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INFLUENCE OF BIOMASS TYPE AND TORREFACTION ON THE PHYSICAL INTEGRITY AND DENSITY OF BRIQUETTED SOLID BIOFUELS

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Abstract - This study explores the mechanical durability, apparent density, and impact resistance of torrefied and non-torrefied briquettes from Green Algae, MSW, Cassava Rhizomes, and Elephant Grass. Standard tests (ASTM E873, D1037, EN ISO 17831-2) evaluated physical strength and compaction. One-way ANOVA showed significant differences (p < 0.001) across biomass types and treatment conditions. Torrefaction often reduced durability and density, especially in Elephant Grass. MSW and Cassava Rhizomes maintained higher resistance under impact forces. The study's novelty lies in comparing both conventional and underutilized feedstocks, notably algae and MSW, using an integrated mechanical assessment. It offers insights into how torrefaction affects different biomass types. This helps optimize briquette quality and resilience during handling and transport. Findings support the expansion of sustainable bioenergy feedstocks. They also validate and build upon earlier densified biomass research. Overall, the work advances solid biofuel performance understanding.

Keywords: Biomass briquettes; Mechanical durability; Apparent density; Impact resistance; Solid biofuels

I. INTRODUCTION

The global transition toward sustainable energy systems has intensified interest in biomass-based solid fuels as viable alternatives to fossil fuels due to their renewability, carbon neutrality, and potential for waste valorization. Among densified biofuels, briquettes offer advantages in terms of bulk density, transport ability, and combustion efficiency, making them attractive for both industrial and household energy applications (Thompson et al., 2016; Basu, 2013). However, the physical quality of briquettes particularly their mechanical durability, apparent density, and impact resistance is crucial for ensuring reliable performance during handling, storage, and transportation (Kaliyan & Morey, 2009; Vassilev et al., 2012). These attributes are

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influenced by both feedstock composition and pre-treatment methods, notably torrefaction, a mild pyrolysis process carried out at 200–300°C in an oxygen-deprived environment. Torrefaction enhances the energy density, hydrophobicity, and grindability of biomass by removing bound moisture and partial volatiles (Chen et al., 2011; van der Stelt et al., 2011). Nevertheless, this thermal treatment may also compromise the structural cohesion of biomass by breaking down hemicellulose and weakening the binding matrix, thereby reducing mechanical integrity (Zhao et al., 2013; Phanphanich & Mani, 2011).

While torrefaction has been widely studied in traditional feedstocks such as wood chips and agricultural residues, less attention has been given to non-conventional materials like municipal solid waste (MSW) and green algae, despite their abundant availability and potential in circular bioeconomy models (Naqvi et al., 2010; Bridgeman et al., 2008). Moreover, impact resistance testing, which reflects briquette robustness under real-world mechanical shock, remains underutilized in densification studies.

This study aims to evaluate and compare the mechanical durability, apparent density, and impact resistance of briquettes produced from four biomass types Green Algae, MSW, Cassava Rhizomes, and Elephant Grass under both torrefied and non-torrefied conditions. The research introduces a multi-criteria physical performance assessment that integrates standardized testing protocols to establish a more comprehensive understanding of feedstock behavior. The novelty of this work lies in its use of underexplored biomass types, application of impact resistance as a performance metric, and the comparative analysis of torrefaction effects on different feedstocks. These findings are intended to inform biomass selection and pre-treatment optimization for improved briquette performance in renewable energy systems.

II. METHODOLOGY

2.1 Feedstock Collection and Preparation

Biomass feedstocks comprising Elephant Grass (Pennisetum purpureum), Cassava Rhizomes (Manihot esculenta), Green Algae, and mixed Municipal Solid Waste (MSW) were collected from agricultural and municipal waste sources near São Paulo State University (UNESP), Brazil. Samples were oven-dried at 105°C until reaching a moisture content of approximately 12%, consistent with standard protocols for biomass densification (Kaliyan & Morey, 2009). Subsequently, the dried biomass was milled using a MACONI MA-1680 grinder. Granulometric analysis classified the material into three particle size fractions (0.85 mm, 0.6 mm, and fines), which were volumetrically blended in a 2.5:1.5:1.0 ratio to ensure homogeneity and optimize particle packing, following established densification practices (Kaliyan & Morey, 2009).

2.2 Briquette Production

Cylindrical briquettes, each weighing 50 g, were produced using an electric briquetting press operated under a constant compaction pressure. This procedure was replicated for both torrefied and non-torrefied biomass samples to facilitate comparative analysis of treatment effects, following methodologies outlined in previous studies (Phanphanich & Mani, 2011).

2.3 Torrefaction Process

Torrefaction was conducted in a laboratory-scale muffle furnace at 290°C for 45 minutes under oxygen-limited conditions to simulate mild pyrolysis, as recommended in the literature (Chen et al., 2011; van der Stelt et al., 2011). After treatment, samples were cooled in desiccators to prevent moisture reabsorption prior to subsequent testing.

2.4 Mechanical Durability Testing

Mechanical durability (DU) of the briquettes was evaluated following ASTM E873-82 (ASTM, 2013). Briquettes were subjected to tumbling in a rotating drum apparatus, simulating handling and transport stresses. The durability percentage was calculated as follows:

$$DU = \frac{M_b}{M_a} \times 100 \quad (1)$$

Where;
DU is the Mechanical Durability (%)
Ma is the initial mass and
Mb is the mass retained after tumbling.

2.5 Apparent Density Measurement

Apparent density (Pa) was determined according to ASTM D1037-12 (ASTM, 2012) by measuring briquette mass and calculating volume based on cylindrical geometry. Dimensions (radius and height) were measured using digital calipers, and volume was calculated by:

$$V = \pi r^2 h \quad (2)$$

Density was then computed as:

$$Pa = \frac{M}{V} \quad (3)$$

where:
M = mass of briquette (kg)
V = volume of briquette (m^3)

2.6 Impact Resistance Assessment

Impact Resistance Index (IRI) was measured following EN ISO 17831-2 (2015). Each briquette was dropped from a height of 2 m onto a steel plate for a total of ten drops. Mass was recorded before and after the drops, and the IRI was calculated by:

$$IRI = \frac{N_b}{N_a} \times 100 \quad (4)$$

Note: Na and Nb are additional parameters related to fragment counts and drop counts as specified by the standard; however, the mass retention calculation provides the primary durability measure.

2.7 Statistical Analysis

All experimental data were subjected to one-way Analysis of Variance (ANOVA) at a significance level of 0.05. Significant differences among biomass types and treatment groups were identified using Duncan’s Multiple Range Test for mean separation (Montgomery, 2017).

III. RESULTS

3.1 Mechanical Durability

The results indicated significant differences in mechanical durability among biomass types ($p < 0.001$). Non-torrefied briquettes exhibited high durability values ranging from 97.91% to 99.74% (Table 1 and Fig 1), consistent with strong inter-particle bonding and minimal structural degradation (Kaliyan & Morey, 2009). In contrast, torrefaction substantially decreased durability, most notably in Elephant Grass briquettes, which showed a drastic reduction to 23.64%. This sharp decline aligns with previous findings that torrefaction induces brittleness and weakens lignocellulosic binding matrices (Chen et al., 2011; Zhao et al., 2013). Green Algae, MSW, and Cassava Rhizomes maintained relatively higher durability post-torrefaction, reflecting inherent differences in biomass composition and structural resilience.

Table 1: The Mechanical Durability of the Briquettes.

Biomass Type	Non- Torrefied (%)	Torrefied (%)
Green Algae	99.56^{ab}	98.73^{a}
MSW	99.74^{a}	97.91^{a}
Cassava Rhizomes	99.10^{ab}	91.72^{b}
Elephant Grass	97.91^{c}	23.64^{c}

*The mean followed by the same letter in the same column are not significantly different ($P \leq 0.05$).

Fig 1: Mechanical Durability

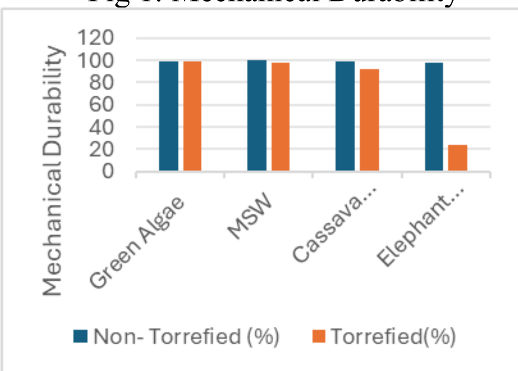
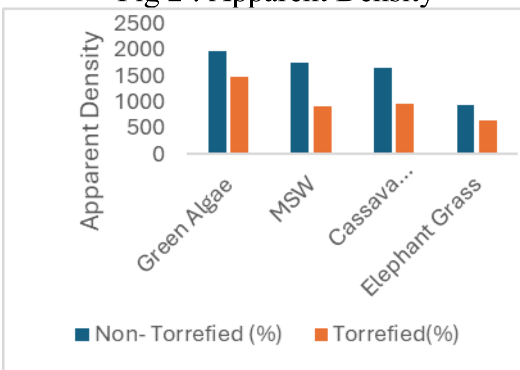


Fig 2 : Apparent Density



3.2 Apparent Density

Apparent density varied significantly by biomass type ($p < 0.001$). Green Algae briquettes showed the highest apparent density values of 1970.78 kg/m³ non-torrefied; 1481.3 kg/m³ torrefied (Table 2 and Fig 2), likely due to their finer particle size distribution and inherently higher biomass density (Vassilev et al., 2012). Elephant Grass exhibited the lowest densities, consistent with its fibrous structure and low bulk density, which limits particle packing efficiency (Phanphanich & Mani, 2011). Density reductions following torrefaction are attributable to mass loss and increased porosity caused by devolatilization and structural degradation, as documented in prior research (Chen et al., 2011).

Table 2: The Apparent Densities for the Non-Torrefied and Torrefied Briquettes.

Biomass Type	**Non- Torrefied** P_a **(kg/m³)**	**Torrefied** P_a **(kg/m³)**
Green Algae	1970.78[a]	1481.3[a]
MSW	1740.46[b]	918.3[bc]
Cassava Rhizomes	1657.75[c]	956.3[b]
Elephant Grass	929.02[d]	653.1[d]

*The values with the same letters in the same row are significantly different (P≤ 0.05).

3.3 Impact Resistance

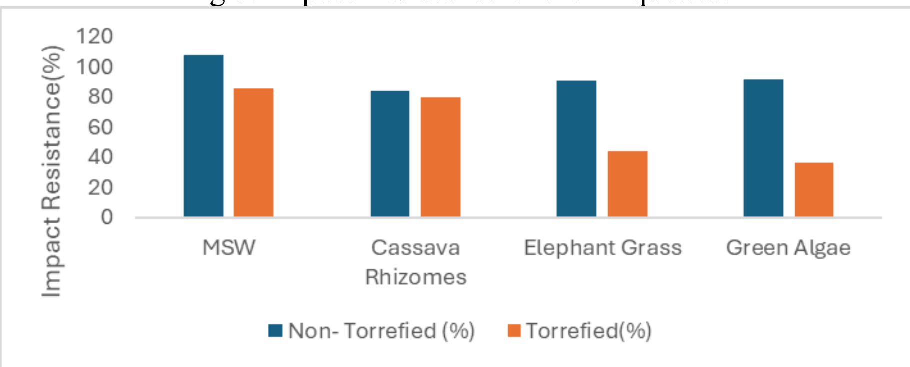
The Impact Resistance Index (IRI) results (Table 3 and Fig 3) demonstrated that MSW and Cassava Rhizomes briquettes retained superior structural integrity under both torrefied and non-torrefied conditions. Conversely, non-torrefied Green Algae and Elephant Grass briquettes were more prone to fragmentation during impact testing. Interestingly, torrefaction enhanced IRI values across all feedstocks, notably increasing MSW briquette rigidity to 108.20%. This phenomenon reflects the complex trade-offs induced by torrefaction while the process generally reduces mechanical durability by increasing brittleness, it can simultaneously improve rigidity and resistance to deformation under sudden impact, as observed in related studies (Zhao et al., 2013; Cieślik et al., 2018).

Table 3. Impact Resistance Index (IRI) of Briquettes.

Biomass Type	**IRI Torrefied (%)**	**IRI Non-Torrefied (%)**
MSW	108.20[a]	85.67[a]
Cassava Rhizomes	83.73[a]	80.20[a]
Elephant Grass	90.90[a]	44.42[a]
Green Algae	91.99[a]	36.37[a]

*The values with same letters in the same columns are not significantly different (P≤ 0.05)

Fig 3: Impact Resistance of the Briquettes.



IV. CONCLUSION

This study evaluated the mechanical durability, apparent density, and impact resistance of torrefied and non-torrefied briquettes produced from four biomass feedstocks: Green Algae, Municipal Solid Waste (MSW), Cassava Rhizomes, and Elephant Grass. The results showed that:

a) Non-torrefied briquettes consistently outperformed their torrefied counterparts in terms of mechanical durability, indicating stronger interparticle bonding and better structural integrity without the influence of thermal degradation.

b) Green Algae briquettes recorded the highest apparent densities, both torrefied and non-torrefied, suggesting their suitability for high-energy-density applications. In contrast, Elephant Grass briquettes displayed the lowest densities due to their fibrous morphology and low initial bulk density.

c) Impact Resistance Index (IRI) improved following torrefaction for all biomass types, particularly for MSW, which achieved the highest IRI among the torrefied samples. This suggests increased rigidity post-torrefaction, despite reduced durability

These findings reveal trade-offs in briquette quality influenced by feedstock characteristics and torrefaction treatment. While torrefaction enhances impact resistance, it compromises mechanical durability especially in biomass with high fiber content like Elephant Grass. Thus, selecting appropriate biomass or optimizing torrefaction parameters is crucial for balancing fuel quality and mechanical stability.

5.1 Recommendations:

1. Blending Strategies: To enhance briquette performance, future work should consider blending fibrous biomass such as Elephant Grass with high-density materials like MSW or Green Algae to mitigate durability losses from torrefaction.
2. Optimizing Torrefaction Conditions: Lower torrefaction temperatures or shorter residence times may help preserve mechanical durability while still improving combustion properties and hydrophobicity.
3. Binder Application: Incorporating natural or waste-derived binders (e.g., starch, molasses, or corrugated cardboard) may improve the structural integrity of torrefied briquettes, particularly those from low-durability feedstocks.
4. Prioritize MSW and Green Algae for briquette production due to superior mechanical and physical properties.
5. Policy and Implementation Support: Encouraging the use of agro-waste and MSW in energy generation through briquetting can reduce environmental pollution and promote circular bioeconomy initiatives, especially in developing countries.

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