

Design Modification and Initial Performance Evaluation of a Multivariant Briquette Press for Multiple Biomass Feedstocks

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ARTICLE INFO

Article history:

Published
October 6, 2026

Keywords:

Biomass briquette
Pneumatic briquette press
Modular mold
Adjustable compression
Functional validation

ABSTRACT

Biomass residues can be densified into solid fuel, but small-scale presses often rely on fixed dies and feedstock-specific operating conditions. This study modified a pneumatic briquette press around a removable mold-insert concept, adjustable pressure regulation, and assisted demolding, and then conducted an initial functional validation using coconut-shell, sawdust, and corn-cob charcoal. One press architecture was used for all three feedstocks without changing the main frame or actuator. Each batch contained 1,000 g of charcoal and 100 g of tapioca binder (10% of charcoal mass), and three replicate specimens per feedstock were evaluated for moisture content, laboratory texture/hardness response, and ash content. All three feedstocks formed intact briquettes. Mean moisture contents were $4.7142 \pm 0.0141\%$ for coconut shell, $4.3147 \pm 0.5643\%$ for sawdust, and $6.3146 \pm 1.1283\%$ for corn cob. Coconut shell produced the highest relative texture response (3808.67 ± 203.38) and the lowest ash content ($3.1150 \pm 0.0433\%$). Because this baseline campaign did not record calibrated working pressure, cylinder dimensions, press-cycle time, or insert-change time, those quantities are not retrospectively estimated; the texture values are also retained only as relative instrument responses because the laboratory report did not state a scientific unit. The results therefore demonstrate cross-feedstock functional feasibility rather than optimized machine performance. The next stage should calibrate pressure-force behavior, quantify cycle and mold-change times, and standardize mechanical and fuel-quality testing.

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I. Introduction

Agricultural and forestry residues are substantial but underused renewable-energy resources. Briquetting can increase the volumetric energy density of dispersed biomass, improve handling and storage, and support local substitution of conventional solid fuels. Romero et al. showed that agricultural residues can provide meaningful household-energy substitution when local resource availability and conversion technology are matched to demand [1]. Feedstock dependence is also evident in other biomass-conversion systems; recent J. Inotera work reported different biogas responses among household-scale feedstocks [2]. These findings establish an important engineering premise for small-scale densification: the press should tolerate material variability rather than assume that all biomass responds identically to a single die and a single compaction setting.

Briquette quality is governed by both material and process variables. Particle-size distribution, moisture, binder type and concentration, compaction pressure, and retention time alter particle rearrangement, interparticle contact, densification, and product integrity. Yirijor and Bere demonstrated that coconut-shell charcoal briquette density and handling performance changed with



particle size and binder condition [3]. Demirel and Gurdil likewise reported pressure- and particle-size-dependent physical-mechanical properties of hazelnut-husk briquettes [4]. A machine optimized around a fixed mold and fixed loading condition can therefore under-compact one feedstock while over-compressing or damaging another.

Pressure control is especially important because the force transmitted to the material determines particle rearrangement, deformation, and the final density profile. Adam et al. studied an industrial stamp briquetting machine over pre-densification pressures of 13-40 MPa, main pressures of 100-200 MPa, and retention times of 0-10 s and showed that process settings altered briquette density and mold-pressure distribution [5]. Nganko et al. similarly found significant effects and interactions among compaction pressure, binder percentage, and retention time for carbonized sawdust briquettes [6]. At lower pressure, Brunerova et al. demonstrated that one press concept can process different biomass mixtures when material preparation and tooling are appropriately matched [7]. The engineering challenge is therefore not only to generate pressure, but to make the pressure and tooling adaptable to the feedstock.

A previous pneumatic briquette press developed in Gorontalo used a 10-cavity square mold (4 x 3 cm per cavity) and produced approximately one 10-briquette cycle per minute; the resulting coconut-shell briquettes were later tested at 14.553-17.410 kN in a compression-testing procedure [8]. The present work extends that fixed-mold architecture toward a multivariant concept based on a removable mold insert, adjustable pneumatic regulation, and assisted demolding. Pneumatic actuation was retained because a regulator permits operating pressure to be changed without altering the mechanical drive geometry, while the actuator and valve system remain comparatively simple for small-scale fabrication and maintenance. This choice also has a limitation: compressed air is compliant, so repeatable compaction force cannot be assumed from valve position alone and must be established by pressure and actuator calibration. Low-cost programmable regulation for pneumatic systems has been demonstrated by Ritonga et al. [10], while the importance of structured die-change procedures is consistent with the setup-time reductions reported by Sumasto et al. [9].

The research gap is thus more specific than the availability of a briquette press. Existing small-scale systems commonly use a fixed cavity geometry and report performance for one feedstock or one narrow operating window, whereas a practical community-scale machine should permit tooling changes and pressure adjustment without rebuilding the frame or drive system. This study therefore aimed to (i) establish a clear multivariant press configuration based on an interchangeable insert, (ii) verify that one pneumatic architecture can form briquettes from three carbonized feedstocks under a common baseline formulation, and (iii) quantify the resulting screening-level moisture, ash, and relative texture responses. The study is intentionally a first-stage functional validation; calibrated working pressure, actuator dimensions, cycle time, and insert-change time were not instrumented in the available baseline record and are not inferred. These variables define the next engineering validation stage together with structured optimization of pressure, binder ratio, particle size, and material condition [11].

II. Method

A. Research design and site

The study used a research-and-development approach covering design modification, prototype fabrication, functional operation, briquette production, and laboratory screening. Development activities were conducted at the Renewable Energy Laboratory over a three-month period, followed by product testing at the Agricultural Product Technology Laboratory, Politeknik Gorontalo. This paper reports the first-stage baseline dataset and separates functional feasibility from later machine optimization. No factorial or response-surface optimization was performed in this stage.

B. Multivariant briquette press concept

The press was developed from a pneumatic briquetting architecture comprising power/control elements, an air compressor, pressure regulation, a structural frame, a vertical pneumatic actuator, a pressing platen, a mold carrier, and an ejector/demolding path. The key modification is the mold interface: the product-forming cavity is treated as a removable insert within the carrier so that feedstock-specific inserts can be exchanged while the main frame and actuator remain unchanged.

The intended changeover sequence is to retract the actuator and isolate the air supply, release the insert retaining mechanism, remove and seat the replacement insert, re-lock and align the insert, and complete a no-load cycle before refilling. Figure 1 redraws this architecture as a publication-quality functional schematic and explicitly separates the retained machine structure from the exchangeable tooling.

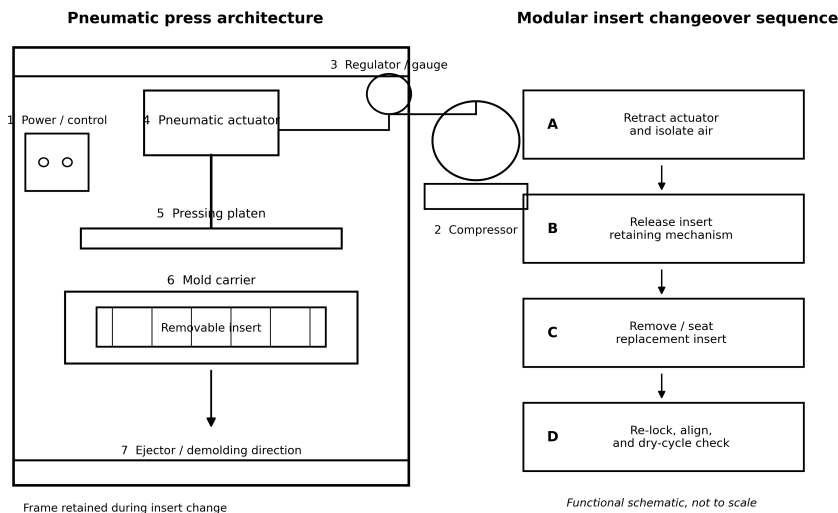


Fig. 1. Functional schematic of the multivariant pneumatic briquette press and modular insert changeover sequence. The drawing is not to scale; the main frame and actuator are retained while the mold insert is exchanged.

For traceability, the 10-cavity 4 x 3 cm die and approximately one-minute cycle reported in [8] belong to the earlier base platform and are not presented here as measurements of the modified multivariant prototype. The baseline records used for the present manuscript did not contain calibrated regulator pressure, pneumatic-cylinder bore or stroke, measured compaction force, current cycle time, or insert-change time. These values were therefore not reconstructed from photographs or assumed from the previous machine. In the next stage, compaction force should be obtained from the measured pressure-force relation ($F = P A$, with A determined from the effective piston area) and verified with a load cell, while cycle time, throughput, and insert-change time should be logged directly.

C. Briquette preparation and testing

Three carbonized biomass feedstocks were evaluated: coconut shell, corn cob, and sawdust. A common formulation was used so that the baseline comparison emphasized feedstock response rather than formulation differences. Each batch contained 1,000 g of biomass charcoal and 100 g of tapioca flour, equivalent to 10% binder relative to charcoal mass. The tapioca was dispersed in clean water and heated to form a homogeneous adhesive, mixed with the ground charcoal, loaded into the mold, compacted with the multivariant press, demolded, and dried before laboratory testing. The available laboratory record did not state the final sieve size or a standardized drying endpoint; these preparation variables are therefore identified as controls that must be fixed and reported in the optimization stage rather than being retrospectively assigned.

For each feedstock, three replicate specimens were tested for moisture content, laboratory texture/hardness response, and ash content. Moisture and ash were reported as percentages. The laboratory report supplied numerical texture/hardness readings but did not provide the instrument model, probe geometry, loading rate, or scientific unit. Accordingly, the present manuscript reports those readings only as relative instrument units and does not convert them to N, kN, kPa, or MPa or label them as standardized compressive strength. This restriction is essential for reproducibility and prevents comparison of the numerical texture values with standard mechanical-strength data in the literature. Because the study was exploratory and $n = 3$ per feedstock, analysis was limited to the mean and sample standard deviation; no inferential significance test was applied.

III. Results and Discussion

A. Functional validation and laboratory results

The modified press formed and demolded intact briquettes from coconut-shell, sawdust, and corn-cob charcoal using the same machine architecture and baseline binder ratio. This observation supports functional cross-feedstock feasibility at the screening level. It does not, however, establish calibrated machine performance because pressure, compaction force, cycle time, throughput, and insert-change time were not recorded in the present campaign. Table 1 therefore reports the product-level replicate measurements that are supported by the laboratory record.

Table 1. Laboratory test results for biomass briquettes

Biomass	Moisture content (%)			Texture response (relative units)			Ash content (%)		
	U1	U2	U3	U1	U2	U3	U1	U2	U3
Coconut shell	4.7246	4.6981	4.7198	3978.8	3863.8	3583.4	3.0998	3.1638	3.08134
Sawdust	4.9662	3.9801	3.9979	3365.1	3292.3	3087.2	3.2203	3.2801	3.2198
Corn cob	6.9517	6.9803	5.0118	2873.5	2996.5	2652.8	3.2873	3.2996	3.3016

The replicate data show the largest between-feedstock separation in the relative texture response and the largest within-feedstock moisture variation for corn cob. Ash values are comparatively close across the three groups. Coconut shell also shows the tightest moisture replication, whereas the sawdust mean moisture is lower despite its larger spread.

Table 2. Mean characteristics of tested briquettes

Biomass	Moisture (%)	Texture response (relative units)	Ash (%)
Coconut shell	4.7142 ± 0.0141	3808.67 ± 203.38	3.1150 ± 0.0433
Sawdust	4.3147 ± 0.5643	3248.20 ± 144.10	3.2401 ± 0.0347
Corn cob	6.3146 ± 1.1283	2840.93 ± 174.15	3.2962 ± 0.0077

Table 2 summarizes the screening statistics. Sawdust had the lowest mean moisture content (4.3147%), coconut shell had the highest relative texture response (3808.67) and the lowest mean ash content (3.1150%), and corn cob had the highest moisture mean and variability. These values are descriptive only; with three replicates and a non-standard texture output, they should not be interpreted as inferential evidence that one feedstock is universally superior.

B. Moisture content

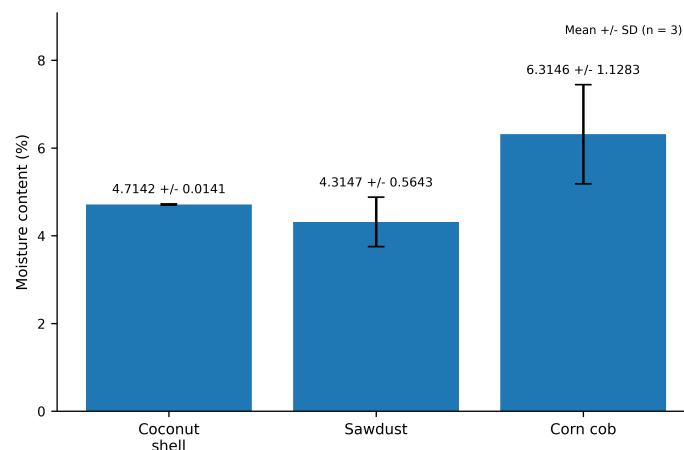


Fig. 2. Mean moisture content of coconut-shell, sawdust, and corn-cob briquettes. Error bars represent standard deviation (n = 3).

The moisture pattern (Fig. 2) indicates two different issues: average moisture and repeatability. Sawdust had the lowest mean (4.3147%), whereas coconut shell showed the most repeatable result (SD 0.0141%). Corn cob had both the highest mean (6.3146%) and the largest variation (SD 1.1283%), suggesting that drying or binder-moisture distribution was less uniform in that batch.

Low moisture is generally advantageous for solid fuel because less energy is consumed evaporating water at ignition. The present range (4.3147-6.3146%) is comparable with the moisture levels reported by Yirijor and Bere for coconut-shell charcoal briquettes across particle-size and binder combinations [3] and falls within the broader range reported by Nurkina et al. for briquettes from organic and industrial wastes [12]. The comparison is limited to moisture magnitude because the feedstocks, carbonization history, binders, and test procedures differ.

For a multivariant press, this variability is operationally important: adjustable tooling does not compensate for inconsistent feed preparation. Moisture, particle-size distribution, binder viscosity, and mass charged to each cavity should therefore be standardized before the effect of pressure is isolated. In the next experimental stage, these variables should be recorded as controlled inputs rather than treated as unmeasured background conditions.

C. Instrumental texture response and compaction behavior

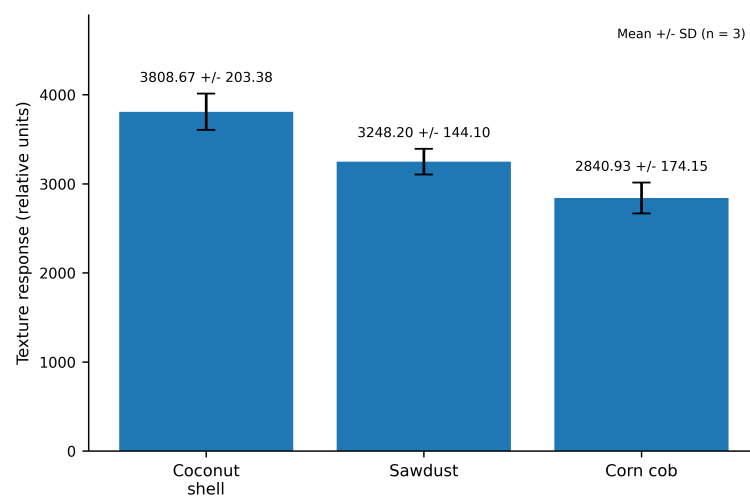


Fig. 3. Mean laboratory texture response of coconut-shell, sawdust, and corn-cob briquettes. Values are relative instrument units; error bars represent standard deviation ($n = 3$).

Figure 3 shows a consistent ranking in the laboratory texture response: coconut shell (3808.67 ± 203.38), sawdust (3248.20 ± 144.10), and corn cob (2840.93 ± 174.15). The ranking is useful for within-study screening because the specimens were tested by the same laboratory procedure, but it is not a standardized compressive-strength ranking because the unit and loading protocol were not documented.

The separation among feedstocks is nevertheless consistent with the broader densification literature, which identifies feedstock density, particle-size distribution, particle shape, porosity, surface chemistry, moisture, binder distribution, and structural compressibility as determinants of packing and interparticle bonding [13], [14]. Yirijor and Bere, for example, reported that finer coconut-shell charcoal particles could produce higher briquette density under specific binder conditions because of improved packing [3]. In the present experiment, a plausible explanation for the higher coconut-shell response is therefore a more favorable combination of particle packing, contact area, and binder distribution than occurred in the corn-cob batch. This mechanism remains a hypothesis because bulk density, true density, particle-size distribution, pore structure, and microscopy were not measured.

Chemical composition must also be interpreted carefully. Lignin can act as a natural thermoplastic binder during densification of non-carbonized lignocellulosic biomass, and particle constituents and moisture influence bond formation [14]. Here, however, all three

feedstocks were used as charcoal. Carbonization changes the original lignocellulosic matrix, so native lignin content should not be used as a direct causal explanation without characterizing both the raw biomass and the carbonization conditions. For these carbonized materials, the defensible interpretation is that differences in the carbonized particle matrix, packing geometry, residual porosity, moisture, and tapioca distribution collectively affected the relative response. Pressure remains a key machine variable: Demirel and Gurdil [4], Adam et al. [5], and Nganko et al. [6] all show that densification outcomes change with applied pressure and retention time. The adjustable-pressure feature is therefore technically justified, but its feedstock-specific set points must be established with calibrated force measurements rather than inferred from the present texture readings.

D. Ash content and overall performance

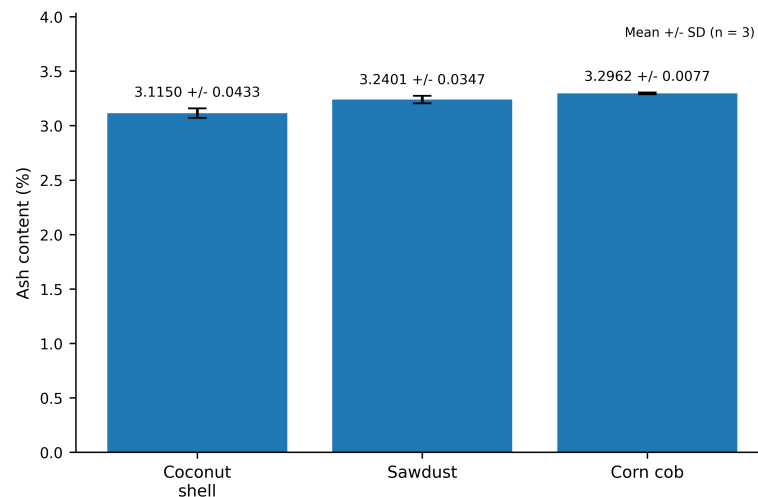


Fig. 4. Mean ash content of coconut-shell, sawdust, and corn-cob briquettes. Error bars represent standard deviation ($n = 3$).

Ash content differed much less than moisture or the relative texture response (Fig. 4). Coconut shell had the lowest mean ash content (3.1150%), followed by sawdust (3.2401%) and corn cob (3.2962%). Because the absolute spread was small, these values should be interpreted as feedstock/batch characteristics rather than as evidence of press performance.

The narrow ash range is expected to be less sensitive to the pressing mechanism than properties such as density, strength, or durability, although binder and feedstock mineral content can shift the final value. The coconut-shell result is close to the 3.01% ash reported by Nganko et al. under an optimized carbonized sawdust condition [6], but the comparison is contextual only because feedstock, carbonization, binder, and analytical protocol differ.

Taken together, the baseline results show that one press architecture can produce intact specimens from all three carbonized feedstocks, while the product responses remain feedstock-dependent. Coconut shell combined the highest relative texture response, the lowest ash value, and highly repeatable moisture; sawdust had the lowest mean moisture; and corn cob showed the greatest moisture variation and the lowest relative texture response. The machine-related conclusion is therefore versatility, not an optimized operating point. This distinction is important because feedstock flexibility is the design objective, whereas product optimization requires calibrated control of material preparation and compaction conditions.

The current dataset should be treated as material screening and prototype functional validation rather than final optimization. The next stage should record regulator pressure, cylinder dimensions, force/load-cell response, pressing and dwell time, briquettes per hour, insert-change time, and unsuccessful ejection or damage events. Product testing should add bulk and briquette density, standardized compressive strength in N or MPa, shatter/durability indices, calorific value, ignition and burning behavior, and a documented particle-size distribution. These measurements would support a

factorial or response-surface design across biomass type, pressure, binder ratio, and particle size and would define a reproducible operating window for each insert.

IV. Conclusion

The modified multivariant concept achieved its first-stage objective: a single pneumatic press architecture formed and demolded intact briquettes from coconut-shell, sawdust, and corn-cob charcoal using the same 1,000 g charcoal to 100 g tapioca formulation. This supports the feasibility of combining a retained frame/actuator with exchangeable tooling for different feedstocks. At the product level, coconut shell produced the highest relative laboratory texture response (3808.67 ± 203.38) and the lowest ash content ($3.1150 \pm 0.0433\%$), sawdust had the lowest mean moisture ($4.3147 \pm 0.5643\%$), and corn cob had the highest and most variable moisture ($6.3146 \pm 1.1283\%$). These results do not yet constitute calibrated machine-performance data: the present baseline did not record working pressure, cylinder geometry, compaction force, cycle time, throughput, or insert-change time, and the texture readings were not supplied with a standard scientific unit. The next validation stage should therefore calibrate pressure against force, document cylinder bore and stroke, quantify cycle and changeover time, standardize particle size and moisture, and measure briquette density, compressive strength, durability, calorific value, and combustion behavior. Only after those measurements should feedstock-specific pressure and binder settings be optimized and the system advanced to field validation with small-scale users.

Acknowledgements

The authors acknowledge Universitas Negeri Gorontalo for the 2026 Non-Tax State Revenue (PNBP) research grant under Decree No. 847/UN47/HK.02/2026 (April 30, 2026) and Contract No. 1043/UN47.D1/PT.01.03/2026 (May 4, 2026).

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