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Effect of Biomass Composition on the Mechanical Strength of Pellets Made from Coffee Parchment and Sugarcane Bagasse

17 *Abstract*—**The purpose of this study was to determine the proportions of sugarcane bagasse (SB) and coffee parchment (CP) that would facilitate the pellets' manufacture with superior mechanical characteristics to withstand transportation related damage. These two biomasses, predominant in the area, constitute a potentially useful resource for the manufacture of sustainable solid biofuels. ASTM standard sieves were used to classify the particles according to their size. The analysis of particle size distribution showed that both CP and SB have particle sizes that produce weak and inconsistent pellets. This discovery evidenced the importance of an initial grinding phase to enhance the cohesion and strength of the pellets. Additionally, because pelleting with natural binders is gaining importance as means to reduce manufacturing costs, aloe vera solutions diluted 75:25 (aloe vera: water) were prepared and applied at a percentage of 20% by weight on each batch of biomass to promote the creation of cohesive pellets. To determine the ideal pelleting conditions, the relative ratio of bagasse to parchment (0%, 25%, 50%, 50%, 75% and 100%) and the particle's size were varied. As a resistance measure, a piston press machine was used. The final results showed a marked tendency that, with a higher percentage of sugarcane bagasse, the resistance increases.**

Index Terms—**Sugarcane fiber, Coffee husk layer, physical properties, Solid biofuel pellet, Resistance, Particle size distribution.**

I. Introduction

The search for new sustainable energy sources has led to the creation of solid biofuels as an alternative to fossil fuels. Among solid biofuels, pellets stand out due to their compact structure, high energy density, and the fact that they facilitate transportation [2]. Sugarcane bagasse and coffee parchment are two of the most abundant and underutilized biomass resources, particularly in tropical and subtropical regions [14], [15] like Honduras. Sugarcane bagasse is commonly used as boiler fuel in sugar mills due its moderate energy content, while coffee parchment has been identified as a high calorific biomass reporting energy values of 18.2 MJ/kg[1].

Factors such as compression pressure and biomass ratios affect pellet's density and heating value [2]. Also, previous studies have emphasized that the wrong particle size can lead to poor pellet integrity [11], [12]. This is why ascertaining whether these two biomasses require a pretreatment is a really important parameter. In addition, the use of natural binders, such as aloe vera, can improve the cohesion of biomass particles without adding any chemicals. Using it makes pellets a cost-effective and environmentally friendly alternative to synthetic additives [13].

Besides that, one of the most important things to consider when working with biomass pellets is their resistance. This property plays a big role in measuring whether the pellets can handle being transported or moved around without falling apart [2]. If the pellets are not strong enough, they can break during shipping or handling, which not only causes material loss, but also creates dust and reduces their overall energy efficiency when used [2].

This study aims to evaluate the pellets' resistance produced from mixtures of SB and CP with a piston press and using aloe vera as the binder. By determining the ideal bagasse to parchment ratio and particle size. This research contributes to the sustainable use of Honduran biomass for energy applications and to make storage and transport of biomass easier.

II. Experimental procedure

A. Granolumetric analysis of raw biomass

ASTM standard sieves were used to carry out a granolumetric classification of the biomass and the same numbering of the sieves was used to record the particle size. The characterization of the particle size distribution of both biomasses in their natural state is done by means of random samples, which are analyzed by sieving, recording the accumulated masses on each sieve. The results for both biomasses are summarized in Figures 1 and 2. The low percentages of biomass retained in the lower numbers are evidence of the need to include milling as a pretreatment since the most resistant pellets are those with the lowest particle sizes. The wider whiskers in the bagasse sieve analysis are due to the fibrous form of the biomass, which generates more variance in the individual results.

B. Milling and screening of raw material

A high-speed grinder, as shown in Figure 3, was employed to reduce the particle sizes of both bagasse and parchment. Throughout the study, numerous tests were conducted where the grinder's operation time was varied, but it was always run at full capacity to ensure consistent processing. After careful

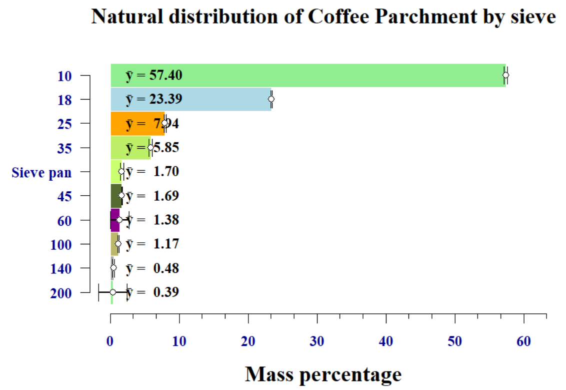

Fig. 1. Natural distribution of coffee parchment

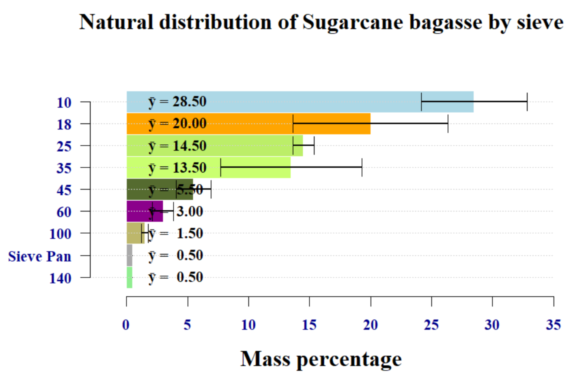

Fig. 2. Natural distribution of Sugarcane bagasse

experimentation, it was determined that grinding for approximately 30 seconds produced the most desirable particle size distribution. Following the grinding process, the material was classified using ASTM standard sieves to separate particles by size. The results showed a higher accumulation of particles on the finer sieves, particularly those with smaller openings such as sieve numbers 35 and 60. This indicated that the grinder was effective at producing a significant amount of fine material, which is essential for achieving optimal pellet quality and compaction in subsequent steps.

C. Pelletizing

Once the biomass was classified by particle size, the next step involved preparing mixtures with varying proportions of parchment, ranging from 0% to 100% in increments of 25%. For each mixture, the percentage referred specifically to the amount of parchment added, with the remainder being bagasse and to ensure consistency and uniformity, the components were thoroughly homogenized before proceeding. Additionally, a natural binder composed of aloe vera and water in a 75/25 ratio was incorporated into the mixture prior to pelletization; this binder helped improve the cohesion of the pellets.

Fig. 3. Biomass Sprayer

The pelletizing process was carried out using a flat plate pelletizing machine, which was used for all the different mixtures prepared. It is important to note that the process itself tends to reduce particle size, making it difficult to maintain complete control over this parameter. To better understand and observe the effects of pelletizing on particle size, imaging devices could be employed, as illustrated in Figures 4 and 5. However, the use of such equipment is reserved for future research.

D. Endurance tests

After the pellets were produced using the pelletizer, they were carefully categorized based on two key variables: their sieve size and the ratio of parchment to bagasse used in their formulation. In this particular batch of samples, moisture content (specifically 20% due to the implementation of a water - aloe vera additive during the pelletization process) was maintained constant across all formulations to ensure that any variations in performance could be attributed primarily to material composition and not differences in water content. This controlled approach helped isolate the effect of the parchment–bagasse ratio on the mechanical behavior of the pellets.

Once categorized, the pellets underwent compressive strength testing to evaluate their structural resistance. For this, a Humboldt Master Loader 5030 piston press was used, a precision instrument capable of applying steady and measurable pressure to assess the point at which each pellet would fail. This test is critical in determining the mechanical integrity of the pellets, especially when considering their handling, and transport.

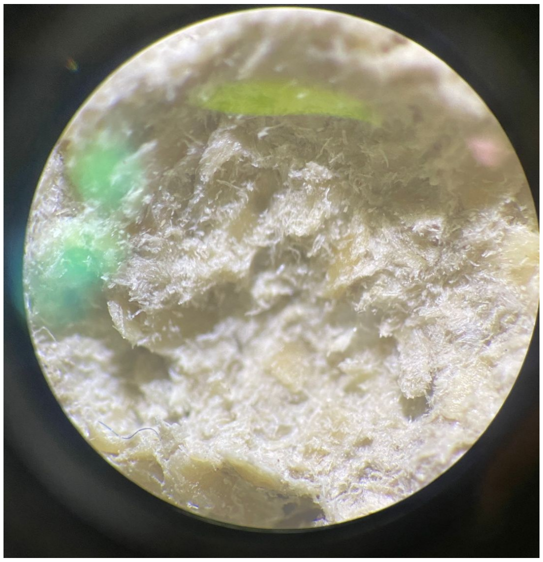

Fig. 4. 100/0 Pellet Coffee Parchment - Sugarcane Bagasse ratio

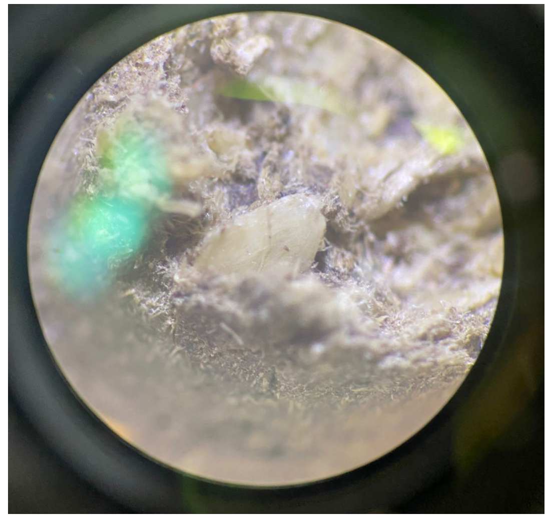

Fig. 5. 50/50 Pellet Coffee Parchment - Sugarcane Bagasse ratio

The test was performed consistently for all pellet types under the same conditions. Each composition—whether it consisted of 100% parchment, 100% bagasse, or various intermediate blends: was tested fifteen times to account for natural variability in the material and to ensure that the results were meaningful. This approach allowed for a meticulous comparison of how particle size and material composition influenced the structural strength of the final pellets.

19 By maintaining moisture constant and carefully controlling test conditions, the experiment offered valuable insights into the role of raw material ratios and particle sizes in optimizing pellet durability.

The testing procedure began by carefully filing down both ends of each pellet to remove any irregular or sharp tips that had formed during the pelletizing process. This step was important to ensure that the compressive strength test would measure the pellet's true structural resistance without being affected by imperfections. To standardize the testing conditions, each pellet was trimmed to a precise length of 1 centimeter, once prepared, each pellet was positioned carefully
23 at the center of the lift plate within the testing machine.

The lift plate then gradually raised the pellet and pressed it firmly against a fixed metallic cylinder located at the top of the device. During this compression, the machine continuously recorded the load applied to the pellet in kilonewtons (kN) at specific time intervals, as illustrated in Figure 7. The critical value taken from each test was the maximum load reached. To ensure statistical reliability and account for natural variability, every unique combination of particle size and biomass ratio was tested fifteen times, resulting in a total of 225 individual repetitions.

III. Results and Discussion

The compressive strength tests conducted using the piston press revealed consistent trends influenced by both particle size and the composition of parchment and bagasse in the pellet mixtures. One of the clearest patterns observed was that pellets made mostly from bagasse consistently exhibited stronger mechanical resistance than those composed solely of parchment. This was true across all particle sizes. When parchment and bagasse were mixed in varying ratios—particularly in equal parts (50/50 blends)—the resulting strength values tended to fall in between those of the pure materials. However, in some cases, these mixtures not only matched but even outperformed the 100% bagasse or 100% parchment samples, depending on the particle size and how the materials interacted.

For the finest particles, represented by sieve 60, the compressive strength results were generally moderate, though some variability was noted. Among all samples tested under this condition, the pellet composed mostly of bagasse displayed the highest compressive strength, reaching up to 0.50 kN. On the other hand, the 100% parchment pellet presented the lowest value observed in this sieve category, at 0.15 kN, although in one isolated case it peaked at 0.63 kN. That said, this exceptional result was not commonly repeated and most 100% parchment samples fell within a more typical range of 0.15 to 0.40 kN. The 50/50 blend of parchment and bagasse showed a respectable average strength of 0.30 kN, while the 25% parchment - 75% bagasse mixture performed better, averaging around 0.37 kN and reaching a maximum of 0.53 kN. In contrast, the 75% parchment mixture recorded the weakest performance in the sieve 60 group, with a minimum value of 0.13 kN. These findings support the idea that finer particles benefit from a higher bagasse content, which appears to offer better structural cohesion.

Shifting to sieve 35, which included medium-sized particles, a general improvement in compressive strength was observed across all blends. The pellet made entirely from parchment reached up to 0.39 kN, while the 100% bagasse pellet outperformed it slightly, achieving 0.49 kN at its peak. Interestingly, the 50/50 mixture showed a stronger average performance

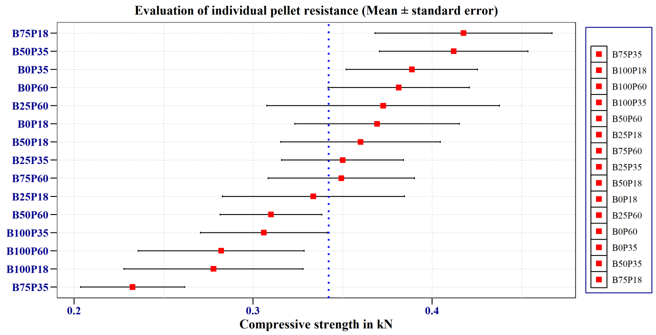

Fig. 6. Performance of different pellets

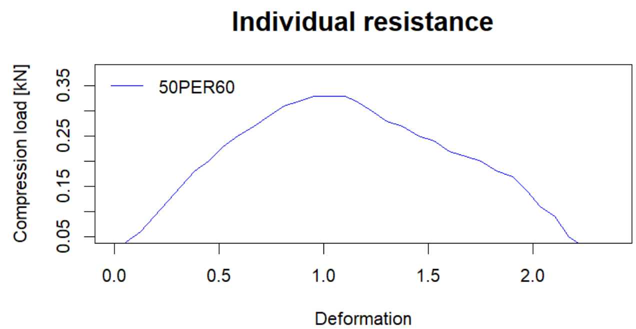

Fig. 7. A example of the endurance of a single pellet (50PER60)

Fig. 8. Humboldt Master Loader 5030 piston press

here compared to sieve 60, registering an average of 0.41 kN. The 25% parchment mixture followed closely behind, with an average of 0.37 kN, but one specific trial reached as high as 0.66 kN, marking one of the most outstanding results in the medium particle size group. In contrast, the 75% parchment blend remained the least structurally sound in this sieve category, with the lowest recorded value of 0.15 kN. These results suggest that medium particle sizes allow for more effective compaction overall, though the type of material remains a key factor—again, bagasse contributing more to mechanical strength than parchment.

The most compelling outcomes were observed with the coarsest particle size, corresponding to sieve 18. Here, pure material compositions still showed wide variability. The 100% parchment pellet ranged from 0.13 to 0.50 kN, and the 100% bagasse pellet had a similar spread, from 0.11 to 0.50 kN. However, the performance of the blended samples in this group was particularly noteworthy. The 50/50 mixture recorded an average strength of 0.36 kN, and the 75% parchment blend edged slightly higher with an average of 0.39 kN. The standout in this category—and the entire study—was the 25% parchment - 75% bagasse blend, which achieved the highest compressive strength of all tests at 0.66 kN.

In summary, the findings consistently highlight the advantageous role of bagasse in reinforcing pellet strength across all particle sizes. While parchment alone tends to produce weaker and less cohesive pellets, mixing it with bagasse—especially in lower proportions—can result in significantly stronger pellets. This research emphasizes the importance of not only selecting the right raw materials but also optimizing their ratios and controlling particle size during preparation. When these factors are balanced properly, the result is a durable and well-compacted biomass pellet with enhanced mechanical properties, suitable for practical applications.

As can be seen in Figure 6, except for B75P18, the pellets with the least amount of parchment are those that exceed or are close to exceeding the overall average.

IV. Conclusions

Based on the resistance testing results, it can be observed that pellets composed primarily of bagasse generally demonstrated higher compressive strength than those made mostly of coffee parchment. This points to bagasse offering better structural integrity and compactibility. While the role of particle size (as determined by mesh size) was not entirely conclusive, some patterns emerged. Pellets made from finer particles tended to offer moderate resistance with a fair amount of variability, however no relationship between particle size and structural resistance could be proven.

Interestingly, the medium particle size group (mesh 35) often yielded the best performance in terms of both strength and consistency. This mesh size seemed to strike a balance, allowing effective packing without introducing too much structural weakness. On the other hand, the coarser particles (mesh 18) produced the most inconsistent results: while some combinations reached high resistance values, others showed very low strength, likely due to poor compaction.

In terms of application, pellets with higher proportions of bagasse are likely more suitable for uses requiring mechanical durability, meanwhile, parchment-rich pellets may still serve in contexts where structural strength is not a primary concern. Moving forward, further research should focus on identifying the factors contributing to result variability, optimizing material blends, and examining the long-term stability of the pellets. Greater control over particle size distribution during the pelletizing process could be a promising avenue to improve the overall quality and performance of the final product.

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Data availability

For access to the databases, please contact Clara I. Ortiz-Valdez

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