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Article

Potential Utilization of Rice Waste in the Construction Sector: A Multi-Criteria Decision Analysis Approach

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Abstract: Effective management of agricultural waste is an important contribution to environmental sustainability and economic development, especially considering the significant volume of agricultural residues produced worldwide. Rice is a widely cultivated crop in Colombia, and its high production results in a high amount of wastes, which is often underutilized due to a lack of knowledge regarding its potential value-added applications. On the other hand, the construction industry has become increasingly aware of the necessity to develop materials with reduced environmental impact. Therefore, this study explores the application of the Analytic Hierarchy Process (AHP) to evaluate various alternatives for utilizing rice waste in construction materials; the alternatives were evaluated based on criteria tailored to the needs of local agricultural communities in the Tolima region of Colombia. The findings highlight the potential of rice husk ash (RHA) as an environmentally responsible alternative in the construction sector, offering a viable solution for waste management while contributing to the economic development of small-scale farmers.

Keywords: rice waste valorization; analytic hierarchy process (AHP); sustainable construction

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1. Introduction

Colombia, as identified by the United Nations Food and Agriculture Organization (FAO), stands out as a nation with immense potential in agricultural production, and it is also positioned as one of the key countries poised to become a significant contributor to global food supply [1,2]. Historically, Colombia's agricultural Gross Domestic Product (GDP) has been primarily composed of six major products: flowers, bananas, coffee, sugar, rice, and potatoes.

Rice cultivation is a critical agricultural activity in Colombia, significantly contributing to the country's food security and rural livelihoods. It is one of the primary staples in the Colombian diet [3,4], providing essential nutrients to millions of people. The rice industry also supports thousands of smallholder farmers, enhancing their income and quality of life. The importance of rice as a staple highlights the need to continue improving the rice industry's efficiency [5].

The Tolima region plays a significant role in Colombia's agricultural economy, with rice, coffee, and cacao being its primary crops. The region benefits from diverse thermal floors, which allow for the cultivation of a variety of agricultural products. Tolima is one of the country's top rice producers, contributing significantly to both local and national food security. Despite its strong agricultural base, the region faces economic challenges related to technological development and access to markets, which limit the added value of its agricultural products [6].

Rice husks, which are the outer coverings of the grains, can be utilized as a biomass fuel, soil conditioner, or in the production of building materials. Rice bran, the layer between the husk and the grain, is rich in nutrients and is commonly used in animal feed and for extracting rice bran oil. Additionally, rice straw, the stalks left after harvesting, can be used for livestock bedding, mushroom cultivation, and as a raw material for paper production [7–11].

Recent research has highlighted the potential of various agricultural wastes as sustainable materials in construction. Sugarcane bagasse ash, for instance, has been studied for its ability to enhance the properties of concrete, such as reducing permeability and increasing durability, as demonstrated by Sobuz et al. (2024) [12]. Coconut shell, another widely available agricultural byproduct, has been used to develop lightweight aggregates for concrete, contributing to improved thermal insulation and reduced structural weight [13,14]. Corn cob ash has also been explored as a partial replacement for cement, offering environmental benefits and maintaining adequate mechanical strength in concrete applications [15,16]. Additionally, banana fibers have been used to reinforce concrete, showing enhanced tensile strength and crack resistance [17]. These studies underscore the versatility and sustainability of agricultural waste in developing construction materials, contributing to waste reduction and promoting greener building practices.

Regarding rice waste, there are studies that show its applications in the development of construction materials. This is driven by the construction sector's urgent need to create materials that have a reduced environmental impact. Consequently, various studies have focused on developing construction materials using different types of waste. For example, several researchers have evaluated the potential of using recycled plastic in construction materials [18–22], while others have investigated the use of biomass to reinforce cement-based materials [23–27]. Although research has been conducted on the incorporation of different types of waste into construction materials, the large amount of waste generated in the rice value chain, including straw, husk, and bran, has traditionally been underutilized, with most of this waste being reincorporated into the soil or discarded without significant added value [2].

The need to utilize these wastes and the growing demand in the construction industry for more sustainable materials that reduce environmental impact without compromising the mechanical properties required for common applications is a priority. Using rice waste not only helps to minimize the ecological footprint of the construction sector but also provides a solution for managing agricultural residues that would otherwise contribute to environmental degradation. Internationally, previous research has highlighted the potential of biomass in enhancing construction materials, such as the use of rice husk ash in the production of concrete and mortar [28,29]. However, these studies have primarily focused on different regions or contexts, without addressing the specific needs of rice producers in Colombia, where technological resources and infrastructure often differ significantly from those in more industrialized countries.

The lack of studies that consider key local criteria for rice producers—such as ease of implementation, costs associated with waste pretreatment, and the marketability of the resulting products—necessitates the use of prioritization techniques to determine the best applications for rice waste

The use and potential of rice waste depend heavily on the specific community, necessitating an evaluation of multiple factors to determine the most effective utilization. These factors include economic viability, environmental sustainability, and social acceptance. Multi-criteria analysis methods, such as the Analytic Hierarchy Process (AHP), are effective tools in this context. AHP is a structured and logical method designed to optimize complex decision-making by breaking down the problem into a hierarchical structure [30]. Its strength lies in its ability to handle both tangible and intangible criteria within a coherent framework.

In the agricultural sector, AHP has been widely employed to prioritize alternatives based on specific challenges, thereby making the decision-making process more balanced and informed. For instance, Mardani et al. (2015) applied AHP to assess sustainable agriculture practices, highlighting its effectiveness in weighing environmental, economic, and social criteria [31]. Similarly, Zhang et al. (2017) used AHP to identify the best practices for integrated pest management, balancing ecological benefits and cost-effectiveness through expert opinions [32]. Another study by Kumar et al. (2020) utilized AHP to prioritize water conservation strategies in irrigation, demonstrating how this method can enhance resource efficiency [33]. Additionally, Tovar-Perilla et al. (2018) employed AHP to determine the optimal distribution of resources for improving the agricultural sector [34], and Salazar-Camacho et al. (2024) used AHP to find alternatives for cocoa wastes [35].

In this study, rice chain residues were analyzed to explore alternatives for developing construction materials. These alternatives were evaluated using the AHP method, based on criteria defined by the region's specific needs.

2. Materials and Methods

2.1. Exploration of Current Rice Waste Uses

To understand the current uses of rice waste in the central region of Colombia, a survey-based methodology was employed. Surveys were designed to gather information directly from local farmers involved in rice production; they were crafted to cover topics related to the uses of rice waste. It included both quantitative and qualitative questions, and questions were structured to explore areas such as current practices in rice waste management, uses of rice waste, barriers to recycling or repurposing these materials, and potential economic and environmental benefits.

2.2. Analytic Hierarchy Process Methodology

This research utilizes the Analytic Hierarchy Process (AHP) as a systematic approach to organize and analyze potential applications of rice waste in the development of construction materials, ensuring an evaluation of alternatives. For developing the method, the following steps were carried out.

Overview of the Problem: The initial phase of the study involved organizing the decision-making problem into a coherent hierarchy of interconnected elements. Beginning with the primary objective at the apex—utilizing rice waste in construction materials—the process involved identifying various criteria and sub-criteria, specifically tailored to the context of local farmers with the aim of delineating a list of viable alternatives.

Search for alternatives: Through a process of gathering and researching internal and external information, such as technological surveillance (TS), an exploration of alternatives for the utilization of waste produced by the rice agro-chain was developed. Taking into account the UNE 166006 standard from 2006 [36], the methodology of [37], and the surveillance model proposed by [38], a model and a methodology for the current technological surveillance were adapted. Figure 1 shows the technological surveillance method carried out in this study.

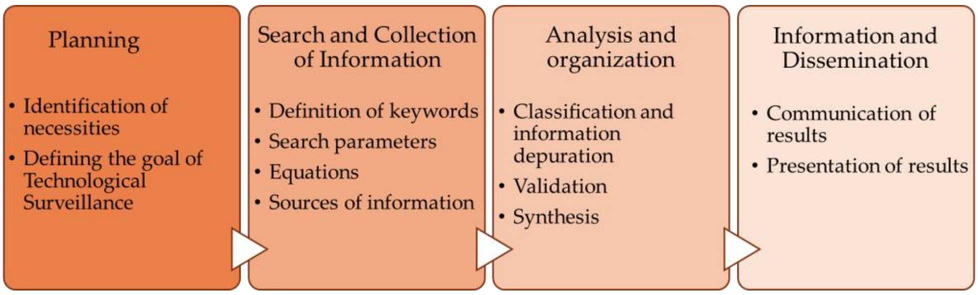

Figure 1. Technological surveillance process for identifying alternatives for rice waste in construction materials.

The studies, articles, papers, and data gathered from the previous phase were collected, ensuring that the information contributed to the objective of technological surveillance (TS). This validation facilitated the subsequent classification and synthesis of the resultant studies. Upon obtaining the results of the technological surveillance, a preliminary selection process was conducted to narrow down the options to a maximum of five alternatives for the final decision-making. This preselection process involved considering the context of rice producers, the feasibility of each alternative, and the elimination of any redundant options.

Modeling: At this phase, criteria were established for evaluating the alternatives identified through technological surveillance (TS). These criteria were defined to reflect the priorities of rice producers in Tolima, focusing on the aspects they deem most crucial when selecting an alternative use for their products. A total of five criteria were determined, ensuring they aligned with the specific needs and considerations of the local agricultural context.

Constructing Pairwise Comparison Matrices: For each level in the hierarchy, pairwise comparison matrices were constructed. In these matrices, the selected alternatives were evaluated against each other, two at a time, with respect to their impact on an element above them in the hierarchy. To construct the comparison matrix for the criteria, we utilized the expertise of specialists who assessed these criteria using the Saaty scale. Additionally, to evaluate each alternative against the established criteria, secondary information was employed. Experts assigned weights to elements by answering how much more important or preferable one criterion was over another. The AHP scaled these judgments to derive numerical values, which were then used to calculate the relative weights of the elements. A consistency ratio was calculated to ensure the consistency of the judgments. If the consistency ratio exceeded a certain threshold (usually 0.1), the evaluation process was revisited to correct for inconsistencies.

In the revision, the pairwise comparison judgments could be adjusted to identify which comparisons were contributing most to the inconsistency. This process involved slightly modifying the values in the inconsistent judgments and recalculating the CR to observe its impact on overall consistency. If the CR improved, the revised judgments could be retained.

Final decision: The relative weights were combined across the entire hierarchy through a process of weighted synthesis. This involved multiplying the weights of the elements at each level of the hierarchy by the weights of their respective parent elements, and then summing these for each alternative. The alternative with the highest overall score was considered the best option. However, the decision-making process also involved a qualitative analysis of the results, ensuring that the numerical outcome aligned with a logical and justifiable decision.

3. Results

3.1. Exploration of Currect Rice Wastes Uses

The survey commenced with an initial section dedicated to collecting personal information, comprising three identification questions aimed at the respondents. These questions were designed to ascertain the name, position, and the specific municipality where the respondent's farm or mill is situated. Participants represent various companies within the rice production industry and are located in the Department of Tolima, with 67% based in Ibagué and its surrounding areas and 33% from municipalities near the capital of Tolima.

Following the identification of the respondents, the survey proceeded to the first section titled "Resources", which consisted of sixteen questions. The initial question aimed to ascertain the total area of the farm in hectares (ha), identifying the range within which the farm's total land area fell. The subsequent question focused on the total area cultivated with rice in hectares (ha), determining the range of the cultivated area based on the land size specified in the preceding question. These ranges were established based on a scale reflecting the approximate hectares owned by small-, medium-, and large-scale producers.

From these questions, it became clear that the respondents were categorized into two distinct ranges. A significant majority, 83%, own land exceeding 20.1 hectares in total area—including those situated in Ibagué, its plateau, and Alvarado—designated for rice cultivation. Conversely, a smaller portion, 17%, located in the municipality of Piedras, falls within the 2 to 5 hectares range for both total land area and area cultivated with rice.

Progressing through the survey, the fourth question addressed the stages of rice production conducted on the respondents' farms. A substantial 83% of participants reported engaging in planting, harvesting, and transporting the rice to the collection center. Additionally, half of the respondents, 50%, extend their activities to include the polishing process, necessitating several stages before delivering a finished product. Meanwhile, a minority of 17%, represented by a single respondent, completes the final step, concluding the entire productive cycle.

In response to the queries regarding marketing strategies and annual sales volumes in kilograms (kg) or tons (ton), the survey identified two main products marketed by the participants. Green paddy rice, with volumes ranging from 1000 to 10,000 tons per year, is the most commonly sold product, representing 50% of the respondents. The remaining respondents focus on white rice, distributed through two distinct channels: 33% sell it in bulk, amounting to approximately 5000 tons annually, while 17% market around 2000 tons per year as a finished and packaged product.

Rice harvesting generates several valuable by-products. These by-products enhance the sustainability of rice farming. The respondents were asked about these by-products and the uses they assign to them. One of the identified wastes was rice straw. The vast majority of respondents were unaware of the amount produced. The main reason for not quantifying it is due to its disposal method; they reincorporate it into the soil to utilize it as fertilizer. Only two respondents provided estimates of rice straw production, reporting 50 tons per year and between 10 and 12 tons per hectare, respectively. Other uses for this residue were also identified, including its sale or combining the straw with other products like molasses and urea to serve as livestock feed on farms.

In the drying/dehusking process, considered as two phases in one, the grain is initially dried to reduce its moisture content and then the husk is removed. This husk represents the residue generated at this stage of the rice production process. It is one of the main residues of this cereal and is produced in large quantities. According to the respondents' answers, 50% carry out this process and quantify the residue, reporting annual amounts of 1000, 1050, and 1900 tons, respectively. Additionally, 33% sell this residue, while 17% repurpose it within their production process, transforming it from a waste product into fuel for boilers or other equipment.

Concerning rice wastes, two questions were defined: "Do you know of any other uses for the process residues that you do not implement? Please specify the residue and its use" and "If you know of any use for the residues generated in the process that you do not implement, why do you not implement it?". It was identified that the majority of respondents (83%) are unaware of any uses for the residues generated in rice production. The remaining 17% mentioned an additional use for rice straw related to mushroom production; however, this waste use is not practiced. Finally, regarding the residues, most respondents agree that the husk is the residue that generates the most environmental impact due to the large quantities produced and the lack of knowledge about possible available uses.

3.2. Analytic Hierarchy Process Methodology

Search for alternatives

During the planning phase and based on an assessment of the current uses of rice waste, it was identified that there is a need to explore alternatives for producing construction materials from rice by-products.

To obtain the information, the following key words were used "Rice husk", "Rice husk ashes", "Rice bran", "Recycling", "Cement", "Agricultural waste", "Sustainable", "Construction", "Ecomaterial", "Tamo de arroz", "Cascarilla de arroz", "Ceniza de cascarilla de arroz", "Salvado de arroz", "Reciclaje", "Concreto", "Residuos agrícolas", "Sostenibilidad", "Construcción" and "Ecomaterial". With those words, four searching equations were generated (Table 1).

Table 1. Keywords and searching equations for technological surveillance.

Key Words	Searching Equations
Rice, subproducts, waste	("rice") AND (subproduc* OR waste*)
Rice straw, construction, concrete, ecomaterial	("rice straw") AND (construction OR concrete OR ecomaterial) NOT (food OR animals)
Rice husk, rice husk ashes, concrete, cement	concrete, cement ("rice") AND (husk* OR husk ash*) AND (construction OR concrete)
Sustainable cement, rice husk, rice husk ashes	(sustainable cement) AND (rice husk OR rice husk ash* OR rice waste*)

The equations were applied in academic databases, considering studies in Spanish, English, and Portuguese that demonstrated the application of rice by-products in construction materials. This referenced information was limited to studies published within the last 10 years.

Alternative of construction materials with rice chain subproducts

After applying the search equations and defining the parameters, a total of 40 results were obtained. Among these results, only two subproducts were identified: rice straw and rice husk. Both subproducts yielded results in two different presentations. Forty construction materials were identified through this technological surveillance; Table 2 summarizes the information gathered through technological surveillance on the uses of rice waste in construction materials.

Table 2. Information of technological surveillance on the uses of rice waste in construction materials.

Rice Waste	Construction Material	References
RH and RHA	Concrete	[28,29,38–56]
RH, RSA and RHA	Mortar	[41,57–63]
RH and RS	Panels	[64–71]
RSA	Ceramic material	[70,71]
RS and RHA	Pavers	[10,72,73]

RHA—rice husk ash; RSA—rice straw ash; RS—rice straw; RH—rice husk.

Criteria definitions

The criteria were determined considering the economic, technical, and environmental capabilities of the rice producers in the region, as well as characteristics present in technological surveillance. With this information, the following four criteria were defined:

Ease of implementation: This criterion assesses the cost and availability of materials, tools, and machinery required to produce construction materials with rice husk ash. The implementation costs were defined from the previous studies.

Pretreatments for Raw Material: this criterion evaluates the processes needed to prepare rice husk ash for use in construction, based on a review of methodologies from prior studies.

Reproducibility of studies: this criterion assesses how many alternatives have been successfully produced and documented in other studies.

Marketability: this criterion is proposed with the objective of identifying the alternative that may present the greatest supply/demand in the construction materials market.

Based on the previous information regarding the alternatives and evaluation criteria, the decision tree for the problem was created and is presented in Figure 2.

Constructing Pairwise Comparison Matrices

The criteria weight assignment process in the AHP analysis was based on the Saaty scale. To evaluate the criteria analyzed, the data were derived from the literature review and secondary sources. From the studies presented in Table 2, data on associated costs and the required pre-treatments for raw materials were extracted and analyzed. This allowed for a comprehensive evaluation of the economic and technical factors involved in implementing RHA-based construction solutions. Alternatives with higher associated costs were assigned lower weights, as they were deemed less feasible for practical implementation. Similarly, materials requiring extensive pre-treatment processes were given lower weights due to the added complexity and resource demands. Additionally, the reproducibility of studies criterion was also informed by the literature review. The more studies available that successfully utilized rice husk ash (RHA) to produce construction materials, the higher the weight assigned to this criterion.

Finally, the criterion marketability was based on secondary data regarding sales in the construction market in Colombia, sourced from the web portal "contratistas.co", a community of construction contractors in Latin America.

Overall, this approach ensured that the weighting of each criterion accurately reflected the balance between feasibility, cost, technical requirements, research support, and market potential. Based on the comparison between criteria, "waste pretreatment" was identified as the most important criterion, holding a 51% weight in the evaluation of alternatives (Table 3).

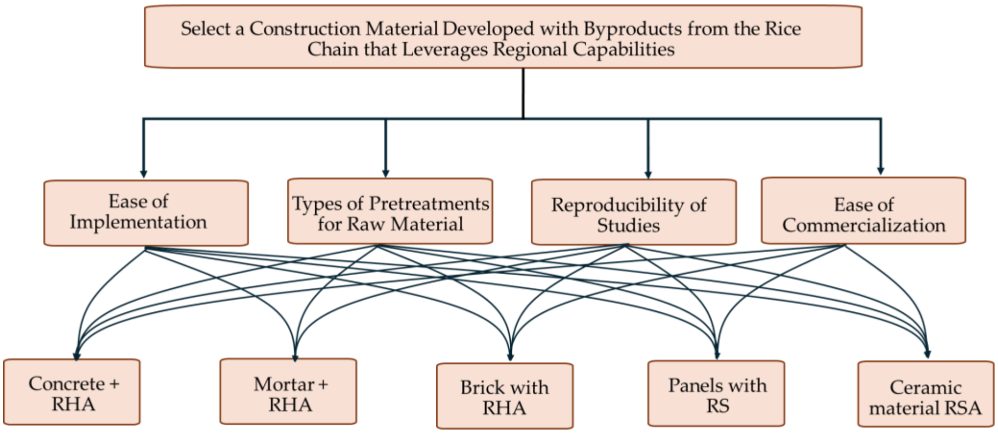

Figure 2. Analytical Hierarchy Process for selecting construction material. RHA—rice husk ash; RSA—rice straw ash; RS—rice straw; RH—rice husk.

Table 3. Comparison matrix of established criteria.

Criteria	Ease of Implementation	Types of Pretreatments	Reproducibility of Studies	Ease of Marketing
Ease of implementation	1	0.14	7	3
Types of Pretreatments	7	1	7	7
Reproducibility of studies	0.14	0.14	1	0.14
Ease of marketing	0.33	0.14	7	1

The weight for each criterion and the average weight value/priority vector are determined using the criteria weights (Table 4).

Table 4. Table weight by criterion and priority vector of the AHP model.

Criteria	Weight Criterion	Weight Criterion/Priority Vector
Ease of implementation	0.26	4.462
Types of Pretreatments	0.51	7.697
Reproducibility of studies	0.03	5.162
Ease of marketing	0.20	2.989
Average		5.07

The evaluation of the alternatives in each criterion was conducted by three specialists: one of them in civil engineering, one in sustainable construction materials and one in agricultural value chain design. The experts were selected based on their experience in construction, the use of sustainable materials, and the local context of the Tolima region. Each expert participated in structured interviews where they were asked to make pairwise comparisons of the criteria using the Saaty scale. To consolidate the judgments provided by the three experts, we applied the geometric mean to combine their pairwise comparisons into a single decision matrix. Each expert independently provided their evaluations using the Saaty scale, comparing the relative importance of the criteria.

After evaluating the criteria and the alternatives for each criterion, a consistency analysis was performed to verify that the scores assigned in the pairwise comparison matrices were appropriate and that their calculated value was less than or equal to 0.1, indicating a consistency ratio of 10%. The λmax represents the eigenvalue of the matrix and was calculated for each criterion to determine the consistency index (*CI*).

$$CI = \frac{\lambda \max - n}{n - 1}$$

where n is the number of criteria.

Then, the consistency ratio (*CR*) is determined by

$$CR = \frac{CI}{RI}$$

where the random index (*RI*) is 1.12 due to the size of the matrices of order 5 [30]. Table 5 shows the consistency analysis of each alternative for each criterion.

Table 5. Consistency index analysis of the evaluation of alternatives for each criterion.

	λmax	CI	CR
Criteria	5.08	0.019	0.02
Ease of implementation	5.05	0.013	0.01
Types of Pretreatments	5.23	0.057	0.05
Reproducibility of studies	5.31	0.077	0.07
Ease of marketing	5.09	0.023	0.02

After completing the individual pairwise comparison matrices and verifying that the consistency ratio was below 0.1, we proceeded to calculate the weighted scores for the alternatives based on the selection criteria. The geometric mean was applied to each corresponding entry in the matrices to combine the expert judgments into a single comparison matrix (Table 6). This method was selected because it maintains the consistency and proportionality of the experts' evaluations, ensuring that no single expert's opinion disproportionately influenced the final matrix.

Table 6. Final hierarchy matrix of alternatives and criteria for selecting a construction material using rice chain waste.

	Concrete	Mortar	Bricks	Panels	Ceramic
Ease of implementation	0.037	0.067	0.478	0.154	0.154
Types of Pretreatments	0.087	0.144	0.476	0.048	0.048
Reproducibility of studies	0.494	0.288	0.037	0.086	0.086
Ease of marketing	0.407	0.275	0.200	0.040	0.040
Results	0.15	0.15	**0.41**	0.07	0.21

According to the results in Table 6, the criteria "ease of implementation of the alternative" and "waste pretreatment (raw material)" revealed, through their comparison matrix, that cement bricks with rice ash were the best-rated alternative. This is because their implementation involves the lowest costs for machinery and other raw materials and has a short production process. Additionally, the husk ash is incorporated into the cement for brick formation, requiring only a single combustion process.

On the other hand, the criteria "reproducibility of studies" and "ease of marketing", through their respective comparison matrices, identified concrete with rice husk ash as the best-rated alternative. This is due to the numerous references of studies that manufacture this construction material with rice husk ash. Additionally, according to secondary sources, "cement and concrete" are the most widely used and, therefore, the most marketed materials in the construction industry in Colombia [74].

According to the results presented in Table 6, the brick with rice husk ash (RHA) alternative was the highest rated, achieving an overall score of 0.41, primarily due to its strong performance in the "ease of implementation" and "types of pretreatment" criteria. This alternative stands out for its low production costs and simple manufacturing process. On the other hand, concrete with RHA also performed well, with a score of 0.21, due to the reproducibility of studies and ease of commercialization. In contrast, other alternatives, such as panels and ceramic materials, scored lower due to their limited implementation and market potential in the regional context.

The use of rice husk ash (RHA) as a construction material offers significant environmental benefits, primarily by reducing waste and lowering the carbon footprint associated with conventional building materials. Its utilization in construction could prevent it from being disposed of in landfills. Furthermore, RHA's high silica content makes it an effective supplementary cementitious material, reducing the need for Portland cement production, which is responsible for approximately 7–8% of global CO_2 emissions [75,76]. By partially replacing cement with RHA, the overall energy consumption in construction can be lowered, as cement production is highly energy-intensive. Moreover, incorporating RHA reduces the consumption of natural resources like limestone and clay, contributing to the preservation of these raw materials. The use of RHA as a construction material aligns with the principles of the circular economy by turning agricultural waste into a new resource, promoting both environmental sustainability and economic efficiency.

3.3. Performance of Pavers with Rice Husk Ash

Based on the results of the AHP method, cement bricks with rice husk ash were manufactured to evaluate the potential of this waste in construction materials. The manufacturing process began with the weighing of each component and the sieving of the sand to ensure adequate fineness. Subsequently, the sand, cement, and calcined rice husk were mixed homogeneously, with the calculated amount of water added (see Table 7). During molding, diesel oil (ACPM) was applied to the wooden molds to prevent the pavers from sticking. The mixture was poured into the molds in three layers, with each layer compacted 25 times using a metal rod and a rubber mallet to minimize air content. After two days, the pavers were demolded and cured in water according to the NSR 10 guidelines.

Table 7. Values of cement mix compounds for pavers.

% RHA	Cement [kg]	Sand [m^3]	Water [L]	RHA [kg]
20	2.62	0.01	1.80	0.65
25	2.45	0.01	1.80	0.82
30	2.29	0.01	1.80	0.98

To assess the strength and durability of pavers made with varying proportions of calcined rice husk, compression tests were conducted at intervals of 7, 14, 28, and 56 days, with the average compression value of three samples calculated for each interval (Figure 3). These tests were carried out in accordance with the NTC 3819 technical standard, enabling the evaluation of how the incorporation of this material influences the mechanical properties of the pavers over time [77].

Pavers with rice husk ash achieved a peak compressive strength of 13.28 MPa, making them suitable for pedestrian traffic applications. These pavers can be classified as Type III, which are exposed to low abrasion according to NTC 3829 [78]. Also, it was potentially observed that a higher percentage of calcined rice husk in the mix results in a lower compressive strength of the material, in accordance with previous works [79–81].

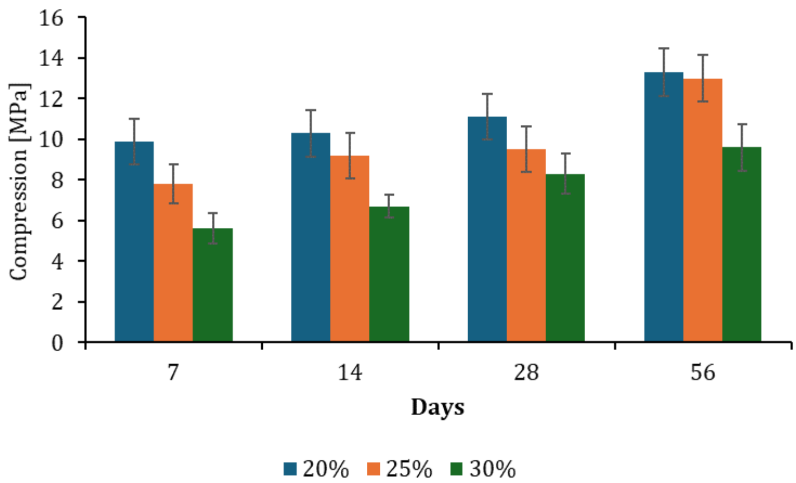

Figure 3. Results of compression tests for pavers with RHA replacement at 7, 14, 28, and 56 days.

Due the AHP an alternative that requires minimal investment in machinery and resources should be prioritized in order to accommodate the limited financial capacity of small-scale farmers. To adopt these solutions, small-scale farmers can integrate themselves in supply chains with most value added such as sustainable construction materials, potentially increasing their market opportunities. While initial investments in equipment may be required, the reduced production costs and growing demand for eco-friendly construction materials could offer financial benefits.

4. Conclusions

Local rice producers acknowledge that the rice production chain generates a significant amount of waste, which, to date, has not been utilized in a way that adds value for them. The use of these residues in the production of construction materials presents a promising opportunity to enhance the quality of life for small farmers by incorporating these by-products into a new value chain.

The utilization of rice waste not only contributes to the reduction in agricultural waste but also offers an environmentally sustainable solution. The AHP method enabled the evaluation and prioritization of rice waste usage to produce construction materials based on criteria tailored to the needs of local producers.

The pavers developed with rice husk ash exhibited compressive strength suitable for light traffic applications under low-abrasion conditions. The results indicated that increasing the replacement of cement with rice husk ash leads to a reduction in mechanical performance, with the optimal response achieved at a 20% replacement level. This finding highlights the potential of rice husk ash as a sustainable alternative in construction materials, particularly for applications where lower mechanical demands are acceptable.

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Data Availability Statement: The original contributions presented in the study are included in the article; further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

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