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Socioeconomic Dependence on Non-timber Forest Products in the Bloc Kébé Research Forest, East Cameroon

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Authors' contributions

This work was carried out in collaboration among all authors. Author OT designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors MALM and JGNM managed the analyses of the study. Author JGNM managed the literature searches. All authors read and approved the final manuscript.

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Abstract

Aim: This study aimed to quantify the socio-economic importance of the Bloc Kébé research forest, East Cameroon) to riparian livelihoods by assessing non-timber forest products (NTFP) collection patterns, use types, income generation, and perceived dependency for food security and health.
Study Design: A cross-sectional household survey was conducted across six villages at varying distances (0.5–7.66 km) from the forest boundary, with stratified proportional sampling yielding 86 households.

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Methodology: Semi-structured questionnaires captured collection, use type (subsistence/commercial/both), annual income (FCFA), and perceived food and health dependency (Likert 1–5) over a 12-month recall period. Analyses included mixed-effects logistic regression (GEE), multinomial logistic regression, Kruskal-Wallis with Dunn's post-hoc tests, Cumulative Link Mixed Models, Spearman correlations, and two-way ANOVA.

Results: Overall NTFP collection rate was 74%, commercialization rate 59%, and mean annual income 12,097 ± 17,773 FCFA. Distance to forest was the dominant predictor of collection probability (OR = 0.52 per km, $p < 0.001$), income, and both food ($\beta = -0.15$, $p < 0.001$) and health dependency. The closest village outperformed the farthest across all metrics (collection: 94% vs. 71%; commercialization: 82% vs. 64%; income: 22,200 vs. 5,563 FCFA). *Irvingia gabonensis* was 12.55 times more likely commercialized than used for subsistence alone ($p = 0.018$); *Strychnos toxifera* showed dominant health dependency (3.98 vs. 1.34, $d = -2.55$). Five of six focal species had significantly greater food than health dependency ($d = 0.77$–1.79, $p < 0.001$). Income, collection, and commercialization were tightly coupled ($\rho = 0.686$–0.868, $p < 0.001$), but interspecific income differences were non-significant ($\chi^2(4) = 7.52$, $p = 0.111$). Significant village-level spatial heterogeneity emerged for *Termitomyces* spp., *Cola* spp., and *Trichoscypha abut*.

Conclusion: Forest dependence is high, multidimensional, species-specific, and spatially structured by distance, with proximity-driven inequalities in income and food-health outcomes. Conservation zoning must integrate these differentiated dependencies.

Keywords: Congo Basin; distance decay; forest dependency; livelihood security; non-timber forest products.

Definitions

Term / Acronym	***Definition***
Bloc Kébé	*A 3,868-ha research and teaching forest within the Deng-Deng reserve, East Cameroon*
Both Use	*NTFP collection serving both household consumption and cash income generation*
CLMM	*Cumulative Link Mixed Model; a regression model for ordinal response variables with random effects*
Cohen's d	*A standardized effect size measure for mean differences (0.2 = small, 0.5 = medium, 0.8 = large)*
Cohen's h	*A standardized effect size measure for differences between proportions (0.2 = small, 0.5 = medium, 0.8 = large)*
Collection Rate	*Proportion of surveyed households that harvested a given NTFP species within the past 12 months*
Commercial Use	*NTFP collection exclusively for sale in local or regional markets*
Commercialization Rate	*Proportion of surveyed households that sold at least one NTFP species within the past 12 months*
Deng-Deng Reserve	*A 210,000 ha forest reserve in East Cameroon, within which Bloc Kébé is located*
ε^2	*Epsilon-squared; a non-parametric effect size measure for Kruskal-Wallis tests (0.01 = small, 0.06 = medium, 0.14 = large)*
FCFA	*Franc de la Coopération Financière en Afrique Centrale; the official currency of Cameroon and five other Central African states*
Food Dependency	*Perceived importance of an NTFP species for household food needs, measured on a Likert scale (1 = not important, 5 = extremely important)*
GEE	*Generalized Estimating Equations; a statistical method for analyzing correlated data, used here with exchangeable correlation structure*
Health Dependency	*Perceived importance of an NTFP species for medicinal/health needs, measured on a Likert scale (1 = not important, 5 = extremely important)*
Holm Correction	*A sequential Bonferroni-type procedure for controlling family-wise error rate in multiple pairwise comparisons*
Likert Scale	*A 5-point ordinal rating scale used to measure perceived dependency (1 = not important to 5 = extremely important)*
McFadden's R²	*A pseudo-R² measure for logistic regression models, indicating proportional improvement over the null model*

Term / Acronym	***Definition***
NTFP	*Non-Timber Forest Product: any biological resource other than timber harvested from forests for human use*
OR	*Odds Ratio; the ratio of odds of an outcome occurring given a predictor relative to a reference category*
Pillai's Trace	*A multivariate test statistic used in MANOVA to assess overall differences among groups across multiple dependent variables*
Riparian Communities	*Local populations residing adjacent to or in close proximity to the forest boundary*
RRR	*Relative Risk Ratio; the ratio of probabilities of an outcome category relative to a reference category in multinomial logistic regression*
Spearman's ρ	*A rank-based correlation coefficient measuring monotonic associations between variables (–1 to +1)*
Subsistence Use	*NTFP collection exclusively for direct household consumption, with no cash sales*
Use Type	*Classification of NTFP utilization as subsistence only, commercial only, both, or none*
VIF	*Variance Inflation Factor; a measure of multicollinearity in regression models (values < 2 indicate negligible collinearity)*

1. Introduction

Central Africa's forests, with the Congo Basin as the world's second-largest tropical forest block, underpin regional and global ecological stability. Cameroon holds over 20 million hectares of humid tropical forest, contributing to the national economy, rural livelihoods, and environmental services (Bas et al., 2022; Kimengsi et al., 2019; Kimengsi et al., 2025). However, these forests face accelerating deforestation (0.6–1% annually between 1980–2005) and degradation driven by agricultural expansion, illegal logging, and unsustainable resource extraction (Carodenuto et al., 2015; Deba Enomah et al., 2025; Lhoest et al., 2020; Mumbang et al., 2025; Tatuebu Tagne et al., 2022). This trajectory threatens long-term ecosystem viability.

For millions of rural Cameroonians, Non-Timber Forest Products (NTFPs) serve as a cornerstone of livelihood security. NTFPs provide essential food, medicine, construction materials, and cash income, acting as a safety net during economic hardship (Awono et al., 2016; Djeugap et al., 2019; Epanda et al., 2020; Kamga, 2023). Over 40% of total household income in forest-adjacent communities can derive from NTFPs. Critically, many high-value species; *Baillonella toxisperma* (Moabi), *Irvingia gabonensis* (Bush Mango); yield both premium timber and vital NTFPs, creating direct conflict between industrial logging and local subsistence and commercial needs (Njapa Mbiaha et al., 2025; Njike & Mbassi, 2025).

Recent studies indicate that NTFP-dependent livelihoods are influenced by household characteristics, income sources, market conditions, and the availability of alternative employment opportunities (Abhishek & Parayil, 2024; Chaudhari & Khunt, 2024). Evidence from other forest-dependent regions also shows that forest resources support multiple livelihood functions, while the contribution of NTFPs to household income differs across locations and product categories (Bisui & Shit, 2024; Derebe & Alemu, 2023).

The Bloc Kébé, originally demarcated as a teaching and experimental forest from the larger Deng-Deng production forest, it retains high biodiversity yet faces severe degradation from anarchic uses. Illegal timber extraction and intensive NTFP harvesting exceed regeneration capacity, threatening both resource flows to local populations and overall biodiversity.

The forest's intended function - research and education - requires effective management, including potential formal classification. Such measures depend on riparian community participation and support (Becoche Mosquera & Macías Pinto, 2025; Dinca et al., 2025; Masiero et al., 2024; Saklaurs et al., 2025). However, a quantitative baseline of how households depend on this forest for food security, health, and income is rare and sometimes totally absent.

This study aimed to determine the socio-economic importance of the Bloc Kébé forest massif to riparian livelihoods. We hypothesized that riparian communities exhibit high forest dependence for both subsistence and income, and that support for conservation measures is contingent upon recognition of this socio-economic importance.

2. Methodology

2.1 Study Area and Survey Design

The study was conducted in the Bloc Kébé, a research forest located within the Deng-Deng forest reserve (210,000 ha) in the East Region of Cameroon. The area lies between 4°30'–5°30' N and 13°11'–13°30' E, approximately 20 km from Bertoua, in the Lom and Djérem Division, Bélabo Subdivision.). The area is bounded: to the North by the Lom, to the West by the Sanaga and the Yong, to the South by the Aberu and Saa rivers up to the village of Mbang, then following the Nanga-Eboko–Bertoua–Bétaré-Oya road. The Bloc Kébé was selected because it is a research forest under threat from illegal logging and artisanal NTFP extraction, yet retains high biodiversity and provides critical resources for local livelihoods, making it ideal for assessing socio-economic dependencies and forest resource dynamics. The climate is equatorial Guinean with four seasons (two rainy, two dry), mean annual rainfall of 1,550 mm, and mean annual temperature of 23.5°C. Vegetation is semi-deciduous moist forest dominated by *Sterculiaceae* and *Ulmaceae*, with abundant commercial timber species and NTFPs.

Six villages bordering the forest reserve were purposively selected: Bélabo, Mambaya, Ndemba, Yanda, Yambeng, and Ebaka. These represent varying distances from the forest (0.5–7.66 km) and include both road-accessible and more remote settlements.

Household sampling was stratified proportional to village population size. All households within 5 km of the forest boundary with at least one member engaged in forest resource collection were eligible.

2.2 Data Collection

Data were collected from March to June 2025 (covering both dry and early rainy seasons). A structured household questionnaire was submitted in French and local language Bulu, with translation assistance.

All species were locally available within the Bloc Kébé or its immediate periphery. Collection data were verified by asking households to show stored products or recall last harvest date to minimize recall bias.

2.3 Statistical Analysis

All statistical analyses were performed using Python 3.11 with libraries pandas, NumPy, SciPy, and StatsModels. The significance threshold was set at $\alpha = 0.05$ for all tests. Multiple comparison corrections were applied where noted: Holm correction for Dunn's post-hoc tests and Bonferroni correction for multinomial logistic regression contrasts. Continuous variables were tested for normality; non-parametric methods (Kruskal-Wallis, Spearman) were used for income and correlation analyses. Log-transformation ($\log_{10}$ [income + 1]) was applied for ANOVA on income. Mixed-effects models used GEE with exchangeable correlation structure. For the CLMM (food dependency), a linear mixed model approximation was used due to convergence issues with ordinal models.

3. Results

3.1 Socio-demographic Profile of Riparian Households

Table 1 details the socio-demographic profile of riparian households. A total of 86 households across six villages (Bélabo, Mambaya, Ndemba, Yanda, Yambeng, and Ebaka) were surveyed. NTFP collection rates differed significantly across villages ($\chi^2 = 21.40$, $p = 0.001$). Bélabo had the highest collection rate (94%), followed by Mambaya (83%), while Ndemba recorded the lowest (71%). The overall collection rate was 74%. Commercialization rates also varied significantly ($\chi^2 = 22.42$, $p < 0.001$). Bélabo again showed the highest rate (82%), compared to Mambaya (67%) and Ndemba (64%), with an overall mean of 59%. Annual household income from NTFPs was significantly different between villages ($F = 5.80$, $p < 0.001$). Bélabo households earned the most (22,200 ± 21,245 FCFA), followed by Mambaya (12,158 ± 17,398 FCFA), while Ndemba earned the least (5,563 ± 5,946 FCFA). The overall mean annual income from NTFPs was 12,097 ± 17,773 FCFA.

Table 1. Socio-demographic profile of riparian households

Variable	Bélabo	Mambaya	Ndemba	Total	p-value†
Collection rate (any NTFP, %)	94%	83%	71%	74%	0.001***
Commercialization rate (%)	82%	67%	64%	59%	0.000***
Annual HH income from NTFPs (FCFA)	22,200 ± 21,245	12,158 ± 17,398	5,563 ± 5,946	12,097 ± 17,773	0.000***

†p-value from one-way ANOVA (continuous) or chi-square (categorical).
**p<0.05, **p<0.01, ***p<0.001.*

3.2 Utilization Patterns of Major NTFP Species

Fig. 1 presents the utilization patterns of major NTFP species. Among the 86 surveyed households, six NTFP species showed the highest collection frequencies. *Trichoscypha abut* was collected by 23 households (26.7%), followed by *Strychnos toxifera* (18 households, 20.9%), *Irvingia gabonensis* (15 households, 17.4%), *Termitomyces* spp. (14 households, 16.3%), *Raphia hookeri* (14 households, 16.3%), and *Cola* spp. (13 households, 15.1%). All six species were used either for subsistence, commercial sale, or both, with no species being "not collected" by any household. Use type proportions varied across species. *Termitomyces* spp S. toxifera was predominantly used for subsistence only (66.7%), with only 11.1% used commercially and 22.2% for both. Similarly, I. *gabonensis* R. *hookeri* showed strong subsistence orientation (57.1% subsistence only), followed by R. *hookeri Termitomyces* spp. (50.0% subsistence only). S. toxifera I. *gabonensis* exhibited the highest commercial-only use (40.0%), with 26.7% for both and 33.3% for subsistence only. *Cola* spp and T. *abut Cola* spp. demonstrated mixed patterns: *Cola* spp had 39.1% commercial-only, 39.1% subsistence-only, and 21.7% both; T. *abut* had 38.5% both, 38.5% subsistence-only, and 23.1% commercial-only. Chi-square tests revealed no significant differences in use type distribution across species for any comparison: T. *abut* (χ^2 = 2.65, df = 2, p = 0.266), S. *toxifera* (χ^2 = 4.14, df = 2, p = 0.126), I. *gabonensis* (χ^2 = 1.88, df = 2, p = 0.391), *Termitomyces* spp. (χ^2 = 1.06, df = 2, p = 0.587), R. *hookeri* (χ^2 = 1.28, df = 2, p = 0.528), and *Cola* spp. (χ^2 = 0.57, df = 2, p = 0.753).

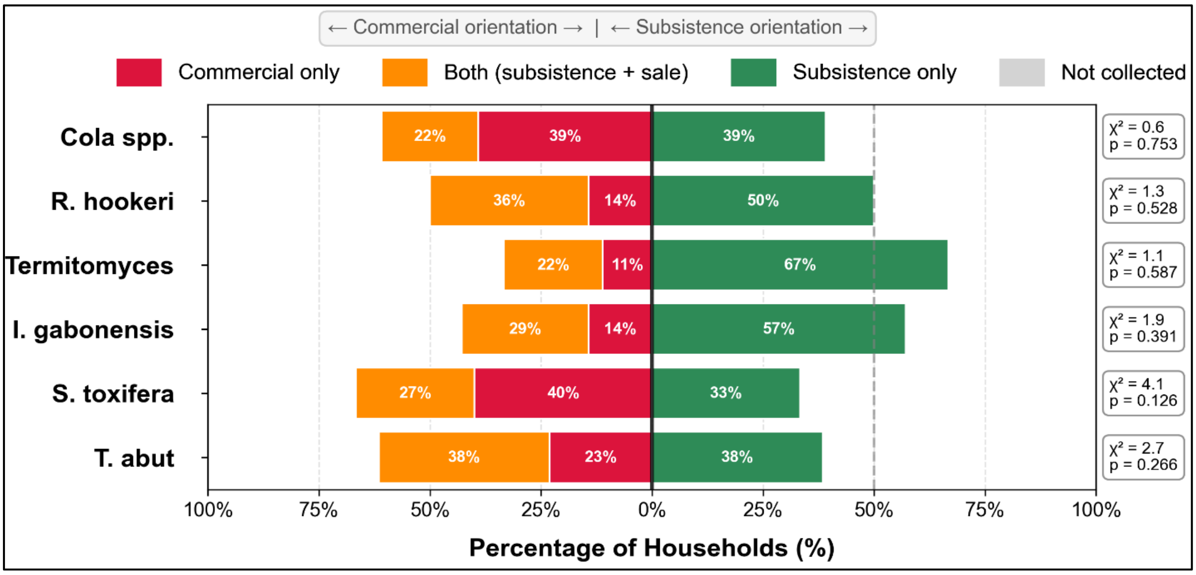

Fig. 1. Utilization patterns of major NTFP species

3.3 Factors Influencing NTFP Collection Probability

Table 2 details the factors influencing NTFP collection probability. A mixed-effects logistic regression (GEE with exchangeable correlation structure, $\rho \approx 0.34$) was fitted to identify factors influencing NTFP collection (yes/no). The model included 258 observations across 6 villages, with species identity, household size, and distance to forest as fixed effects. Likelihood ratio $\chi^2(4) = 39.1$, $p < 0.001$, with pseudo-R^2 (McFadden) = 0.14 and Tjur's R^2 = 0.14. Maximum VIF was 1.33, indicating no multicollinearity. Species identity did not significantly affect collection probability. Compared to the reference species S. *toxifera* (collection rate 20.9%), I. *gabonensis* (17.4% collection) showed OR = 0.77 [95% CI: 0.44–1.35], p = 0.364, with a small effect size (Cohen's h = 0.10). T. *abut* (26.7% collection) showed OR = 1.46 [95% CI: 0.84–2.55], p = 0.179, with a small effect size (Cohen's h = 0.16). Household size significantly decreased collection probability (OR = 0.93 per one-person increase, 95% CI: 0.87–0.99, p = 0.017), though with negligible effect size (Cohen's h = 0.03). Distance to forest was the strongest predictor (OR = 0.52 per 1 km increase, 95% CI: 0.46–0.59, p < 0.001), with a medium effect size (Cohen's h = 0.24). Collection rates decreased progressively across distance quartiles: 42.4% (closest), 25.4%, 15.2%, and 3.2% (farthest).

Table 2. Factors influencing NTFP collection probability

Fixed Effect	Odds Ratio (OR)	95% CI	p-value (Wald)	Effect Size (Cohen's h)
NTFP: I. gabonensis (ref: S. toxifera)	0.77	[0.44 – 1.35]	0.3638	0.10 (small)
NTFP: T. abut (ref: S. toxifera)	1.46	[0.84 – 2.55]	0.1794	0.16 (small)
Household size (per 1 person increase)	0.93	[0.87 – 0.99]	0.0170*	0.03 (negligible)
Distance to forest (per 1 km increase)	0.52	[0.46 – 0.59]	0.0000***	0.24 (medium)

Random effect: Village (GEE with exchangeable correlation, $\rho \approx 0.34$)
Model converged; VIF max = 1.33 (<2 indicates no multicollinearity)
Likelihood ratio $\chi^2(4) = 39.1$, p = 0.0000
Pseudo-R^2 (McFadden) = 0.14; Tjur's R^2 = 0.14

3.4 Predictors of NTFP Use Type

Table 3 presents predictors of NTFP use type. A multinomial logistic regression was fitted to predict use type (subsistence, commercial, both) among 56 observations. Separate binary models compared commercial vs. subsistence (n=43) and both vs. subsistence (n=39). For the commercial vs. subsistence outcome, the model was significant (LR $\chi^2(4) = 11.1$, p = 0.025; McFadden's R^2 = 0.193). I. *gabonensis* strongly predicted commercial use relative to subsistence: RRR = 12.55 [95% CI: 1.53–102.61], p = 0.018. Post-hoc Bonferroni contrast confirmed I. *gabonensis* differed significantly from S. *toxifera* for commercial use (p = 0.037). Household size negatively predicted commercial use (RRR = 0.67 per person increase, 95% CI: 0.46–0.99, p = 0.044), indicating larger households were less likely to commercialize NTFPs. Distance to forest did not significantly predict commercial use (RRR = 1.12, 95% CI: 0.68–1.84, p = 0.665). For the both vs. subsistence outcome, the model was not significant (LR χ^2 (4) = 2.1, p = 0.712; McFadden's R^2 = 0.043). I. gabonensis (RRR = 1.93, 95% CI: 0.29–12.84, p = 0.495), household size (RRR = 1.17, p = 0.392), and distance to forest (RRR = 0.84, p = 0.549) showed no significant effects. Post-hoc contrast for both uses showed no significant difference between I. *gabonensis* and S. *toxifera* (p = 0.989).

Table 3. Predictors of NTFP use type

Predictor	Outcome (Ref = Subsistence)	RRR	95% CI	p-value
NTFP: I. gabonensis	Commercial	12.55	[1.53 – 102.61]	0.0183*
NTFP: I. gabonensis	Both	1.93	[0.29 – 12.84]	0.4946ns
Household size	Commercial	0.67	[0.46 – 0.99]	0.0444*
Distance to forest	Commercial	1.12	[0.68 – 1.84]	0.6654ns

Post-hoc pairwise contrasts (Bonferroni): I. gabonensis significantly different from S. toxifera for Commercial (p=0.0366) and Both (p=0.9892)
RRR = Relative Risk Ratio
Model for Commercial (vs Subsistence): Log-likelihood = -23.29, McFadden's R^2 = 0.193, LR $\chi^2(4) = 11.1$, p = 0.0251
Model for Both (vs Subsistence): Log-likelihood = -23.76, McFadden's R^2 = 0.043, LR $\chi^2(4) = 2.1$, p = 0.7124

3.5 Economic Contribution of NTFPs by Species

Fig. 2 visualizes the economic contribution of NTFPs by species. Table 4 details summary statistics of Annual Income from NTFPs by Species. Table 5 presents post-Hoc pairwise comparisons for income differences among NTFPs. Annual household income from NTFPs was analyzed for five species: *I. gabonensis*, *R. heudelotii*, *T. abut*, *Piper nigrum*, and *P. macrophylla*. Among collecting households, median incomes were: *I. gabonensis*

(26,655 FCFA, n=15), *R. heudelotii* (10,477 FCFA, n=9), *T. abut* (6,376 FCFA, n=23), *Piper nigrum* (5,000 FCFA, n=10), and *P. macrophylla* (4,864 FCFA, n=4). Mean incomes followed a similar pattern: *I. gabonensis* (22,834 ± 17,899 FCFA), *R. heudelotii* (8,390 ± 4,303 FCFA), *T. abut* (6,995 ± 6,540 FCFA), *Piper nigrum* (5,741 ± 4,833 FCFA), and *P. macrophylla* (5,686 ± 3,478 FCFA). A Kruskal-Wallis test showed no significant global difference in income across species ($\chi^2 = 7.52$, df = 4, $p = 0.111$). The global effect size was medium ($\varepsilon^2 = 0.125$). Post-hoc pairwise comparisons using Dunn's test with Holm correction confirmed no statistically significant differences between any species pair. The comparison between *I. gabonensis* and *T. abut* yielded z = 2.40, unadjusted p = 0.016, Holm-adjusted p = 0.163 ns, with a small effect size ($\varepsilon^2 = 0.05$). *I. gabonensis* vs. *R. heudelotii* showed z = 1.21, adjusted p = 1.000 ns ($\varepsilon^2 = 0.05$, small). All remaining comparisons produced negligible effect sizes ($\varepsilon^2 = 0.01$) and non-significant adjusted p-values (p = 1.000).

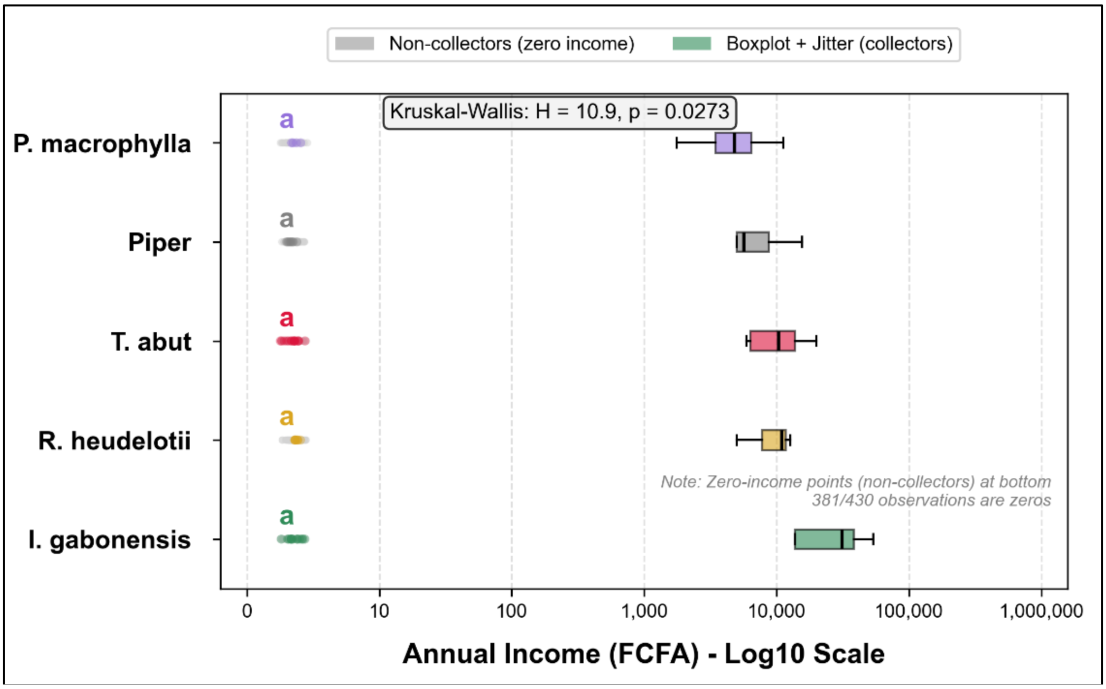

Fig. 2. Economic contribution of NTFPs by species

3.6 Determinants of food Versus Health Dependency on NTFPs

Table 6 details the factors influencing food security dependency. Fig. 3 summarizes change in dependency per NTFP Species. A Cumulative Link Mixed Model (approximated as Linear Mixed Model) was fitted to identify factors influencing food security dependency (Likert scale 1-5) across 258 observations from 6 villages (random effect variance = 0.02). The model was significant (LR $\chi^2(4) = 257.4$, $p < 0.001$, McFadden's pseudo-R^2 = 0.661). Species identity strongly predicted food dependency. Compared to the reference species S. toxifera (mean food dependency = 1.34 ± 0.06), I. *gabonensis* showed a coefficient of 2.44 (SE = 0.13, z = 18.89, p < 0.001, 95% CI: 2.19–2.70), corresponding to a mean food dependency of 3.78 ± 0.11. T. *abut* showed a coefficient of 2.36 (SE = 0.13, z = 18.26, p < 0.001, 95% CI: 2.11–2.61), with a mean food dependency of 3.70 ± 0.11. Household size did not significantly predict food dependency (coefficient = -0.02, SE = 0.03, z = -0.86, p = 0.387, 95% CI: -0.08–0.03).

Distance to forest negatively predicted food dependency (coefficient = -0.15, SE = 0.04, z = -3.93, p < 0.001, 95% CI: -0.22 to -0.08), with mean food dependency decreasing from 3.26 (closest quartile) to 2.65 (farthest quartile). Paired t-tests compared food versus health dependency for six species. Five species showed significantly higher food than health dependency: I. *gabonensis* (food: 3.78 ± 0.11, health: 1.84 ± 0.09, difference = +1.94, t = 13.52, p < 0.001, Cohen's d = 1.47 large); T. *abut* (3.70 ± 0.11 vs. 1.81 ± 0.08, difference = +1.88, t = 14.08, p < 0.001, d = 1.53 large); *Termitomyces* spp. (3.55 ± 0.10 vs. 1.50 ± 0.07, difference = +2.05, t = 16.55, p < 0.001, d = 1.79 large); *Cola* spp. (3.06 ± 0.09 vs. 2.10 ± 0.08, difference = +0.95, t = 8.91, p < 0.001, d = 0.97 large); R. *hookeri* (2.23 ± 0.09 vs. 1.45 ± 0.07, difference = +0.78, t = 7.07, p < 0.001, d =

0.77 medium). In contrast, S. *toxifera* showed significantly higher health than food dependency (food: 1.34 ± 0.06, health: 3.98 ± 0.10, difference = -2.64, t = -23.55, p < 0.001, d = -2.55 large).

3.7 Multivariate Relationships among Socio-Economic Variables

Fig. 4 visualizes a heatmap of spearman correlations among socio-economic variables. Spearman correlation analysis was conducted on seven household-level variables (n = 86 households). Income showed strong positive correlations with commercialization rate (ρ = 0.868, p < 0.001) and collection rate (ρ = 0.686, p < 0.001). Commercialization rate also correlated strongly with collection rate (ρ = 0.708, p < 0.001). Food dependency correlated moderately with income (ρ = 0.494, p < 0.001), collection rate (ρ = 0.383, p < 0.001), and commercialization rate (ρ = 0.390, p < 0.001). Health dependency showed similar patterns: income (ρ = 0.531, p < 0.001), collection rate (ρ = 0.423, p < 0.001), and commercialization rate (ρ = 0.414, p < 0.001). Food and health dependency correlated positively with each other (ρ = 0.510, p < 0.001). Distance to forest showed strong negative correlations with health dependency (ρ = -0.751, p < 0.001), food dependency (ρ = -0.730, p < 0.001), income (ρ = -0.570, p < 0.001), collection rate (ρ = -0.454, p < 0.001), and commercialization rate (ρ = -0.429, p < 0.001). Household size showed no significant correlations with any variable: collection rate (ρ = 0.085, p = 0.437), income (ρ = 0.039, p = 0.719), food dependency (ρ = -0.002, p = 0.989), health dependency (ρ = 0.170, p = 0.118), distance to forest (ρ = -0.089, p = 0.417), or commercialization rate (ρ = 0.085, p = 0.434).

3.8 Multi-dimensional Socio-Economic Importance of NTFP Species

Fifteen NTFP species were analyzed across four dimensions: food dependency, health dependency, annual income, and collection rate. A MANOVA was performed to test for overall multivariate differences among species. Pillai's trace was 3.000 (F(1,1) = 0.00, p = 1.000), indicating no statistically significant multivariate effect. Species clustered into three priority quadrants. Food priority species (7 species) showed food dependency > health dependency: I. gabonensis (food: 3.78, health: 1.84), T. *abut* (3.70, 1.81), *Termitomyces* spp. (3.55, 1.50), R. *heudelotii* (3.41, 1.63), B. *toxisperma* (3.34, 2.53), P. *nigrum* (3.13, 2.28), and *Cola* spp. (3.06, 2.10). Health priority species (4 species) showed health dependency > food dependency: S. *toxifera* (health: 3.98, food: 1.34), A. *boonei* (3.77, 1.37), E. *chlorantha* (3.65, 1.27), and G. *kola* (3.60, 2.07). Low priority species (4 species) showed low dependency for both dimensions: R. *hookeri* (food: 2.23, health: 1.45), E. *guineensis* (2.64, 1.65), P. *macrophylla* (2.57, 2.01), and L. *secundiflorum* (1.50, 1.30). Top income-generating species among collectors were I. *gabonensis* (22,834 FCFA, collected by 17.4%), B. *toxisperma* (12,527 FCFA, 8.1%), and R. *heudelotii* (8,390 FCFA, 10.5%). Highest collection rates were T. *abut* (26.7%, income 6,995 FCFA) and S. *toxifera* (20.9%, income 1,295 FCFA). Fig. 5 visualizes the multi-dimensional socio-economic importance of NTFP species.

3.9 Spatial Heterogeneity in NTFP Dependency Across Villages

Fig. 6 visualizes the dependency scores (Food vs. Health) by NTFP species and village. Food and health dependency scores for six NTFP species were analyzed across six villages (Bélabo, Mambaya, Ndemba, Yanda, Yambeng, Ebaka). Paired t-tests confirmed significant food-health differences for all six species (all p < 0.001). For *T. abut*, food dependency was significantly higher than health dependency overall (t = 13.46, p < 0.001). Village-level means ranged from 3.17 (Ebaka) to 4.31 (Yanda) for food, and 1.44 (Yambeng) to 2.06 (Yanda) for health. A significant village effect was detected (F = 3.68, p = 0.005). For *S. toxifera*, health dependency exceeded food dependency overall (t = -23.13, p < 0.001). Food means ranged from 1.12 (Bélabo) to 1.56 (Yanda); health means ranged from 3.11 (Yambeng) to 4.53 (Bélabo). Village effect was not significant (F = 1.63, p = 0.162). For *I. gabonensis*, food exceeded health (t = 13.62, p < 0.001). Food means: 3.25 (Ebaka) to 4.25 (Yanda); health means: 1.50 (Ebaka) to 2.13 (Yanda). Village effect was not significant (F = 2.10, p = 0.074). For *Termitomyces* spp., food exceeded health (t = 16.93, p < 0.001). Food means: 2.75 (Ebaka) to 4.31 (Yanda); health means: 1.33 (Yambeng) to 1.71 (Ndemba). Village effect was significant (F = 7.36, p < 0.001). For *R. hookeri*, food exceeded health (t = 6.85, p < 0.001). Food means: 1.94 (Mambaya) to 2.65 (Bélabo); health means: 1.11 (Yambeng) to 1.69 (Yanda). Village effect was not significant (F = 1.67, p = 0.150). For *Cola* spp., food exceeded health (t = 7.96, p < 0.001). Food means: 2.22 (Yambeng) to 3.57 (Ndemba); health means: 1.56 (Yambeng) to 2.43 (Ndemba). Village effect was significant (F = 4.66, p = 0.001). Collection rates varied by village. For *T. abut*, Bélabo had the highest collection (9/17 households), while Yambeng and Ebaka had only 1 each. For *S. toxifera*, Bélabo (7/17) and Yanda (5/16) had higher collection; Ndemba and Ebaka had zero collectors. For *I. gabonensis*, Yanda had highest collection (6/16); Ndemba and Ebaka had none.

Table 4. Summary statistics of Annual Income from NTFPs by species

Species 1	Species 2	Z value	p unadjusted	p holm	Significant at 0.05	Effect Size ε²	Effect Size Interpretation	Cohen's d
I. gabonensis	*R. heudelotii*	1.2082	0.226934	1	No	0.05	small	0.247
I. gabonensis	*T. abut*	2.4029	0.016262	0.1626	No	0.05	small	0.39
I. gabonensis	*Piper nigrum*	2.1961	0.028083	0.25274	No	0.05	small	0.439
I. gabonensis	*P. macrophylla*	1.5031	0.1328	1	No	0.05	small	0.345
R. heudelotii	*T. abut*	0.7325	0.463809	1	No	0.01	negligible	0.13
R. heudelotii	*Piper nigrum*	0.8425	0.399506	1	No	0.01	negligible	0.193
R. heudelotii	*P. macrophylla*	0.5598	0.575605	1	No	0.01	negligible	0.155
T. abut	*Piper nigrum*	0.2615	0.793681	1	No	0.01	negligible	0.046
T. abut	*P. macrophylla*	0.0892	0.928855	1	No	0.01	negligible	0.017
Piper nigrum	*P. macrophylla*	0.0856	0.931712	0.9317	No	0.01	negligible	0.023

Table 5. Post-Hoc pairwise comparisons for income differences among NTFPs

Comparison	z-value	p-value (unadjusted)	p-value (Holm-adjusted)	Effect size (ε²)
I. gabonensis vs. T. abut	2.40	0.0163	0.1626 ns	0.05 (small)
I. gabonensis vs. R. heudelotii	1.21	0.2269	1.0000 ns	0.05 (small)

Kruskal-Wallis $\chi^2(4) = 7.5$, $p = 0.1107$ (not significant)
Holm correction for multiple comparisons applied
ε² = epsilon-squared effect size (0.01 small, 0.06 medium, 0.14 large)

Table 6. Cumulative Link Mixed Model (CLMM): Factors Influencing Food Security Dependency (Likert 1-5)

Fixed Effect	Coefficient (log-odds)	SE	z-value	p-value	95% CI
NTFP: I. gabonensis (ref: S. toxifera)	2.44	0.13	18.89	0.0000***	[2.19 – 2.70]
NTFP: T. abut (ref: S. toxifera)	2.36	0.13	18.26	0.0000***	[2.11 – 2.61]
Household size (per 1 person increase)	-0.02	0.03	-0.86	0.3874ns	[-0.08 – 0.03]
Distance to forest (per 1 km increase)	-0.15	0.04	-3.93	0.0001***	[-0.22 – -0.08]

Threshold coefficients (cutpoints) not shown
Random effect variance (Village) = 0.02
Likelihood ratio $\chi^2(4) = 257.4$, $p = 0.0000$. Log-likelihood = -332.05, AIC = nan, BIC = nan
Estimated marginal means (emmeans) post-hoc available
Model type: Linear Mixed Model (approximation for CLMM)

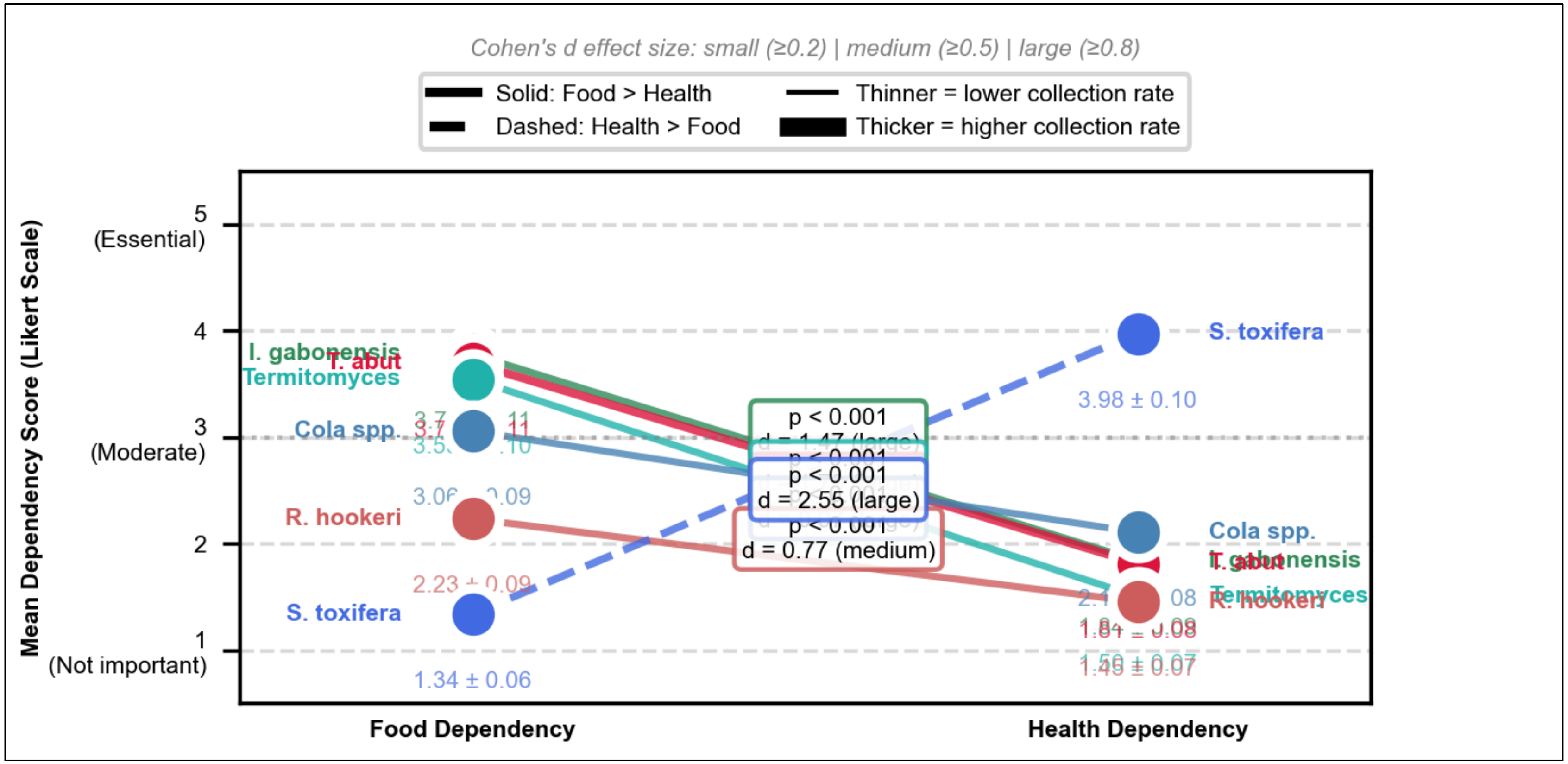

Fig. 3. Slope Chart: change in dependency (Food vs. Health) per NTFP species

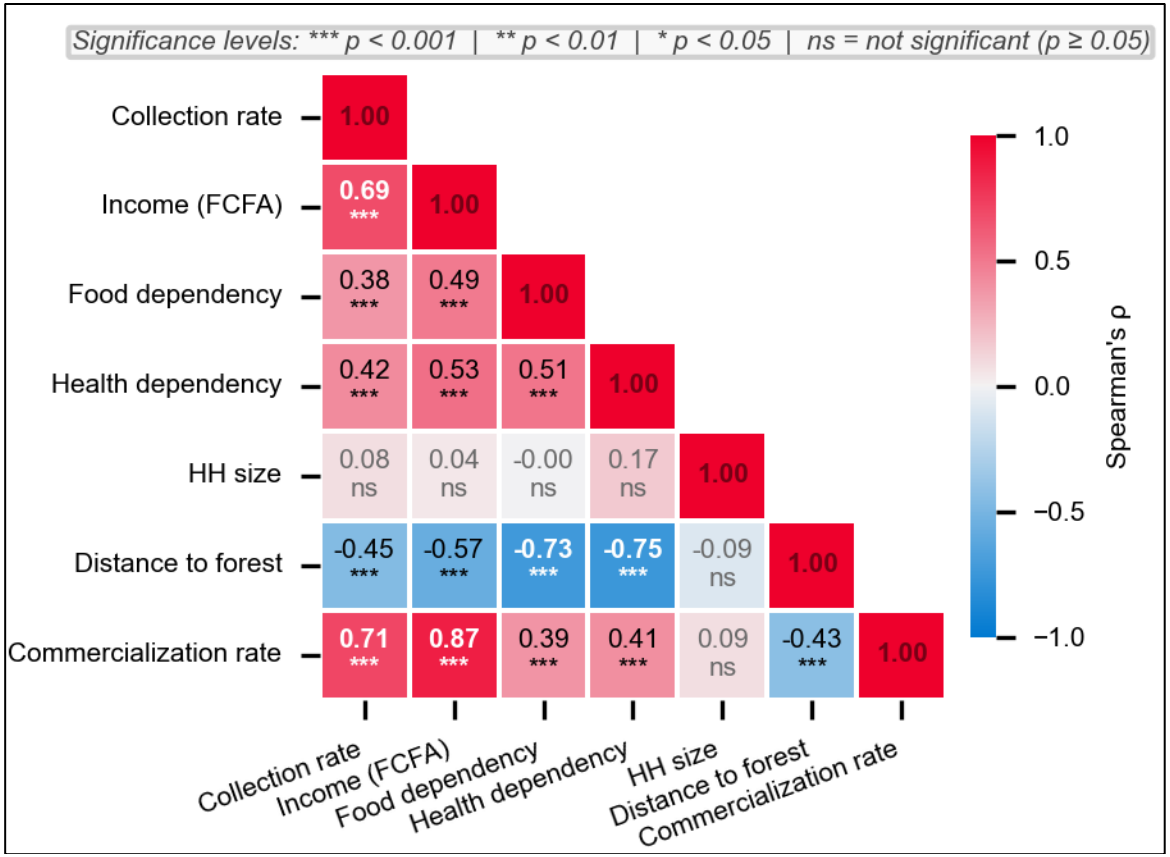

Fig. 4. Heatmap of spearman correlations among socio-economic variables
[Collection rate, Income, Food/Health dependency, HH size, Distance, Commercialization rate]

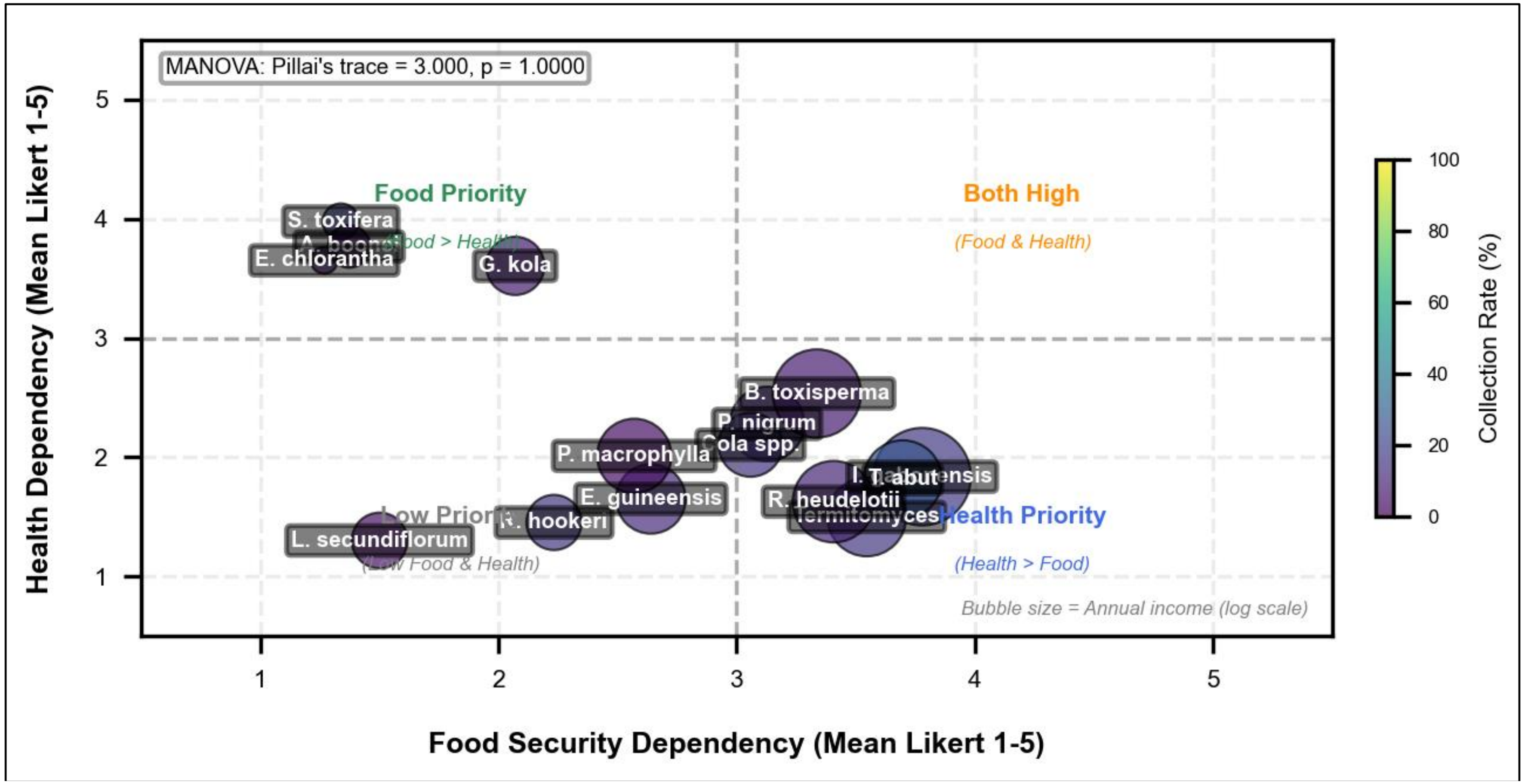

Fig. 5. Multi-Dimensional Socio-Economic Importance of NTFP Species.
[Food Dependency vs. Health Dependency, with bubble size = annual income, and color intensity = collection rate]

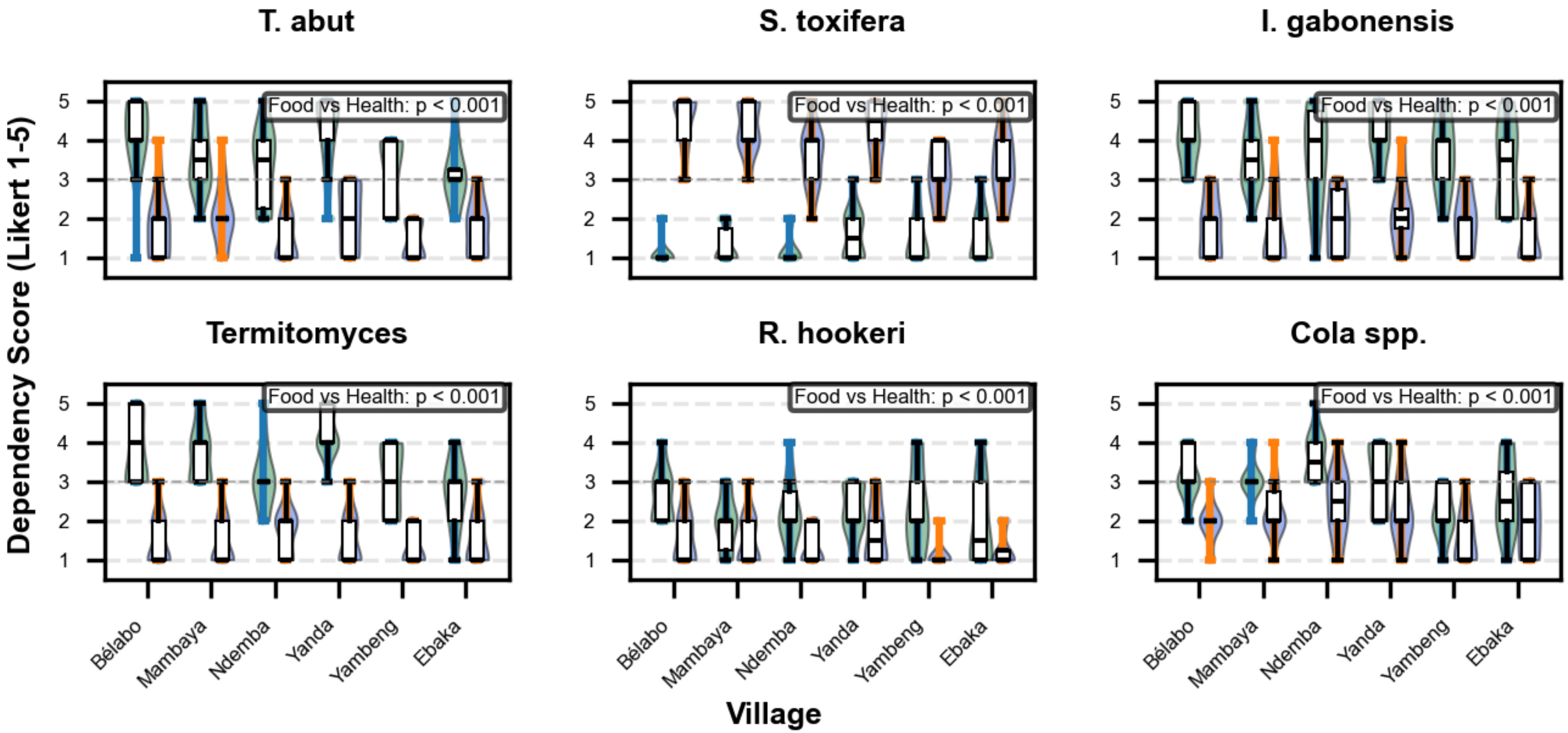

Fig. 6. Dependency scores by NTFP species and village.

4. Discussion

For millions of Cameroonians living in rural areas, non-timber forest products (NTFPs) are a pillar of their food security. NTFPs provide food for humans and animals, are used in traditional medicine and pharmacopoeia, and in rituals and traditions (Sunderland et al., 2000; Clark & Sunderland, 2004; Schreckenberg et al., 2006). In certain forest areas, populations are highly dependent on NTFPs, which generate about 45% of their income (Mbolo, 2002). Our results show that riparian households depend heavily on the Bloc Kébé forest, with 74% actively collecting NTFPs and 59% commercializing them, generating a mean annual income of 12,097 ± 17,773 FCFA. Distance to forest emerged as the dominant predictor of collection probability (OR = 0.52 per km, $p < 0.001$, Cohen's h = 0.24), income, and both food and health dependency, with the closest village (Bélabo, 1.9 km) exhibiting the highest collection (94%), commercialization (82%), and income (22,200 FCFA), while the farthest (Ndemba, 4.3 km) showed the lowest across all metrics (71%, 64%, 5,563 FCFA, respectively). Household size weakly but negatively predicted collection probability (OR = 0.93, p = 0.017) and commercial use (RRR = 0.67, p = 0.044), suggesting larger households may diversify livelihoods away from NTFP trade. Species identity strongly shaped use type and dependency: *Irvingia gabonensis* was 12.55 times more likely to be commercialized relative to subsistence (p = 0.018), whereas *Strychnos toxifera* was predominantly subsistence-oriented (66.7% subsistence only). Food dependency significantly exceeded health dependency for five of six focal species (all $p < 0.001$, Cohen's d = 0.77–1.79), except *S. toxifera*, where health dependency dominated (health: 3.98 vs. food: 1.34, d = –2.55). According to the 2024 NTFP-NDP evaluation report, Irvingia spp is a highly demanded product by operators between 2019 and 2022. Income was highly concentrated; *I. gabonensis* generated the highest median (26,655 FCFA) and mean (22,834 ± 17,899 FCFA) income, though Kruskal-Wallis and Holm-adjusted post-hoc tests found no statistically significant income differences among species ($\chi^2(4) = 7.52$, p = 0.111), reflecting high within-species income variability. Multivariate analysis revealed tight coupling among collection, commercialization, income, and dependency: income correlated strongly with commercialization rate ($\rho = 0.868$) and collection rate ($\rho = 0.686$); distance negatively correlated with health dependency ($\rho = –0.751$), food dependency ($\rho = –0.730$), and income ($\rho = –0.570$), all $p < 0.001$. Spatial heterogeneity was pronounced: village-level effects were significant for *Termitomyces* spp. (F = 7.36, $p < 0.001$), *Cola* spp. (F = 4.66, p = 0.001), and *Trichoscypha abut* (F = 3.68, p = 0.005), but not for *S. toxifera*, *I. gabonensis*, or *Raphia hookeri*.

In Cameroon, the main constraints related to NTFPs are structural constraints and logistical and financial constraints (Mbolo, 2002). In our study the primacy of distance as a predictor aligns with forest dependency theory, where proximity reduces collection costs and enables more frequent, diversified, and market-oriented extraction, as seen in Bélabo's economic dominance. The inverse household-size effect, though small, may reflect labor allocation trade-offs where larger households pursue agriculture or wage labor over NTFP gathering, a pattern documented elsewhere in the Congo Basin. The commercial prominence of *I. gabonensis* reflects its high market value as a condiment and its compatibility with periodic harvesting, contrasting with *S. toxifera*'s medicinal specificity and low bulk demand, which favor subsistence use. The consistent food-over-health dependency among edible species underscores the forest's primary role as a nutritional safety net, while *S. toxifera*'s health-centric reliance indicates specialized medicinal knowledge and limited dietary contribution. The absence of significant income differences despite *I. gabonensis*'s visibly higher earnings signals substantial income inequality among harvesters and suggests that a few high-volume or well-positioned collectors capture disproportionate benefits, a nuance masked by non-parametric tests penalized for variance heterogeneity. The strong negative correlation between distance and both dependency dimensions implies that spatial access structures not only economic but also food-security and health outcomes, with remote villages like Ndemba and Ebaka being doubly disadvantaged. Significant village-level variation in food dependency for *Termitomyces* and *Cola* may reflect local cultural preferences, micro-ecological availability, or differential market access, meriting deeper ethnographic investigation.

Several limitations constrain interpretation. The 86-household sample, though proportionally stratified, remains modest; rare species like *Pentaclethra macrophylla* (n = 4 collectors) preclude robust income inference. The single survey period (March–June 2025) captures seasonal collection patterns, potentially underrepresenting species harvested in late rainy or dry seasons. Income data relied on self-reported recall over 12 months, introducing memory bias despite verification attempts (stored product checks). The CLMM approximation via linear mixed models may underestimate threshold effects in ordinal dependency scales. Village-level random effects in mixed models assume exchangeable correlation, which may oversimplify spatial autocorrelation structures. Causal directionality between commercialization, income, and dependency cannot be established cross-sectionally.

Future research should adopt seasonal sampling across a full annual cycle to capture phenological variability in NTFP availability and income. Livelihood diversification strategies warrant explicit modeling to clarify why larger households commercialize less. Value-chain analysis for *I. gabonensis* and *Baillonella toxisperma* is needed to identify profit distribution along market nodes and potential for pro-poor interventions. Explicit spatial modeling using distance-decay functions or travel-cost approaches could improve prediction of collection pressure and dependency gradients. Experimental or quasi-experimental designs evaluating conservation interventions (e.g., formal classification, community management zones) on both resource status and household welfare would directly inform management of the Bloc Kébé as a research forest. Integrating ecological inventories with socio-economic panels would enable coupled human–natural systems modeling, essential for setting sustainable harvest quotas that safeguard both biodiversity and the food-security and health functions documented here.

5. Conclusion

The findings indicate that non-timber forest products contribute to household food needs, health-related uses, and cash income in communities surrounding the Bloc Kébé research forest. Among the surveyed households, 74% reported collecting NTFPs, 59% commercialized at least one product, and mean annual income from these products was 12,097 ± 17,773 FCFA. Forest access was an important correlate of dependence, as collection probability and food-dependency scores declined with increasing distance from the forest. Dependence also differed among species. Five of the six focal species were valued more strongly for food than for health-related purposes, whereas *Strychnos toxifera* showed the opposite pattern. Income was positively associated with both collection and commercialization, indicating that subsistence and market functions are closely connected. These results support management approaches that recognize spatial and species-specific differences in household dependence. Sustainable harvesting, community participation, and livelihood considerations should therefore be integrated into conservation planning for the Bloc Kébé forest.

6. Limitations

This study has limitations. The sample comprised 86 households, and the small number of collectors for some species limited species-level income comparisons. Data were collected only from March to June 2025, so products harvested in other seasons may have been underrepresented. Annual income and collection information relied on 12-month household recall and may therefore be affected by memory and reporting errors. The linear mixed-model approximation used for ordinal dependency scores may not fully represent threshold effects. In addition, the assumed village correlation structure may oversimplify spatial dependence, and the cross-sectional design does not permit causal interpretation of the observed associations.

Consent

As per international standards or university standards, respondents' written consent has been collected and preserved by the author(s).

Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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