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RESEARCH ARTICLE

PREDICTING STRENGTH FROM DENSITY IN SELECTED AFRICAN TIMBERS: ACCURACY AND SENSITIVITY OF SIMPLE MODELS

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Abstract

Background: Density offers an accessible input for preliminary estimates of wood strength. This exploratory documentary case study assesses how accurately density at 12% moisture content (ρ_{12}) predicts mean bending strength (f_m) and mean compression strength parallel to grain ($f_{c,0}$) for selected African timber references.

Methods: Thirteen reference means from Tropix (CIRAD, 2023–2026), spanning 380–1060 kg/m³, were analysed. Proportional, affine and power models were compared with a mean-only baseline using internal leave-one-out and leave-one-genus-out cross-validation. Twelve genera were represented, with only one repeated genus. Deterministic deletion scenarios and influence diagnostics assessed sensitivity.

Results: The proportional model achieved internal genus-out RMSE values of 8.96 MPa in bending and 2.97 MPa in compression, equivalent to 9.47% and 5.27% of the respective mean responses. These are errors against held-out documentary means, not laboratory measurement uncertainties or specimen-level prediction errors. Relative to the mean-only baseline, RMSE decreased by 73.2% and 84.4%. Density remained informative across the examined deletion scenarios, although model-form rankings could reverse.

Conclusion: Density provides useful predictive information for the selected reference means within this corpus, and a simple proportional relation captures most of the observed benefit. The findings offer hypotheses and candidate density ranges for future timber testing in Guinea and West Africa. Independent paired measurements are needed to establish accuracy for pieces and regional lots.

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Introduction:-

Estimating wood strength from density offers a practical route from a simple physical measurement to a first assessment of mechanical performance. Mass and volume measurements are more accessible than destructive strength testing, making density an attractive input when information must be gathered before committing resources to a mechanical testing programme. Previous studies have established associations between apparent density and

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wood strength, including analyses of multiple properties across forty Brazilian timbers and longitudinal compression across seventy-two hardwood species (Dias and Lahr, 2004; Lahr et al., 2021). The useful scientific question is therefore how much predictive information density supplies, with what error, and at which material scale. Density reflects the amount of material within an apparent volume, while mechanical behaviour also depends on anatomical organisation, grain direction, moisture and defects. These additional factors explain why density does not uniquely determine strength (Senalik and Farber, 2021). Bending and compression parallel to grain must be considered separately: the response mechanisms differ, and predictive accuracy for one property cannot simply be assigned to the other. Moisture must also be specified because changes in water content affect both mass and dimensions (Glass and Zelinka, 2021).

Published timber reference means provide an accessible basis for evaluating predictive relationships. Their statistical interpretation is nevertheless specific. A relationship among mean densities and mean strengths describes differences between references; it does not directly describe differences between pieces within a species. The present corpus contains thirteen documentary means, including commercial groups that may encompass several species, without associated sample sizes or variances (CIRAD, 2023–2026). Defining the reference mean as the prediction target allows these data to be used productively without attributing specimen-level accuracy to them. A second consideration is evaluation beyond fitting. Comparing density models with a mean-only baseline reveals the information gained by measuring density. Predicting references excluded from fitting then provides an internal assessment of predictive error. Group-aware validation can address identifiable dependencies, although it does not remove dependencies that are absent from the source metadata (Roberts et al., 2017). With a small corpus, the stability of both performance and model ranking is as informative as the minimum error obtained from a single comparison.

This exploratory documentary case study asks how accurately density at 12% moisture content can estimate mean bending and parallel-to-grain compressive strengths for selected African timber references. Its objectives are to quantify improvement over a predictor-free baseline, compare simple functional forms, evaluate individual errors and composition sensitivity, and define conditions for preliminary use. Its contribution is a joint assessment of within-corpus predictive benefit and sensitivity, rather than a claim of external validity for African timber generally. This distinction is particularly useful for developing timber research in Guinea and West Africa. Some species associated with the selected references occur in Guinea (Gosline et al., 2023), providing a concrete reason to investigate these relationships with locally sourced material. Documentary estimates can help organise an initial test programme and formulate expectations across a density range. Establishing their accuracy for regional supplies remains a separate empirical question. Figure 1 sets out this progression from reference data to internal assessment and subsequent field-relevant validation.

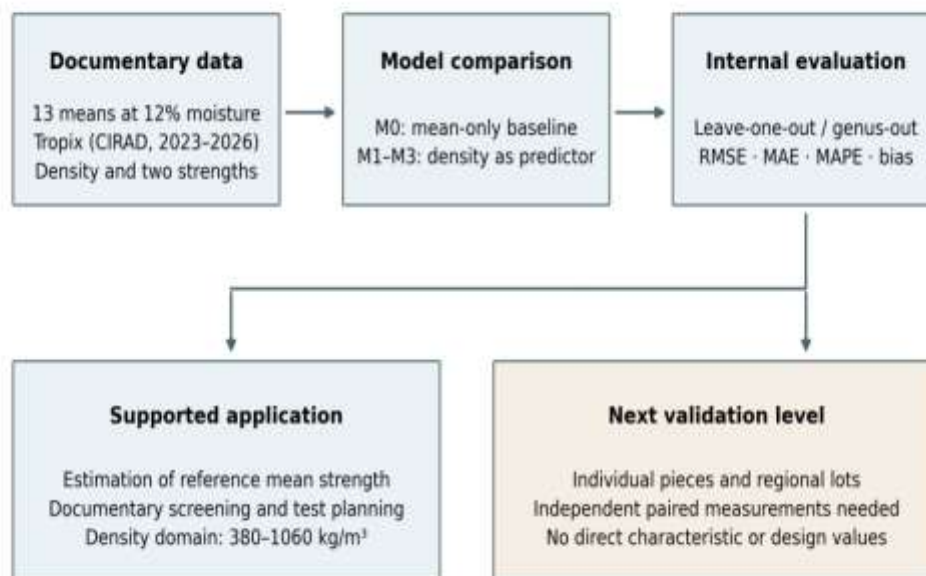


Figure 1. Analytical framework and scope. All inputs are published reference means. M0 is the mean-only baseline; M1–M3 use density. Independent measurements are needed before transferring the reported accuracy to pieces or regional lots.

Materials and Methods:-

Documentary corpus and selection:-

The analysis used thirteen technical sheets from the African timber section of Tropix (CIRAD, 2023–2026): African mahogany, afrormosia, avodiré, ayous, azobé, bilinga, bubinga, ilomba, iroko, limba, okoumé, ovengkol and sapelli. The selection linked commercial designations in the African scope of Table 5–5a of the Wood Handbook (Senalik and Farber, 2021) to sheets providing all three required properties. Ayous, bilinga, ovengkol and sapelli correspond commercially to obeche, opepe, ovankol and sapele in that scope. These naming correspondences define the selection and do not establish identical underlying populations. All numerical observations came from CIRAD sheets. The selection flow was: 17 entries carrying the African code in Table 5–5a of the Wood Handbook; 13 documented matches to archived African technical sheets with all three properties; four unmatched entries; 13 complete references analysed. No verified matched sheet was subsequently excluded for a missing response. Angelin, Benge, Cypress Mexican and Ekop were excluded because an eligible match was not established in the archived sheet selection, not because their properties were proved unavailable. Appendix A records these decisions. No residual-based selection was applied.

The Wood Handbook provided the named selection framework only. Its values were not used as independent validation because equivalence of density definitions, material populations and underlying source campaigns was not established. The matching exercise is a reproducible convenience selection within the archived list, not an exhaustive search under every botanical synonym or commercial alias. Appendix A separates analytical inputs from contextual sources. Table 1 gives the complete numerical dataset and botanical names as reported by Tropix (CIRAD, 2023–2026). The statistical unit is one documentary commercial reference. African mahogany, bilinga, bubinga and iroko list multiple non-synonym species; the other nine sheets list one species after excluding explicitly marked synonyms. No species-specific values were reconstructed from grouped means. Thirteen references represent twelve genera, with two Guibourtia entries. Equal row weights reflect the absence of source-specific

sampling variances, not equal biological replication. The sheets state mature wood and a 12% moisture reference. For the extracted means, sample sizes, within-reference variances, campaign identifiers, specimen dimensions, mechanical test standards and conditioning procedures are not specified. Geographic occurrence and generic standards cited elsewhere in a sheet do not identify the provenance or test protocol of a particular mean. Source_metadata.csv records these fields explicitly as not reported. Unknown shared campaigns and protocol differences may contribute to between-reference heterogeneity independently of density.

Table 1. Documentary mean properties at 12% moisture content from Tropix (CIRAD, 2023–2026).

Reference	Botanical names ¹	ρ_{12} (kg/m ³)	f_m (MPa)	$f_{c,0}$ (MPa)
African mahogany	Khaya anthotheca; Khaya grandifoliola; Khaya ivorensis	570	77	46
Afromosia	Pericopsis elata	740	93	64
Avodiré	Turraeanthus africana	580	94	52
Ayous	Triplochiton scleroxylon	380	52	30
Azobé	Lophira alata	1060	162	96
Bilinga	Nauclea diderrichii; Nauclea gillettii; Nauclea xanthoxylon	760	95	63
Bubinga	Guibourtia demeusei; Guibourtia pellegriniana; Guibourtia tessmannii	920	137	76
Ilomba	Pycnanthus angolensis	490	63	38
Iroko	Milicia excelsa; Milicia regia	640	87	54
Limba	Terminalia superba	540	80	47
Okoumé	Aucoumea klaineana	440	62	36
Ovengkol	Guibourtia ehie	820	127	69
Sapelli	Entandrophragma cylindricum	690	102	62

Note: f_m denotes bending strength and $f_{c,0}$ compression parallel to grain. ¹ Non-synonym names listed by the source; this is not an independent taxonomic revision. Full names, marked synonyms, genera, URLs and sheet dates are retained in Source_metadata.csv. African mahogany is a commercial group, not one species.

Density and prediction targets:-

Apparent density is the ratio of mass to volume at the same moisture state. Moisture content u is expressed relative to oven-dry mass; $u = 0.12$ represents 12% (Glass and Zelinka, 2021). The symbols m_u , V_u and m_0 denote mass and volume at u and oven-dry mass, respectively.

$$\rho_u = \frac{m_u}{V_u}; \quad u = \frac{m_u - m_0}{m_0} \quad (1)$$

In the CIRAD Tropical Timber Atlas, relative density is defined as the ratio of wood mass density to that of pure water at 4 °C, conventionally 1000 kg/m³, and is specified for wood at 12% moisture content (Gérard et al., 2016). The “Densité” values in Tropix (CIRAD, 2023–2026) carry the corresponding 12% property footnote. Thus $d_{12} = \rho_{12}/\rho_w$ is dimensionless, and equation (2) expresses the same physical quantity in kg/m³. For African mahogany, $d_{12} = 0.57$ gives $\rho_{12} = 570$ kg/m³. This is neither a moisture correction nor a conversion from basic density.

$$\rho_{12} = d_{12}\rho_w = 1000d_{12} \text{ kg/m}^3 \quad (2)$$

Bending strength f_m and compressive strength parallel to grain $f_{c,0}$ were modelled separately in MPa. The target is the published mean for a reference, not the failure load of a structural element. Density measured at an unknown moisture content is not directly compatible with these equations. No moisture-correction relationship was inferred from this dataset.

Models and fitting:-

Four models were fitted independently for each response. M0 predicts the training-set mean; M1 is proportional; M2 is affine; M3 is a power function normalised by $\rho_0 = 700 \text{ kg/m}^3$. Throughout the model equations, ρ denotes ρ_{12} and A denotes the training set.

$$\text{M0: } \hat{f} = \frac{\sum_{j \in A} f_j}{n_A}; \quad \text{M1: } \hat{f} = c\rho \quad (3)$$

$$\text{M2: } \hat{f} = \alpha + \beta\rho; \quad \text{M3: } \hat{f} = a(\rho/\rho_0)^b \quad (4)$$

The coefficients c and β have units $\text{MPa} \cdot \text{m}^3/\text{kg}$, α and a are in MPa, and b is dimensionless. M1 has one fitted coefficient; M2 and M3 have two. Parameters minimise equally weighted squared errors on the original MPa scale. Linear least squares were used for M1 and M2. M3 was fitted by nonlinear least squares with positive amplitude and exponent starting values of 0.5, 1 and 2; the converged solution with the lowest sum of squares was retained. No logarithmic transformation changed the fitting criterion. The zero intercept in M1 is a parsimonious empirical constraint within 380–1060 kg/m^3 , not evidence for a constitutive law extending to zero density. M1 is used as an illustrative simple relationship rather than declared the intrinsically best model. No arbitrary percentage threshold was used to select a winner. Small performance differences were interpreted alongside composition sensitivity.

The candidate set deliberately spans one coefficient, an added intercept and smooth power curvature; the power form already provides a simple allometric alternative. The purpose is a bounded comparison of interpretable low-parameter relationships, not selection from a large model library. Quadratic and segmented forms would add curvature or breakpoints unsupported by thirteen means, while robust regression would change the fitting criterion without evidence that an influential sheet is erroneous. M1 is illustrative because of its comparable internal error, direct interpretation and modest coefficient changes across the examined deletions.

Internal cross-validation and error measures:-

Leave-one-out (LOO) validation fitted each model to twelve references and predicted the omitted reference. Leave-one-genus-out (LOGO) validation removed all references belonging to a genus and re-estimated the model before predicting them. Because only *Guibourtia* contains two references, LOGO adds limited grouping beyond LOO. Both procedures are internal to the same documentary compilation; neither evaluates a new laboratory, provenance or independent regional lot (Roberts et al., 2017). Genus replication is weak: only one genus has more than one reference. LOGO should therefore not be interpreted as strong evidence of generalisation to unseen genera, and it cannot address unknown campaign or provenance dependence.

Every coefficient, including the M0 mean, was re-estimated in every fold. Scores give equal weight to the thirteen held-out predictions. Prediction error is defined as predicted minus published strength, so positive errors denote overestimation. Root mean square error (RMSE), mean absolute error (MAE), bias and mean absolute percentage error (MAPE) summarise complementary aspects of performance.

$$e_i = \hat{f}_i - f_i; \quad \text{RMSE} = \sqrt{\frac{\sum_i e_i^2}{n}}; \quad \text{MAE} = \frac{\sum_i |e_i|}{n} \quad (5)$$

$$\text{Bias} = \frac{\sum_i e_i}{n}; \quad \text{MAPE} = \frac{100}{n} \sum_i \left| \frac{e_i}{f_i} \right| \quad (6)$$

We also report counts within $\pm 10\%$ and $\pm 20\%$, the maximum absolute error, and the empirical 90th percentile of absolute errors using the upper-rank convention: rank $[0.90n]$, or the twelfth ordered error for $n = 13$. These are descriptive error summaries, not regulatory acceptance criteria or probabilistic prediction limits. RMSE in MPa is the primary error measure. As a complementary scale-free description, mean-normalised RMSE is $\text{NRMSE} = 100 \times \text{RMSE} / \bar{f}$, where $\bar{f}$ is the mean published response in the evaluated corpus. This denominator is used only for

reporting, never in model fitting. MAPE remains informative for positive responses but gives more weight to a given absolute error at lower strengths; it is therefore interpreted alongside RMSE and NRMSE.

Composition sensitivity and influence diagnostics:-

Each of the twelve genera was then removed from the corpus in turn, and the complete LOGO procedure was repeated on the remaining eleven or twelve references for every model. Within each scenario, models were compared on the same retained references. Across scenarios, the test population changes. Minimum–maximum ranges therefore describe deterministic sensitivity to composition, not confidence intervals from independent samples. The paired difference $RMSE(M1) - RMSE(M3)$ was used to examine ranking reversals. Proportional coefficients were also fitted to each reduced corpus. Their descriptive coefficient of variation was calculated as 100 times the standard deviation divided by the mean coefficient, using divisor 11 for the standard deviation across twelve scenarios. Because scenarios overlap, this dispersion is not a coefficient standard error. Additional fits excluded azobé, ayous, or both density extremes. These overlapping deletions do not estimate sampling uncertainty. Confidence intervals for population slopes are not reported because independent sampling units, source sampling variances and a defensible target-population sampling model are unavailable.

For M1 and M2, leverage, internally studentised residuals and Cook's distance were computed on the full-corpus fit, following standard regression diagnostics (NIST, n.d.). With design matrix X , leverage h_i is the diagonal of $X(X^T X)^{-1} X^T$; the residual variance is $SSE/(n - p)$, with $p = 1$ for M1 and $p = 2$ for M2. Internally studentised residuals use $e_i/[s\sqrt{(1 - h_i)}]$, retaining the prediction-minus-observation sign convention. Cook's distance is $e_i^2 h_i / [ps^2(1 - h_i)^2]$. No observation was removed automatically because of a diagnostic threshold. Residual plots were examined for systematic patterns and changing dispersion (NIST/SEMATECH, n.d.). Targeted sensitivity checks additionally omitted bubinga or ovengkol separately and removed the four sheets listing multiple non-synonym species. Each reduced corpus was refitted and internally cross-validated; no grouped mean was split into invented species observations. Additional diagnostics.csv reports all candidate models, Pearson correlations, residual standard error $\sqrt{[SSE/(n - p)]}$ and descriptive centred $R^2 = 1 - SSE/\Sigma(f_i - \bar{f})^2$. The centred denominator is retained even for zero-intercept M1; no uncentred R^2 is substituted. These diagnostics are descriptive and do not imply independent biological replication.

Results:-

Predictive information supplied by density:-

For the thirteen reference means, M1 yielded internal LOGO RMSE values of 8.96 MPa in bending and 2.97 MPa in compression (Table 2). The corresponding mean-normalised errors were 9.47% and 5.27%, with mean responses of 94.69 and 56.38 MPa. These errors compare predictions with published documentary means; they do not isolate laboratory measurement uncertainty or within-reference variation. Compared with M0 values of 33.49 and 19.03 MPa, the relative reductions were 73.2% and 84.4%, respectively. These percentages describe the benefit over this particular baseline within the selected corpus.

Table 2. Internal validation RMSE for all models, in MPa.

Model	Bending LOO	Bending LOGO	Compression LOO	Compression LOGO
M0	32.78	33.49	18.80	19.03
M1	8.78	8.96	2.94	2.97
M2	8.60	8.75	2.90	3.06
M3	8.44	8.57	2.97	3.11

Note: M0, mean-only; M1, proportional; M2, affine; M3, power. All coefficients are re-estimated within each fold. LOGO is internal genus-out validation.

Model forms and an illustrative simple relationship:-

In bending, LOGO RMSE decreased from 8.96 MPa for M1 to 8.75 MPa for M2 and 8.57 MPa for M3. The 0.40 MPa difference between M1 and M3 is small compared with the overall predictive gain from density. In compression, M1 had the lowest observed RMSE, 2.97 MPa, compared with 3.06 and 3.11 MPa. Figures 2 and 3 show the fitted relationships and held-out predictions. These comparisons support the usefulness of simple equations without identifying a unique functional form.

Table 3. Coefficients estimated using all thirteen references.

Response	M1: c	M2: α ; β	M3: a ; b
Bending	0.14367	-9.272 ; 0.15661	99.859 ; 1.1114
Compression	0.08545	-4.649 ; 0.09194	59.510 ; 1.0822

Note: density in kg/m³ and strength in MPa; c and β in MPa·m³/kg, α and a in MPa, b dimensionless. M3 uses $\rho_0 = 700$ kg/m³. These full-corpus coefficients differ from fold-specific coefficients used to calculate validation errors.

$$\hat{f}_m = 0.14367 \rho_{12} \quad (7)$$

$$\hat{f}_{c,0} = 0.08545 \rho_{12} \quad (8)$$

Bending strength

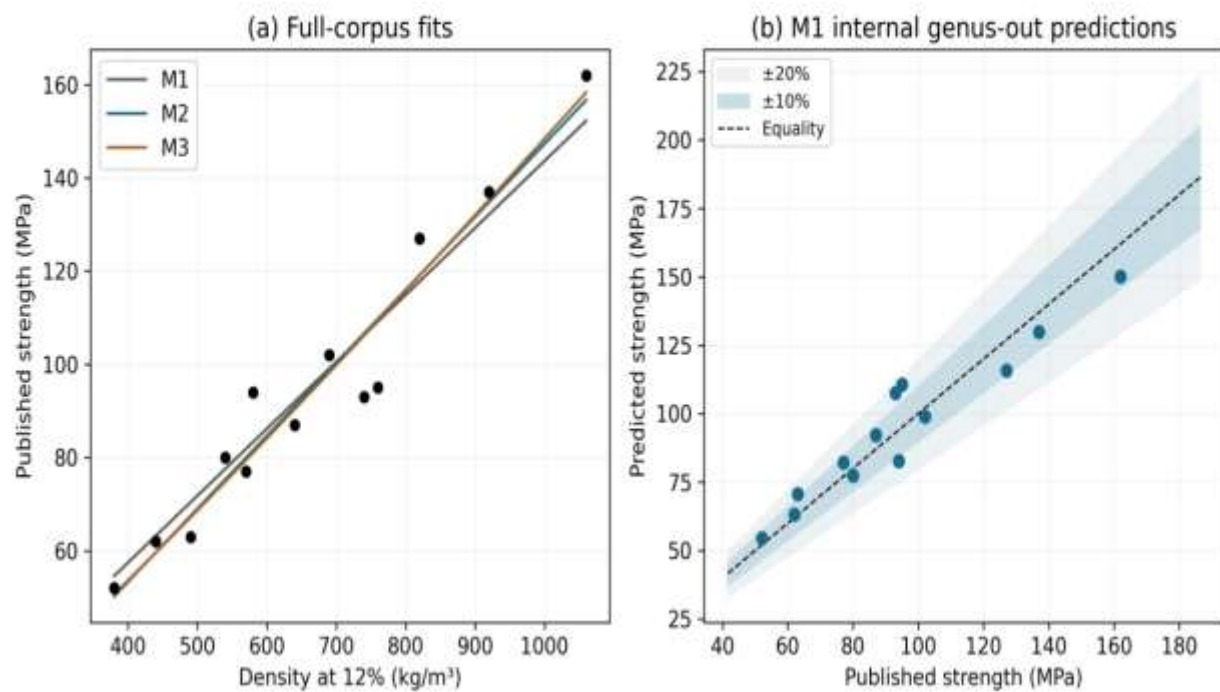


Figure 2. Bending strength. (a) Fits on all thirteen references. (b) M1 predictions from internal LOGO validation versus published means. Shaded $\pm 10\%$ and $\pm 20\%$ bands are descriptive, with no probabilistic coverage implied.

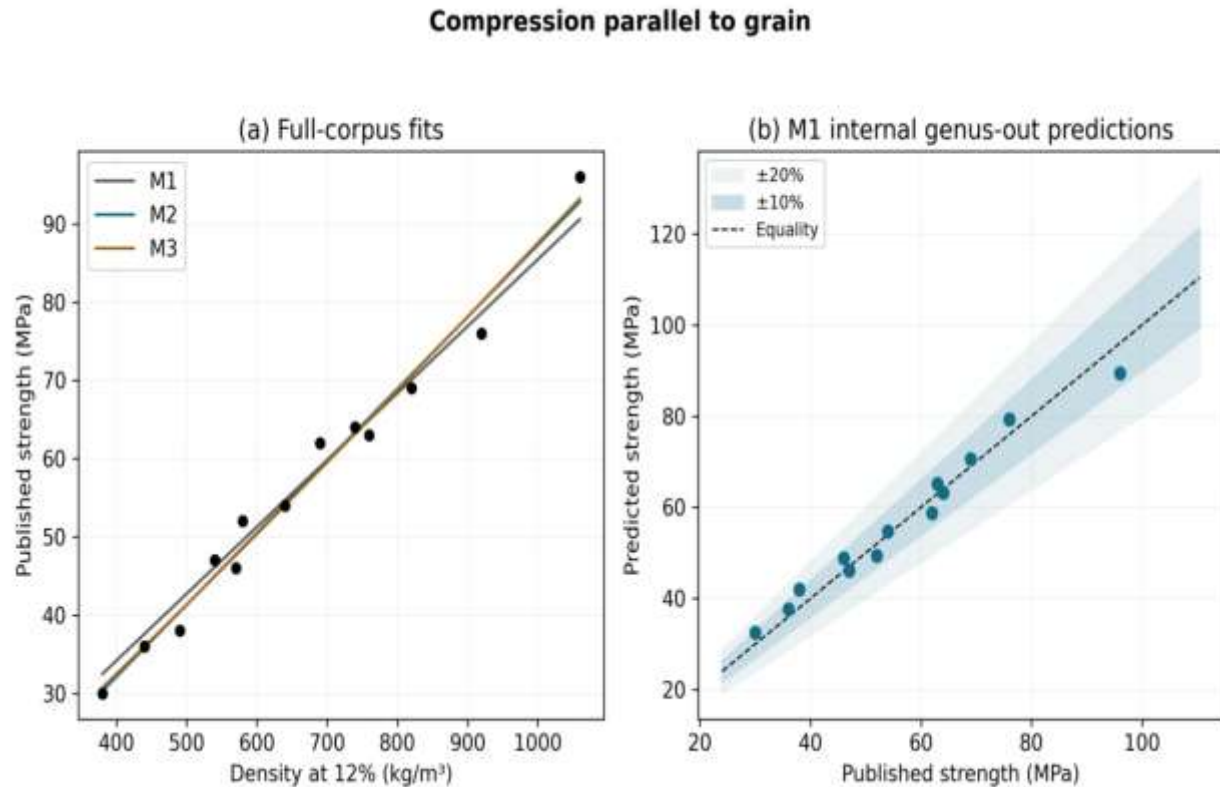


Figure 3. Compression parallel to grain. (a) Full-corpus fits. (b) M1 internal LOGO predictions. The equality line and percentage bands provide visual reference points, not specimen-level prediction intervals.

Magnitude and distribution of prediction errors:-

Table 4 characterises the errors of M1. MAPE was 8.00% in bending and 4.74% in compression, with mean biases below 0.40 MPa. Nine bending predictions and twelve compression predictions were within $\pm 10\%$; all thirteen were within $\pm 20\%$ for both responses. Compression therefore had lower relative errors in this corpus. The maximum errors, 15.65 and 6.62 MPa, also show why an average error should not be interpreted as a bound applying to every reference.

Table 4. Internal LOGO errors for the illustrative proportional model.

Metric	Bending	Compression
RMSE (MPa)	8.96	2.97
MAE (MPa)	7.66	2.55
Bias (MPa)	0.39	0.36
MAPE (%)	8.00	4.74
90th percentile absolute error (MPa)	14.61	4.03
Maximum absolute error (MPa)	15.65	6.62
References within $\pm 10\%$	9	12
References within $\pm 20\%$	13	13
Mean-normalised RMSE (%)	9.47	5.27

Note: positive bias indicates overestimation. Counts are out of thirteen; the percentile uses upper rank 12. These statistics describe held-out documentary means.

Stability across composition scenarios:-

The predictive benefit of density persisted throughout the twelve genus-deletion scenarios. For M1, recomputed LOGO RMSE ranged from 7.95 to 9.43 MPa in bending and from 2.29 to 3.13 MPa in compression (Table 5; Figure 4). These ranges remained well below those of M0. The result is encouraging because the main conclusion does not depend on one exact selection of the thirteen references.

Table 5. Range of internal LOGO RMSE after removing each genus and repeating validation, in MPa.

Model	Bending range	Compression range
M0	27.75–35.18	15.34–19.95
M1	7.95–9.43	2.29–3.13
M2	7.33–10.91	2.27–3.29
M3	7.20–11.67	2.19–3.34

Note: twelve overlapping deterministic scenarios; ranges are sensitivity summaries, not confidence intervals.

By contrast, the paired difference $RMSE(M1) - RMSE(M3)$ ranged from -2.54 to $+1.09$ MPa in bending and from -0.53 to $+0.88$ MPa in compression. Its sign reversal shows that the preference between proportional and power forms depends on composition. The robust finding is the information gained from density; the exact shape of the relationship remains less firmly identified.

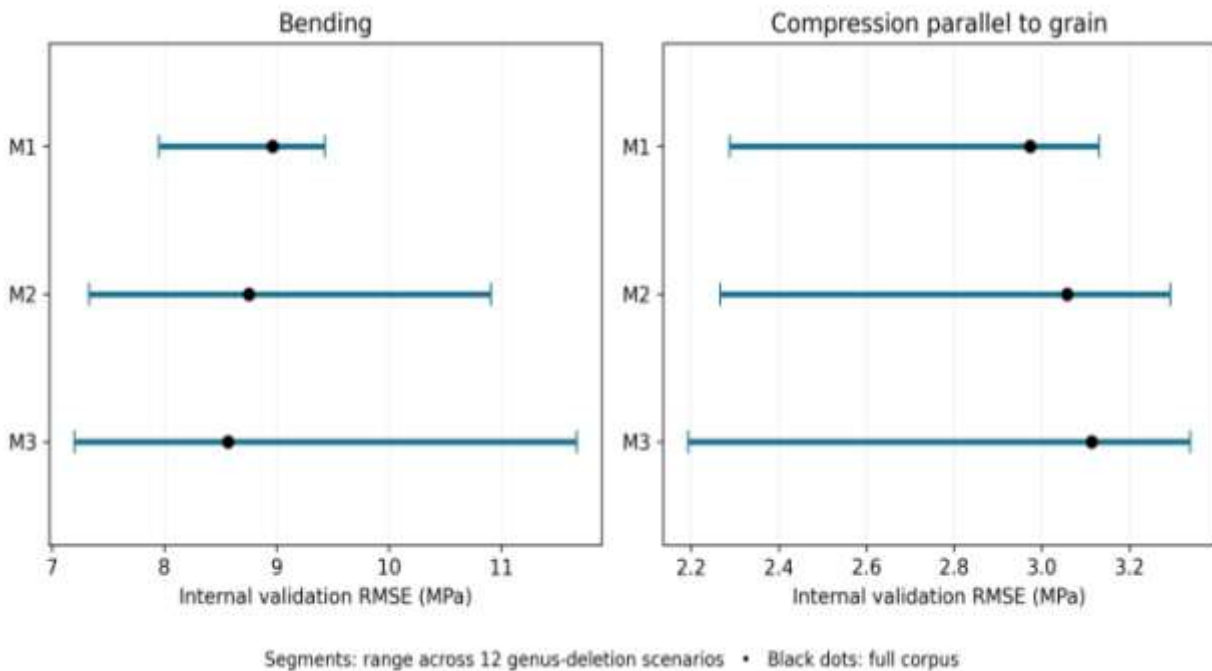


Figure 4. Sensitivity of model performance to corpus composition. Segments span minimum to maximum RMSE over twelve deterministic genus-deletion scenarios; black dots show full-corpus internal LOGO RMSE. These descriptive ranges are not confidence intervals.

Coefficient stability and influence of extreme references:-

The proportional coefficients varied modestly across the examined deletion scenarios. The bending coefficient ranged from 0.14110 to 0.14559 MPa·m³/kg, with descriptive deletion-scenario CV 0.93%; the compression coefficient ranged from 0.08432 to 0.08616 MPa·m³/kg, with CV 0.53%. These CVs are sensitivity measures, not

standard errors or confidence intervals. Their small values characterise these overlapping perturbations and should not be interpreted as high population-level coefficient precision.

Table 6. Proportional coefficients following deletion of density extremes, in MPa·m³/kg.

Corpus	Bending c	Compression c
Full corpus	0.14367	0.08545
Without azobé	0.14164	0.08432
Without ayous	0.14383	0.08561
Without both	0.14178	0.08447

Note: coefficients are fitted to retained references. They are distinct from errors obtained by repeating internal validation within a reduced corpus. Reported CVs are descriptive deletion-scenario CVs, not coefficient standard errors or confidence intervals. Removing azobé reduced the coefficients by 1.42% in bending and 1.33% in compression; removing ayous increased them by 0.11% and 0.18% (Table 6). This asymmetry is consistent with the squared-density leverage of a proportional fit without an intercept. Azobé had leverage 0.182 under M1 and 0.422 under M2. Its M1 Cook's distance in compression was 1.074, identifying meaningful influence but not invalidating the observation. The modest coefficient changes show that the global relationship was not determined by this reference alone.

Table 7. Full-fit influence diagnostics for the density extremes.

Model	Reference	Leverage	r bending	D bending	r compression	D compression
M1	Azobé	0.182	-1.30	0.374	-2.20	1.074
M1	Ayous	0.023	0.32	0.002	0.92	0.020
M2	Azobé	0.422	-0.85	0.261	-1.68	1.033
M2	Ayous	0.254	-0.25	0.011	0.13	0.003

Note: r, internally studentised residual with prediction-minus-observation sign; D, Cook's distance. No automatic exclusion threshold was used. Cook's distance summarises the change in a fitted regression associated with deleting an observation; a large value signals influence and does not by itself diagnose erroneous data.

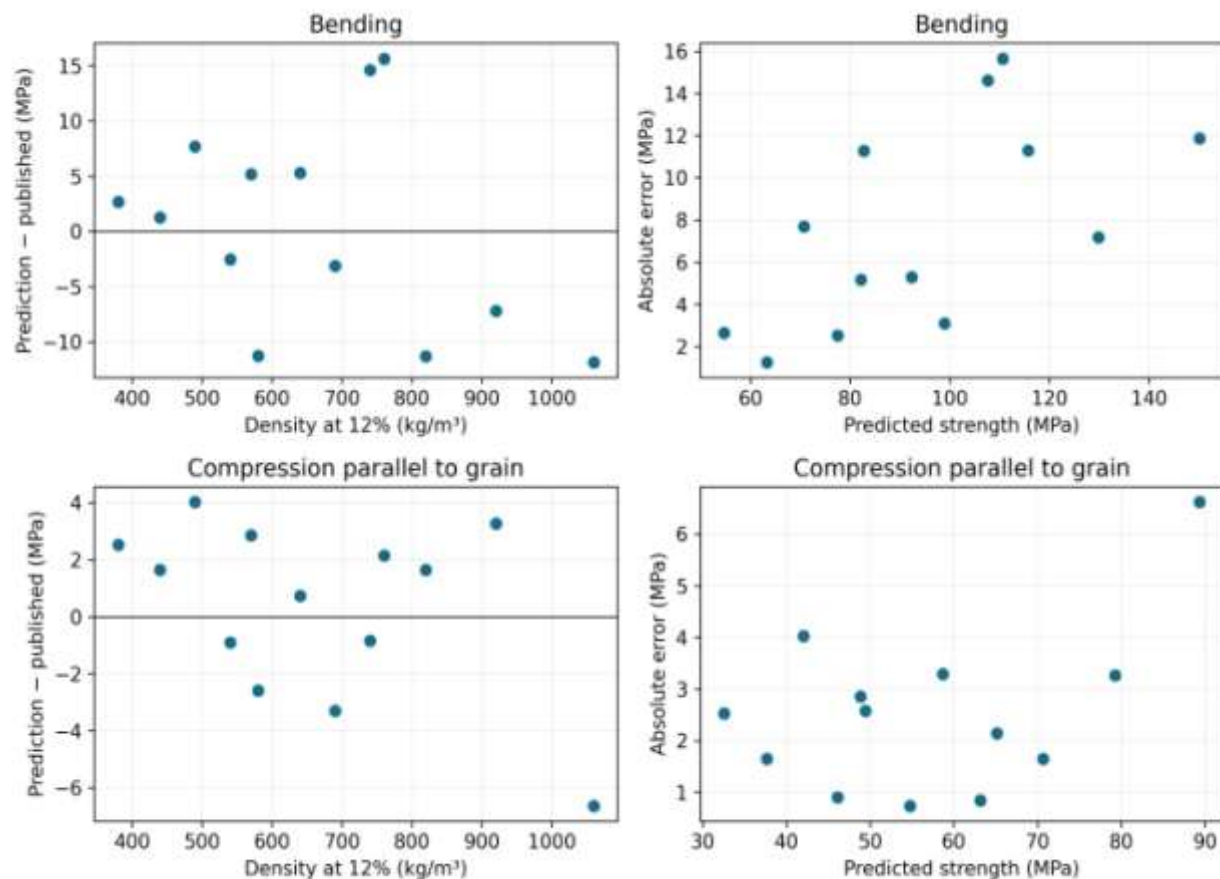


Figure 5. M1 internal LOGO residuals against density and absolute errors against predicted strength. Patterns describe errors among reference means; thirteen observations do not establish a reliable variance model.

Residuals changed sign at similar densities. In compression, azobé produced the largest absolute held-out error. The plots do not provide enough evidence to specify a stable heteroscedastic error model, and no additional response-dependent weighting was imposed. Omitting azobé left Pearson density–strength correlations of 0.949 in bending and 0.988 in compression, compared with 0.969 and 0.991 for the full corpus. M1 centred fit R^2 changed from 0.931 to 0.899 and from 0.977 to 0.976; residual standard errors changed from 8.27 to 8.00 MPa and from 2.72 to 2.20 MPa. Recomputed internal LOGO RMSE was 9.01 MPa in bending and 2.29 MPa in compression. Together with the slope changes in Table 6, these diagnostics support an approximately proportional descriptive trend after removal, while showing its effect on the upper density range. Errors across these different test populations are sensitivity comparisons, not performance gains on an unchanged population.

Omitting bubinga or ovengkol separately gave M1 internal RMSE values of 9.17/2.94 MPa and 8.76/3.08 MPa, respectively (bending/compression). Restricting the dataset to the nine single-species sheets gave 8.68/3.05 MPa. Density remained more informative than the mean-only baseline in these checks, without resolving unknown campaign dependence. Full results are provided in `Additional_diagnostics.csv`; the original thirteen-reference corpus remains the primary analysis.

Discussion:-

What the results add:-

The clearest finding is the scale of improvement delivered by density relative to a predictor-free estimate. Reductions of 73.2% and 84.4% in internal RMSE demonstrate that this simple physical variable is informative for the analysed reference means. The contribution extends established density–strength associations (Dias and Lahr, 2004; Lahr et al., 2021) by quantifying held-out accuracy, documenting individual error magnitudes and testing how the conclusion changes with corpus composition. The distinction between predictor usefulness and model-form

preference is particularly valuable. Density retained a large predictive advantage across all examined deletions, and proportional coefficients showed small descriptive variation. At the same time, ranking reversals caution against treating the small full-corpus RMSE differences as evidence of an exact underlying law. A single-coefficient equation captured most of the observed predictive benefit while remaining straightforward to interpret and reproduce. This makes it a useful starting point for independent testing. The two responses also yield complementary information. Compression had lower relative errors here, including a MAPE of 4.74%, compared with 8.00% in bending. This comparison is a finding about the present corpus rather than a universal statement that compression must always be more predictable. Differences in source populations, measurement protocols or aggregation could alter the relationship in another dataset.

Aggregation and the three levels of interpretation:-

The fitted relation concerns reference means, expressed conceptually as $\bar{f}_j = g(\bar{\rho}_j) + \varepsilon_j$. A specimen-level relation would instead link f_{ij} to ρ_{ij} , with additional within-reference variation. Without individual paired measurements, these between- and within-reference components cannot be separated. Averaging can smooth variability and contribute to apparently favourable errors. Consequently, the compression MAPE of 4.74% is not an expected error for a randomly selected piece of iroko, azobé or another timber. Figure 6 separates three questions. Documentary error is quantified by held-out residuals. Composition sensitivity is explored by overlapping deterministic deletions. Transfer to pieces, trees, lots and provenances remains to be measured. Neither the empirical error percentiles nor the min-max sensitivity ranges have guaranteed probabilistic coverage. Making these distinctions explicit gives the equations a clear and useful domain rather than an unspecified claim of reliability.

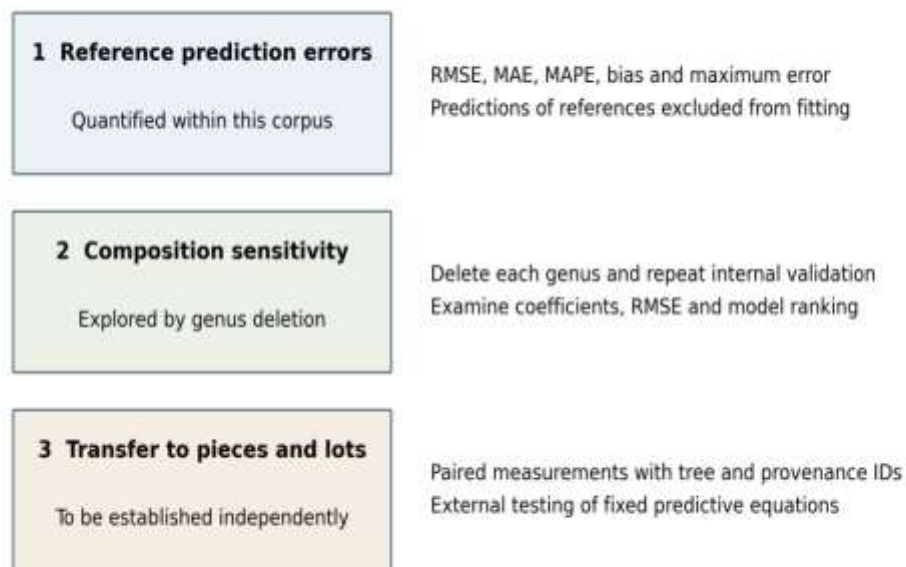


Figure 6. Three distinct levels of interpretation. Observed documentary errors and composition sensitivity are evaluated here; predictive accuracy for individual pieces and independent regional lots requires new data.

Illustrative reference-mean estimate:-

For an illustrative reference-mean estimate, take $\rho_{12} = 700 \text{ kg/m}^3$. The mass-to-volume arithmetic below uses hypothetical values of 0.700 kg and 1000 cm³ at 12% moisture solely to explain the density input; it is not a specimen test or a specimen-strength prediction.

$$\rho_{12} = \frac{0.700 \text{ kg}}{0.001 \text{ m}^3} = 700 \text{ kg/m}^3 \quad (9)$$

Equations (7) and (8) give illustrative reference-mean estimates of 100.6 MPa in bending and 59.8 MPa in compression. Table 8 gives similar central estimates within the fitted domain. These are not characteristic or design strengths and do not certify an individual piece or lot.

Table 8. Illustrative reference-mean strength estimates; not characteristic or design strengths.

ρ_{12} (kg/m ³)	Bending (MPa)	Compression (MPa)
400	57.5	34.2
500	71.8	42.7
600	86.2	51.3
700	100.6	59.8
800	114.9	68.4
900	129.3	76.9
1000	143.7	85.5

Note: estimates apply to the reference-mean relationship and are not characteristic or design strengths. The fitted density domain is 380–1060 kg/m³.

Appendix A Documentary selection and source roles:-

Table A1. Roles of the information sources. Only the first row supplies model observations.

Information	Source	Role in numerical models
Density and both strength means	Tropix (CIRAD, 2023–2026)	Yes: all 39 numerical inputs in Table 1
Named selection framework	Wood Handbook, Table 5–5a (Senalik and Farber, 2021)	No training or independent validation values
Physical definitions and prior findings	Gérard et al. (2016); Glass and Zelinka (2021); cited research	Context and interpretation only
Guinean botanical occurrence	Gosline et al. (2023)	Context only; no Guinean strength observations
Structural design distinction	CEN (2008); Swedish Wood (2022)	Context only; no model calibration

Selection flow: 17 AF-coded handbook references considered → 13 verified matches in the archived African sheet list → 13 with all required properties → 13 analysed. The four excluded entries below have no verified eligible match in the archived selection. This does not prove global database absence or missing mechanical properties under every alias.

Table A2. Excluded handbook entries and documented exclusion status.

Handbook designation	Botanical designation in handbook	Reason for exclusion
Angelin	Andira inermis	No eligible match established in archived African sheet selection
Benge	Guibourtia arnoldiana	No eligible match established; bubinga or ovengkol not substituted
Cypress Mexican	Cupressus lustianica (source spelling)	No eligible match established in archived African sheet selection
Ekop	Tetraberlinia tubmaniana	No eligible match established; broad commercial aliases not substituted

The archived list and the seventeen-entry crosswalk are supplied in the supplement. The audit establishes the matches actually used, not the completeness of an unrestricted database search. No verified matched sheet was removed because its fitted residual was large or because one of the three extracted properties was missing.

Input quality remains important. For a proportional equation, a density perturbation $\Delta\rho$ changes the estimate by $c\Delta\rho$. An illustrative $\pm 20 \text{ kg/m}^3$ perturbation therefore produces approximately $\pm 2.87 \text{ MPa}$ in bending and $\pm 1.71 \text{ MPa}$ in compression. These are arithmetic sensitivity values, not measured instrument uncertainties. They cannot be combined with validation RMSE as independent random components without an appropriate error model. Moisture state, specimen geometry and any deterioration should be checked before using a mass-to-volume ratio as the input.

Relevance to Guinea and West Africa:-

For Guinea, the selected references provide hypotheses and candidate density ranges for future testing. *Lophira alata*, *Triplochiton scleroxylon* and *Terminalia superba* are documented in the Guinean flora (Gosline et al., 2023), which supports botanical relevance but does not establish local predictive accuracy. Neither Guinean sampling origins nor the representativeness of these means for local commercial supplies have been demonstrated. A practical application is to use documentary estimates to plan which density ranges and materials to include in a mechanical testing programme. Researchers can compare anticipated mean strengths across candidate references, identify materials for which direct evidence is sparse, and reserve independent lots to assess prediction errors. In this role, the present equations provide quantitative expectations and an explicit benchmark against which a local validation can be judged. The same approach can support comparable work in other West African countries when material identity and moisture conditions are verified.

The proposed validation sequence is: documentary training dataset $\rightarrow$ fixed equations $\rightarrow$ independent regional lots with paired density and strength measurements $\rightarrow$ assessment of prediction errors $\rightarrow$ recalibration only if justified. Piece, tree, lot and provenance identifiers would allow variation at different levels to be separated. If local recalibration is undertaken, further reserved lots should assess the updated equations. Sample size should be designed around expected variability and the intended precision. This is a prospective programme, not an experiment reported here.

Distinction from structural design values:-

A predicted documentary mean cannot replace a characteristic or design strength. EN 1995-1-1:2004+A1:2008, clause 2.4.1(1)P, distinguishes characteristic properties from design values through load-duration/moisture and partial factors (CEN, 2008; Swedish Wood, 2022). This edition is cited only to clarify the distinction, not as a statement of the code applicable in Guinea or another project jurisdiction. Subtracting a documentary RMSE from the predicted mean would not establish a valid characteristic fractile.

Limitations and perspectives:-

The evidence is limited to thirteen selected reference means, with unknown source sample sizes and within-reference variances. Four sheets list multiple species; testing-protocol differences and shared source campaigns cannot be quantified from the available records. Genus replication is weak, and all cross-validation remains internal. Thus specimen-level errors, biological variance components, coefficient confidence intervals with credible population coverage, and geographic transferability cannot be established. The supplementary metadata register identifies missing fields rather than assigning unsupported values. These gaps motivate independent, traceable sampling; they do not require expanding the present exploratory study into a new experimental programme. Within that scope, the analysis offers a reproducible and practically interpretable result. Additional statistical complexity would not resolve the missing specimen-level evidence. The most productive improvement is independent data collection that separates within-species variation from differences among species and tests whether the observed predictive advantage persists for local timber lots.

Conclusion:-

Density at 12% moisture content supplied substantial predictive information for the mean strengths of thirteen African timber references. The proportional equations $\hat{f}_m = 0.14367\rho_{12}$ and $\hat{f}_{c,0} = 0.08545\rho_{12}$, with density in kg/m^3 and strength in MPa, achieved internal genus-out RMSE values of 8.96 and 2.97 MPa. These represent improvements of 73.2% and 84.4% over a mean-only baseline, with lower relative errors for compression in this corpus. The predictive benefit within this corpus persisted across the examined deletion scenarios. Proportional coefficients showed descriptive deletion-scenario CVs below 1%, while ranking reversals between functional forms prevented a robust claim that one shape is superior. These sensitivity results complement the internal prediction

errors; they do not quantify population coefficient uncertainty. The study provides a quantitative starting point for documentary screening and for defining hypotheses and density ranges to test in Guinea and West Africa. Independent regional measurements remain a perspective necessary to assess practical transfer. The demonstrated result is an informative relationship among selected reference means, not a validated method for characterising individual timber pieces.

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Declarations:-

Ethics: This study analysed published timber-property data and involved no human participants or animals.

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Conflicts of interest:-

The authors declare no conflict of interest.

References:-

1. CEN (2008). EN 1995-1-1:2004+A1:2008. Eurocode 5: Design of timber structures—Part 1-1: General—Common rules and rules for buildings. European Committee for Standardization, Brussels. Clause 2.4.1(1)P, equation (2.14). Includes the June 2006 corrigendum.
2. CIRAD (2023–2026). Tropix: technical sheets for thirteen African timbers. Individual sheet versions, dates and URLs are provided in the supplementary source register. <https://tropix.cirad.fr/> (source extraction: 19 September 2026).
3. Dias, F. M., and Lahr, F. A. R. (2004). Estimativa de propriedades de resistência e rigidez da madeira através da densidade aparente. *Scientia Forestalis*, 65, 102–113. <https://www.ipef.br/publicacoes/scientia/nr65/cap10.pdf>
4. Gérard, J. (coord.), Guibal, D., Cerre, J.-C., and Paradis, S. (2016). Atlas des bois tropicaux: caractéristiques technologiques et utilisations. Éditions Quæ, Versailles. ISBN 978-2-7592-2550-7. <https://www.quae.com/produit/1408/9782759225521/atlas-des-bois-tropicaux>
5. Glass, S. V., and Zelinka, S. L. (2021). Moisture relations and physical properties of wood. In *Wood Handbook—Wood as an Engineering Material*, Chapter 4. FPL-GTR-282. USDA Forest Service. <https://research.fs.usda.gov/download/treesearch/62243.pdf>
6. Gosline, G., Bidault, E., van der Burgt, X., et al. (2023). A Taxonomically-verified and Vouchered Checklist of the Vascular Plants of the Republic of Guinea. *Scientific Data*, 10, 327. <https://doi.org/10.1038/s41597-023-02236-6>. Checklist version 1.10: <https://doi.org/10.5281/zenodo.7734985>
7. Lahr, F. A. R., Arroyo, F. N., Rodrigues, E. F. C., et al. (2021). Models to estimate longitudinal compressive strength of Brazilian hardwood based on apparent density. *BioResources*, 16(1), 1373–1381. <https://doi.org/10.15376/biores.16.1.1373-1381>
8. NIST (n.d.). Regression Diagnostics. *Dataplot Reference Manual*. <https://www.itl.nist.gov/div898/software/dataplot/refman1/auxillar/regdiag.htm>
9. NIST/SEMATECH (n.d.). How can I tell if a model fits my data? e-Handbook of Statistical Methods, Section 4.4.4. <https://www.itl.nist.gov/div898/handbook/pmd/section4/pmd44.htm>
10. Roberts, D. R., Bahn, V., Ciuti, S., et al. (2017). Cross-validation strategies for data with temporal, spatial, hierarchical, or phylogenetic structure. *Ecography*, 40(8), 913–929. <https://doi.org/10.1111/ecog.02881>
11. Senalik, C. A., and Farber, B. (2021). Mechanical properties of wood. In *Wood Handbook—Wood as an Engineering Material*, Chapter 5. FPL-GTR-282. USDA Forest Service. <https://research.fs.usda.gov/download/treesearch/62244.pdf>
12. Swedish Wood (2022). Design of Timber Structures. Volume 2: Rules and Formulas According to Eurocode 5. Third edition. <https://www.swedishwood.com/siteassets/5-publikationer/pdfer/sw-design-of-timber-structures-vol2-2022.pdf>