

Revalorization of Shihuahuaco Wood Waste (*Dipteryx Micrantha*) for Briquette Production

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Abstract

The wood industry in Metropolitan Lima generates significant amounts of Shihuahuaco (*Dipteryx micrantha*) sawdust, which remains underutilized despite its high calorific potential. This study evaluates the technical and preliminary industrial feasibility of revalorizing this residue through pellet production as a precursor to briquette manufacturing. Different formulations incorporating natural binders—tara gum, molasses, and corn starch—were experimentally assessed to determine their effects on mechanical durability, calorific value, and gaseous emissions. Pellets were produced under controlled compaction and drying conditions and tested using the MICUM abrasion method, bomb calorimetry, and flue gas analysis (CO, CO₂, NO_x, SO₂, HC). Results indicate that tara gum is the most effective binder, achieving low abrasion indices (1.39–3.35%) and competitive calorific values, with the optimal formulation reaching 22.32 MJ/kg, comparable to commercial charcoal used in Peruvian food establishments. Beyond technical validation, the study identifies potential end users—particularly small and medium-scale rotisserie restaurants in Lima—with stable demand for solid biofuels. From an Industrial Engineering perspective, the proposal integrates waste valorization, process optimization, and circular economy principles, highlighting the potential for sustainable energy substitution and improved industrial waste management in urban Peru.

Keywords

Biomass, Sawdust, Pellet characterization, Combustion gases, Shihuahuaco.

1. Introduction

In the Peruvian wood industry, the management of residues derived from the processing of tropical timber such as Shihuahuaco (*Dipteryx micrantha*) represents a significant environmental and economic challenge. In Metropolitan Lima, sawmills generate considerable volumes of sawdust that are commonly underutilized or burned without process optimization.

Simultaneously, Peru faces increasing demand for solid biofuels in commercial food sectors, particularly in rotisserie chicken restaurants (“pollerías”), which rely heavily on charcoal and firewood.

Densified biomass briquettes offer an opportunity to integrate waste valorization with renewable energy production under a circular economy framework. However, most previous studies focus primarily on technical pellet performance without explicitly addressing market applicability and industrial feasibility.

This study aims to evaluate the mechanical, thermal, and environmental performance of pellets produced from Shihuahuaco sawdust using natural binders and to assess their potential application within the Peruvian urban energy market from an Industrial Engineering perspective.

2. Problem Formulation

The processing of tropical hardwoods such as Shihuahuaco (*Dipteryx micrantha*) in Peru generates significant quantities of sawdust that are often underutilized despite their energy potential. Previous studies have shown that sawdust-based briquettes can achieve favorable calorific values and mechanical resistance when appropriate binders and compaction parameters are applied (Mendoza et al. 2020; García et al. 2019).

Binder selection and moisture control significantly influence structural stability and combustion efficiency (Manyuchi et al. 2018; Huamán et al. 2021). However, limited research has focused specifically on optimizing Shihuahuaco-based pellet formulations and evaluating their potential substitution for commercial charcoal in the Peruvian market.

2.1 Biomass Densification Technologies

Biomass densification has been widely studied as a strategy to improve energy density, handling efficiency, and combustion stability of forestry and agricultural residues. Mendoza et al. (2020) demonstrated that densified briquettes produced from sawdust exhibit higher thermal efficiency compared to loose biomass. Similarly, Yank et al. (2016) reported that low-pressure densification improves structural cohesion and transport efficiency in rural applications.

Particle size and moisture content are critical parameters influencing briquette performance. García et al. (2019) found that smaller particle sizes improve bonding and surface finish during compaction, while Huamán et al. (2021) emphasized that optimal moisture content between 8% and 15% ensures proper agglomeration and prevents structural defects.

Compaction technologies vary depending on scale and application. Industrial hydraulic presses and rotary systems have been shown to produce cylindrical briquettes with improved mechanical durability (Urbina 2023). These technologies form the technical basis for scalable biomass densification processes.

2.2 Influence of Natural Binders on Pellet Performance

The selection and proportion of binders significantly influence mechanical resistance and calorific performance. Manyuchi et al. (2018) demonstrated that molasses enhances cohesion due to its sugar composition, reducing fragmentation during handling. Similarly, Ifa et al. (2020) reported that binder optimization improves density and thermal stability in bio-briquettes derived from agro-industrial waste.

Natural polymers such as starch and lignin-based additives have also been investigated. Abedi et al. (2018) showed that lignin incorporation increases energy density and combustion stability, while García et al. (2019) explored corn starch as a low-cost binder for sawdust agglomeration.

However, binder proportion must be optimized. Mendoza et al. (2020) observed that mixtures containing 56–60% binder achieved favorable mechanical properties but noted that excessive binder may reduce calorific performance. These findings highlight the trade-off between structural durability and energy density.

2.3 Environmental Performance of Biomass Briquettes

Environmental performance is a critical criterion for industrial implementation. Combustion emissions such as CO, CO₂, NO_x, SO₂, and hydrocarbons (HC) provide insight into combustion efficiency and pollutant formation.

Alarcón et al. (2017) demonstrated that densified agricultural biomass pellets produce more stable combustion profiles compared to loose residues. Huamán et al. (2021) further emphasized that incomplete combustion is directly associated with poor compaction and excessive moisture.

International standards such as ISO 17225-3 (2021) define quality classes for solid biofuels, including mechanical durability and moisture requirements, reinforcing the importance of standardized evaluation methods.

2.4 Research Gap

Although previous studies have examined binder optimization and mechanical performance, limited research integrates experimental pellet characterization with preliminary industrial applicability in a specific national context.

In Peru, tropical hardwood residues such as Shihuahuaco remain underexplored as a biofuel source. Existing studies primarily focus on laboratory performance (Mendoza et al. 2020; García et al. 2019), without addressing market substitution feasibility, commercial demand, or industrial scalability.

Therefore, this study addresses both experimental optimization and preliminary industrial feasibility, incorporating technical performance, environmental evaluation, and potential energy substitution analysis from an Industrial Engineering perspective. Additionally, the potential end users of briquettes produced from wood residues such as small and medium scale food establishments, particularly rotisserie chicken restaurants (“pollerías”), bakeries, and other commercial cooking operations have not been sufficiently considered in previous research. These sectors represent a stable demand for solid fuels traditionally supplied by charcoal.

3. Methods

Shihuahuaco (*Dipteryx micrantha*) sawdust was collected from a sawmill in Metropolitan Lima, Peru. The material was dried, milled, and sieved to particle sizes below 125 µm to ensure mixture uniformity (García et al. 2019). Three natural binders were evaluated: tara gum, sugarcane molasses, and corn starch. Nineteen formulations were prepared by varying binder proportions which were established through the analysis of experiments using the statistical software minitab.

Pellets were produced using a hydraulic press with a cylindrical stainless-steel mold (20 mm length, 7.26 mm diameter) and dried at 90 °C for 24 hours to achieve moisture content between 8% and 15% (Huamán et al. 2021). Mechanical durability was assessed using the MICUM abrasion method with 25 pellets per formulation.

$$AI = \frac{\text{Mass below 2mm}}{\text{Initial mass}} \times 100$$

Higher heating value (HHV) was measured using bomb calorimetry according to ASTM E871-82 (2013). Combustion emissions (CO, CO₂, NO_x, SO₂, and HC) were analyzed using a portable flue gas analyzer during controlled combustion tests.

3.1 Materials

Shihuahuaco sawdust was obtained from a sawmill located in Metropolitan Lima. The selection of this tropical hardwood was based on its high density and calorific potential, characteristics previously associated with improved energy performance (López et al. 2019).

Natural binders evaluated included tara gum, sugarcane molasses, and corn starch. Molasses has been widely studied as an effective binder due to its cohesive properties (Manyuchi et al. 2018), while starch-based binders have been explored for cost-effective agglomeration (García et al. 2019).

The materials and equipment used in the laboratory were as follows:

- Shihuahuaco sawdust obtained from IMK Maderas.
- Molasses (sugarcane molasses, Mundo Vegetalia, 500 g).
- Corn starch (Maizena Duryea, 500 g).
- Tara gum (MASAC).
- Oster blender, Osterizer 4655 model, 220 V.
- OHAUS digital balance, Scout SPX6201 model, approximate maximum capacity of 6100 g, 220 V.
- Stainless steel pellet mold.
- Hydraulic press.
- Binder laboratory oven, ED 56 model, 230 V, 50/60 Hz.
- Retsch stainless steel sieves, 125 µm.
- Pyrex beakers, Griffin Low Form model, borosilicate glass, variable capacities (100–1000 mL).
- Aluminum laboratory stirring rod, 15 cm in length.
- Rotary mill with PVC body, polypropylene side covers, ASTM A36 steel gears, 200 RPM gear motor, final speed of 35 RPM, 220 V.

- Portable Flue Gas Analyzer, Gasboard 3800E.
- Bomb calorimeter, Universidad de Lima.

3.2 Pellet Production

Sawdust was milled to particle sizes below 125 μm following recommendations by García et al. (2019), who highlighted the importance of uniform particle distribution for improved bonding. Moisture content was adjusted within the optimal range of 8–15%, as suggested by Huamán et al. (2021), to ensure adequate compaction (Table 1).

Table 1. Formulations

Samples	Composition			
	Sawdust	Tara gum	Molasses	Cornstarch
AA	40%	60%		
AB	60%	40%		
AC	70%	30%		
AD	30%	70%		
AE	50%	50%		
BA	70%		30%	
BB	60%		40%	
BC	30%		70%	
BD	40%		60%	
BE	50%		50%	
CA	30%			70%
CB	70%			30%
CC	40%			60%
CD	60%			40%
CE	50%			50%
DA	33,33%		33,33%	33,33%
DB	33,33%	33,33%	33,33%	
DC	33,33%	33,33%		33,33%
DE	25,00%	25,00%	25,00%	25,00%

Subsequently, the mixture is compacted to obtain cylindrical pellets with a length of 20 mm and a diameter of 7.26 mm using a stainless-steel mold (Figure1). Once compacted, the pellets are removed from the mold and subjected to a drying process by placing them in a laboratory oven at 90 °C for 24 hours until a moisture content between 8% and

15% is achieved, resulting in dried pellets (Figure 1 and Figure 2).



Figure 1. Pellet mold.



Figure 2. Finished pellets.

3.3 Pellet Characterization

The mechanical durability of the pellets was evaluated by determining the abrasion index (AI) ASTM C131 for each formulation. For this purpose, a sample of 25 pellets was introduced into a rotary mill operating at 35 RPM (Figure 5).

Subsequently, combustion tests were conducted using a bomb calorimeter (Figure 4) to analyze combustion gases with a Portable Flue Gas Analyzer, Gasboard 3800E (Figure 3). Combustion time and temperature variation were also recorded to calculate the calorific capacity. Small pellets were placed in a combustion chamber, where they were

burned to analyze the resulting flue gases (Alarcón et al., 2017). A mass of 0.5 g of pellet was placed in the calorimeter chamber (Figure 4), and three samples of each pellet type were evaluated to obtain an average value. Each sample was ignited for approximately 25 minutes, while combustion gases were sampled every 5 minutes to assess gaseous emissions and measure the calorific value (Ponce, 2017).



Figure 3. Gas analyzer.

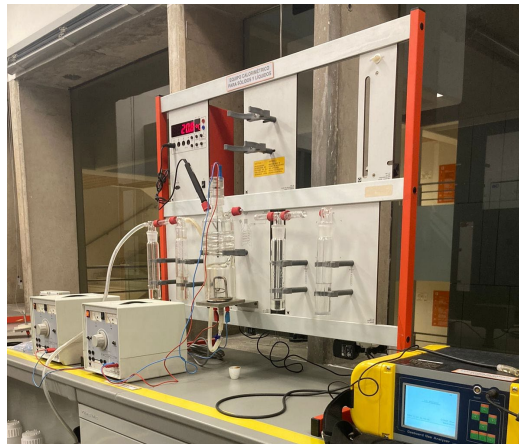


Figure 4. Combustion equipment.

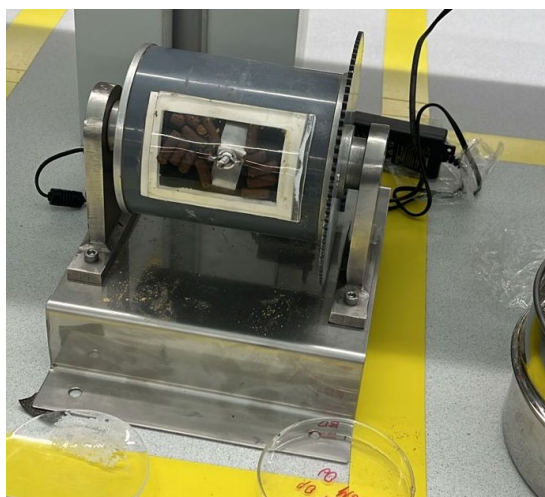


Figure 5. Rotary mil

4. Data Collection

A total of 19 formulations were evaluated. For each formulation, three replicates were tested to ensure repeatability. Abrasion index (AI), calorific value (HHV), and gaseous emissions were recorded.

Gas concentrations were sampled at five-minute intervals during combustion to monitor stability, following methodologies comparable to those used by Alarcón et al. (2017). Average values were calculated to reduce experimental variability.

5. Results and Discussion

5.1 Numerical Results

As shown in Table 2, tara gum formulations achieved the lowest abrasion index, particularly sample AD (AI = 1.39%), while maintaining a high calorific value of 22.32 MJ/kg.

These results are consistent with findings by Manyuchi et al. (2018), who reported improved structural durability when cohesive binders are incorporated. The calorific range observed aligns with values reported by Mendoza et al. (2020) for densified sawdust briquettes.

Table 2. Abrasion index and calorific value results

Samples	Composition				IA (%)	Calorific value (MJ / Kg)
	Sawdust	Tara gum	Molasses	Cornstarch		
AA	40%	60%			2,92%	17,27
AB	60%	40%			3,35%	13,15
AC	70%	30%			15,11%	15,44
AD	30%	70%			1,39%	22,32

AE	50%	50%			1,86%	15,84
BA	70%		30%		1,79%	11,97
BB	60%		40%		0,32%	9,27
BC	30%		70%		0,70%	13,93
BD	40%		60%		1,42%	12,92
BE	50%		50%		1,81%	10,09
CA	30%			70%	20,10%	14,39
CB	70%			30%	13,61%	12,75
CC	40%			60%	39,47%	12,61
CD	60%			40%	11,30%	14,09
CE	50%			50%	15,44%	15,63
DA	33,33%		33,33%	33,33%	2,21%	16,51
DB	33,33%	33,33%	33,33%		3,90%	16,18
DC	33,33%	33,33%		33,33%	4,83%	15,88
DE	25,00%	25,00%	25,00%	25,00%	3,93%	15,7

5.2 Graphical Results

Figure 6 illustrates the performance trend across formulations, highlighting the trade-off between binder proportion and calorific output.

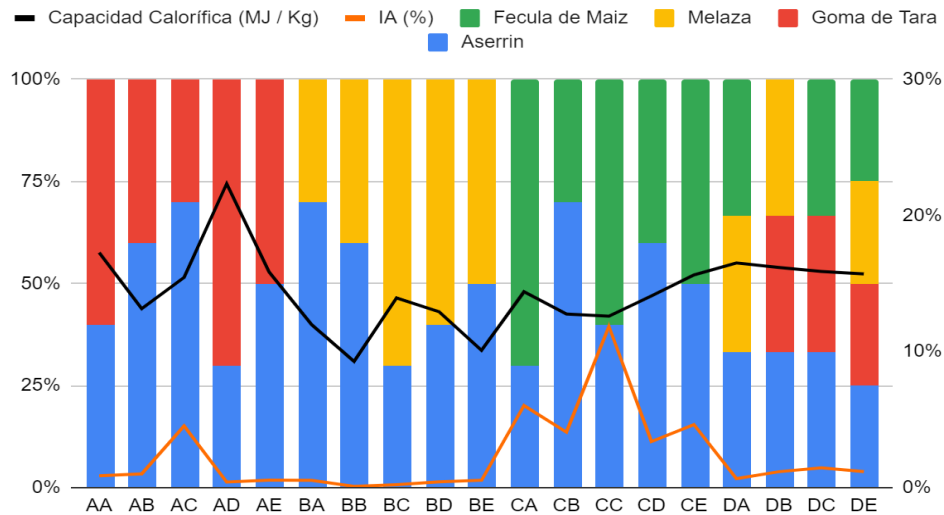


Figure 6. Calorific value and abrasion index versus pellet composition

Table 3. Combustion gas emissions

Samples	Gases				
	SO ₂ (ppm)	NO _X (ppm)	CO (ppm)	CO ₂ (%)	HC (ppm)
AA	45	56	5944	10.5	882
AB	87	44	2257	10.5	718
AC	2	26	3	0.34	11
AD	33	9	598	0.14	93
AE	68	51	2527	25.27	536
BA	27	32	2901	7.39	34
BB	23	54	2901	21.18	132
BC	44	36	2904	2.13	57
BD	11	12	2658	439	49
BE	91	3	5346	22.11	137
CA	2	19	2509	18.37	48
CB	37	31	1587	5.97	79
CC	21	21	5933	08.08	139
CD	18	15	2921	3.45	77
CE	48	32	3519	10.52	129
DA	22	24	2980	11.3	94
DB	26	27	3175	11.9	107
DC	28	29	3340	12.6	119
DE	30	31	3515	13.1	132

As presented in Table 3, tara gum mixtures showed relatively stable combustion profiles. Corn starch formulations exhibited higher CO and HC concentrations, suggesting incomplete combustion, consistent with observations by Huamán et al. (2021).

5.3 Proposed Improvements

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Based on experimental results and comparative literature, formulation AD is proposed as the optimal configuration. Similar binder optimization approaches have been recommended in techno-economic assessments of bio-briquettes (Ifa et al. 2020).

Integration of a briquetting unit within existing sawmill operations would align with circular economy principles and reduce waste disposal costs.

5.4 Validation

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The calorific values obtained (up to 22.32 MJ/kg) fall within the range of commercial charcoal (18–30 MJ/kg), supporting substitution feasibility.

Mechanical durability values below 5% are consistent with acceptable pellet standards described in ISO 17225-3 (2021). These comparisons validate the technical feasibility and industrial applicability of the proposed formulation.

6. Conclusion

This study demonstrated the technical feasibility of revalorizing Shihuahuaco (*Dipteryx micrantha*) sawdust generated in Metropolitan Lima through pellet production as a precursor to briquette manufacturing. The results confirmed that binder type significantly affects mechanical durability, calorific value, and combustion behavior.

Among the evaluated formulations, tara gum showed the best overall performance. Formulation AD achieved the lowest abrasion index (1.39%) and the highest calorific value (22.32 MJ/kg), indicating strong structural stability and competitive energy output. These values fall within the range of commercial charcoal used in small and medium-scale food establishments in Lima, supporting substitution potential in the 2025–2026 Peruvian context.

From an Industrial Engineering perspective, the study integrates biomass waste valorization, process optimization, and circular economy principles. The findings provide a technical foundation for future techno-economic analysis and industrial-scale implementation of biomass briquetting systems in Peru.

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Biographies

Brener Fabricio Valencia Nuñez was born in Arequipa, Peru. He is a graduate in Industrial Engineering from the Universidad de Lima. His academic interests include industrial process optimization, renewable energy systems, and sustainable waste valorization within the Peruvian industrial context. He has professional experience in the metal-mechanical sector, specializing in the design and manufacturing of components for the mining industry and other heavy industrial applications. His work integrates technical design, production processes, and efficiency improvement using Industrial Engineering methodologies.

Aleksa Kovac Alvarado was born in Lima, Peru. He is a graduate in Industrial Engineering from the Universidad de Lima. His academic and professional interests focus on the development of high-value functional products, process optimization in emerging industries, and the integration of scientific research into scalable business models. He is particularly interested in nutraceutical formulation, natural bioactive compounds, sustainable manufacturing systems, and the strategic design of brands aligned with health, performance, and conscious consumption.