonstrate the effectiveness of castor oil-based PU resin as an adhesive for particleboards (Duran et al., 2025b), with BSPP and BSCP showing results similar to panels produced using only sugarcane bagasse (Duran et al., 2023).

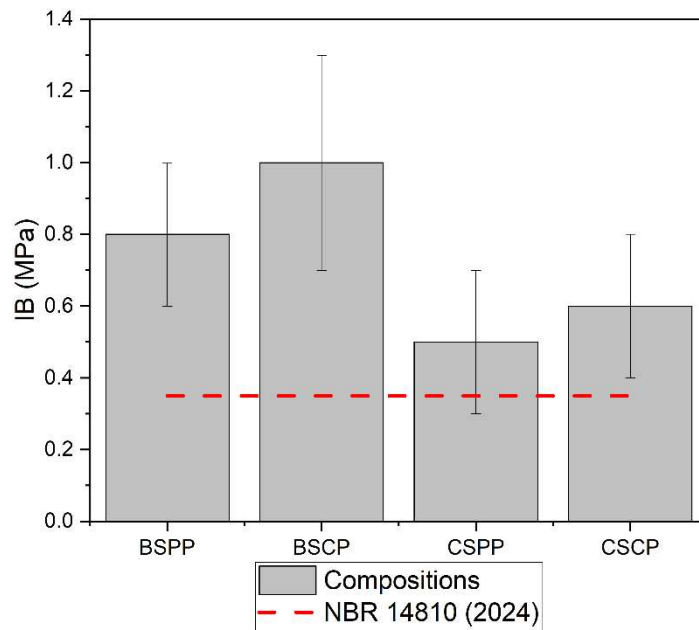


Figure 9. Mean IB values of sargassum-based panels.

The TS property (Figure 10) once again highlighted the comparable performance between pelagic and benthic sargassum particles, as well as the superior behavior of sugarcane bagasse particles relative to coconut husk fibers when combined for panel production. The results demonstrated that BSPP and BSCP compositions meet the requirements of NBR 14810-2 (2024) for non-structural use under dry conditions. For the WS property, an exception in the performance pattern was observed, with distinct statistical groupings. The BSPP composition exhibited superior performance compared with the other compositions, indicating a significant statistical difference between panels containing pelagic and benthic sargassum particles. Nevertheless, both types of sargassum displayed structural porosity conducive to water absorption.

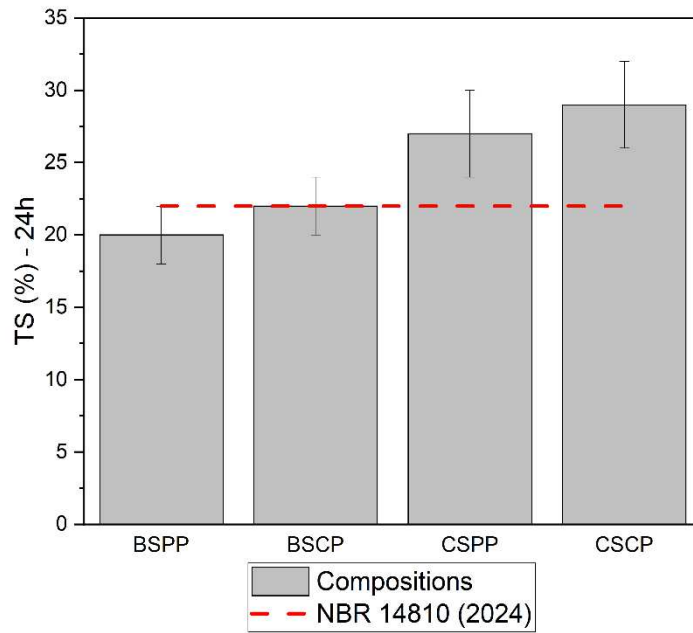


Figure 10. Mean TS values of sargassum-based panels.

Figure 11 presents cross-sectional images of BSPP (a), CSPP (b), BSCP (c), and CSCP (d) panels obtained by SEM at 50× magnification. Figures 11a and 11c show that sugarcane bagasse particles displayed greater cohesion during compaction and fewer voids, corroborating the superior physical and mechanical performance of panels produced with these particles.

Conversely, Figures 11b and 11d show the arrangement of coconut husk fibers within the panels, indicating insufficient compaction and a higher number of voids, which consequently affected the physical and mechanical properties, particularly the physical ones, due to increased dimensional instability and a high water absorption capacity.

The SEM images reveal that coconut husk fibers exhibit finer and more elongated morphologies compared to sugarcane bagasse particles. In this context, particle size and distribution control appeared to be less effective for the coconut husk fibers, resulting in less efficient compaction due to their lower packing ability. Consequently, longer particles tend to generate a higher proportion of internal voids and reduced interparticle contact, which ultimately impairs the physical and mechanical performance of the panels (Engehausen et al., 2025; Iswanto et al., 2018).

The mean thickness of the compositions further emphasized this compaction difference between sugarcane bagasse particles and coconut husk fibers. BSPP and BSCP panels exhibited average thicknesses of 14.98 ± 0.18 mm and 14.53 ± 0.15 mm, respectively, whereas CSPP and CSCP panels showed 15.34 ± 0.30 mm and 15.25 ± 0.17 mm, respectively.

The holocellulosic content of the particles plays a crucial role in determining the mechanical properties of the panels, particularly influencing MOR and MOE (Baharoğlu et al., 2013; Mensah et al., 2023). Although coconut husk fibers exhibited a high cellulose content in their initial characterization, other factors also influence the physical and mechanical behavior of particleboards, such as the compaction ratio (Brito et al., 2020). Therefore, under the production parameters established in this study, coconut husk fibers did not provide satisfactory structural performance.

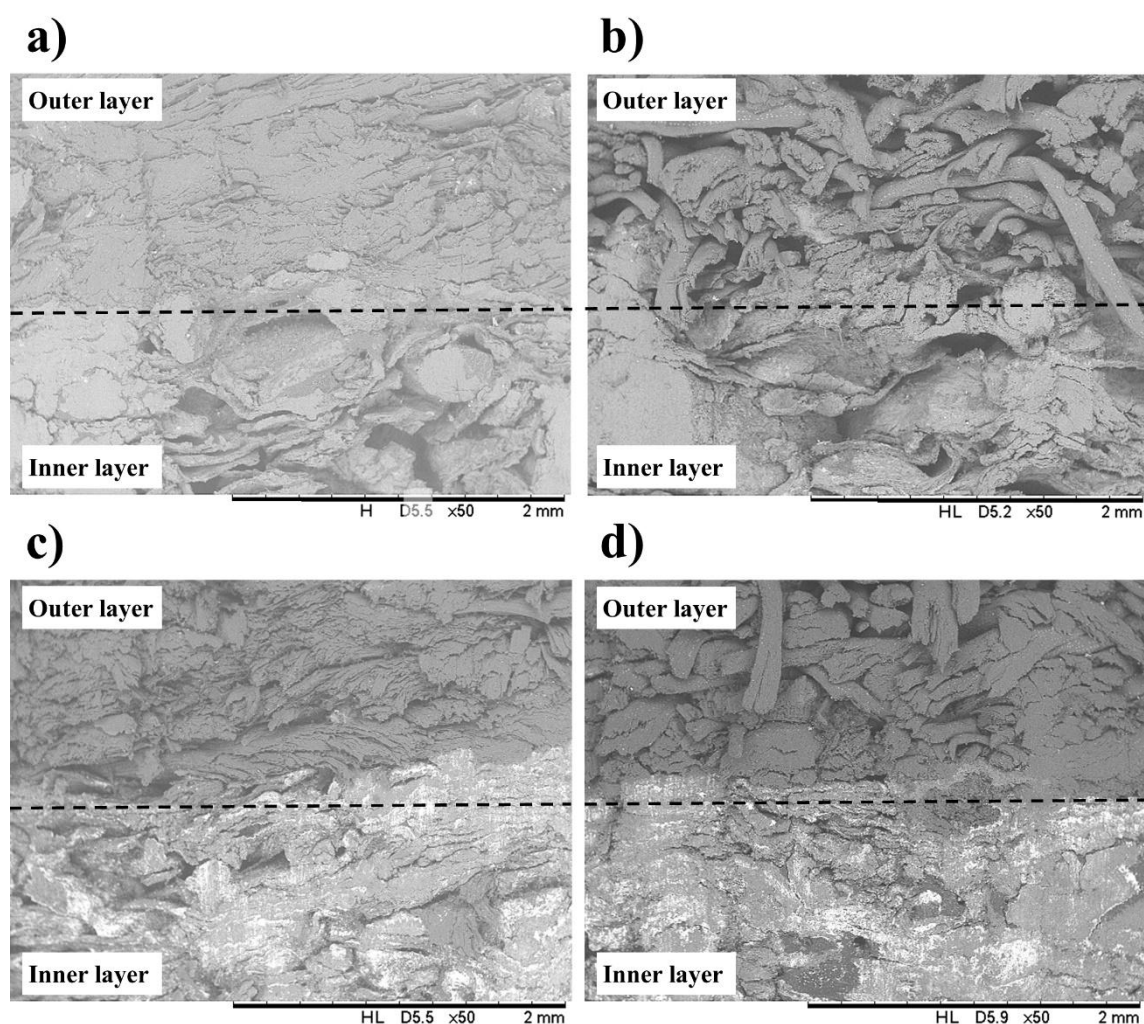


Figure 11. Images of sargassum particleboards obtained by SEM at 50x magnification. a) Image of BSPP. b) Image of CSPP. c) Image of BSCP. d) Image of CSCP.

In contrast, sugarcane bagasse particles played a relevant structural role, ensuring physical and mechanical performance comparable to that of panels produced entirely from sugarcane bagasse as the lignocellulosic raw material (Duran et al., 2023), even when 30% of the composition by mass was replaced with sargassum particles (pelagic and *cymosum*). These results highlight the potential for valorizing agro-industrial residues with significant

lignocellulosic content, enabling their use in higher value-added applications that can substitute virgin raw materials, such as wood.

Furthermore, SEM images revealed that the inner layers of panels containing sargassum biomass particles presented significant voids, which may affect the physical properties of these composites. Based on the initial characterization of both sargassum species, their lignocellulosic content appeared to be limited, with porous morphology and high dimensional variability, thereby promoting water absorption. As also reported by Duran et al. (2024), the incorporation of such algal particles may increase thickness swelling due to their dimensional instability.

Nevertheless, the initial physical and mechanical evaluations of this study indicated that incorporating both sargassum species as filler materials is technically feasible when combined with another lignocellulosic raw material capable of providing structural support, such as sugarcane bagasse.

The thermal conductivity results of the panels that met all the physical and mechanical requirements established by the relevant standards are presented in Table 4. In this context, it is observed that multilayer panels using sugarcane bagasse and sargassum biomass as core material exhibit thermal conductivity values consistent with those recommended by standards for wood-based construction elements, with no statistically significant differences between pelagic and benthic sargassum, according to Tukey's test.

Fiorelli et al. (2019) also evaluated medium-density particleboards produced with agro-industrial residues, reporting satisfactory results for thermal insulation. Finally, the thermal conductivity results of these sargassum-based panels are also consistent with those reported by Stanislas et al. (2026), who found lower conductivity values compared to conventional construction materials such as concrete, brick, or metal, thus supporting the feasibility of using these composites as thermal insulation materials.

Table 4 - Average values of the thermal conductivity for sugarcane bagasse particleboard formulations in relation to the applicable normative standards

Compositions	Thermal Conductivity (W/m.K)
BSCP	0.170 ± 0.002^a
BSPP	0.175 ± 0.004^a
NBR 15220 (2023) – Thermal performance of buildings	
EN 13986 (2004) – Wood-based panels for use in construction	≈ 0.17

* Means followed by different letters in each column differ significantly at 5 % by the Tukey's Test

Final considerations

Although *Sargassum cymosum* particles exhibited higher water absorption compared to pelagic sargassum, both algal species provided similar physical and mechanical performance in the produced panels. Therefore, sargassum biomass, regardless of its origin, pelagic or benthic, can be utilized for the production of medium-density particleboards that comply with non-structural dry-use standards, such as partition in offices and homes (Stanislas et al., 2026) and show potential for application in the furniture industry.

In addition, producing panels using sargassum particles combined with sugarcane bagasse and castor-oil-based polyurethane resin may result in lower environmental impacts compared with conventional particleboards, particularly in categories such as human toxicity, due to the substitution of virgin raw materials and the use of a more sustainable bioresin (Duran et al., 2024; Gavioli et al., 2025). Utilizing sargassum biomass derived from beaching events may also represent an alternative pathway to mitigate the environmental impacts associated with its decomposition, potentially reducing toxic gas emissions and soil contamination (Bueno et al., 2023; Rossignolo et al., 2022).

The feasibility of using different sargassum species in combination with agro-industrial lignocellulosic residues for particleboard production represents an opportunity to promote circular economy practices and enhance the sustainability of communities affected by these phenomena, an approach aligned with the United Nations Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action).

Future studies should explore the combination of sargassum biomass with other lignocellulosic residues, as well as its partial substitution for wood, to expand viable raw material options according to regional availability. Considering the high water absorption capacity of sargassum biomass, additional production parameters should also be investigated to enhance the physical performance of sargassum-based panels, particularly regarding thickness swelling.

Conclusion

This study provides both quantitative and qualitative insights into the utilization of sargassum biomass, specifically pelagic and *cymosum* species, in combination with sugarcane bagasse particles and coconut husk fibers as raw materials for particleboard production.

Preliminary characterizations of the lignocellulosic raw materials were performed, followed by an evaluation of the panels' technical performance, aiming to propose a sustainable alternative for biomass valorization that aligns with the principles of the blue economy.

Whereas the lignocellulosic materials contained high levels of cellulose, hemicellulose, and lignin, the sargassum samples were distinguished by high ash and soluble polysaccharide contents, along with alginate and cellulose present in the water- and alcohol-insoluble fraction corresponding to the cell wall material of the brown seaweed.

The analysis of physical and mechanical properties revealed that particleboards incorporating sugarcane bagasse exhibited superior structural performance compared to those containing coconut husk fibers, regardless of the associated sargassum biomass.

Both BSPP and BSCP panels complied with the minimum requirements established by the NBR 14810-2 (2024), NBR 15220 (2023) and ISO 16893 (2016) standards, confirming their suitability for non-structural applications in dry environments, thermal conductivity for insulation applications and potential use in the furniture industry.

Although the sargassum biomasses did not display properties favorable for structural functions when used as primary raw materials, the findings demonstrate their feasibility as filler components in particleboard manufacturing.

This study advances the field of sustainable materials, presenting results that highlight a promising strategy for utilizing sargassum biomass, encompassing both pelagic and benthic species, in particleboard production. This alternative valorization pathway enhances the value of agro-industrial residues, offers potential to mitigate the environmental impacts affecting coastal communities impacted by massive sargassum landings, and contributes to strengthening the circular economy in these regions.

Acknowledgements

This study was financed, in part, by the São Paulo Research Foundation (FAPESP), Brazil (Process Number #2023/12355-0 and #2024/16946-5). We acknowledge the support of the Government of Canada's New Frontiers in Research Fund (NFRF) (NFRF I-2023-00653) to the Principal Investigator, Maycira Costa, and to Gabriela Pitolli Lyra. This work was carried out with support from the National Council for Scientific and Technological Development (CNPq), Brazil (Process 303850/2024-8).

Author contributions

Afonso José Felício Peres Duran: conceptualization, methodology, investigation, data curation, writing, reviewing and supervision. **Gabriela Pitolli Lyra:** investigation, data curation, writing and reviewing. **Francisco Ailton Gomes da Silva:** methodology, investigation and reviewing. **Luiz Eduardo Campos Filho:** methodology, and reviewing. **Gabriel Affonso da Costa Held:** methodology and reviewing. **André Ferraz:** methodology, investigation, data curation, writing and reviewing. **Maycira Costa:** reviewing. **Juliano Fiorelli:** data curation and reviewing. **João Adriano Rossignolo:** conceptualization, reviewing and supervision.

Data availability

Data will be made available on request.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used CHATGPT5.0 to revise the grammar of certain sections. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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.

References

- Amador-Castro, F., García-Cayuela, T., Alper, H.S., Rodriguez-Martinez, V., Carrillo-Nieves, D., 2021. Valorization of pelagic sargassum biomass into sustainable applications: Current trends and challenges. *J. Environ. Manage.* 283. <https://doi.org/10.1016/j.jenvman.2021.112013>
- American Society for Testing and Materials (ASTM). ASTM E1530-11: Evaluating the Resistance to Thermal Transmission of Materials by the Guarded Heat Flow Meter Technique. West Conshohocken, 2014.
- American Society for Testing and Materials (ASTM), 2020. ASTM D1037-12: Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials. <https://doi.org/10.1520/D1037-12R20>
- Associação Brasileira de Normas Técnicas (2023). NBR 15220: Thermal performance of buildings. Rio de Janeiro: ABNT.
- Associação Brasileira de Normas Técnicas (ABNT), 2024. NBR 14810-2: Medium density

particleboards: Part 2: Requirements and the test methods

- Baghel, R.S., Reddy, C.R.K., Singh, R.P., 2021. Seaweed-based cellulose: Applications, and future perspectives. *Carbohydr. Polym.* 267, 118241. <https://doi.org/10.1016/j.carbpol.2021.118241>
- Baharoğlu, M., Nemli, G., Sari, B., Birtürk, T., Bardak, S., 2013. Effects of anatomical and chemical properties of wood on the quality of particleboard. *Compos. Part B Eng.* 52, 282–285. <https://doi.org/10.1016/j.compositesb.2013.04.009>
- Bertolini, M. da S., de Morais, C.A.G., Christoforo, A.L., Bertoli, S.R., dos Santos, W.N., Lahr, F.A.R., 2019. Acoustic absorption and thermal insulation of wood panels: Influence of porosity. *BioResources* 14, 3746–3757. <https://doi.org/10.15376/biores.14.2.3746-3757>
- Bispo, R.A., Trevisan, M.F., da Silva, S.A.M., Aquino, V.B. de M., Saraiva, R.L. de P., Arroyo, F.N., Molina, J.C., Chahud, E., Branco, L.A.M.N., Panzera, T.H., Lahr, F.A.R., Christoforo, A.L., 2022. Production and evaluation of particleboards made of coconut fibers, pine, and eucalyptus using bicomponent polyurethane-castor oil resin. *BioResources* 17, 3944–3951. <https://doi.org/10.15376/biores.17.3.3944-3951>
- Brito, F.M.S., Bortoletto Júnior, G., Paes, J.B., Belini, U.L., Tomazello-Filho, M., 2020. Technological characterization of particleboards made with sugarcane bagasse and bamboo culm particles. *Constr. Build. Mater.* 262. <https://doi.org/10.1016/j.conbuildmat.2020.120501>
- Bueno, C., Rossignolo, J.A., Gavioli, L.M., Sposito, C.C.A., Tonin, F.G., Veras, M.M., Moraes, M.J.B. de, Lyra, G.P., 2023. Life Cycle Assessment Applied to End-of-Life Scenarios of *Sargassum* spp. for Application in Civil Construction. *Sustain.* 15. <https://doi.org/10.3390/su15076254>
- Buzo, A.L.S.C., Silva, S.A.M., de Moura Aquino, V.B., Chahud, E., Branco, L.A.M.N., de Almeida, D.H., Christoforo, A.L., Almeida, J.P.B., Lahr, F.A.R., 2020. Addition of sugarcane bagasse for the production of particleboards bonded with urea-formaldehyde and polyurethane resins. *Wood Res.* 65, 727–736. <https://doi.org/10.37763/WR.1336-4561/65.5.727736>
- Cangussu, N., Vieira, M.L.C., Maia, L., 2023. Environmental Analysis of the Incorporation of Sugarcane Bagasse in Medium Density Particleboard Panels through Life Cycle Assessment. *Recycling* 8. <https://doi.org/10.3390/recycling8020044>
- Carvalho Araújo, C.K., Bigarelli Ferreira, M., Salvador, R., de Carvalho Araújo, C.K.C., Camargo, B.S., de Carvalho Araújo Camargo, S.K., de Campos, C.I., Piekarski, C.M., 2022. Life cycle assessment as a guide for designing circular business models in the wood panel industry: A critical review. *J. Clean. Prod.* 355. <https://doi.org/10.1016/j.jclepro.2022.131729>
- Costa, G.B., Ramlov, F., de Ramos, B., Koerich, G., Gouvea, L., Costa, P.G., Bianchini, A., Maraschin, M., Horta, P.A., 2019. Physiological damages of *Sargassum cymosum* and *Hypnea pseudomusciformis* exposed to trace metals from mining tailing. *Environ. Sci.*

- Pollut. Res. 26, 36486–36498. <https://doi.org/10.1007/s11356-019-06691-w>
- Cunningham, E.M., O’Kane, A.P., Ford, L., Sheldrake, G.N., Cuthbert, R.N., Dick, J.T.A., Maggs, C.A., Walsh, P.J., 2023. Temporal patterns of fucoxanthin in four species of European marine brown macroalgae. *Sci. Rep.* 13, 1–10. <https://doi.org/10.1038/s41598-023-47274-7>
- de Souza, M.J.C., de Melo, R.R., Guimarães Junior, J.B., Mascarenhas, A.R.P., de Oliveira Paula, E.A., Pedrosa, T.D., Maskell, D., Mensah, P., Rodolfo Junior, F., 2023. Eco-friendly particleboard production from coconut waste valorization. *Environ. Sci. Pollut. Res.* 30, 15241–15252. <https://doi.org/10.1007/s11356-022-23273-5>
- Duran, A.J.F.P., Lopes Júnior, W.E., Pavesi, M., Fiorelli, J., 2023. Assessment of medium density panels of sugarcane bagasse. *Cienc. Florest.* 33, 1–16. <https://doi.org/10.5902/1980509869624>
- Duran, A.J.F.P., Lyra, G.P., Campos Filho, L.E., Bueno, C., Rossignolo, J.A., Alves-Lima, C., Fiorelli, J., 2024. The Use of Sargasso Seaweed as Lignocellulosic Material for Particleboards: Technical Viability and Life Cycle Assessment. *Buildings* 14, 1403. <https://doi.org/10.3390/buildings14051403>
- Duran, A.J.F.P., Campos Filho, L.E., Lyra, G.P., Costa Held, G.A. da, Rossignolo, J.A., Fiorelli, J., 2025a. Evaluation of physical and mechanical properties in medium density particleboards made from sugarcane bagasse and plastic waste (HDPE) at different pressing temperatures. *Ind. Crops Prod.* 223, 120190. <https://doi.org/10.1016/j.indcrop.2024.120190>
- Duran, A.J.F.P., Lyra, G.P., Campos Filho, L.E., Martins, R.H.B., Bueno, C., Rossignolo, J.A., Fiorelli, J., 2025b. The Use of Castor Oil Resin on Particleboards: A Systematic Performance Review and Life Cycle Assessment. *Sustainability* 17, 3609. <https://doi.org/10.3390/su17083609>
- Engehausen, N., Benthien, J.T., Lüdtke, J., 2025. Investigation on the influence of particle size and surface-specific adhesive amount on mechanical properties and sorption behavior of particleboard. <https://doi.org/10.1007/s00107-025-02275-3>
- European Committee for Standardization (2004). EN 13986: Wood-based panels for use in construction – Characteristics, evaluation of conformity and marking. Brussels: CEN.
- Faria, D.L., Gonçalves, F.G., Maffioletti, F.D., Scatolino, M.V., Soriano, J., Protásio, T. de P., Lopez, Y.M., Paes, J.B., Mendes, L.M., Guimarães Junior, J.B., Tonoli, G.H.D., 2024. Particleboards based on agricultural and agroforestry wastes glued with vegetal polyurethane adhesive: An efficient and eco-friendly alternative. *Ind. Crops Prod.* 214. <https://doi.org/10.1016/j.indcrop.2024.118540>
- Ferraz A., Baeza J., Rodriguez J., Freer J., 2000. Estimating the chemical composition of biodegraded pine and eucalyptus wood by DRIFT spectroscopy and multivariate analysis. *Bioresource Technology* 74: 201-212. [https://doi.org/10.1016/S0960-8524\(00\)00024-9](https://doi.org/10.1016/S0960-8524(00)00024-9).

- Fiorelli, J., Gomide, C.A., Lahr, F.A.R., do Nascimento, M.F., de Lucca Sartori, D., Ballesteros, J.E.M., Bueno, S.B., Belini, U.L., 2014. Physico-chemical and anatomical characterization of residual lignocellulosic fibers. *Cellulose* 21, 3269–3277. <https://doi.org/10.1007/s10570-014-0398-9>
- Fiorelli, J., Bueno, S.B., Cabral, M.R., 2019. Assessment of multilayer particleboards produced with green coconut and sugarcane bagasse fibers. *Constr. Build. Mater.* 205, 1–9. <https://doi.org/10.1016/j.conbuildmat.2019.02.024>
- Gavioli, L., Lopes Silva, D.A., Bueno, C., Rossignolo, J.A., 2025. Life cycle assessment as a circular economy strategy to select eco-efficient raw materials for particleboard production. *Resour. Conserv. Recycl.* 212. <https://doi.org/10.1016/j.resconrec.2024.107921>
- Gómez-Ordóñez, E., Rupérez, P., 2011. FTIR-ATR spectroscopy as a tool for polysaccharide identification in edible brown and red seaweeds. *Food Hydrocoll.* 25, 1514–1520. <https://doi.org/10.1016/j.foodhyd.2011.02.009>
- Gower, J., King, S., 2020. The distribution of pelagic Sargassum observed with OLCI. *Int. J. Remote Sens.* 41, 5669–5679. <https://doi.org/10.1080/01431161.2019.1658240>
- IBÁ, 2024. Brazilian Tree Industry – Annual Report (in Portuguese), 2024. <<https://iba.org/wp-content/uploads/2025/05/relatorio2024.pdf>>.
- International Standard Organization (ISO), 2016. ISO 16893:2016: Wood -Based Panels - Particleboard.
- Iswanto, A.H., Prabuningrum, D.S., Azhar, I., 2018. Effect of Particle Length to The Quality Particleboard Made from Sorghum Bagasse of 01, 16–23. <https://doi.org/10.32734/jsi.v1i1.423>
- Johns, E.M., Lumpkin, R., Putman, N.F., Smith, R.H., Muller-Karger, F.E., T. Rueda-Roa, D., Hu, C., Wang, M., Brooks, M.T., Gramer, L.J., Werner, F.E., 2020. The establishment of a pelagic Sargassum population in the tropical Atlantic: Biological consequences of a basin-scale long distance dispersal event. *Prog. Oceanogr.* 182, 102269. <https://doi.org/10.1016/j.pocean.2020.102269>
- Klímek, P., Wimmer, R., Meinlschmidt, P., Kúdela, J., 2018. Utilizing Miscanthus stalks as raw material for particleboards. *Ind. Crops Prod.* 111, 270–276. <https://doi.org/10.1016/j.indcrop.2017.10.032>
- Kostas, E.T., Wilkinson, S.J., White, D.A., Cook, D.J., 2016. Optimization of a total acid hydrolysis based protocol for the quantification of carbohydrate in macroalgae. *J. Algal Biomass Utiln* 7, 21–36.
- Le, D.L., Salomone, R., Nguyen, Q.T., 2023. Circular bio-based building materials: A literature review of case studies and sustainability assessment methods. *Build. Environ.* 244, 110774. <https://doi.org/10.1016/j.buildenv.2023.110774>
- Lee, S.H., Lum, W.C., Boon, J.G., Kristak, L., Antov, P., Pedzik, M., Rogozinski, T.,

- Taghiyari, H.R., Lubis, M.A.R., Fatriasari, W., Yadav, S.M., Chotikhun, A., Pizzi, A., 2022. Particleboard from agricultural biomass and recycled wood waste: a review. *J. Mater. Res. Technol.* 20, 4630–4658. <https://doi.org/10.1016/j.jmrt.2022.08.166>
- Lima Mesquita, A., Barrero, N.G., Fiorelli, J., Christoforo, A.L., De Faria, L.J.G., Lahr, F.A.R., 2018. Eco-particleboard manufactured from chemically treated fibrous vascular tissue of acai (*Euterpe oleracea* Mart.) Fruit: A new alternative for the particleboard industry with its potential application in civil construction and furniture. *Ind. Crops Prod.* 112, 644–651. <https://doi.org/10.1016/j.indcrop.2017.12.074>
- Maraveas, C., 2020. Production of sustainable construction materials using agro-wastes. *Materials (Basel)*. 13. <https://doi.org/10.3390/ma13020262>
- Martin, L.M., Taylor, M., Huston, G., Goodwin, D.S., Schell, J.M., Siuda, A.N.S., 2021. Pelagic Sargassum morphotypes support different rafting motile epifauna communities. *Mar. Biol.* 168, 1–17. <https://doi.org/10.1007/s00227-021-03910-2>
- Martins, R.S.F., Gonçalves, F.G., Segundinho, P.G. de A., Lelis, R.C.C., Paes, J.B., Lopez, Y.M., Chaves, I.L.S., Oliveira, R.G.E. de, 2021. Investigation of agro-industrial lignocellulosic wastes in fabrication of particleboard for construction use. *J. Build. Eng.* 43, 102903. <https://doi.org/10.1016/j.jobe.2021.102903>
- Masarin, F., Gurpilhares, D.B., Baffa, D.C.F., Barbosa, M.H.P., Carvalho, W., Ferraz, A., Milagres, A.M.F., 2011. Chemical composition and enzymatic digestibility of sugarcane clones selected for varied lignin content. *Biotechnol. Biofuels* 4, 1–10. <https://doi.org/10.1186/1754-6834-4-55>
- Mensah, P., Govina, J., Owusu-Asante, J.O., Seidu, H., Junior, F.R., de Oliveira Paula, E.A., Pedrosa, T.D., de Melo, R.R., 2023. Durability and resistance of eco-friendly particleboards produced from agroforestry residues. *Rev. Mater.* 28, 1. <https://doi.org/10.1590/1517-7076-RMAT-2023-0027>
- Narciso, C.R.P., Reis, A.H.S., Mendes, J.F., Nogueira, N.D., Mendes, R.F., 2021. Potential for the Use of Coconut Husk in the Production of Medium Density Particleboard. *Waste and Biomass Valorization* 12, 1647–1658. <https://doi.org/10.1007/s12649-020-01099-x>
- Nogueira, N.D., Narciso, C.R.P., de Lima Felix, A., Mendes, R.F., 2022. Pressing Temperature Effect on the Properties of Medium Density Particleboard Made with Sugarcane Bagasse and Plastic Bags. *Mater. Res.* 25. <https://doi.org/10.1590/1980-5373-MR-2021-0491>
- Pędzik, M., Kwidziński, Z., Janiszewska-Latterini, D., Rogoziński, T., 2024. Particleboard from the residues of wooden door production as a closed material cycle. *Ind. Crops Prod.* 222. <https://doi.org/10.1016/j.indcrop.2024.119653>
- Peres, L.M.C., Gouvêa, L.P., Hayden, J., Burle, G., Bastos, E., Carneiro, A., Horta, P.A., 2023. Effects of ocean warming and pollution on Sargassum forests. *Mar. Environ. Res.* 191, 1–8. <https://doi.org/10.1016/j.marenvres.2023.106167>
- Resiere, D., Valentino, R., Nevière, R., Banydeen, R., Gueye, P., Florentin, J., Cabié, A.,

- Lebrun, T., Mégarbane, B., Guerrier, G., Mehdaoui, H., 2018. Sargassum seaweed on Caribbean islands: an international public health concern. *Lancet* 392, 2691. [https://doi.org/10.1016/S0140-6736\(18\)32777-6](https://doi.org/10.1016/S0140-6736(18)32777-6)
- Ribeiro, D.P., Vilela, A.P., Silva, D.W., Napoli, A., Mendes, R.F., 2020. Effect of Heat Treatment on the Properties of Sugarcane Bagasse Medium Density Particleboard (MDP) Panels. *Waste and Biomass Valorization* 11, 6429–6441. <https://doi.org/10.1007/s12649-019-00882-9>
- Rodrigues, D., Freitas, A.C., Pereira, L., Rocha-Santos, T.A.P., Vasconcelos, M.W., Roriz, M., Rodríguez-Alcalá, L.M., Gomes, A.M.P., Duarte, A.C., 2015. Chemical composition of red, brown and green macroalgae from Buarcos bay in Central West Coast of Portugal. *Food Chem.* 183, 197–207. <https://doi.org/10.1016/j.foodchem.2015.03.057>
- Rodríguez-Muñoz, R., Muñoz-Castillo, A.I., Euán-Avila, J.I., Hernández-Núñez, H., Valdés-Lozano, D.S., Collí-Dulá, R.C., Arias-González, J.E., 2021. Assessing temporal dynamics on pelagic Sargassum influx and its relationship with water quality parameters in the Mexican Caribbean. *Reg. Stud. Mar. Sci.* 48, 102005. <https://doi.org/10.1016/j.rsma.2021.102005>
- Roe, H.S.J., Freestone, D., Sapsford, F., 2022. The Sargasso Sea High Seas EBSA After Ten Years: Is It Still Relevant and How Has It Helped Conservation Efforts? *Front. Mar. Sci.* 9, 1–12. <https://doi.org/10.3389/fmars.2022.821182>
- Rossignolo, J.A., Felício Peres Duran, A.J., Bueno, C., Martinelli Filho, J.E., Savastano Junior, H., Tonin, F.G., 2022. Algae application in civil construction: A review with focus on the potential uses of the pelagic Sargassum spp. biomass. *J. Environ. Manage.* <https://doi.org/10.1016/j.jenvman.2021.114258>
- Sissini, M.N., De Barros Barreto, M.B.B., Szećhy, M.T.M., De Lucena, M.B., Oliveira, M.C., Gower, J., Liu, G., De Oliveira Bastos, E., Milstein, D., Gusmão, F., Martinelli-Filho, J.E., Alves-Lima, C., Colepicolo, P., Ameka, G., De Graftjohnson, K., Gouvea, L., Torrano-Silva, B., Nauer, F., Marcos De Castronunes, J., Bonomibarufi, J., Rörig, L., Riosmena-Rodríguez, R., Mello, T.J., Lotufo, L.V.C., Horta, P.A., 2017. The floating Sargassum (Phaeophyceae) of the South Atlantic Ocean - Likely scenarios. *Phycologia* 56, 321–328. <https://doi.org/10.2216/16-92.1>
- Sluiter, J.B., Ruiz, R.O., Scarlata, C.J., Sluiter, A.D., Templeton, D.W., 2010. Compositional analysis of lignocellulosic feedstocks. 1. Review and description of methods. *J. Agric. Food Chem.* 58, 9043–9053. <https://doi.org/10.1021/jf1008023>
- Soares, S.S., Guimarães Júnior, J.B., Mendes, L.M., Mendes, R.F., Protásio, T. de P., Lisboa, F.N., 2017. Valorization of sugarcane bagasse for production of low density particleboards. *Rev. Ciência da Madeira - RCM* 8, 64–73. <https://doi.org/10.12953/2177-6830/rcm.v8n2p64-73>
- Solarin, B.B., Bolaji, D.A., Fakayode, O.S., Akinnigbagbe, R.O., 2014. Impacts of an invasive seaweed Sargassum hystrix var. fluitans (Børgesen 1914) on the fisheries and other economic implications for the Nigerian coastal waters. *IOSR J. Agric. Vet. Sci.* 7, 01–06. <https://doi.org/10.9790/2380-07710106>

- Stanislas, T.T., Bilba, K., On, C., Ars, M., 2026. Assessment of the valorisation of Sargassum seaweed in the production of PLA-based multilayer particleboards 515.
<https://doi.org/10.1016/j.conbuildmat.2026.145649>
- Sugahara, E.S., da Silva, S.A.M., Buzo, A.L.S.C., de Campos, C.I., Morales, E.A.M., Ferreira, B.S., Azambuja, M. dos A., Lahr, F.A.R., Christoforo, A.L., 2019. High-density particleboard made from agro-industrial waste and different adhesives. *BioResources* 14, 5162–5170. <https://doi.org/10.15376/biores.14.3.5162-5170>
- Tsilomelekis, G., Orella, M.J., Lin, Z., Cheng, Z., Zheng, W., Nikolakis, V., Vlachos, D.G., 2016. Molecular structure, morphology and growth mechanisms and rates of 5-hydroxymethyl furfural (HMF) derived humins. *Green Chem.* 18, 1983–1993.
<https://doi.org/10.1039/c5gc01938a>
- Uemura Silva, V., Nascimento, M.F., Resende Oliveira, P., Panzera, T.H., Rezende, M.O., Silva, D.A.L., Borges de Moura Aquino, V., Rocco Lahr, F.A., Christoforo, A.L., 2021. Circular vs. linear economy of building materials: A case study for particleboards made of recycled wood and biopolymer vs. conventional particleboards. *Constr. Build. Mater.* 285, 122906. <https://doi.org/10.1016/j.conbuildmat.2021.122906>
- van Dam, J.E.G., van den Oever, M.J.A., Keijzers, E.R.P., van der Putten, J.C., Anayron, C., Josol, F., Peralta, A., 2006. Process for production of high density/high performance binderless boards from whole coconut husk. Part 2: Coconut husk morphology, composition and properties. *Ind. Crops Prod.* 24, 96–104.
<https://doi.org/10.1016/j.indcrop.2005.03.003>
- van Tussenbroek, B.I., Hernández Arana, H.A., Rodríguez-Martínez, R.E., Espinoza-Avalos, J., Canizales-Flores, H.M., González-Godoy, C.E., Barba-Santos, M.G., Vega-Zepeda, A., Collado-Vides, L., 2017. Severe impacts of brown tides caused by *Sargassum* spp. on near-shore Caribbean seagrass communities. *Mar. Pollut. Bull.* 122, 272–281.
<https://doi.org/10.1016/j.marpolbul.2017.06.057>
- Wang, M., Hu, C., Barnes, B.B., Mitchum, G., Lapointe, B., Montoya, J.P., 2019. The great Atlantic *Sargassum* belt. *Science* (80-.). 364, 83–87.
<https://doi.org/10.1126/science.aaw7912>
- Wang, W., Fu, Y., Xu, J., Gao, X., Fu, X., Wang, L., 2024. Optimization of hydrolysis conditions of alginate based on high performance liquid chromatography. *Heliyon* 10.
<https://doi.org/10.1016/j.heliyon.2024.e29738>
- Wargacki, A.J., Leonard, E., Win, M.N., Regitsky, D.D., Santos, C.N.S., Kim, P.B., Cooper, S.R., Raisner, R.M., Herman, A., Sivitz, A.B., Lakshmanaswamy, A., Kashiyama, Y., 2012. An Engineered Microbial Platform for Direct Biofuel Production from Brown Macroalgae. *Science* (80-.). 230502, 308–314.
- Yano, B.B.R., Silva, S.A.M., Almeida, D.H., Aquino, V.B.M., Christoforo, A.L., Rodrigues, E.F.C., Junior, A.N.C., Silva, A.P., Lahr, F.A.R., 2020. Use of sugarcane bagasse and industrial timber residue in particleboard production. *BioResources* 15, 4753–4762.
<https://doi.org/10.15376/biores.15.3.4753-4762>

945
946
947