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RESEARCH ARTICLE

Multi-Criteria Decision-Making Analysis of Natural Fibers as Ceiling Liners in the Automotive Industry

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ABSTRACT – The development of biomass technology for the generation of bio-based goods and bioenergy will enable more economic and wise use of indigenous natural sources like agricultural residues, trees, and crops. Improving the recyclability and generation of new cars with natural-based materials is becoming increasingly important for car manufacturers as environmental protection becomes a top priority. In this study, a multiple-criteria decision analysis (MCDM) was carried out to obtain the most suitable natural fiber in terms of technical and structural properties in the case of the use of natural fiber-based materials as ceiling liners in the automotive industry. For this purpose, natural fiber materials that are used in the automotive industry as interior parts were investigated. Taking into account the required characteristics for ceiling liner production, the technical and structural properties of the 13 most commonly used materials were determined. A cross-comparative hierarchy analysis was then used to obtain the most proper natural fiber for ceiling liner material production in the automotive sector. The numerical results indicate that the weighted priority scores of 0.1383 and 0.1149 for pineapple and coir are higher than those for the remaining fiber types, making them attractive alternatives. The results of the research are important for decision-makers, automotive manufacturers, and engineers to use natural fibers appropriately and in the right place in the automotive industry.

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1. INTRODUCTION

Natural fiber production is increasing in parallel with the surge in industrial demand [1]. Depending on where they come from, natural fibers can be broadly classified as either plant- or animal-based. Natural fibers make up green composites, also known as biocomposites. Recently, researchers from academia and industry have become highly interested in natural fibers because of their accessibility, environmental friendliness, and biodegradability. Food packaging, automotive, and construction industries are also major users of natural fiber-supported polymer composite materials in their products [2]. Automotive manufacturers are very interested in using natural fibers or green composites because of the recycling and reuse capabilities of automotive resources. In automotive applications, reinforced composites with natural fiber can reduce material waste and component costs. Natural fiber composites have excellent acoustic and thermal insulation features, high fracture resistance, and exceptional strength and stiffness. Over the past decade, European car manufacturers have increased the use of natural fiber composite in automotive implementations to meet the growing demand for lighter, safer, and more fuel-efficient vehicles. After two decades of intensive research, natural plant fibers, including hemp, jute, banana, sisal, flax, kenaf, coir, and many more, are becoming more popular than their synthetic counterparts.

Studies have shown that there are numerous technological and financial benefits to using natural fibers such as kenaf, ramie, flax, hemp, and cotton in automotive composites [3]. These bio-based composites will reduce production costs, fix passenger-vehicle safety and crush resistance in extreme temperatures, improve mechanical strength and acoustic performance, and make interior parts biodegradable [4]. They will also decrease processing time and material weight. However, the utilization of natural fiber-based composites in automobile manufacturing is currently limited, in contrast to the artificial fiber-reinforced plastic materials that have historically dominated the manufacturing of automobile interiors [5], the majority of which are made of composite structures and petroleum-based polymer materials, making them particularly challenging to recycle. These interiors are currently disposed of by incineration or landfill. A potential solution to this problem could be using biodegradable materials or a single polymer to manufacture the interior components. In general terms, natural fibers derived from vegetables comprise hemicellulose, cellulose, and lignin, while those derived from animals, like silk and wool, are composed of proteins. The potential of natural fiber-reinforced polymer composites has attracted increasing research interest as a replacement for glass or carbon fiber composites, which are made from synthetic fibers [6]. Natural fiber composites have several advantages, including good specific strength, lightweight, low cost, stiffness, availability, and renewability of raw materials. Biodegradable polymers are predicted to replace artificial polymers in the next few years, at least in some specific implementations where a short product life is highly desirable. A relatively new class of composites is thermoplastic natural fiber composites. These composites are

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produced by combining a thermoplastic (polyethylene, polypropylene, PVC, etc.) with a natural fiber or filler (wood, kenaf, sisal, hemp). The automotive industry has seen a sharp increase in the utilization of thermoplastics and thermoset-sourced natural fiber composites in recent years. Reasons for this growth include the materials' environmental friendliness, renewability, ability to reduce noise, and improved fuel efficiency due to reduced component weight [7]. Natural fibers are combined with various polymer matrices or resins to form natural fiber polymer composites. These composites have achieved great economic success in both semi-structural and structural applications.

Nowadays, long-fiber thermoplastic composites are gradually finding sectoral implementations as engineering materials, filling traditional “glass fiber” needs in industries such as automotive components, building panels, packaging, sporting goods, electrical components, and prosthetics [8]. In particular, long-fiber thermoplastic composites are being rapidly adopted by the automotive industry for both exterior and interior components [9]. In recent years, the automotive sector has developed a number of novel components using natural fiber composites. The global production of motor vehicles reached 85.4 million units, demanding more and more natural fibers [10]. The leading automotive manufacturers and parts suppliers have been investigating the potential of using natural fibers as a reinforcement to synthetic or bio-based matrices since the start of the twentieth century [11]. Each new car model introduced increases demand by 0.5 to 3 kt per year, depending on the model [12]. Nearly 5 to 10 kg of natural fibers (jute, hemp, flax, and so on) are used per car in those countries that use them. There would be a market for between 80 and 160 kilotons of natural fibers per year if the entire European automotive industry used them for molded automotive parts.

Natural fibers are becoming increasingly popular in composite plastics for use in seat backs, boot liners, door panels, dashboards, parcel shelves, headliners, and interior parts of automobiles. This is due to the growing demand for ecologically friendly materials and the perfect properties of natural fibers. Today, polymeric materials make up about half of the interior components of cars; in developed countries, the average amount of polymer used in the car is 120 kg, while this number is closer to 105 kg, or about 11% of the whole weight of the vehicle. Germany has taken the lead in the use of natural fiber composites. Natural fiber composites for exterior and interior implementations have been introduced by German car manufacturers. Germany accounts for 2/3 of overall biofibers used in the European automobile sector. Car manufacturers demand every part of their cars be recyclable or biodegradable.

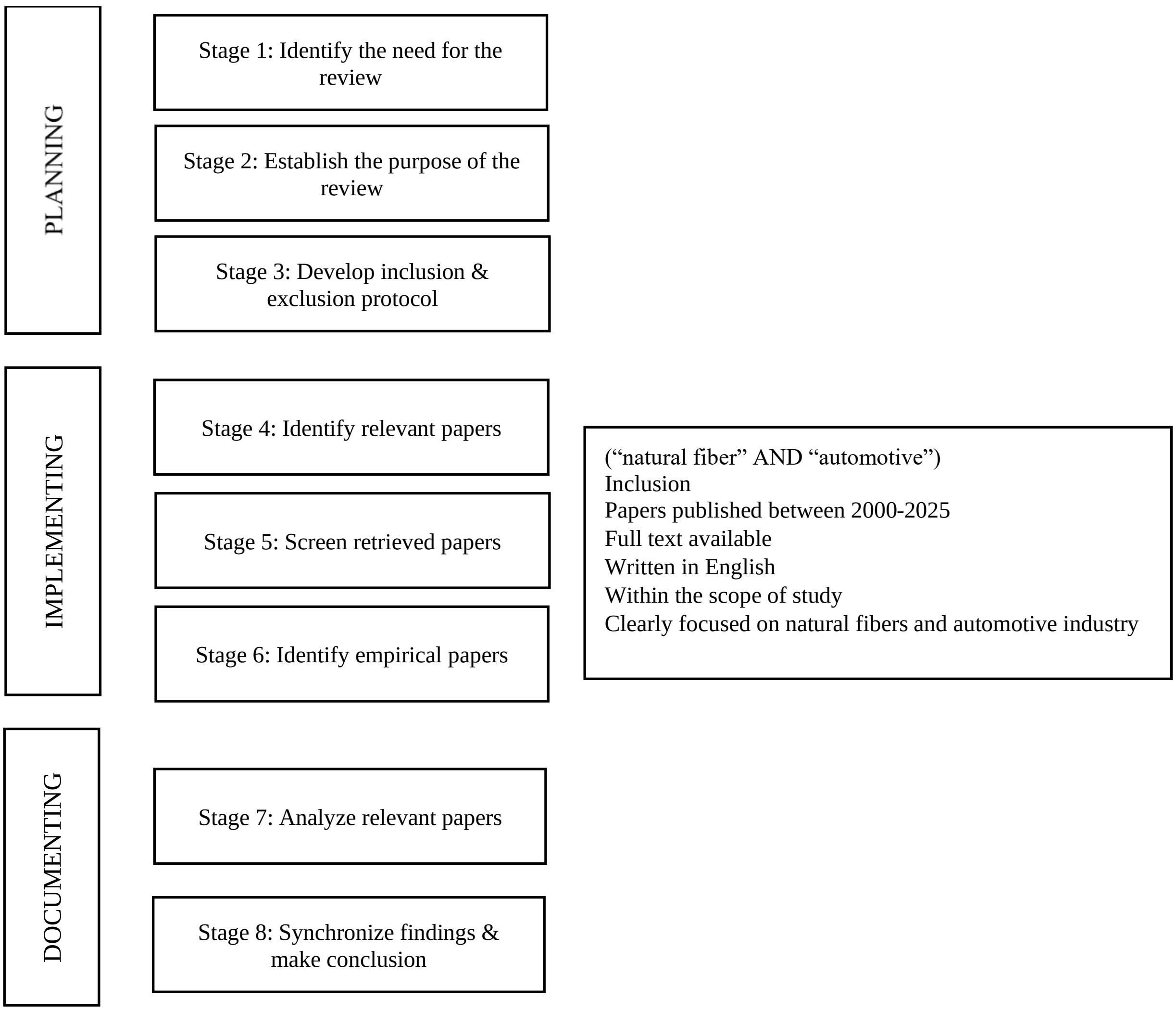

Figure 1. Article selection and screening process

In the rest of this paper, natural fiber materials that are used in the automotive industry as interior parts are investigated. Although a number of researchers have conducted a review of natural fibers, this study is the first one to review their applications in the automotive industry, along with a quantitative multi-criteria decision-making method evaluating natural fibers based on a number of criteria. The present study exemplifies an approach to mapping the expanding body of research on the utilization of natural fibers in the automotive industry and contributes a review aimed at informing scholarly activities and professional practices. By elucidating the current state and emerging trajectories within this field of inquiry, this paper serves to enrich academic deliberations, guide practical implementations, and advise strategic decision-making pertaining to the selection of natural fibers for ceiling liners in the sector. Moreover, the paper contributes to advancing prior research by the use of a multi-criteria decision-making method. This methodology provides insights into the decision-making practices from a quantitative perspective. Figure 1 illustrates the review process employed in this study for the selection of the previous studies.

The rest of the paper is structured as follows: Section 2 provides a review of the literature resulting from the screening process outlined in Figure 1. Section 3 introduces the decision-making method used to determine the optimum natural fiber subject to a set of criteria. Section 4 provides the results and conclusions, while Section 5 suggests the future direction of research and recommendations.

2. LITERATURE REVIEW

This part provides an overview of available literature on the use of natural fiber in the automotive industry. The areas of natural fiber used in automotive implementations are given in Table 1.

Table 1. Natural fiber in automotive implementations [13]

Parts in vehicle	Natural fiber
Inserts, instrument panels (foamed), covered components and inserts, seatback panels, seatback cushions	Wood
Rear-seat covers, upholstery,	Wool
Armrest, door panels	Wood Flour
Interior panels, door linings	Sisal/Flax
Trunk panel, soundproofing, ınsulation material	Cotton
Mats, seat mattresses, seat covers	Coir
Dashboard, door panels, dashboards, headliner parts in railway coach	Jute
Wrapping paper	Banana
Floor panel, body panel,	Abaca
Dashboard door panels, seat-back panels	Hemp
Seat-back panels, armrests, covered inserts, instrument panels covered, door-panel cover, glove box	Flax

The benefits of biodegradable and renewable materials have been investigated extensively. According to Elfaleh et al. [14], utilizing green composite materials reduces the use of fossil sources. It has the potential to benefit manufacturers, consumers, and the environment [15]. According to Olanrewaju et al. [16], the natural fibers' low cost and availability have resulted in these materials being favored as reinforcements or fillers in composite materials. A well-integrated natural fiber and polymer-sourced matrix can result in excellent material efficiency [17]. Natural fiber's distinct properties would indicate varying efficiencies in terms of mechanical, physical, chemical, and ecological features [18]. Pickering et al. conducted extensive research on polymer-based composite materials supported by hemp fibers during the injection casting operation. The researchers investigated fiber treatments and modifications, as well as the optimization of hemp fiber quality [19]. Some researchers investigated the features of plastic/jute composite materials in terms of thermal stability, crystallinity, durability, weathering resistance, and fiber modification. Furthermore, the convenience of such a hybrid material in the car sector was researched across ecological planning elements [20].

Ullah et al. studied the physical and thermal features of different bio-based materials, particularly in automotive applications, evaluating their compatibility with different matrix materials [21]. Skosana et al. investigated the landscape of natural fiber-reinforced polymer composites in the context of automotive applications with an overview of the ecological urgency and regulatory framework driving sustainable automotive materials [22]. In addition, the convenience of natural fiber composites for industrial applications was researched through parametric research and ecological planning. It was recorded that impact analyses were conducted to investigate the impact resistance of bamboo fiber composite materials, and the fiber operation improved the bond powers between the matrix and the fillers, resulting in an increase in effect resistance [23]. Such processes also ensured efficient strength to micro-scale propagation. Bishop et al. also conducted a comparison of biobased plastics with petrochemical plastics [24]. On the other hand, there have been several research studies on the clear selection of the proper natural fiber composite materials for a specific implementation.

Mann et al. examined the mechanical and thermal features of animal-based fiber composite materials to determine the natural fiber composite materials' potential in areas such as biomedical, construction, and automotive industries [25]. For the dashboard panel of a car, Sapuan et al. utilized the analytic hierarchy methodology to choose the best material. The materials considered in that research had only tensile strength, density, and Young's modulus [26]. Lacostea et al. have improved recycled cotton fiber/wood fiber composite materials utilizing Na-alginate as a binder. The coefficients of heat conductivity varied from 0.089 W/mK to 0.078 W/mK for density values of 333–308 kg/m^3 [27].

Palumbo et al. have improved insulating panels from 3 binders, such as sodium alginate, corn starch, and casein, and three produce wastes, such as rice husk, corn pith, and barley straw. The outputs displayed that the alginate-sourced composite materials had lower density values and, therefore, obtained lower thermal conductivity coefficients. The minimal heat conductivity coefficient of 0.052 W/mK was reported for the composite material from alginate and corn pith with a density value of 80 kg/m^3 [28]. Mati-Baouche et al. have improved bio-based insulation composite materials from chitosan and stalk particles of sunflowers with density values of 200–150 kg/m^3 and heat conductivity of 0.058–0.056 W/mK [29]. Zhao et al. recorded that agrarian straw-waste insulating material has a life cycle expense of 7.06 \$/m^2 for a period of twenty-five years, which is less than industrial solid-waste and conventional insulating materials (i.e., EPS, glass wool, XPS, rock wool, etc.) [30]. As mentioned above, many industrial products have been developed to replace petroleum-derived products by using natural fibers in composite materials for different purposes. When studies on the choice of the most proper option for the purpose of use by evaluating different materials in terms of their technical properties are investigated, the number of studies on natural fibers is limited. Balo and Sua evaluated the performance of natural fibers as alternative sustainable insulation materials in terms of energy efficiency in green building envelope studies [31]. In two different studies, the same authors applied the expert decision mechanism in selecting the optimal fiber for green building planning components and hierarchical modeling for optimizing natural fiber selection operations for building eco-design [32, 33].

Mastura et al. used the quality function deployment for an environmental approach in conjunction with the analytical hierarchy process to determine which natural fiber would be the best for an integrated eco-composite material for an automobile anti-roll bar design [34]. For example, Mansor et al. utilized the analytical hierarchy methodology to decide which natural fiber would work best when combined with artificial fiber-reinforced polymer composites. The center lever parking brake, another vehicle component, was designed using the hybrid biocomposite materials produced. Thirteen possibilities for natural fiber materials were evaluated based on three primary performance criteria and the product design specifications [35]. The analytical hierarchy process was also utilized to evaluate and select the best composite materials for use in automotive interior construction, considering fifteen possible non-woven natural fiber/polypropylene-based composite alternatives, using tensile modulus, tensile strength, flexural modulus, flexural strength, maximal water absorption, and impact strength of the composites as selection criteria [36]. Sapuan et al. used AHP to choose the most efficient composite materials with natural fiber for an instrument panel design. They evaluated 29 NFRC substitutes based on their features, like density, tensile strength, and elasticity modulus [37]. In a material selection study, Hambali et al. showed how it could be used to determine which of six composite materials would be the best for an automotive bumper beam design. Twelve sub-factors and eight primary selection factors were evaluated. The most suitable material was identified by the analytical hierarchy process based on each composite's priority vector values [38].

In certain material selection methods, the demand is to discuss material features, attributes, characteristics, and efficiency parameters. Thus, the aim of this analysis is to supply efficiency characteristics and propose the most efficient material. This research focuses on a comparative examination of natural fiber material alternatives selected for automotive interior parts. This research's unique contribution lies in the comparative analysis of various alternative materials for different components according to their material performances and features. Thus, to choose the most efficient material from various options, data regarding elastic modulus, density, tensile strength, elongation, and chemical structure properties of natural fiber materials are taken into consideration for ceiling liner production.

3. METHODOLOGY

Planning engineers should utilize practical and powerful material selection tools in multi-attribute decision analysis that can save both time and cost. Most of the research on multi-attribute decision-analysis methods indicates the disadvantages and advantages of each of the methodologies. A list of various MCDM techniques used in natural fiber research is given in Table 3 [39].

The most popular multi-criteria decision tool used in many material selection studies is the analytical hierarchy process. Since its introduction, the analytical hierarchy process has undergone continuous development. In order to arrive at appropriate decisions, the three primary steps of the analytical hierarchy process must be completed. Creating a hierarchical structure depending on the complex decision problem is the first step. Within the hierarchical structure, there are several subproblems, such as objectives, criteria and subcriteria, and decision alternatives. The primary goal must be at the top. The primary criteria of the problem, the supporting criteria, and the decision options are arranged in a hierarchical framework. The relative weight of each criterion at each level of the system is defined in the second stage by pairwise comparisons of alternatives, criteria, and their subcategories. The evaluation model is organized hierarchically;

the same evaluation method is applied to each node in the hierarchy, and pairwise comparisons are the basis for evaluating the "child" nodes of a general "parent" node. These are the main features of the analytical hierarchy process evaluation model construction method.

Table 3. MCDM techniques used in natural fiber research

MCDM Method	Disadvantages	Advantages
VIKOR	The process needed unclear data, which was subjectively weighted during the process selection.	Ranking the alternatives with competing factors and comparing how near they are to the ideal option.
SAW	The estimation may not accurately reflect the actual circumstance, and the outcome may not make sense.	Straightforward computation that doesn't call for sophisticated computer programs.
PROMETHEE	No assignment of weights.	Using the outranking method, every option must be taken into account when comparing two options. Clear, stable, and easy to understand
DEA	Does not work with inaccurate data; complete input and output information is necessary.	Able to manage several inputs and outputs and demonstrate the process's effectiveness.
ELECTRE	The decision-making process can be influenced by the introduction of additional thresholds.	Every pair of alternatives was taken into consideration in the outranking step. Both qualitative and quantitative data might be entertained by it.
PSI	The application of a scaling system for qualitative criteria may result in user bias.	Without any weighting or ranking, the rating score is calculated directly to assess the alternative's performance.
TOPSIS	It is difficult to weigh and maintain consistency of assessment when you ignore the association between the traits.	Compensatory techniques that permit criterion trade-offs, whereby a successful outcome in one criterion can offset a poor performance in another.
MAUT	A bug of input is needed, and the preference must be exact.	Considers ambiguity and has the ability to take choice into account.
ANP	The uncertainty makes the result unconvincing.	Elements do not need to be independent of one another. The answer can raise the amount of accuracy by improving the priority.
AHP	The final alternative score is significantly impacted by the weight assigned to each criterion. Subjective issues plagued the weighting evaluation.	Simple to use, users may tune the selection process and change the relative score for each selected criterion throughout the pairwise comparison.

3.1 Experimental Design

The study employs the MCDM approach to analyze and evaluate natural fibers for ceiling liner applications in the automotive industry. It uses the AHP methodology, comparing 13 natural fiber types based on mechanical and chemical criteria. The natural fibers' individual mechanical features are displayed in Table 4 [40]. The chemical features of general natural fibres are displayed in Table 5 [41].

Table 4. Mechanical features of fiber types

Code	Fiber type	Elastic modulus [GPa]	Tensile strength [MPa]	Elongation [%]	Density [g/cm^3]
F1	Pineapple	82.0	1627	2.4	1.56
F2	Abaca	33.6	815	1.5	1.50
F3	Sugarcane bagasse	6.2	350	7.9	1.60
F4	Ramie	130.0	1000	4.0	1.55
F5	Coir	7.0	593	40.0	1.60
F6	Bamboo	40.0	575	3.2	1.50
F7	Cotton	15.1	800	12.0	1.60
F8	Jute	81.0	850	3.3	1.50
F9	Banana	32.7	789	3.5	1.50
F10	Hemp	70.0	1735	4.0	1.60
F11	Flax	40.0	1600	12.0	1.60
F12	Sisal	55.0	700	2.1	1.50
F13	Kenaf	60.0	1191	4.3	1.50

Table 5. Chemical features of fiber types

Code	Fiber type	Silica (%)	Ash (%)	Waxes (%)	Pectin (%)	Hemicellulose (%)	Lignin (%)	Cellulose (%)
F1	Pineapple	–	0.9–4.7	3.3	1.1	80.7	4.4–10.1	57.5–74.3
F2	Abaca	–	1.0–3.2	0.1	0.3–1.0	15.0–17.0	7.0–13.0	56.0–63.0
F3	Sugarcane	0.7–3.5	1.5–5.0	–	–	27.0–32.0	19.0–24.0	32.0–48.0
F4	Ramie	–	5.0	0.3	1.9	5.0–16.7	0.6–0.7	68.0–91.0
F5	Coir	–	–	–	4.7–7.0	11.9–15.4	32.7-3.3	19.9–36.7
F6	Bamboo	0.7	1.7–5.0	–	0.37	12.5–73.3	10.2–31.0	26.0–73.8
F7	Cotton	–	0.8–2.0	0.6	0–5.7	1.0–5.7	0.7–28.2	82.7–90.0
F8	Jute	–	0.5–8.0	0.5	0.2–11.8	12.0–21.0	0.2–26.0	45.0–71.5
F9	Banana	–	2.1	3.0–5.0	2.1–4.1	10.2–15.9	14.4–1.6	48.0–60.0
F10	Hemp	–	0.5–8.0	0.2–0.8	0.9–3.0	12.0–22.4	2.6–13.0	55.0–80.2
F11	Flax	–	13.1	1.5–1.7	1.8–2.3	16.7–20.6	2.0–2.2	64.1–71.0
F12	Sisal	–	0.6–4.2	0.3–2.0	0.8–10.0	10.0–24.0	7.0–14.0	47.0–78.0
F13	Kenaf	–	2.0–5.1	0.5	3.0–8.9	18.0–24.0	8.0–21.0	31.0–57.0

The fibers were characterized by collecting data on their mechanical and chemical properties from prior studies. The properties were normalized to ensure comparability. Data for mechanical properties such as tensile strength and density were extracted directly, while chemical properties were assessed for their suitability in composite applications. Data for mechanical and chemical properties of the fibers were compiled from a comprehensive review of published literature. This included direct measurement values and derived properties relevant to automotive ceiling liners.

The Analytic Hierarchy Process (AHP) was applied for pairwise comparisons of criteria. Both chemical and mechanical criteria are used in an attempt to choose the most feasible natural fiber type for ceiling liner production. Mechanical criteria are subdivided into elastic modulus, tensile strength, elongation, and density properties of fiber types. Meanwhile, chemical criteria are subdivided into silica, ash, waxes, pectin, hemicellulose, lignin, and cellulose properties. The ability of the Analytic Hierarchy Process to evaluate multi-level decision criteria poses itself as an appropriate decision-making method. Figure 2 illustrates the hierarchy of criteria. As we build the decision-making hierarchy, we compare all the criteria that are taken into account.

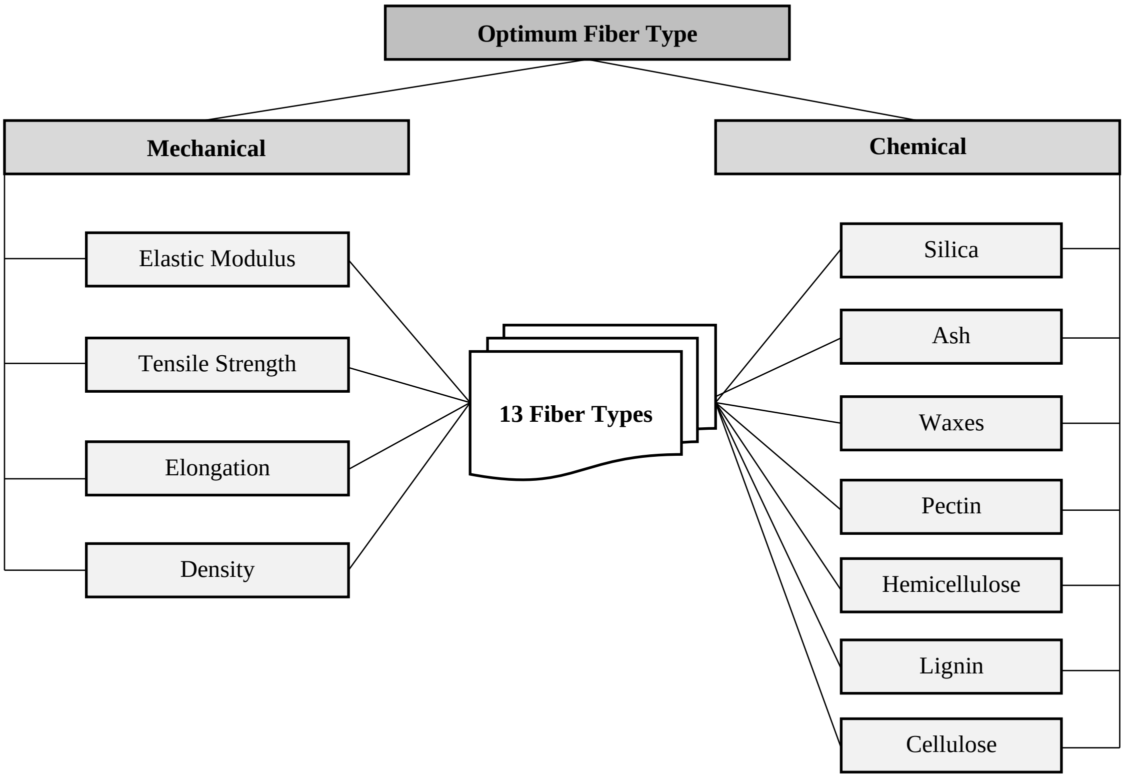

Figure 2. Decision hierarchy for fiber selection

Decision matrices were constructed for both mechanical and chemical properties. The properties were normalized and weighted, resulting in the weighted scores for each fiber type. The fibers were ranked based on their weighted scores to determine suitability. There were four levels of evaluation in this study, with the parent node of the primary criteria level at the top of the hierarchy, symbolized by the purpose of the research. Eleven primary criteria nodes, each of which was the parent node, were at the second level. There were thirteen natural fibers among the alternatives for ceiling liner production. Each of the parent nodes implies an order n x n decision matrix, where n is the child nodes' number. The methodology ensures reproducibility by standardizing criteria (mechanical and chemical properties), using normalized data for objective comparison, and applying a widely recognized decision-making method. The study's findings can be replicated by researchers following the same normalization and weighting process described.

3. RESULTS AND DISCUSSION

This section provides step-by-step results of the analysis. The first step involves a pairwise comparison of two main criteria, mechanical and chemical, which are rated equally important in the selection of the best natural fiber for ceiling liner production. In the next step, mechanical sub-criteria are compared in pairs, leading to the decision matrix provided in Table 6. Similarly, pairwise comparisons are made for chemical sub-criteria. Table 7 presents the resulting decision matrix.

Table 6. Mechanical comparison matrix

	Elastic modulus	Tensile strength	Elongation	Density
Elastic modulus	1	0.16	2	0.14
Tensile strength		1.00	7	1.00
Elongation			1	0.11
Density				1.00

Table 7. Chemical comparison matrix

	Silica (%)	Ash (%)	Waxes (%)	Pectin (%)	Hemicellulose (%)	Lignin (%)	Cellulose (%)
Silica (%)	1	2	0.11	0.20	0.14	0.16	0.20
Ash (%)		1	0.11	0.25	0.35	0.5	0.33
Waxes (%)			1.00	5.00	2.00	7.00	9.00
Pectin (%)				1.00	0.33	0.5	0.50
Hemicellulose (%)					1.00	5.00	9.00
Lignin (%)						1.00	2.00
Cellulose (%)							1.00

The decision matrices provided in Table 5 and Table 6 result in the relative weights below for the chosen criteria, as they are presented in Figure 3.

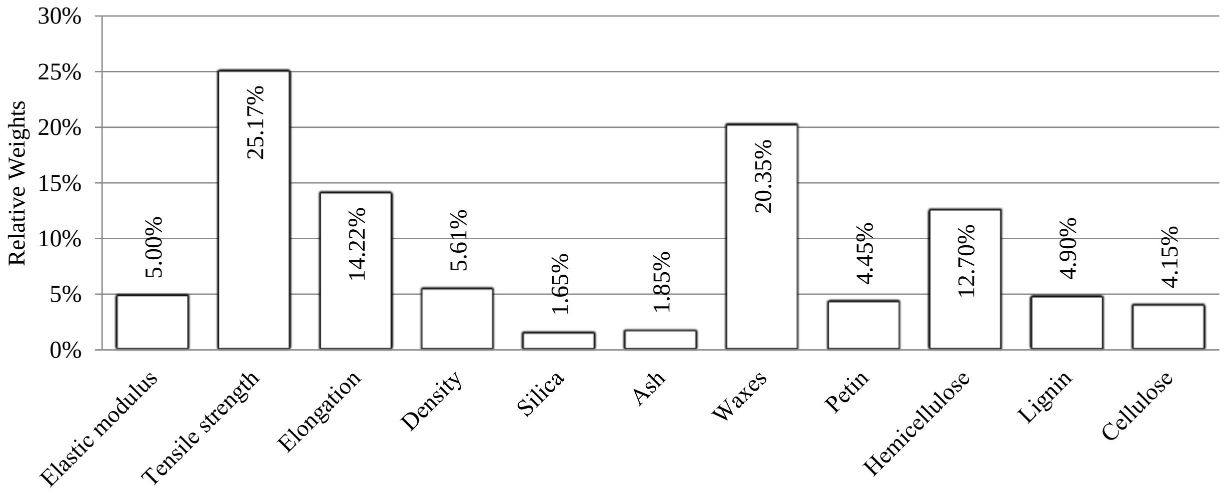

Figure 3. Relative weights of mechanical and chemical criteria

The priority weights illustrated in the figure highlight the significance of various selection criteria for evaluating natural fibers as ceiling liners in the automotive industry. As the figure displays, tensile strength has the greatest effect on the attractiveness of a fiber type for ceiling liner production. This priority indicates that the ability to withstand tension is a key determinant for material selection in automotive applications. Waxes are the second-highest priority, suggesting their significant influence on fiber processing and properties like water resistance and adhesion in composites. This importance reflects the need for fibers that can maintain structural integrity under varying environmental conditions. Elongation, the ability of a fiber to stretch without breaking, is the third most important factor. Its weight reflects the need for flexibility in ceiling liners, ensuring they can adapt to design constraints and impact forces. Hemicellulose contributes to the structural integrity and thermal properties of the fibers, which are important for high-performance applications in vehicles. Elastic modulus, a measure of stiffness, has a moderate weight, reflecting its importance in balancing flexibility and rigidity in the material. Density's contribution highlights its role in reducing vehicle weight for improved fuel efficiency while maintaining adequate strength. Lignin's weight suggests its importance in enhancing mechanical strength and resistance to environmental degradation. The moderate weight of cellulose indicates its essential role in defining the mechanical and physical characteristics of the fibers. The relatively low weight of pectin shows its minor yet important role in the binding properties of the fibers. These criteria have the lowest weights, reflecting their limited impact on the overall performance, but are still relevant for specific applications such as thermal resistance and processing behavior.

Since the values of diverse characteristics utilized in Table 4 and Table 5 have a wide range of scales, these values require to be normalized for comparison purposes. Normalized values in Table 8 are computed utilizing Formula 1:

$$n_{ij} = x_{ij} \,/ \sum\nolimits_{j=1} x_j \; for \; \forall i = 1,\dots,m \tag{1}$$

where $x_{ij} = value\ of\ j^{th} fibre\ for\ the\ i^{th} criterion$ and $n_{ij} = value\ of\ j^{th} fibre\ for\ the\ i^{th} criterion$

Table 8. Normalized values

	Pineapple	Abaca	Sugarcane bagasse	Ramie	Coir	Bamboo	Cotton	Jute	Banana	Hemp	Flax	Sisal	Kenaf
Elastic modulus	0,126	0,051	0,010	0,199	0,011	0,061	0,023	0,124	0,050	0,107	0,061	0,084	0,092
Tensile strength	0,129	0,065	0,028	0,079	0,047	0,046	0,063	0,067	0,062	0,137	0,127	0,055	0,094
Elongation	0,024	0,015	0,079	0,040	0,399	0,032	0,120	0,033	0,035	0,040	0,120	0,021	0,043
Density	0,078	0,075	0,080	0,077	0,080	0,075	0,080	0,075	0,075	0,080	0,080	0,075	0,075
Silica	0,077	0,077	0,077	0,077	0,077	0,077	0,077	0,077	0,077	0,077	0,077	0,077	0,077
Ash	0,054	0,041	0,063	0,097	0,077	0,064	0,027	0,083	0,041	0,083	0,255	0,047	0,069
Waxes	0,202	0,006	0,077	0,018	0,077	0,077	0,037	0,031	0,245	0,031	0,098	0,070	0,031
Petin	0,027	0,016	0,077	0,047	0,143	0,009	0,070	0,149	0,076	0,048	0,062	0,132	0,144
Hemicellulose	0,264	0,052	0,096	0,035	0,044	0,160	0,010	0,054	0,042	0,056	0,061	0,056	0,069
Lignin	0,043	0,056	0,126	0,004	0,192	0,119	0,087	0,077	0,084	0,053	0,012	0,061	0,085
Cellulose	0,087	0,078	0,052	0,104	0,037	0,066	0,113	0,076	0,071	0,088	0,088	0,083	0,058

To determine how much each criterion contributes to the overall attractiveness of each fiber type, the values in Table 8 should be multiplied by the proportional weight of each criterion. These normalized values above are multiplied by the relative weights of each criterion given in Figure 3, using Formula 2 to produce the weighted scores of the alternatives shown in Table 9:

$$y_{ij} = n_{ij} * w_i \; for \; \forall j = 1, \dots, n \tag{2}$$

where $y_{ij} = weighted\ value\ of\ j^{th} fibre\ for\ the\ i^{th} criterion$ and $w_i = weight\ of\ i^{th} criterion$

Table 9. Weighted scores of fiber types

	Pineapple	Abaca	Sugarcane bagasse	Ramie	Coir	Bamboo	Cotton	Jute	Banana	Hemp	Flax	Sisal	Kenaf
Elastic modulus	0,0063	0,0026	0,0005	0,0100	0,0005	0,0031	0,0012	0,0062	0,0025	0,0054	0,0031	0,0042	0,0046
Tensile strength	0,0324	0,0162	0,0070	0,0199	0,0118	0,0115	0,0159	0,0169	0,0157	0,0346	0,0319	0,0140	0,0237
Elongation	0,0034	0,0021	0,0112	0,0057	0,0568	0,0045	0,0170	0,0047	0,0050	0,0057	0,0170	0,0030	0,0061
Density	0,0044	0,0042	0,0045	0,0043	0,0045	0,0042	0,0045	0,0042	0,0042	0,0045	0,0045	0,0042	0,0042
Silica	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013	0,0013
Ash	0,0010	0,0008	0,0012	0,0018	0,0014	0,0012	0,0005	0,0015	0,0008	0,0015	0,0047	0,0009	0,0013
Waxes	0,0411	0,0012	0,0157	0,0037	0,0157	0,0157	0,0075	0,0062	0,0498	0,0062	0,0199	0,0143	0,0062
Petin	0,0012	0,0007	0,0034	0,0021	0,0064	0,0004	0,0031	0,0066	0,0034	0,0021	0,0028	0,0059	0,0064
Hemicellulose	0,0335	0,0066	0,0122	0,0045	0,0056	0,0203	0,0012	0,0068	0,0054	0,0071	0,0078	0,0071	0,0087
Lignin	0,0021	0,0027	0,0062	0,0002	0,0094	0,0058	0,0042	0,0038	0,0041	0,0026	0,0006	0,0030	0,0042
Cellulose	0,0036	0,0032	0,0022	0,0043	0,0015	0,0027	0,0047	0,0032	0,0029	0,0037	0,0037	0,0034	0,0024
Total	0,0838	0,0065	0,0046	-0,0014	-0,0487	0,0243	-0,0118	-0,0014	0,0468	0,0212	0,0220	0,0095	0,0083

The analysis demonstrated that natural fibers such as jute and hemp outperform synthetic materials in terms of tensile strength. These properties are crucial for ceiling liners as they must withstand vibrations, pressure variations, and potential impacts during vehicle use. The superior mechanical performance of certain natural fibers reinforces their suitability for automotive applications, especially in terms of ensuring passenger safety and durability. However, some natural fibers, like abaca and sisal, scored lower on parameters such as elongation at break, which could affect their ability to absorb energy under stress. These findings indicate that while natural fibers are promising, they may require treatment or blending with synthetic reinforcements to optimize their mechanical characteristics.

Natural fibers excelled in lightweight characteristics, a critical factor in automotive design aimed at improving fuel efficiency and reducing carbon emissions. Jute and flax, in particular, showed optimal density-to-strength ratios, making them ideal candidates for ceiling liner applications. The low thermal conductivity of these fibers also contributes to better cabin insulation, enhancing passenger comfort. However, the study identified variability in fiber dimensions and quality as a challenge. This variability underscores the need for standardized processing techniques to ensure consistency in physical properties, particularly for large-scale industrial applications.

The comparison of fiber alternatives based on the selected criteria and their relative weights is shown in Figure 4 below.

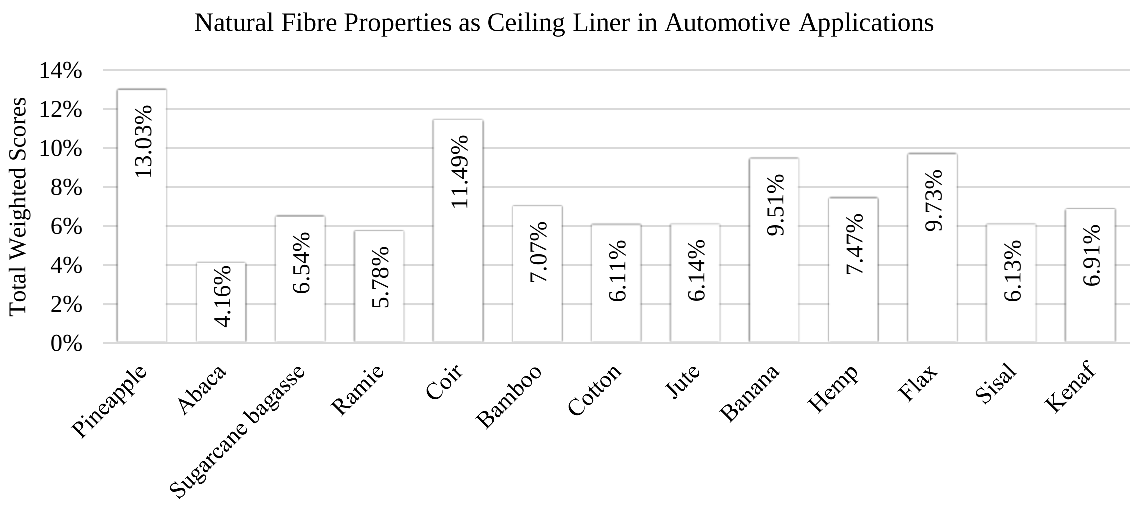

Figure 4. Comparative results of fiber types

The results of the MCDM analysis of natural fibers as ceiling liners in the automotive industry reveal significant insights into their suitability based on mechanical, chemical, physical, and environmental factors. This discussion highlights the implications of these findings, their alignment with industry needs, and potential areas for further research.

The growing need and popularity of environmentally friendly natural resources has led to a significant shift in the automotive sector. For some time now, the automotive industry has been using more and more natural fiber bio-composites. The fibers with excellent tensile strength, such as carbon, glass fiber, kevlar, etc., are very expensive to produce and difficult to recycle. Therefore, the growing demand for natural fiber composites is parallel to the negative environmental impact of artificial materials and the increasing cost of these man-made materials.

4. CONCLUSION

This research presents a comprehensive analysis using a multi-criteria decision-making method to evaluate a number of natural fibers for their suitability as ceiling liners in the automotive industry. The findings revealed that pineapple and coir fibers, with weighted priority scores of 0.1383 and 0.1149, respectively, are the most promising alternatives due to their superior mechanical and chemical properties. These results align with the research objective of identifying optimal materials for sustainable and efficient automotive applications. The study contributes significantly to the field by providing a structured decision-making framework for selecting natural fibers based on a combination of mechanical and chemical criteria. This approach enhances the understanding of the material properties required for specific applications in the automotive sector and offers a replicable methodology for future studies. Meanwhile, the practical implications of this research are substantial. By integrating natural fibers into automotive manufacturing, manufacturers can achieve lighter, more fuel-efficient vehicles with improved recyclability and reduced environmental impact. Additionally, the superior tensile strength and density-to-strength ratios of the identified fibers contribute to enhanced passenger safety and durability. Consequently, this paper emphasizes more critical characteristics that designers have to consider concerning the selection of natural fiber materials and their elements for better efficiency in their designs. Also, it applies several pair-wise comparisons among various fiber types concerning attributes to accentuate the requirement for better natural fiber assessments for ceiling liner production.

However, the study also acknowledges limitations. Variability in natural fiber quality and dimensions poses challenges for large-scale industrial applications. Furthermore, while AHP is a robust method, its reliance on criteria weights may introduce bias. Future research should explore hybrid composites that combine natural and synthetic fibers to optimize performance and address these challenges. Additional investigations into standardized processing techniques and broader criteria, such as cost-effectiveness and lifecycle assessment, are also recommended. Further comparisons between the elements of natural fiber (matrices and fillers) are still needed in comprehensive ways concerning combined and integrated criteria and factors that may affect their selection in different applications to be concluded with proper stability, illuminating selection descriptions regarding the natural fibers' capabilities. This would enhance the stability and clarity of fiber selection for various applications. Studies should also explore specific design attributes and limitations in relation to natural fibers, enabling designers to make more informed decisions for efficiency in their applications. It is also critical to focus on evaluating additional critical characteristics necessary for the selection and efficient use of natural fiber materials in automotive applications.

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CONFLICT OF INTEREST

We wish to confirm that there are no known conflicts of interest associated with this publication.

AUTHORS CONTRIBUTION

Figen Balo: Conceptualization, Investigation, Writing- Original draft preparation

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