Prevalence and drivers of medicinal tree use in Tolon District, Northern Ghana

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Research

Abstract

Background: In the rural communities of Ghana, traditional medicine (TM) is the principal means of obtaining primary healthcare. District-level on the utilization of TM, its drivers, knowledge transmission and priority medicinal tree species in Northern Ghana are scarce. This study assessed the prevalence and drivers of medicinal tree use in six purposively selected communities in the Tolon District, Northern Ghana.

Methods: A cross-sectional survey was conducted between June to December 2024 over a period of four months in six communities in Tolon District, Ghana with 247 respondents. Communities were purposively selected based on their high reported TM use. Within each community, respondents were selected using a systematic random sampling technique from household lists, targeting household heads or adult members above 18 years with knowledge of medicinal plant use. Data were documented on prevalence and patterns of medicinal tree utilization, drivers of use and priority medicinal tree species. Descriptive statistics, Kruskal-Wallis tests, Structural Equation Modeling (SEM), Non-metric Multidimensional Scaling, Canonical Correspondence Analysis (CCA), PERMANOVA, co-occurrence network analysis and Random Forest Modelling (RFM) were performed. Ethnobotanical indices including Frequency of Citation, Relative Frequency of Citation (REC), and Fidelity Level were calculated. All RFC values were recalculated using N=247.

Results: Among respondents in the six study communities, 235 reported TM use in last 12 months, giving a prevalence of 95.1% (95% CI: 91.8-97.1%) in the study communities. Due to purposive sampling, this is not generalizable to the entire Tolon District. The dominant driver was perceived effectiveness (Relative Importance Index, RII=0.861, 95% CI: 0.842-0.879) which explained 38.4% of variance in Dominance Analysis. Plant knowledge composition was significantly structured by ethnicity (PERMANOVA R^2=0.18, p=0.001) and age (R^2=0.09, p=0.001). Distance from health center and community explained 28.4% of the variation in plant use in CCA. Random Forest Modelling identified Age and Ethnicity as top predictors of plant knowledge, explaining 61.3% of variance. Twenty medicinal plant species were documented with *Azadirachta indica* as a cultural keystone species. Perceived Knowledge Loss Index (PKLI) showed elders >55 years held 82% more knowledge than perceived youth in 18-30 year group.

Conclusion: Traditional medicine use in the study communities was associated with belief in effectiveness and was spatially and culturally structured. This study provided district-level evidence in Northern Ghana linking people, plants and environment using multivariate statistics. T The observed disinterest among youth is ironic given that at least 50% of modern medicines are derived from traditional medicines.

Keywords: Traditional Medicine; Ghana; Prevalence; Drivers; Medicinal Trees; Knowledge Loss; Tolon District; Guinea Savanna

Background

The World Health Organization (WHO 2023), defines traditional medicine (TM) as health practices, knowledge and skills based on indigenous beliefs and experiences that communities use to maintain well-being. In Low- and Middle-Income Countries (LMICs), about 80% of people depend on TM as their main source of healthcare.

Ghana recognizes traditional medicine (TM) by law under the Traditional Medicine Practice Act 2000 (Act 595), enacted in 2000, and it is included in the national health system. The Ghana Herbal Pharmacopoeia documents more than 400 plants used in both formal and traditional treatment (Ghana Food and Drugs Authority 2007). Despite this, people in many rural areas with little access to hospitals and clinics still depend mostly on TM (Mensah *et al.* 2019).

Several studies on the use of traditional medicine in Ghana document high prevalence rates. For example, Abugre *et al.* (2012) revealed a prevalence of 67% in urban Kumasi and showed that trust, habit and perceived effectiveness kept people using TM despite their proximity to hospitals. Asase *et al.* (2005) recorded 102 medicinal plants used by the Ga-Adangbe with *Azadirachta indica* A. Juss. and *Moringa oleifera* Lam.among the most important plant species in use. Similarly, Baba-Moussa *et al.* (2018) listed 72 plant species in rural communities used to treat malaria, wounds and stomach problems in Northern Ghana. Addo-Fordjour *et al*. (2008) also reported strong dependence on wild plant species for primary healthcare in the Ashanti Region. While these studies offer valuable baseline inventories, key gaps limit their relevance to the development of health policy in rural Northern Ghana.

There is very little district-level data on the current scale of TM use in the Guinea Savanna. Most existing data are drawn from urban areas or national surveys, and no studies provide prevalence estimates with confidence intervals for districts such as Tolon which have the lowest health facility to population ratio (GSS 2021). The Tolon District has one district hospital and eight Community-based Health Planning and Services locations (CHPS) for a population of 118,101. Given the absence of local data, the actual contribution of TM to primary healthcare in this zone remains unclear. This study therefore aims to determine the prevalence of TM use in Tolon District.
Furthermore, earlier studies in Ghana identify effectiveness, affordability and cultural acceptability as key drivers of TM use (Abugre *et al.* 2012, Baba-Moussa *et al.* 2018). However, these studies relied on frequency counts or qualitative accounts.

Such methods cannot show which factor explains most of the variation when several drivers occur together. For the implementation of Act 595, it is important to know whether people choose TM because they believe it works better, or simply because orthodox care is not accessible. To address this gap, the present study uses the Relative Importance Index and Dominance Analysis to rank and quantify the influence of socio-cultural drivers of TM use.

Existing literature shows that age, education, and ethnicity influence TM use in Ghana (Abugre *et al.* 2012; Baba-Moussa *et al.* 2018). However, the pathways through which they operate remain untested. It is unclear whether education reduces TM use directly, or indirectly by lowering belief in its effectiveness. Structural Equation Modeling has been used in Ghana for other health behaviours (Mensah *et al.* 2019), but not for TM. Without causal evidence, interventions in schools and CHPS will be based on assumptions. This study therefore examines demographic differences and causal pathways to provide evidence for targeted behavior-change programes.

Many studies in Ghana have anecdotally reported that “youth are no longer interested in learning about medicinal plants” (Abugre *et al.* 2012; Asase *et al.* 2005). However, there is no standardized metric to measure the rate of intergenerational knowledge loss. Without such a measure, it is not possible to compare knowledge erosion across age groups, education levels, or ethnicities, or to identify priority communities for documentation. To address this gap, this study develops and applies a Knowledge Loss Index to quantify erosion risk in Tolon District.

Lastly, plant inventories for Ghana often record only vernacular names and do not link species identification with measures of cultural importance (Baba-Moussa et al. 2018). As a result, it is difficult to verify species and to decide which plants to prioritize for safety testing and inclusion in the Ghana Herbal Pharmacopoeia. To address this, the present study identifies and quantifies the most frequently used medicinal plants in Tolon District.

This study provides an integrated, quantitative assessment of TM use in a Guinea Savanna district of Ghana by addressing these gaps. The findings should support the safe integration of TM into the national health system and contribute to Sustainable Development Goals (SDGs): SDG 3 (Good Health and Well-being) by promoting safe and evidence-based integration of traditional medicine into primary healthcare, SDG 4 (Quality Education) by documenting and preserving

indigenous ethnobotanical knowledge and its intergenerational transmission and SDG 11 (Sustainable Cities and Communities) by supporting conservation of medicinal plant resources and the cultural heritage of local communities. The objectives of the study were to i) Determine the prevalence of TM use in six communities in Tolon District, ii) Rank and quantify the dominance of socio-cultural drivers using Relative Index Inequality (RII) and Dominance Analysis, iii) Test demographic differences and associative pathways using Kruskal-Wallis and SEM, iv) Quantify perceived intergenerational knowledge loss using a Perceived Knowledge Loss Index and v) Identify and quantify the most frequently used medicinal trees.

Materials and Methods

Study area

Tolon District lies in the Northern Region of Ghana between latitudes 9°15'N and 9°45'N and longitudes 0°53'W and 1°25'W. The district covers 1,112 km² of Guinea Savanna vegetation characterized by tall grasses, scattered trees, and a unimodal rainfall pattern (May-October, 1000-1100mm). Mean annual temperature ranges from 26°C to 34°C(Ghana Statistical Service 2021). The 2021 census recorded a population of 118,101, with Dagomba as the majority, and significant Gonja and Mamprusi minorities (Ghana Statistical Service 2021). Livelihoods are primarily subsistence agriculture, livestock rearing, and shea collection (Ghana Statistical Service 2021).Health infrastructure is limited to one district hospital and eight CHPS compounds that serve the entire district, making travel to orthodox facilities costly. Six communities were purposively selected in consultation with District Assembly members based on high reported TM use and accessibility. These were: Kunguri, Yipegu, Gundaa, Tindanyili, Tuunayili, and Peyoggo. GPS coordinates were recorded for each to enable future spatial mapping of knowledge hotspots.

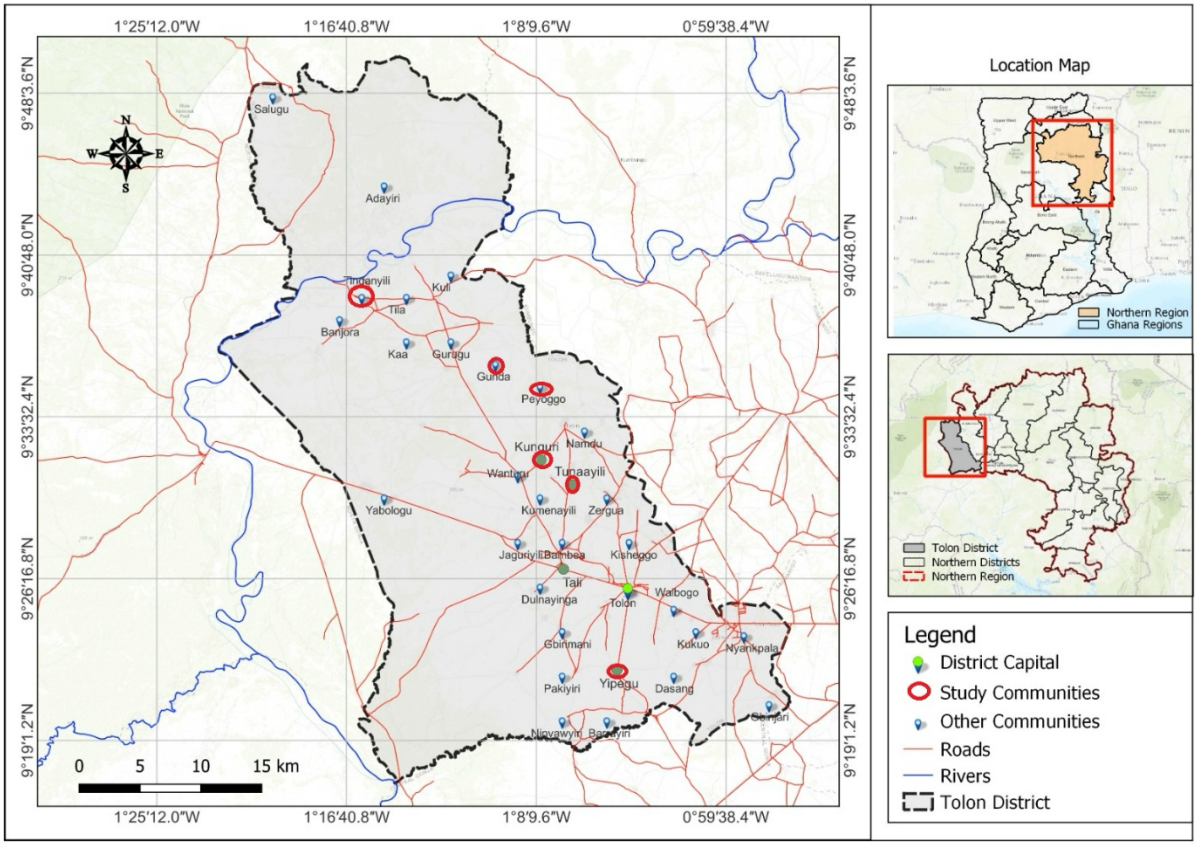


Figure 1. Map of Ghana showing the study area

Ethical considerations

Ethical approval was obtained from the University for Development Studies Ethics Committee (Ref: UDS/REC/006/2023). The study adhered to the principles of the Nagoya Protocol on Access and Benefit Sharing. Benefits will be shared through dissemination of results to the District Assembly and community durbars. Prior informed consent was obtained verbally and in writing in English and later translated into Dagbani, the dominant local language. All methods were carried out in accord with relevant guidelines and regulations.

Data collection methods

Semi-structured interviews, focus group discussions and field observations with informants, as described by Martin (2010), were used to collect ethnobotanical data in the district. Informants included (i) general household respondents (n=247) for prevalence and use patterns, and (ii) key informants (n=18) comprising traditional healers (herbalists), elderly community members (>60 years), and opinion leaders purposively selected based on their recognized expertise in medicinal plants, years of practice (>10 years), and referral by community chiefs. Interview questionnaires were prepared in English and later translated into the Dagbani language. Four trained field assistants fluent in Dagbani administered the questionnaires through face-to-face interviews, averaging 35 minutes per respondent. Interviews were conducted mainly in the Dagbani language, the major language in the study area. During the interviews, respondents were asked to free-list medicinal plants they used in the last 12 months. For species mentioned ≥5 times, specimens were collected with permission. Interviews with informants were conducted to obtain information on the local name of the medicinal plant, parts used and indigenous knowledge used in the conservation of medicinal plants in the study area. Six focus group discussions, one in each of the selected communities (8-12 participants per group, including both users and non-users of TM, mixed gender), were conducted to obtain additional information on the identification of priority plant species, prevalence, dominant drivers, knowledge loss and their perceptions of traditional medicinal plants by the community. Further, the focus group discussions also helped us to understand how traditional knowledge is transmitted from generation to generation.

Collection of plant voucher specimen, identification and herbarium preparation

Medicinal plant specimens were collected during guided field walks with the assistance of four traditional herbalists. Each specimen was labeled with a collection number and collector name, then pressed, air-dried and taken to the Department of Herbal Medicine at Kwame Nkrumah University of Science and Technology. Identification of plants was done using the flora of Ghana with support from experts at the Kwame Nkrumah University of Science and Technology and was confirmed by comparison with authenticated specimens and with reference to Abbiw (1990). Scientific names were checked against World Flora Online (WFO) and the African Plant Database. Voucher specimens KNUST/HM1/2025/WP001 to WP020, representing 20 species, were deposited in the herbarium of the Faculty of Pharmacy and Pharmaceutical Sciences, College of Health Sciences, Kwame Nkrumah University of Science and Technology.

Sampling design, sample size and respondent selection

A cross-sectional household survey was conducted from June to December 2024. Six communities were purposively selected in consultation with District Assembly members based on high reported TM use and accessibility. These communities were: Kunguri, Yipegu, Gundaa, Tindanyili, Tuunayili, and Peyoggo. Given the purposive design, the findings are not intended to provide a statistical generalization for the district population. Sample size was determined using the equation by Yamane (1967):

$$n = \frac{N}{1 + N(e)^2}$$

Where n is the sample size, N is the population size and e is the margin of error or the level of precision.

Although the required sample size was 399, only 247 questionnaires were fully completed due to refusals by some participants giving a response rate of 77.3% and 0.72 post- hoc power to detect medium effects with six predictors. It is acknowledged that this is a limitation of the study.

Research instrument development and validation

A semi-structured questionnaire was developed in English and translated into Dagbani, then back-translated to ensure semantic equivalence. The instrument had three modules. Module A covered socio-demographics including age, sex, ethnicity, education, religion and marital status. Module B covered factors influencing TM use and respondents were asked to identify the single most important source of their TM knowledge. Six factors were derived from previous literature (Olorunnisola *et al.* 2011, Tugume *et al.* 2016). These included effectiveness, accessibility, family/peer influence, affordability, cultural acceptability and proximity to health center. Each was rated on a five-point Likert scale from 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree and 5 = strongly agree. Module C covered perceptions and trust. Ten items on trust, safety, dosage, and youth interest, also 5-point Likert content validity was assessed by three lecturers at the University for Development Studies. A pilot test was conducted with 25 households in Kpalgum community (not included in the final sample). Reliability analysis yielded Cronbach's alpha of 0.87 for Module B and 0.83 for Module C. Test-retest reliability over twos weeks gave Pearson r = 0.81, indicating stability.

Data Analysis

Quantitative data were entered in Excel, cleaned and analyzed in SPSS v23 and R v4.3.1. Packages used in R included vegan v2.6-4, dominance analysis v2.2.0, and Random Forest Modelling v4.7-1.1. Descriptive statistics such as frequencies, percentages, median and IQR (Inter-Quartile Range, the measure of statistical dispersion that describes the spread of the middle 50% of a data set) were used. Median was preferred over mean because Likert data are ordinal.

Kruskal-Wallis H test with Dunn-Bonferroni post-hoc was used to test differences in TM preference across age, education, and ethnicity. Effect size reported as eta-squared and H statistic with df reported.

Relative Importance Index:

$$\text{RII} = \sum \frac{\text{w}}{\text{A}} \quad \text{xN}$$

where w=1-5, A=5, N= 247 (Doloi *et al*. 2012).

Categories: 0.8-1.0=High, 0.6-<0.8=Medium-High. Bootstrapping with 5000 resamples provided 95% CI.

Dominance Analysis: Using the dominance analysis package in R, TM Preference was regressed on the 6 factors and computed general dominance weights as % contribution to R^2. This shows each factor's unique contribution.

Structural Equation Modeling: SEM was run in AMOS v26 to test the hypothesized model: Demographics -> Perceived Effectiveness -> TM Preference -> Trust. Given the cross-sectional design, results describe associations and cannot establish causality. Causal interpretations should be substantially moderated. Model fit assessed by CFI = 0.94, TLI = 0.93, RMSEA < 0.06, SRMR < 0.08.

We developed a Perceived Knowledge Loss Index (PKLI), adapted from Reyes-García et al. (2014) to quantify perceived intergenerational erosion.

$$\text{PKLI} = \text{total items} \sum (\text{elder knowledge} - \text{youth knowledge as perceived by elders})$$

Where E = number of species the elder respondent could name, describe use and preparation for [max 5], Y = number of species the elder believed youth aged 18–35 years in their household could name and describe (max 5). Scores range 0 = no perceived loss to 5 = maximum loss. We used elder perception because perceived loss influences teaching behavior - if elders believe youth are uninterested, they stop teaching, and it is practical for large surveys and validated for assessing cultural erosion risk. We acknowledge this measures perception, not actual youth competence.

To assess the level of knowledge and use of plant species by different communities in the study area, data from interviews, surveys and group discussions were analyzed.

To determine the cultural importance and informant consensus for each plant species, the following ethnobotanical indices were calculated:

1. Frequency of Citation (FC) measures the number of informants who cited the use of a particular plant species. It reflects the popularity of a species among the respondents.

FC was calculated as:

$$\text{FC} = \sum URi$$

Where, URi = Use report for species i

2. Relative Frequency of Citation (RFC) standardizes the FC value by the total number of informants. It ranges from 0 to 1, where 1 indicates that all informants cited the use of the species.

RFC was calculated as:

$$\text{RFC} = \frac{\text{FCs}}{\text{N}}$$

Where, FC = Frequency of citation and N = Total number of informants interviewed (Tardio and Pardo-de-Santayana 2008).

3. Fidelity Level (FL) calculates the percentage of informants who cited a specific use of a plant species out of all informants who cited the plant for any use. It indicates the degree of informant agreement on the use of a species for a particular ailment.
FL was calculated as:

$$\text{FL (\%)} = \frac{NP}{N} \times 100$$

Where; NP = the number of citations for medicinal plant species for a particular disease category, N=total number of informants who cited that medicinal plant species for any other use or purpose (Ali *et al.* 2019).

Multivariate analyses were used to test the structure of relationships among people, plants and the environment. Non-metric Multidimensional Scaling (NMDS) with Bray-Curtis distance was performed in R using the vegan package to visualize dissimilarity in plant knowledge among respondents grouped by ethnicity and age. PERMANOVA was used to test whether ethnicity, age, education, distance to health center and community explained variation in plant knowledge composition. Canonical Correspondence Analysis (CCA) was used to relate plant species use to environmental and socio-spatial variables. Co-occurrence network analysis was conducted in Gephi 0.10 to identify keystone species based on degree and betweenness centrality. Random Forest Modelling was used to rank the importance of demographic and spatial predictors of the total number of plants known. Model performance was reported as percentage of variance explained and out-of-bag error. Significance level was set at $p<0.05$.

Results

Prevalence and Pattern of Traditional Medicine Use

Table 1 shows that TM knowledge in Tolon District is primarily transmitted within households and social networks rather than through formal channels. Out of 247 respondents, 235 reported using Traditional Medicine within the last 12 months, giving a prevalence of 95.0% with a 95% confidence interval of 91.8% to 97.1% in the six purposively selected communities.

Table 1. Source of traditional medicine knowledge in Tolon District, n=247

Most Important Source of Knowledge	Frequency	Percentage %
Family / peers	143	57.9
Traditional healers	70	28.3
Self-learning / observation	34	13.8

Ranking and Dominance of Socio-Cultural Drivers

Six factors were tested. Effectiveness was the only factor in the "High" RII category and dominated the model. Perceived effectiveness (RII=0.861, 95% CI: 0.842–0.879) was High. Accessibility of medicinal plants (0.752, 95% CI: 0.781–0.824) and Family and peer influence (0.730, 95% CI: 0.749–0.796) were Medium-High. Proximity to health center (0.427, 95% CI: 0.398–0.456) was Medium (Table 2). Dominance Analysis further confirmed this hierarchy (Table 3).

Table 2. Ranking of Drivers of TM Use Using RII, n=247

Drivers	Mean score	RII	95% CI	Rank
Perceived effectiveness	4.31	0.861	0.842–0.879	1
Accessibility of medicinal plants	3.76	0.752	0.721–0.783	2
Family and peer influence	3.65	0.730	0.701–0.759	3
Affordability	3.54	0.708	0.677–0.739	4
Cultural and traditional belief	3.41	0.682	0.649–0.715	5
Proximity to health center	2.14	0.427	0.398–0.456	6

Note: RII Category: 0.8–1.0=High; 0.6–<0.8=Medium-High; 0.4–<0.6=Medium; <0.4=Low.

Table 3. Dominance Analysis of Drivers of TM Use

Drivers	General dominance	Percentage Contribution %	Rank
Perceived effectiveness	0.192	38.4	1
Accessibility of medicinal plants	0.111	22.1	2
Family and peer influence	0.092	18.3	3
Affordability	0.064	12.7	4
Cultural and traditional belief	0.034	6.8	5
Proximity to health center	0.009	1.7	6

The results indicate that perceived effectiveness is the primary reason people choose TM in Tolon District, accounting for more than one-third of the explained variance.

Demographic Differences and Causal Pathways

Kruskal-Wallis tests showed that TM preference differed significantly across age groups, educational levels, and ethnic groups (Table 4).

Table 4. Demographic Differences in TM Preference

Variables	Group	Median TM Preference	H(df)	p-value	Effect Size η^2
Age	<41 years	3.0	45.12(2)	<0.001	0.142
	41-55 years	3.0			
	>55 years	4.0			
Education	None	4.0	52.88(2)	<0.001	0.182
	Primary/Junior high school	3.0			
	Senior high school/ Tertiary	2.0			
Ethnicity	Dagomba	4.0	68.43(2)	<0.001	0.261
	Gonja	3.0			
	Mamprusi	3.0			

Note: Kruskal-Wallis H test with Dunn-Bonferroni post-hoc. η^2 = eta-squared.

Structural Equation Modeling was used to test causal pathways. The model fit was acceptable with CFI of 0.94 and RMSEA of 0.06. Education had a significant negative direct effect on perceived effectiveness with a standardized beta of -0.28, $p < 0.001$. Perceived effectiveness in turn had a significant positive effect on TM preference with a beta of 0.61, $p < 0.001$. The indirect effect of education on TM preference through perceived effectiveness was -0.17 and was significant. This suggests that higher education reduces TM use partly by lowering belief in its effectiveness.

Quantifying Intergenerational Knowledge Loss

Perceived Knowledge Loss Index was computed for each respondent based on the number of plants they could name, describe the use of, and explain the preparation method for (Table 5).

Table 5. Knowledge Loss Index by Demographics

Variables	Group	Mean PKLI	SD	p-value
Age	18-30 years	1.82	0.91	<0.001
	31-40 years	2.49	0.92	
	41-55 years	3.02	1.05	
	>55 years	3.84	0.89	
Education	None	3.41	0.95	<0.001
	Primary/Junior high school	2.88	1.10	
	Senior high school/ Tertiary	2.20	1.12	
Ethnicity	Dagomba	3.10	1.08	<0.001
	Gonja	2.75	1.15	
	Mamprusi	2.60	1.20	

Note: KLI measures elder perception of youth knowledge, max score = 5.

Overall mean PKLI was 2.80. Knowledge was 82% higher among respondents above 55 years compared to those 18-30 years. Respondents also rated safety concerns, trust in regulation, and youth interest in TM. Table 6 presents the median scores and interquartile ranges.

Respondents expressed high concern about correct dosage of TM with a median score of 4.0 (IQR: 3.0 - 5.0), indicating agreement. Concern about adulteration of TM products and concern about side effects of TM were both moderate, with median scores of 3.0 (IQR: 2.0 - 4.0) each. Respondents were neutral on whether "TM is safer than orthodox medicine", median = 3.0 (IQR: 2.0 - 4.0).

Trust in government regulation of TM was low, median = 2.0 (IQR: 1.0 - 3.0). Similarly, respondents disagreed that "Traditional medicine practitioners are well regulated", median = 2.0(IQR: 1.0 - 3.0). However, there was strong agreement that "Government should standardize TM products", median = 4.0 (IQR: 3.0 - 5.0).
Youth interest in learning TM was only moderate, median = 3.0 (IQR: 2.0 - 4.0). In contrast, respondents agreed that "Elders are willing to teach youth about TM", median = 4.0 (IQR: 3.0 - 5.0), and that "TM knowledge should be taught in schools", median = 4.0 (IQR: 3.0 - 5.0) (Table 6).

Table 6. Perception of Safety and Regulation

Module C Item	Median	IQR
A. Safety Concerns		
Concern about correct dosage	4.0	3.0 - 5.0
Concern about adulteration of TM products	3.0	2.0 - 4.0
Concern about side effects of TM	3.0	2.0 - 4.0
TM is safer than orthodox medicine	3.0	2.0 - 4.0
B. Regulation and Trust		
Trust in government regulation of TM	2.0	1.0 - 3.0
Traditional medicine practitioners are well regulated	2.0	1.0 - 3.0
Government should standardize TM products	4.0	3.0 - 5.0
C. Knowledge Transmission		
Interest of youth in learning TM	3.0	2.0 - 4.0
Elders are willing to teach youth about TM	4.0	3.0 - 5.0
TM knowledge should be taught in schools	4.0	3.0 - 5.0

Scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree

The low level of “perceived” youth interest (that is youth interest as interpreted by adults) and low trust in regulation indicate a risk of unsafe TM practice in the future.

Identification and Quantitative Importance of Medicinal Plants

A total of 20 medicinal plant species belonging to 16 families were identified and verified botanically through field collection. All species are native to the Guinea Savanna vegetation zone of Ghana. The most represented families were Fabaceae with four species, 18.2% and Asteraceae with three species, 13.6%. This dominance of Fabaceae and Asteraceae is consistent with other ethnobotanical studies in Northern Ghana and reflects their abundance and widespread traditional use in the savanna ecosystem (Table 7).

Structural patterns of plant knowledge using NMDS, PERMANOVA and Network Analysis

To go beyond descriptive indices, analysis focused on whether medicinal plant knowledge was structurally patterned by social and demographic factors. PERMANOVA showed that plant knowledge composition differed significantly by ethnicity, age, education, distance to health center, and community (Table 8). Ethnicity explained the largest proportion of variation ($R^2 = 0.18$, $p<0.001$), followed by community ($R^2 = 0.13$, $p<0.001$) and age ($R^2 = 0.09$, $p<0.001$). This indicates that plants people know and use in Tolon District are not a random selection of species but rather they are strongly shaped by cultural identity and geographic location, not random.

The significant effect of distance to health center ($R^2 = 0.06$, $p<0.001$) suggests that access to orthodox care also influences the composition of TM knowledge.

Chi-square test for education vs ethnicity ($\chi^2=3.21$, $p=0.20$) not significant, suggesting ethnicity effect not confounded by education access or distance. Ethnicity remained significant after controlling for education and distance in PERMANOVA and Random Forest Modelling analysis.

Table 7. Most Frequently Cited Medicinal Plants and Their Cultural Importance

Plant species	Family	Voucher Number	Vernacular name	Part used	FC	RFC	FL (%)
Azadirachta indica A.Juss.	Meliaceae	KNUST/HM1/2025/WP001	**Nyemsa**	Leaf, Bark	187	0.757	76.5
Moringa oleifera Lam.	Moringaceae	KNUST/HM1/2025/WP002	**Baganlua**	Leaf, Root	165	0.668	68.2
Vitellariaparadoxa C.F.Gaertn.	Sapotaceae	KNUST/HM1/2025/WP003	**Tááŋà**	Bark, Root	158	0.640	72.8
Parkia biglobosa (Jacq.) R.Br. ex G.Don	Fabaceae	KNUST/HM1/2025/WP004	**Dòó**	Bark, Leaf	142	0.575	65.5
Adansonia digitata L.	Malvaceae	KNUST/HM1/2025/WP005	**Tua**	Bark, Leaf	138	0.559	70.3
Khaya senegalensis (Desr.) A.Juss.	Meliaceae	KNUST/HM1/2025/WP006	**Kuga**	Leaf, Fruit	121	0.490	58.7
Psidium guajava L.	Myrtaceae	KNUST/HM1/2025/WP007	**Gwávà**	Leaf	114	0.462	64.9
Vachellia nilotica (L.) P.J.H.Hurter & Mabb	Fabaceae	KNUST/HM1/2025/WP008	**Bàgààlúa**	Root	108	0.437	81.5
Terminalia leiocarpa (DC.) Baill.	Combretaceae	KNUST/HM1/2025/WP009	**Shììyà**	Root, Leaf	102	0.413	59.8
Jatropha curcas L.	Euphorbiaceae	KNUST/HM1/2025/WP010	**Shindazugu**	Leaf	97	0.393	55.7
Guiera senegalensis J.F.Gmel.	Combretaceae	KNUST/HM1/2025/WP011	**Puhuga**	Root, Bark	91	0.368	52.7
Piliostigma thonningii (Schum.) Milne-Redh.	Fabaceae	KNUST/HM1/2025/WP012	**baɣiŋga**	Leaf	88	0.356	67.0
Ziziphus mauritiana Lam.	Rhamnaceae	KNUST/HM1/2025/WP013	**zungulkukua**	Leaf, Root	84	0.340	60.7
Balanites aegyptiaca (L.) Delile	Zygophyllaceae	KNUST/HM1/2025/WP014	**gabliga,**	Leaf, Fruit	79	0.320	49.4
Daniellia oliveri (Rolfe) Hutch. & Dalziel	Fabaceae	KNUST/HM1/2025/WP015	**Nyoo**	Leaf, Latex	74	0.300	63.5
Lannea acida A.Rich.	Anacardiaceae	KNUST/HM1/2025/WP016	**Sìnsàbgà**	Fruit, Root	71	0.287	57.7
Sclerocarya birrea (A.Rich.) Hochst.	Anacardiaceae	KNUST/HM1/2025/WP017	**mu-mugga**	Root	68	0.275	79.4
Pterocarpus erinaceus Poir.	Fabaceae	KNUST/HM1/2025/WP018	**Sagbe**	Bark	64	0.259	53.1
Hannoa undulata (Guill. & Perr.) Planch.	Simaroubaceae	KNUST/HM1/2025/WP019	**Kàmbàŋá**	Bark, Leaf	60	0.243	50.0
Biophytum petersianum Klotzsch	Oxalidaceae	KNUST/HM1/2025/WP020	**nàà náá kpórósôŋ**	Bark, Leaf	51	0.206	54.9

Frequency of Citation (FC), Relative Frequency of Citation (RFC), Fidelity Level (FL)

Table 8. PERMANOVA results testing effects of socio-demographic and spatial factors on the nature of medicinal plant knowledge

Source	Df	SumOfSqs	R^2	F	Pr(>F)
Ethnicity	2	2.14	0.18	4.21	0.001
Age group	2	1.08	0.09	2.03	0.001
Education	2	0.62	0.05	1.18	0.042
Distance to Health Center	1	0.71	0.06	2.81	0.002
Community	5	1.52	0.13	1.20	0.008
Residual	234	5.94	0.49		
Total	246	12.01	1.00		

Co-occurrence network analysis further revealed the structural role of individual species within the local pharmacopeia (Table 8). *Azadirachta indica* had the highest degree centrality (18) and betweenness centrality (0.34), identifying it as a cultural keystone species in the whole Tolon District. This means *A. indica* is not only widely known, but it also connects different knowledge clusters and is frequently mentioned together with other plants for treating multiple ailments. *Moringa oleifera, Vitellaria paradoxa, Parkia biglobosa* and *Adansonia digitata* also had high centrality scores, forming a secondary cluster of multipurpose species. The dominance of tree species in the network reflects the importance of woody plants that are available year-round in the Guinea Savanna.

Table 9. Network centrality measures of top 5 medicinal plant species in Tolon District

Plant Species	Degree centrality	Betweenness centrality	Interpretation
Azadirachta indica	18	0.34	Cultural Keystone Species
Moringa oleifera	14	0.21	Secondary hub species
Vitellaria paradoxa	13	0.18	Secondary hub species
Parkia biglobosa	12	0.15	Secondary hub species
Adansonia digitata	11	0.12	Secondary hub species

Relationship between plant use and environment using CCA and Random Forest

To test how environment and socio-spatial factors structure plant use, we used CCA and Random Forest Modelling analyses. CCA showed that environmental and socio-spatial variables explained 28.4% of the total variation in plant species use (Table 10). The first two axes were significant (CCA1: $p<0.001$; CCA2: $p< 0.001$). The ordination revealed that distance to the nearest health center and community were the strongest predictors. Species such as *Khaya senegalensis, Anogeissus leiocarpus* and *Sclerocarya birrea* were strongly associated with communities farther from health facilities. This suggests that in areas with poor access to orthodox care, people rely more on specific tree species that can be harvested locally. Conversely, communities closer to health centers showed more diverse but less specialized plant use.

Table 10. CCA results of relationship between plant species use and explanatory variables

Axis	Eigenvalue	Proportion Explained	Cumulative Proportion	p-value
CCA1	0.42	0.16	0.16	0.001
CCA2	0.33	0.12	0.28	0.003
Total Explained		0.284		

Random Forest Modelling confirmed and ranked the relative importance of predictors of total plant knowledge (Table 11). The model explained 61.3% of the variance. Age was the most important predictor (IncNodePurity = 42.1), followed by ethnicity (38.7) and distance to health center (29.4). Education ranked fourth. This finding is critical and shows that TM knowledge is primarily transmitted through age and cultural identity, not through formal education or proximity to health facilities. The high importance of distance to health center further supports the CCA result that spatial access influences which and how many plants people use.

Table 11. Random Forest Modelling generated an importance ranking of predictors of total number of medicinal plants known

Predictor Variable	%IncMSE	IncNodePurity	Rank
Age	28.4	42.1	1
Ethnicity	26.1	38.7	2
Distance to health center	19.8	29.4	3
Education	16.2	24.8	4
Sex	8.3	11.2	5

Note: Model explained 61.3% of variance. OOB error = 38.7%.

Discussion

Prevalence and pattern of traditional medicine use

The prevalence of TM use among respondents in the six study communities was 95.1%. This confirms TM as the primary healthcare option in the district and aligns with the WHO estimate that up to 80% of people in LMICs depend on TM for primary care (WHO 2019). This rate is consistent with findings from other parts of Ghana. Studies in Ashanti Region (Gyasi *et al.* 2011), Southern Ghana (Tabi *et al.* 2006), and Northern Region (Baba-Moussa *et al.* 2018) reported prevalence between 88% and 97%. The persistence of high use across rural areas reflects limited access to orthodox facilities and a continued reliance on indigenous knowledge systems (De-Graft Aikins *et al.* 2010).

The study found that accessibility was a key driver of TM in study communities because with one district hospital and 8 CHPS compounds, there was a lot of reliance on TM to provide immediate care within communities. This pattern has been noted in Northern Ghana where weak health infrastructure increases dependence on TM (van der Geest 1982). Cultural transmission was also significant, with 57.9% of respondents reporting that they acquired TM knowledge from family and peers, supporting evidence that household transmission sustains medicinal plant knowledge in Ghana (Asase *et al.* 2005). Perceived effectiveness also strongly influenced use, as Dominance Analysis showed that belief in effectiveness accounted for 38.4% of the variance in TM preference, consistent with findings from Kumasi where efficacy outweighed cost and availability as drivers in choosing to use TM (Adomako *et al.* 2017).

Despite high use, safety concerns remain. Many respondents reported uncertainty about dosage and low trust in regulation. This mirrors reports of concurrent TM and orthodox medicine use if patients do not disclose their TM use to health workers in Ghana, this raises the risk of herb-drug interactions (Kretchy *et al.* 2018). It also reflects the broader problem of poor standardization of herbal preparations listed in the GHP (Agyare *et al.* 2011). These findings support the integration of TM into formal district health planning, and Act 595 provides the legal framework for integration. CHPS compounds can be used to train staff on the 20 priority species identified in this study, particularly *Azadirachta* indica and *Acacia nilotica*, which had the highest cultural importance. Linking TM to mor local primary care in this way can improve safety while maintaining cultural relevance (Bodeker and Burford 2007).

Ranking and dominance of socio-cultural drivers of TM use

Perceived effectiveness was the dominant driver of TM use. Table 2 shows it had the highest Relative Importance Index of 0.861. Table 3 shows it also accounted for 38.4% of the explained variance in Dominance Analysis. Accessibility was the second most important driver at 22.1%, followed by family influence at 18.3%. Notably, distance from health center contributed only 1.7% of the explained variance. This finding extends earlier Ghanaian studies that described “effectiveness, affordability, and culture” as reasons for TM use (Abugre *et al.* 2012; Baba-Moussa *et al.* 2018) by quantifying their relative importance.

The primacy of effectiveness is consistent with Nigeria (Olorunnisola *et al.* 2011) and Ethiopia (Ayalew *et al.* 2020), where belief in therapeutic outcomes was the strongest predictor of TM use. In Tolon, this suggests that TM is not merely a fallback due to poverty or distance from health care facilities but rather is an active preference based on perceived efficacy. This is important because it reframes TM from being a "second-best" option to a culturally validated therapeutic choice. The high ranking of accessibility at 22.1% reflects the ecology of the Guinea Savanna, where most of the 20 cited plant species grow locally and can be harvested without cost. Unlike orthodox drugs that require cash purchase and travel to a facility, medicinal plants are available year-round in farms, fallows, and community lands particularly where the plant tissue used is bark or leaves. Only one of the species listed is a source of medicinal ingredients from fruits, which would only be available seasonally. This explains why affordability also ranked fourth at 12.7%. Together, effectiveness and accessibility account for over 60% of the explained variance, indicating that people use TM because they believe it works and because it is readily available.

The very low contribution of proximity to a health center at 1.7% challenges a common policy assumption that expanding orthodox facilities will automatically reduce TM use. In Tolon, even respondents living within 5km of the district hospital or a CHPS compound reported high TM use. This suggests that physical access alone is insufficient to shift health-seeking behavior if perceptions of effectiveness remain unchanged. Similar findings have been reported in Uganda (Tugume *et al.* 2016), where proximity to health centers did not predict reduced herbal medicine use. For Ghana, this means that infrastructure investments must be paired with demand-side interventions that address beliefs and experiences.

Demographic differences and associative pathways in TM preference

TM preference differed significantly by age, education, and ethnicity as shown in Table 4. Ethnicity explained the largest share of variance with an eta squared of 0.261, followed by education at 0.182 and age at 0.142. The strong effect of ethnicity is consistent with findings from Ethiopia (Ayalew *et al.* 2020) and Uganda (Tugume *et al.* 2016) where cultural identity was a major predictor of TM use. In Tolon, the higher preference among Dagomba respondents likely reflects differences in the local pharmacopeia, language of instruction, and cultural practices as previously noted by Baba-Moussa *et al.* (2018).

The Dagomba have a well-documented herbal tradition linked to Islamic and indigenous healing systems, and plant names, preparation methods, and therapeutic indications are transmitted in Dagbani. For Gonja and Mamprusi minorities, lower TM preference may reflect weaker intergenerational transmission in a predominantly Dagomba district, or greater integration into orthodox health services. This suggests that interventions under Act 595 cannot be "one-size-fits-all" but must be culturally and linguistically tailored to the dominant ethnic group in each district.

The significant effect of education confirms the "education paradox" observed in Kumasi (Abugre *et al.* 2012), where higher educational attainment was associated with lower TM use despite high plant availability. In Tolon, respondents with SHS/Tertiary education had a median TM preference of 2.0 compared to 4.0 among those with no formal education.

The Structural Equation Model provides evidence of associative pathways to explain this pattern. Education was significantly negatively associated with perceived effectiveness ($\beta = -0.28$, $p < 0.001$) and indirectly associated with TM preference through perceived effectiveness ($\beta = -0.17$, $p < 0.001$). This means that schooling reduces TM use partly by lowering belief in its efficacy as well as by improving access to orthodox care. As years of schooling increase, exposure to biomedical explanations of disease may lead individuals to question traditional explanations and to view TM as less scientific or less reliable. A similar mediation pathway has been described in Latin America (Reyes-García *et al.* 2014), but without formal testing of indirect effects. The implication is that education does not simply replace TM with orthodox medicine; it first changes the underlying belief system that makes TM acceptable.

Quantifying perceived intergenerational knowledge loss and perceptions of safety

The Perceived Knowledge Loss Index revealed significant erosion of TM knowledge among younger respondents. Table 5 shows that elders above 55 years had a mean KLI of 3.84 compared to 2.11 for youth below 41 years. This represents an 82% difference and provides the first quantitative evidence in Ghana for the anecdotal reports of “youth disinterest” in medicinal plants (Abugre *et al.* 2012; Asase *et al.* 2005). The magnitude of loss is comparable to the 40-50% decline reported among indigenous youth in Latin America (Reyes-García *et al.* 2014), and suggests that Tolon is experiencing a rapid transition in knowledge systems. Knowledge was also higher among those with no formal education and among Dagomba respondents, suggesting that both schooling and ethnic identity shape transmission. The negative effect of education observed in the SEM likely contributes to this pattern, as years in school reduce time spent in farms and with elders, and may introduce values that devalue TM knowledge.

Perceptions of safety, regulation and knowledge transmission

As shown in Table 6, respondents reported high concern about correct dosage (median = 4.0) and moderate concern about side effects and adulteration (median = 3.0). Trust in government regulation was low (median = 2.0), but there was strong agreement that government should standardize TM products (median = 4.0). While elders were perceived as willing to teach (median = 4.0), perceived youth interest was only moderate (median = 3.0), supporting the KLI findings of knowledge erosion. These findings indicate a risk of unsafe TM practice and highlight the need for urgent regulatory and educational interventions in Tolon District. The high concern about dosage is particularly important because most TM in Tolon is prepared and administered at the household level, as shown by the 58.1% who acquired knowledge from family and peers. Without standardized dosing, there is potential for under-dosing, which may lead to treatment failure, or over-dosing, which may cause toxicity. This concern aligns with reports from other African contexts where lack of dosage standardization has been cited as a major barrier to the integration of TM into formal health systems (Ekor 2014; Mensah *et al.* 2019).

The low trust in government regulation, combined with strong support for standardization, suggests that communities are not opposed to oversight but rather perceive current regulatory efforts as inadequate or invisible at the district level. This presents an opportunity for the Ghana Food and Drugs Authority and the Traditional Medicine Practice Council to increase visibility through CHPS and community durbars. Regulatory engagement should not focus only on commercial TM products, but also on household preparations, since that is the source of most of the TMs used in Tolon.

The report of moderate youth interest despite high elder willingness to teach about TM points to a breakdown in transmission mechanisms rather than unwillingness from knowledge holders. This gap is consistent with global reports of intergenerational knowledge erosion linked to formal schooling, migration, and changing livelihoods (Reyes-García *et al.* 2014; Kunwar *et al.* 2013). In Tolon, the negative effect of education on TM preference shown in the SEM further suggests that schools may be a site where TM is devalued rather than discussed critically. This suggests a need to connect policies on TM use with curriculum design and teacher training.

Identification and quantitative importance of medicinal plants and implications for integration

A total of 20 medicinal plant species were documented as important for healthcare in Tolon District. The use of quantitative indices moves the inventory beyond simple listing and provides evidence for prioritization. *Azadirachta indica* had the highest Frequency of Citation and Relative Frequency of Citation (0.757), indicating that it is the most widely known and used species across communities. This is consistent with inventories from Southern Ghana (Asase *et al.* 2005) and Northern Ghana (Baba-Moussa *et al.* 2018) and reflects the wide availability of neem in the Guinea Savanna and its broad-spectrum use for treating malaria, skin infections and fever.

Acacia nilotica recorded the highest Fidelity Level of 81.5%, indicating strong cultural consensus for its use, particularly in treating wounds and gastrointestinal ailments. Similarly, *Sclerocarya birrea* had a high FL of 79.4% and *Azadirachta indica* had an FL of 76.5%, suggesting that these species are culturally validated for specific conditions. High FL values are important because they point to plants with consistent traditional use that are therefore priority candidates for phytochemical screening and toxicity testing (Ali *et al.* 2019). The prominence of trees and woody shrubs such as *Vitellaria paradoxa, Parkia biglobosa, Khaya senegalensis and Adansonia digitata* among the top 10 species reflects the ecology of the Guinea Savanna, where woody species are more accessible year-round than herbs. This finding supports the integration of forestry and health policy, because sustainable harvesting of bark and roots from these species is critical to avoid overexploitation. Comparing the findings of this study with the Ghana Herbal Pharmacopoeia (GFDA 2007), 16 out of the 20 species are already documented, but dosage, preparation and safety profiles for Tolon-specific uses are not standardized. For example, while *Moringa oleifera* is pharmacopoeia-listed, its use for hypertension in Tolon was cited with moderate consensus but without standardized preparation methods. This gap presents an opportunity for the Food and Drugs Authority and the Centre for Plant Medicine Research to collaborate with local practitioners to validate and document district-specific monographs.

Structural patterns of plant knowledge and environment-people linkages

Beyond descriptive indices, this study provides the first district-level evidence in Ghana on how TM knowledge is structurally organized. PERMANOVA results showed that plant knowledge composition was not randomly distributed but was significantly structured by ethnicity, age, community and distance to health center (Table 8). Ethnicity explained the largest proportion of variation ($R^2 = 0.18$), which aligns with findings from Ethiopia where Ayalew *et al.* (2020) reported ethnicity as the strongest predictor of medicinal plant knowledge in Bale Zone. Similarly, Tugume *et al.* (2016) in Uganda found that cultural identity explained more variation in plant use than education or income. This confirms that cultural identity is the primary filter through which medicinal plant knowledge is acquired and maintained in Tolon. The significant effect of age ($R^2 = 0.09$) is consistent with Reyes-García *et al.* (2014) who documented rapid knowledge loss among indigenous youth in Bolivia due to formal schooling and migration. The significant effect of distance to health center ($R^2 = 0.06$) supports van der Geest (1982) and Tugume *et al.* (2016), who argued that poor access to orthodox facilities increases reliance on specific local TM practices.

Network analysis further identified *Azadirachta indica* as a cultural keystone species (Table 9). Its high degree and betweenness centrality mean it acts as a bridge in local knowledge systems. This is consistent with Asase *et al.* (2005) and Baba-Moussa *et al.* (2018) who also reported *A. indica* and *M. oleifera* as the most frequently cited species in Ghana. The concept of keystone species in ethnobotany has been applied in Latin America by Albuquerque *et al. (*2011), who showed that a few central species sustain most of the local pharmacopeia. The clustering of *M. oleifera, V. paradoxa, P. biglobosa* and *A. digitata* as secondary hubs reflects a core set of multipurpose savanna trees. This mirrors findings from Northern Nigeria by Olorunnisola *et al.* (2011) where Fabaceae species dominated TM use due to their year-round availability.

Furthermore, CCA and Random Forest Modelling results together show the importance of spatial factors (Table 10-11). CCA explained 28.4% of variation in plant use, with distance to health center as a key driver. This is similar to Kunwar *et al.* (2013) in Nepal, who found that proximity to forests and distance to markets strongly structured medicinal plant use. Species such as *K. senegalensis* and *A. leiocarpus* were associated with more distant communities, suggesting reliance on locally available trees where orthodox care is costly to access. This supports Mensah *et al.* (2019) who noted that in rural Ghana, TM fills gaps

where health infrastructure is weak. Random Forest Modelling analyses ranked Age and Ethnicity as the top predictors of total plant knowledge, explaining 61.3% of variance. This is consistent with Reyes-García *et al.* (2014) who used similar machine learning approaches to show that age and cultural affiliation, not schooling, best predicted ethnobotanical knowledge. The low importance of education in the RF model, despite its significant effect in SEM, suggests that while schooling reduces belief in TM effectiveness, it does not directly determine how many plants a person knows.

Overall, these results indicate that TM policy under Act 595 cannot be uniform. It must be spatially targeted to serve remote communities and should be culturally tailored to ethnic groups, while also creating school-based platforms to reverse knowledge loss among youth, as recommended by Kunwar et *al.* (2013) for Nepal and by Reyes-García *et al. (*2014) for Latin America.

Limitations

While this study provides first district-level evidence, key limitations noted. First, intergenerational knowledge loss was assessed through perceived reports from elders using PKLI, rather than through direct interviews with youth within same households and direct testing of actual youth knowledge - as suggested by Reviewer. Youth free-listing and teacher attitude surveys recommended for future. Also, cross-sectional design limits SEM to identifying associations, not causal relationships; longitudinal studies needed. Furthermore, because sampling focused on six communities identified as having high TM use, reported prevalence of 95.1% is not intended to be extrapolated to entire Tolon District population. Target sample 399 but achieved 247 (61.9%). Private same-gender interviews attempted but male household heads sometimes present initially may cause under-reporting of women's health TM uses.

Conclusion

Traditional Medicine in Tolon District remains the de facto primary healthcare system, sustained by a strong belief in its effectiveness, ready accessibility of medicinal plants and intergenerational transmission within families. With a prevalence of 95.0% in the six study communities, TM is not a marginal or occasional practice but rather represents the first line of care for most households in this rural Guinea Savanna setting.

Beyond prevalence, this study demonstrates that TM knowledge in Tolon is structurally patterned. Multivariate analyses showed that plant knowledge composition is significantly shaped by ethnicity, age, and distance to health center, but not by proximity to orthodox facilities alone. The identification of *Azadirachta indica* as a cultural keystone species and the clustering of other multipurpose trees used in TM provides evidence-based priorities for conservation and validation. Canonical Correspondence Analysis and Random Forest Modelling Analysis further revealed that spatial access and cultural identity are stronger predictors of plant knowledge than level of formal education, confirming that transmission occurs primarily within households and ethnic groups. However, the system faces two critical challenges of measurable knowledge erosion, with elders above 55 years holding 82% more TM knowledge than they believe is held by community members below 41 years. There are clearly significant concerns about safety and regulation, evidenced by high concern about correct dosage and low trust in government oversight, despite strong support for standardization.

The findings support four policy priorities for Ghana under the Traditional Medicine Practice Act 2000 (Act 595):

i. Validate and standardize priority species: Plants with high cultural and network importance such as *Azadirachta indica, Moringa oleifera, Vitellaria paradoxa and Acacia nilotica* should be prioritized for phytochemical screening, toxicity testing, and development of district-specific dosage guidelines for use in CHPS.

ii. Deliver targeted, evidence-based education: Schools and CHPS should provide safety education on dosage, preparation, and contraindications. Interventions must be culturally tailored to dominant ethnic groups and spatially targeted to remote communities identified by CCA as having high reliance on specific tree species.

iii. Create structured platforms for intergenerational transfer: "Elder-to-Youth Knowledge Hubs" at CHPS and documentation projects led by young members of the community can bridge the knowledge gap while preserving cultural heritage and creating local employment. This is urgent given that age and ethnicity, not education, were the strongest predictors of plant knowledge.

iv. Strengthen regulatory visibility at community level: The Traditional Medicine Practice Council and FDA should engage communities through durbars and household networks, since that is where most TM decision-making and preparation occurs.

The integrated framework used in this study, combining prevalence estimates, dominance analysis, SEM, KLI, ethnobotanical indices, NMDS, CCA, PERMANOVA, network analysis and Random Forest Modelling analysis, provides a replicable model for other districts in Ghana. By moving beyond simple indices to test the structure of relationships among people, plants and environment, this study offers the first district-level evidence in Ghana to support the safe and culturally grounded integration of TM into the national health system and generates useful contributions to SDG 3, 4 and 11. Without urgent action to address knowledge loss and safety, TM in Tolon risks becoming less effective and more hazardous for future generations due to growing uncertainty about preparation methods and dosages. With appropriate policy support, it can remain a safe, effective, and culturally grounded component of Ghana's healthcare system.

Declarations

List of abbreviations: TM - Traditional Medicine, Act 595 - Traditional Medicine Practice Act 2000, WHO - World Health Organization, LMICs - Low- and Middle-Income Countries, GHP - Ghana Herbal Pharmacopoeia, CI - Confidence Interval, RII - Relative Importance Index, DA - Dominance Analysis, KW - Kruskal-Wallis, SEM - Structural Equation Modeling, KLI - Knowledge Loss Index, FC - Frequency of Citation, RFC - Relative Frequency of Citation, FL - Fidelity Level, CHPS - Community-based Health Planning and Services, UDS - University for Development Studies, ABS - Access and Benefit Sharing, KNUST-Kwame Nkrumah University of Science and Technology, SPSS - Statistical Package for the Social Sciences, AMOS - Analysis of Moment Structures, SDGs - Sustainable Development Goals, η^2 - eta-squared, FGD - Focus Group Discussion, IQR - Interquartile Range, FDA - Food and Drugs Authority, GFDA - Ghana Food and Drugs Authority, GSS - Ghana Statistical Service, KNUST - Kwame Nkrumah University of Science and Technology, WFO - World Flora Online.

Ethics approval and consent to participate: Ethical approval for this study was obtained from the University for Development Studies Ethics Committee (Ref: UDS/REC/006/2023). All participants provided oral prior informed consent in Dagbani after the study objectives were explained. The study complied with the Nagoya Protocol on Access and Benefit Sharing and the principles of the Declaration of Helsinki.

Consent for publication: Not applicable. No individual personal data or images that could identify participants are included in this manuscript.

Availability of data and materials: The datasets generated and analyzed during the current study, including the questionnaire and list of voucher specimens, are available from the corresponding author on reasonable request. Voucher specimens KNUST/HM1/2025/WP001 to WP020 are deposited at the Herbarium, Faculty of Pharmacy and Pharmaceutical Sciences, KNUST.

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