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Endogenous Knowledge of Populations on the Uses of *Ximenia americana* L. Organs for the Treatment of Pathologies

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Abstract

Ximenia americana L. is one of the multipurpose plants on which ethnomedicine practised in Africa is based. This study documented the traditional knowledge and reported uses of the organs of the species in Benin. Semi-structured interviews were conducted with 1090 resource persons, selected by purposive and snowball sampling, in five agro-ecological zones (AEZ 2-6) of central and northern Benin where the species occurs. Data were analysed with relative importance indices, use values, chi-square tests, ANOVA and Kruskal-Wallis tests, a Poisson generalized linear model, correspondence analysis (CA) and multiple correspondence analysis (MCA). Fruits (89.3%) were the organ most used for food, whereas leaves (69.53%), bark (62.5%) and roots (61.04%) were mainly cited for medicinal purposes. Malaria, abdominal pain and ulcers were the conditions most frequently associated with the species; leaves were the organ most cited for malaria, whereas roots and bark were mainly cited for abdominal pain and ulcers. Medicinal ($\chi^2 = 194.950$; df = 9; $p < 0.001$) and food uses ($\chi^2 = 300.435$; df = 9; $p < 0.001$) varied significantly among ethnic groups. Use values also differed significantly between agro-ecological zones (ANOVA: $F = 87.92$; df = 4 and 1085; $p < 2 \times 10^{-16}$; Kruskal-Wallis: $\chi^2 = 305.06$; df = 4; $p < 2.2 \times 10^{-16}$). The MCA revealed a strong socio-cultural and agro-ecological structuring of use patterns. These are reported uses, which do not establish clinical efficacy or measured harvesting pressure; they nevertheless justify phytochemical, efficacy and toxicity studies, notably on antimalarial and gastrointestinal activities, and an assessment of the conservation risks associated with root and bark harvesting.

Keywords

Ximenia americana L., Endogenous Knowledge, Ethnobotany, Ethnomedicine, Benin

1. Introduction

In many regions of Sub-Saharan Africa, endogenous knowledge transmitted from generation to generation [1] [2] constitutes an essential heritage of local health systems [3], particularly in rural areas where access to biomedical services sometimes remains limited [4]. Multipurpose plants described in several ethnobotanical studies conducted in West and Central Africa [5] [6] are reported to be used for their leaves, bark, roots and fruits to treat various conditions, including malaria, digestive disorders, abdominal pain and certain infections [7] [8]. However, knowledge about the therapeutic specialization of the different organs of *X. americana* and its variability according to sociocultural groups remains insufficiently documented in Benin. The documentation of this knowledge is all the more important since certain harvesting practices, particularly those involving roots and bark, can affect the survival of individuals and compromise the conservation of natural populations [9] [10]. Reported uses nevertheless reflect knowledge and practice; they are not evidence of clinical efficacy or of actual harvesting pressure. The present study aims to analyse the endogenous knowledge of populations on the uses of *X. americana* organs, to identify the most solicited organs and the most frequently treated pathologies, and to assess the diversity of uses according to the sociocultural characteristics of the respondents.

2. Materials and Methods

2.1. Study Area

The study was carried out in the area from the centre to the north of Benin, located between 7˚ and 12˚30′N latitude and between 1˚ and 3˚40′E longitude (**Figure 1**). Rainfall varies between 900 mm and 1,300 mm per year, with variable soils [11] [12]. Climatically, the area is divided into three units: a sub-equatorial climate with a bimodal rainfall regime from 7˚N to 8˚30′N [7] [13]; a tropical climate with a unimodal rainfall regime from 8˚30′N to 12˚N; and an Atacorian climate in the north-west, in the Atacora range, where 1350 mm per year are recorded at Boukoumbé [14] [15]. According to the fourth General Census of Population and Housing (RGPH4, 2013), the resident population was 4,114,581 inhabitants, unevenly distributed throughout the study area and mainly composed of Fon and related sociolinguistic groups (39%), Adja and related (15%), Yoruba and related (12%) and Bariba and related (9%) [16]. The survey covered agro-ecological zones AEZ 2 to AEZ 6 (Zone 2 Cotton zone of Northern Benin, Zone 3 Southern Borgou food-crop area, Zone 4 Zone Ouest-Atacora, Zone 5 Central cotton zone and Zone 6 Barre land area).

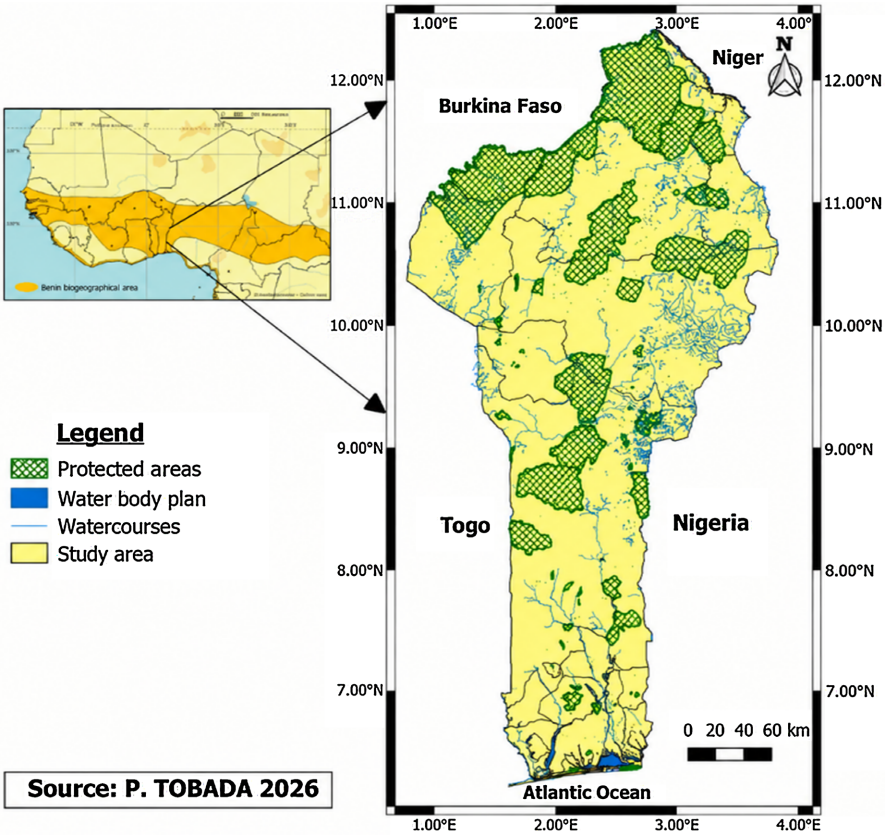


Figure 1. Study area.

2.2. Materials

The equipment consisted of a structured ethnobotanical survey questionnaire, data collection sheets, a Nikon digital camera, a GPS for the location of survey sites and a computer for data processing. The questionnaire was designed to collect the socio-demographic characteristics of the respondents (age, sex, ethnic group, main activity, level of education and municipality of residence), the uses of *X. americana* and the plant organs used in the treatment of pathologies.

2.3. Study Design and Ethical Considerations

A cross-sectional ethnobotanical survey was conducted in agro-ecological zones from the centre to the north of Benin, in order to cover the diversity of ecological and sociocultural contexts where *X. americana* is present and used by local communities, traditional healers, herbalists and other resource persons. Participants were selected by purposive sampling, supplemented in some cases by the snowball method [17] [18]. Two inclusion criteria were used: knowledge of *X. americana* and effective use of the species. This approach aimed to gather information from people with direct experience of the plant and its uses. The results therefore describe this group of resource persons and cannot be extrapolated to the general population.

Informed consent was obtained verbally from each participant prior to data

collection, after the objectives of the study, the voluntary nature of participation and the intended use of the data had been explained; respondents could refuse to answer or withdraw at any time. The anonymity of participants (identification by codes only), the confidentiality of the information collected and respect for traditional knowledge were ensured: information that respondents regarded as secret or sacred was not recorded, and survey locations will be shared only at locality level. Since the study involved neither clinical trials nor biomedical interventions, no formal ethics committee approval was required [19] [20].

2.4. Data Collection

Data were collected through semi-structured interviews, using a questionnaire administered with the KoboCollect application [21] [22]. The questionnaire is accessible at https://kf.kobotoolbox.org/#/forms/aQPVvboGBYMSqjbS9bPuJG/landing.

A total of 1 090 resource persons participated in the survey. Sampling was purposive and not based on quotas; the number of respondents per agro-ecological zone (Table 1) therefore reflects the presence of the species and the availability of resource persons in each zone. The low proportion of respondents in agroecological zone 6 is due to the recruitment criteria. They were required to be familiar with Ximenia americana L. and to report that they actually used it. Based on field observations, the species is currently rare in this zone, which reduced the opportunities to encounter users who met the inclusion criteria. In contrast, in Zone 5, the greater availability of the species made it easier to identify users, and the snowball sampling method allowed for the gradual expansion of the sample by connecting with other users. Purposive sampling thus prioritized the relevance of the information collected, without guaranteeing proportional representation across the zones. This explanation, however, is based on an interpretation derived from observed local realities in the absence of independent data on the species'

Table 1. Respondents by agro-ecological zone and sex, with mean use value (UV ± standard deviation).

Group	n	UV (mean ± SD)
AEZ 2	147	1.374 ± 0.513
AEZ 3	166	1.759 ± 0.574
AEZ 4	258	1.461 ± 0.930
AEZ 5	516	2.461 ± 0.947
AEZ 6	3	1.333 ± 0.577
Women	261	2.161 ± 0.906
Men	829	1.907 ± 0.985
All respondents	1,090	1.968 (global UV)

AEZ: agro-ecological zone; SD: standard deviation. AEZ 6 (n = 3) is reported descriptively only. All 1090 respondents are included.

abundance or the frequency of its use. It does not demonstrate either the rarity of the species or a decline in local knowledge. All 1090 respondents have complete data and were included in the analyses. Taking into account the geographical scope of the study, the survey was carried out in different areas and localities in order to ensure sufficient spatial coverage and to allow comparisons of knowledge and uses of *X. americana* along the studied agro-ecological gradient.

2.5. Coding of Uses and Ethnobotanical Indices

Each interviewee was asked about the uses of the different organs of *X. americana* (leaves, bark, roots, fruits, wood/stem and whole plant). A free-listing of reported uses was carried out following the approach of Gomez-Beloz [23]. The uses were then grouped into six categories inspired by Tardío and Pardo-de-Santayana [24]: food, medicinal, fodder, trade, ritual and construction. Organ-level responses were recorded with finer labels (e.g. cosmetic, artisanal resource, soil restoration, grazing). In order to distinguish knowledge from actual use, respondents assigned an importance score to each category of use: 0 = not used, 1 = low use, 2 = medium use and 3 = high use. The scores were summed over categories to obtain an overall importance of uses per respondent, grouped into four classes (low, medium, high, very high) used in the MCA. The socio-demographic information collected concerned age, sex, ethnic group, main activity, level of education and municipality of residence.

For each use category, the relative importance index (RI) was calculated as the relative frequency of citation: $\mathrm{RI} = \mathrm{FRC} = \frac{n}{N}$, where n is the number of respondents who cited the category and N the total number of respondents. The individual use value (UV) was defined as the number of use categories (0 to 6) cited by a respondent; the global use value is the mean UV over all respondents and is equal to the sum of the RI of the six categories. UV was compared among agro-ecological zones, ethnic groups, sexes and organs (for the organ variable, "None" designates respondents who cited no specific organ).

2.6. Statistical Analysis

Associations between each use category (cited/not cited) and agro-ecological zone or ethnic group were tested with Pearson's chi-square tests. Differences in UV between groups were tested with ANOVA and the non-parametric Kruskal-Wallis test; because UV is a discrete variable bounded between 0 and 6, both tests were applied and are reported. Associations between treated conditions and organs were explored by correspondence analysis (CA) of the condition × organ contingency table. Relationships among uses, ethnic groups and agro-ecological zones were explored by MCA of the 1090 individuals described by eight categorical variables (ethnic group, agro-ecological zone, importance of uses, and presence/absence of food, medicinal, ritual, fodder and commercial uses). The number of use categories cited was modelled with a Poisson generalized linear model (GLM, log

link) [25], with agro-ecological zone, level of education, ethnic group and organ as predictors. Overdispersion was checked from the residual deviance (354.94 on 1061 degrees of freedom, ratio 0.33), which showed no overdispersion; a negative binomial model was therefore not required. All statistical analyses were performed with R version 4.6, and results were interpreted at the 5% significance level. Because AEZ 6 (n = 3), the Adja group (n = 6) and some organ categories (flower, n = 1; stem, n = 2) contain very few observations, their estimates are described but not interpreted, and p-values involving them should be treated with caution (expected counts below 5). No correction for multiple testing was applied; p-values close to 0.05 are therefore considered borderline.

3. Results

3.1. Types of Use Made of *Ximenia americana*

A total of 1090 resource persons were surveyed in the five agro-ecological zones (AEZ 2 to AEZ 6) (Table 1). The relative importance index (RI) made it possible to assess the relative importance of the use categories identified by respondents (Figure 2). It identified six categories of use of *X. americana* in the localities studied: food (81.65%), medicinal (74.86%), fodder (20.46%), commercial (13.76%), ritual (4.13%) and construction (2%). Food and medicinal uses were the most frequently mentioned. The global use value was 1.968, *i.e.* on average each respondent cited nearly two categories of use. These results show that *X. americana* is mainly perceived as a food and medicinal resource, while its fodder, commercial and ritual functions remain secondary, which suggests an important role for the species in the food security and traditional health practices of the communities surveyed.

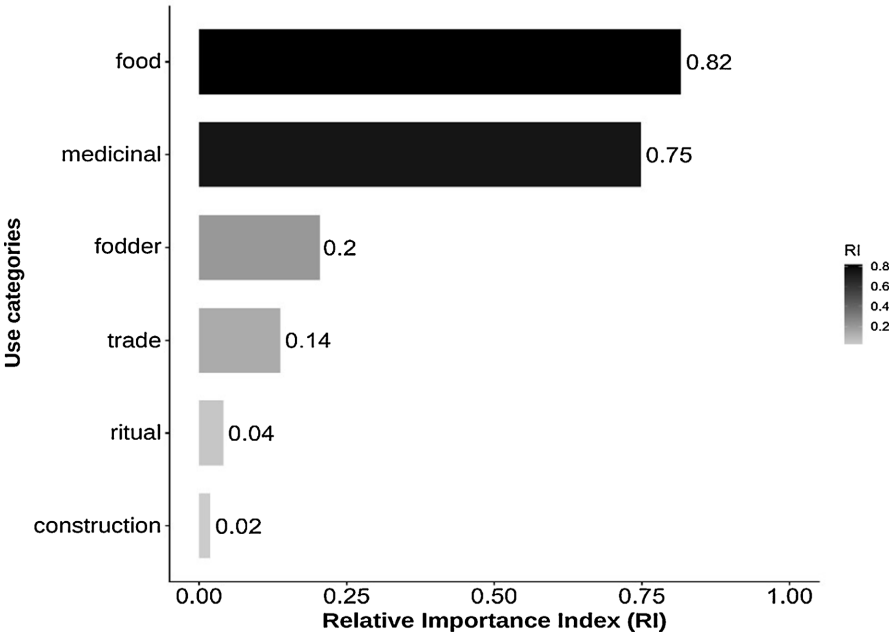


Figure 2. Relative importance index (RI) of the use categories of *Ximenia americana*.

3.2. Distribution of Uses According to the Organs

The analysis of organs used reveals a marked functional specialization of *X. americana* according to use categories (Figure 3). The fruit is the organ mainly valued for food purposes, with 979 citations, or 89.3% of respondents. Medicinal uses of the fruit remain marginal (1.9%). The leaves are mainly associated with medicinal uses, with 762 citations (69.53%). A relatively large proportion of respondents said they did not use the leaves (22.08%), while cosmetic (4.38%), food (2.46%) and forage (1.28%) uses remain secondary. Wood is much less in demand than other organs: most respondents (79.75%) say they do not use it. When it is used, it is mainly for medicinal purposes (16.79%), while cosmetic, food, grazing and artisanal uses remain very limited. This low exploitation of wood may reflect a lesser cultural or economic importance of this organ, or a deliberate preference for preserving adult individuals; this interpretation was not tested in the present study.

The bark is also strongly mobilized in medicinal uses (62.5% of respondents). About one-third of respondents (34.76%) do not use it, and other uses remain marginal. The roots follow a trend comparable to that of the bark: medicinal uses largely dominate (61.04%), while 32.12% of respondents say they do not use them; grazing (4.38%) and cosmetic uses (1.28%) remain secondary. The strong

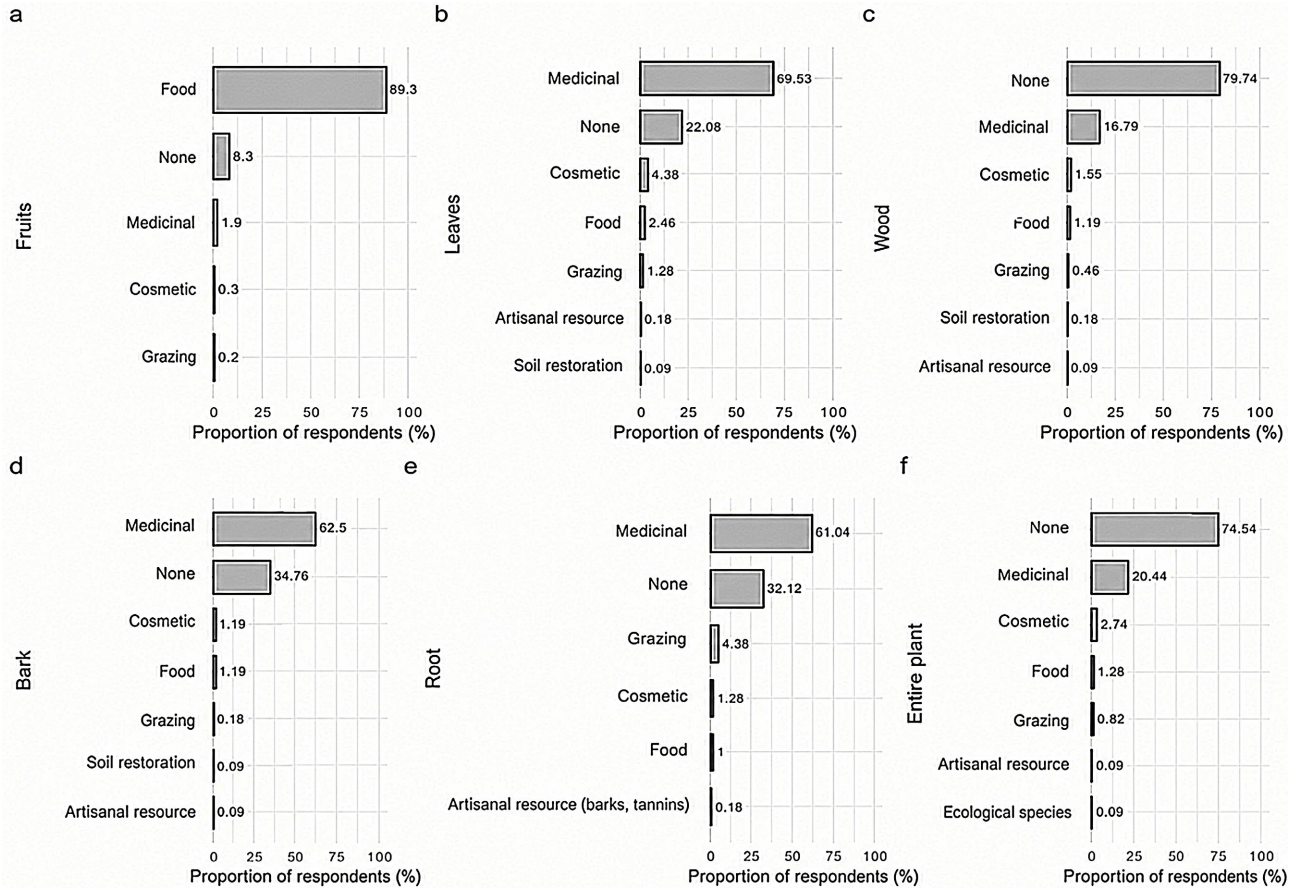


Figure 3. Distribution of uses according to the organs of *Ximenia americana* (a: fruits; b: leaves; c: wood; d: bark; e: roots; f: whole plant).

solicitation of roots for therapeutic purposes deserves attention, because root harvesting can directly affect the survival and regeneration of individuals. Finally, the whole plant is rarely used as such: medicinal uses account for 20.44% of citations, while 74.54% of respondents report not using the whole plant; cosmetic (2.74%), food (1.28%) and grazing (0.82%) uses are poorly represented.

3.3. Analysis by Condition: Specialization of Organs

The cross-analysis of treated conditions and organs used reveals a therapeutic specialization of the organs of *X. americana* (Table 2). Leaves, roots and bark concentrate most medicinal citations, while flowers, fruits and stems are cited for a very limited number of ailments.

Table 2. Distribution of treated conditions according to the organs used for *Ximenia americana* in local medicinal practices (% of citations for each organ; columns sum to 100%).

Treated condition	Bark	Leaves	Flower	Fruit	Root	Stem	Total
Agalactia	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Anaemia	0.0	1.8	0.0	0.0	3.3	0.0	1.7
Angina	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Aphrodisiac	0.0	0.0	0.0	0.0	3.3	0.0	0.7
Asthenia	0.0	0.6	0.0	0.0	1.7	0.0	0.7
Abdominal bloating	0.0	1.2	0.0	0.0	0.0	0.0	0.7
Bilharziasis	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Cancer	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Dental caries	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Spiritual cause	0.0	1.2	0.0	0.0	0.0	50.0	1.0
Headache	0.0	1.8	0.0	0.0	0.0	0.0	1.0
Chronic headache	2.1	0.6	0.0	0.0	0.0	0.0	0.7
Animal dermatosis	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Renal detoxification	2.1	0.0	0.0	0.0	0.0	0.0	0.3
Blood detoxification	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Diabetes	0.0	0.6	0.0	0.0	1.7	0.0	0.7
Diarrhoea	4.3	4.2	0.0	0.0	6.7	0.0	4.5
Abdominal pain	23.4	3.0	0.0	12.5	36.7	0.0	13.7
Teething pain	2.1	0.0	0.0	0.0	0.0	0.0	0.3
Intestinal pain	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Dysmenorrhoea	2.1	2.4	0.0	0.0	1.7	0.0	2.1
Envenomation	2.1	0.0	0.0	0.0	1.7	0.0	0.7
Epilepsy	2.1	0.6	0.0	0.0	0.0	0.0	0.7

Continued

Facilitation of childbirth	4.3	0.6	0.0	0.0	0.0	0.0	1.0
Fatigue	0.0	1.8	0.0	0.0	1.7	0.0	1.4
Fever	0.0	4.8	0.0	0.0	5.0	0.0	3.8
Yellow fever	0.0	1.2	0.0	0.0	0.0	50.0	1.0
Haemorrhoids	2.1	0.0	0.0	0.0	0.0	0.0	0.3
Hypertension	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Hyperthermia	2.1	3.0	0.0	0.0	0.0	0.0	2.1
Impotence	4.3	0.6	0.0	0.0	1.7	0.0	1.4
Indigestion	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Infection	2.1	1.2	0.0	0.0	0.0	0.0	1.0
Genital infection	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Urinary tract infection	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Leucorrhoea	0.0	0.0	0.0	6.3	0.0	0.0	0.3
Respiratory diseases	2.1	0.0	0.0	0.0	0.0	0.0	0.3
Threatened abortion	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Migraine	2.1	0.0	0.0	0.0	0.0	0.0	0.3
Oedema	4.3	0.6	0.0	0.0	1.7	0.0	1.4
Orchitis	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Malaria	10.6	50.3	100.0	75.0	5.0	0.0	35.7
Paralysis	0.0	0.0	0.0	0.0	5.0	0.0	1.0
Parasitoses	0.0	1.2	0.0	0.0	1.7	0.0	1.0
Wound	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Spiritual protection	2.1	0.6	0.0	0.0	0.0	0.0	0.7
Neonatal care	0.0	0.0	0.0	0.0	1.7	0.0	0.3
General tonic	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Geriatric tonic	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Neonatal tonic	4.3	1.2	0.0	0.0	0.0	0.0	1.4
Cough	4.3	3.0	0.0	0.0	0.0	0.0	2.4
Liver disorder	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Memory impairment	0.0	1.2	0.0	0.0	0.0	0.0	0.7
Mental disorder	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Typhoid	0.0	0.0	0.0	0.0	1.7	0.0	0.3
Ulcer	12.8	0.6	0.0	6.3	8.3	0.0	4.5
Anthelmintic (deworming)	2.1	0.0	0.0	0.0	0.0	0.0	0.3

Continued

Dizziness	0.0	0.6	0.0	0.0	0.0	0.0	0.3
Vomiting	0.0	1.2	0.0	0.0	0.0	0.0	0.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Column headings were corrected (previously "Spalls", "Sheets", "Rod") and decimal commas replaced by decimal points. The categories "na" and "not specific" (0% in all columns) are omitted. Percentages for flower, fruit and stem are based on very few citations.

Malaria is the condition most frequently associated with the species. It accounts for 50.3% of the citations for leaves, 100% of those for flowers, 75% of those for fruits and 35.7% of all therapeutic citations, which shows a strong convergence of local knowledge towards this condition. Leaves are thus the main organ cited for malaria, and reproductive organs also seem to be targeted when available; flower, fruit and stem frequencies rest on very few observations and should be interpreted with caution. Abdominal pain is the second major category. It is particularly associated with roots (36.7%) and bark (23.4%), while fruits represent 12.5% of citations for this condition. This distribution suggests that underground and bark organs are considered the most effective for digestive disorders. Ulcers also show organ specialization: bark (12.8%) and roots (8.3%) are the most frequently cited, followed by fruit (6.3%), whereas leaves are very little involved (0.6%).

For diarrhoea, citations are distributed between roots (6.7%), bark (4.3%) and leaves (4.2%), indicating less specialization and some functional redundancy among organs. Fever shows a comparable pattern, with roots (5.0%) and leaves (4.8%). Conditions related to reproductive health and vitality show more specific preferences: dysmenorrhoea mobilizes bark (2.1%), leaves (2.4%) and roots (1.7%); impotence is more associated with bark (4.3%) than with roots (1.7%), while aphrodisiac use is reported exclusively for roots (3.3%). Some conditions show an almost exclusive specialization: leucorrhoea is treated only with fruits (6.3% of fruit citations), whereas uses related to spiritual causes and yellow fever are mainly associated with stems (50% each of the very few citations for this organ).

3.4. Correspondence Analysis of Conditions and Organs

Correspondence analysis (CA) between the treated conditions and the organs of *X. americana* highlights preferential associations between plant parts and categories of conditions (**Figure 4**). The first five dimensions explain all the inertia of the point cloud, but the first three alone account for 91.4% of the total variability: the first dimension explains 43.2% of inertia, the second 26.5% and the third 21.6%.

The first dimension mainly opposes roots and bark to leaves, flowers, fruits and stem. Roots contribute strongly to this axis (46.9%; coordinate = 1.10), followed by bark (15.7%; coordinate = 0.71), whereas leaves (−0.53), flowers (−0.78), fruits (−0.38) and especially stem (−1.87) lie on the negative side. The conditions that

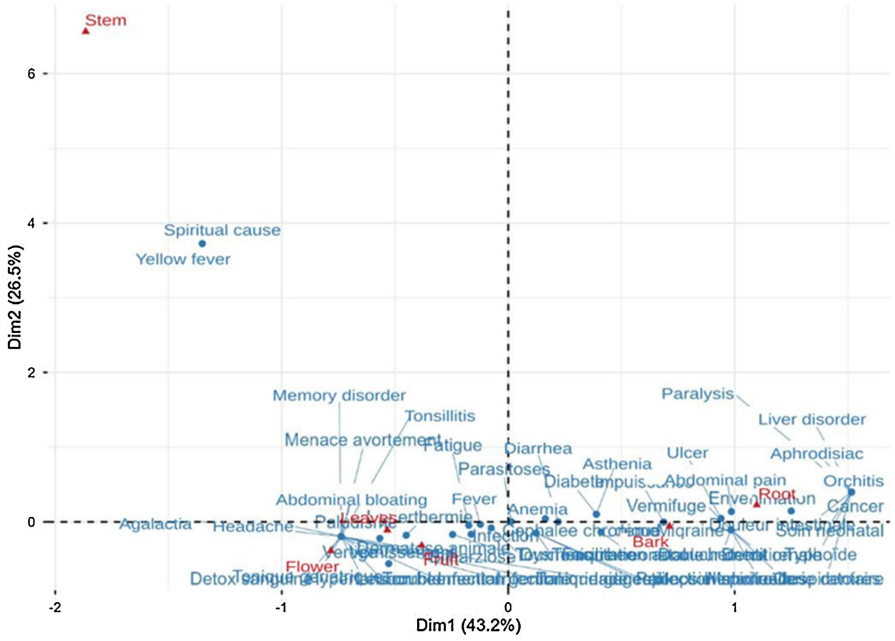


Figure 4. Correspondence analysis of the treated conditions and the organs used.

mainly explain this axis are abdominal pain (25.6% contribution; $\cos^2 = 0.95$), malaria (21.9%; $\cos^2 = 0.79$), ulcers (7.6%; $\cos^2 = 0.77$) and envenomation (2.1%; $\cos^2 = 0.89$). In agreement with Table 2, abdominal pain, ulcers and envenomation are positioned on the side of roots and bark, whereas malaria, which is cited mainly for leaves, flowers and fruits, lies on the opposite side of the axis. This pattern is consistent with ethnobotanical practices reported in several African regions, where underground organs and woody tissues are frequently used for digestive or chronic conditions.

The second dimension (26.5% of inertia) is dominated by the stem, which alone contributes 92.5% (coordinate = 6.56; $\cos^2 = 0.91$). On the condition side, this axis is associated with spiritual causes and yellow fever, which have the largest contributions (44.7% each; coordinate = 3.72). The stem therefore has a very specific use profile, associated with symbolic dimensions or conditions perceived as having a not exclusively biological origin, although it rests on very few citations. The third dimension (21.6%) highlights bark (67.8%) and roots (29.4%); the conditions strongly associated with it include renal detoxification, dental conditions, haemorrhoids and respiratory diseases. Reproductive organs contribute little to the first three dimensions. The fruit is distinguished on the fourth dimension (about 89% of the contribution; $\cos^2 = 0.86$), and the flower on the fifth (98.1%), which represents only 0.21% of the total inertia and therefore has limited importance.

The CA thus highlights a functional specialization of the organs of *X. americana* in the reported therapeutic practices: leaves are the organ most cited for malaria, roots and bark for abdominal pain and ulcers, and the stem has a particular profile associated with spiritual uses. These results point to the importance of perennial

vegetative organs in the reported pharmacopoeia and to the need to consider conservation, since intensive harvesting of roots and bark could constitute pressure on natural populations; this pressure was not measured in the present study.

3.5. Distribution of Uses According to Agro-Ecological Zones

The frequency of use of *X. americana* varies markedly between agro-ecological zones (Figure 5). In general, food and medicinal uses largely dominate in all zones, confirming the multifunctional role of the species; the other categories are more variable and generally less represented. In AEZ 2, food use is the most frequently reported category (113 citations; 77.4% of respondents), followed by medicinal use (86 citations; 58.9%); commercial use remains marginal (2 citations; 1.37%) and ritual use very poorly represented (0.68%), and no construction or fodder use was reported, which reflects a mainly domestic valuation of the species. In AEZ 3, food use reached 94.34% (150 citations) and medicinal use 86.16% (137 citations); ritual and construction uses remain anecdotal (1.26% each) and fodder is weakly mentioned (0.63%). AEZ 4 is characterized by a comparable importance of food (62.15%) and medicinal uses (60.56%) and by a relatively greater contribution of trade (49 citations; 19.52%), fodder (5.18%) and construction (2.39%), suggesting that in this zone the species goes beyond self-consumption to partially enter local exchange circuits.

AEZ 5 is the zone where the range of uses is most diverse and the intensity of use highest: medicinal uses reach 87.13% (440 citations) and food uses 92.67% (468 citations), with high fodder use (209 citations; 41.39%), relatively large commercial use (99 citations; 19.60%) and more frequent ritual use (41 citations; 8.12%) than elsewhere. In AEZ 6, food use is reported by all respondents (100%) and medicinal use by 33.33%, with no ritual, commercial, fodder or construction

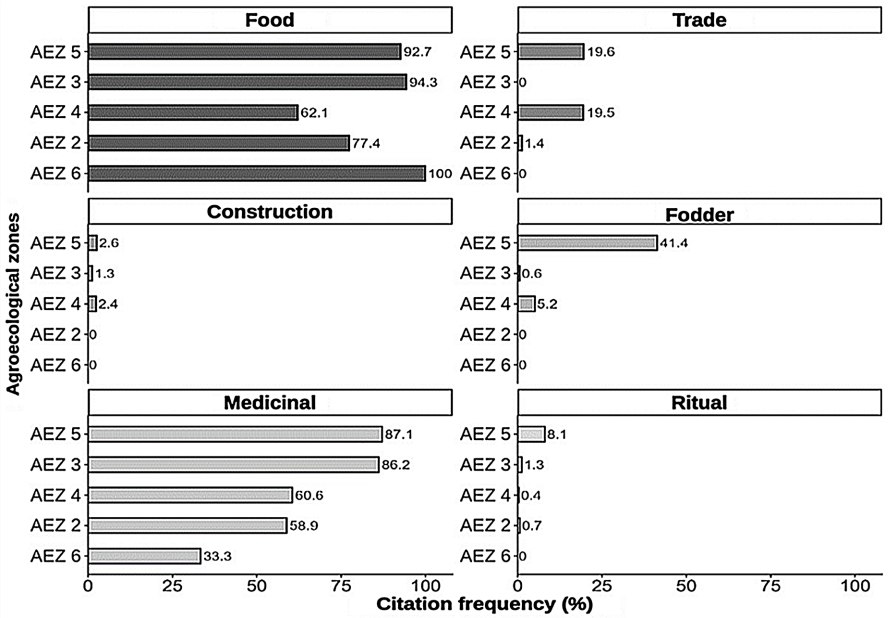


Figure 5. Frequency of use of *Ximenia americana* according to agro-ecological zones.

use; since AEZ 6 includes only three respondents, these values are descriptive only.

3.6. Association between Agro-Ecological Zones and Use Categories

Pearson's chi-square tests reveal a significant association between agro-ecological zones and most use categories (Table 3). Medicinal (χ^2 = 104.302; df = 4; p < 0.001), food (χ^2 = 132.908; df = 4; p < 0.001), ritual (χ^2 = 36.083; df = 4; p < 0.001), fodder (χ^2 = 244.108; df = 4; p < 0.001; the strongest association) and commercial uses (χ^2 = 64.858; df = 4; p < 0.001) differ significantly between zones. Conversely, no significant association was observed for construction use (χ^2 = 4.588; df = 4; p = 0.332). These tests include AEZ 6, whose very small sample (n = 3) contributes little information.

Table 3. Association between agro-ecological zones and use categories of *Ximenia americana* (Pearson chi-square test).

Use category	χ^2	df	p
Medicinal	104.302	4	<0.001
Food	132.908	4	<0.001
Ritual	36.083	4	<0.001
Construction	4.588	4	0.332
Fodder	244.108	4	<0.001
Trade	64.858	4	<0.001

Results are based on non-blank rows and columns in each of the innermost subtables. Significance level: 0.05.

3.7. Distribution of Uses According to Ethnic Groups

The uses of *X. americana* show a general predominance of food and medicinal uses in all ethnic groups surveyed (Figure 6). The highest proportions of food use are observed among Yoa-Lokpa and related (97.06%), Yoruba and related (93.94%), Ottamari and related (92.31%), Dendi and related (91.43%), Peulh (Fulani) and related (87.80%) and Fon and related (87.39%); Bariba and related (86.14%) also show a high frequency, and the lowest values are recorded among Adja and related (50.00%) and respondents whose ethnic group was not declared (50.00%). Medicinal use is also widely represented: the highest frequencies are recorded in the groups Not declared (100%), Others (98.91%), Yoruba and related (91.58%), Yoa-Lokpa and related (85.29%), Bariba and related (77.15%) and Dendi and related (68.57%), and the lowest for Ottamari and related (17.31%) and Peulh and related (60.98%).

Ritual uses are generally low among all groups but more represented among the Fon and related (10.92%), followed by the Yoruba (4.71%), Dendi (2.86%) and Ottamari (1.92%); no ritual use was reported among the Adja, Peulh and Yoa-Lokpa groups. Construction use remains marginal and is mainly reported among Fon

and related (6.72%), Dendi (2.86%), Yoruba (0.67%) and Bariba (0.75%). Fodder use shows greater variation, with the highest frequencies among Yoruba (44.44%), Fon (31.09%), Yoa-Lokpa (23.53%) and Dendi (11.43%). Commercial use is highest among Yoa-Lokpa (85.29%), Dendi (28.57%), Fon (26.47%) and Others (13.04%), and low or zero among several groups, including the Peulh, Ottamari, Adja and respondents with undeclared ethnic group. Estimates for groups with very few respondents (e.g. Adja, n = 6) are descriptive only.

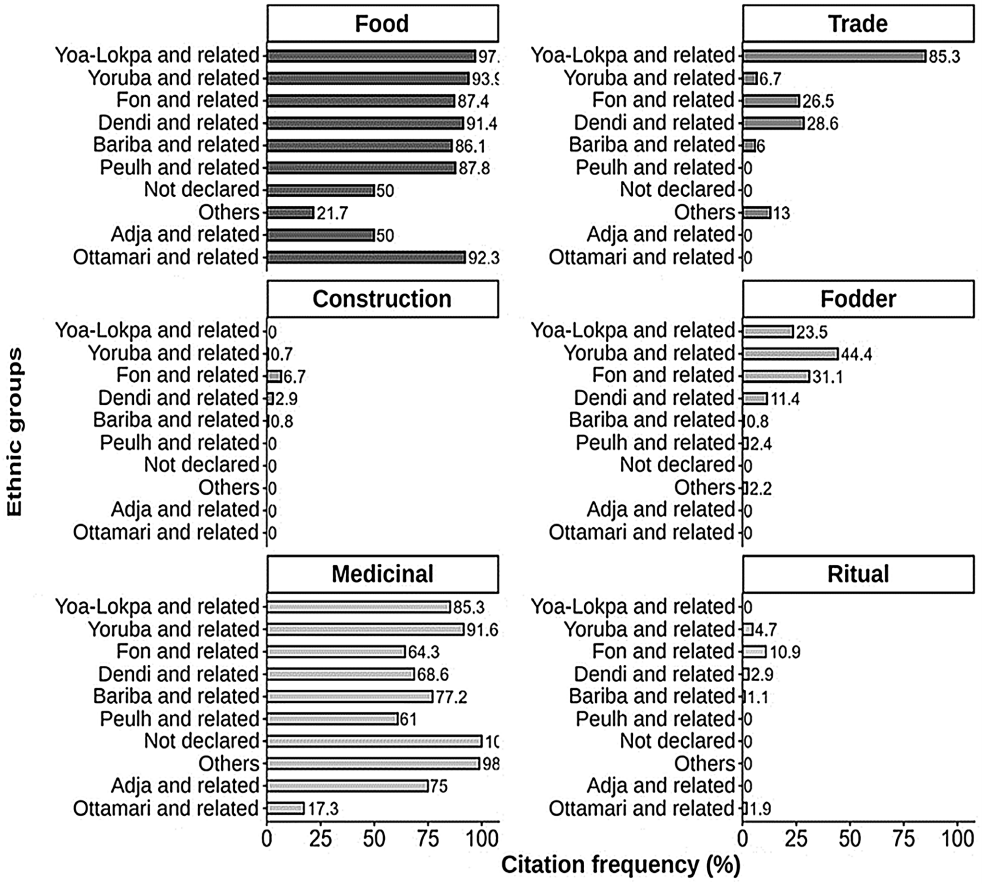


Figure 6. Distribution of uses of *Ximenia americana* by ethnic group.

3.8. Association between Ethnic Groups and Use Categories

Pearson's chi-square tests show a statistically significant association between ethnic group and each use category (**Table 4**): medicinal (χ^2 = 194.950; df = 9; p < 0.001), food (χ^2 = 300.435; df = 9; p < 0.001), ritual (χ^2 = 41.442; df = 9; p < 0.001), construction (χ^2 = 37.120; df = 9; p < 0.001), fodder (χ^2 = 225.520; df = 9; p < 0.001) and commercial use (χ^2 = 222.894; df = 9; p < 0.001). The high values for food, fodder and commercial uses in particular indicate marked differences in the frequency of use among ethnic groups. The use patterns of *X. americana* are therefore not uniformly distributed among the ethnic groups surveyed, for dominant uses (food, medicinal) as well as secondary ones (ritual, construction, fodder, trade).

Table 4. Association between ethnic groups and use categories of *Ximenia americana* (Pearson chi-square test).

Use category	χ^2	df	p
Medicinal	194.950	9	<0.001
Food	300.435	9	<0.001
Ritual	41.442	9	<0.001
Construction	37.120	9	<0.001
Fodder	225.520	9	<0.001
Trade	222.894	9	<0.001

Results are based on non-blank rows and columns in each of the innermost subtables. Significance level: 0.05.

3.9. Ethnobotanical Use Value

The global use value (UV) for *X. americana* is 1.968, indicating that each respondent reported on average nearly two categories of use, mainly food and medicinal and, to a lesser extent, fodder, commercial, ritual and construction uses. UV varies according to agro-ecological zone, ethnic group, sex and organ (Figure 7; Table 1). The highest UV is observed in AEZ 5 (2.461 ± 0.947; n = 516), followed by AEZ 3 (1.759 ± 0.574; n = 166) and AEZ 4 (1.461 ± 0.930; n = 258); the lowest values are recorded in AEZ 2 (1.374 ± 0.513; n = 147) and AEZ 6 (1.333 ± 0.577; n = 3, descriptive only). Among ethnic groups, Yoa-Lokpa and related have the highest mean UV (2.829 ± 1.014; n = 35), followed by Yoruba and related (2.405 ± 0.827; n = 299) and Fon and related (2.177 ± 1.163; n = 248); Dendi and related

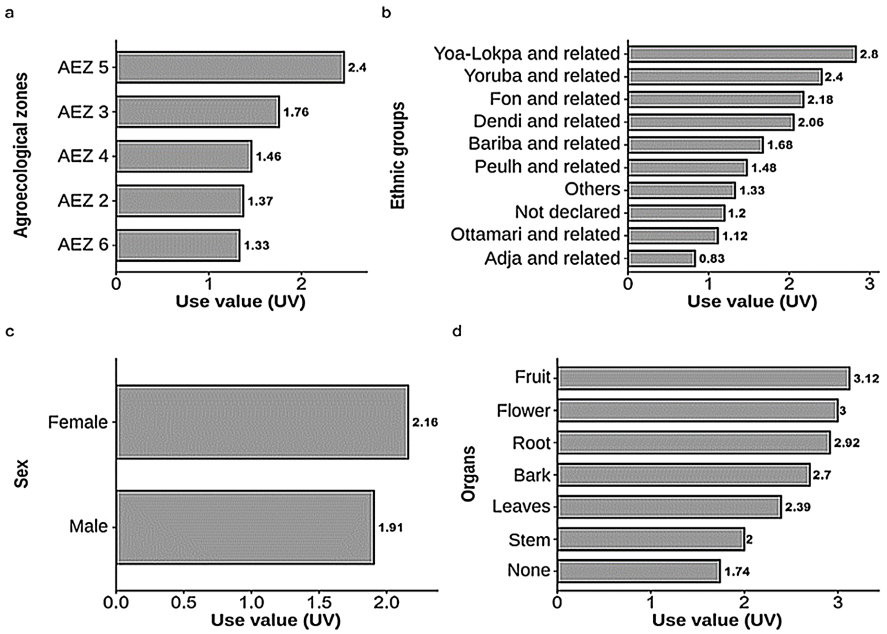


Figure 7. Use value according to (a) agro-ecological zone, (b) ethnic group, (c) sex and (d) organ.

display an intermediate value (2.057 ± 1.083), and the lowest values are observed among Adja (0.833 ± 0.753; n = 6) and Ottamari and related (1.115 ± 0.379; n = 52). The other groups have values between 1.200 and 1.675. Women have a higher mean UV (2.161 ± 0.906; n = 261) than men (1.907 ± 0.985; n = 829).

According to the organ cited, the highest UV are observed for fruits (3.125 ± 0.342; n = 16) and roots (2.917 ± 1.013; n = 60); bark also has a high value (2.702 ± 0.720; n = 47), followed by leaves (2.394 ± 0.747; n = 165). The stem (2.000 ± 0.000; n = 2) and flower (3.000; n = 1) values rest on too few observations to be interpreted. Respondents who cited no specific organ have the lowest UV (1.741 ± 0.923; n = 799).

3.10. Differences in Use Value

ANOVA and the Kruskal-Wallis test gave consistent results (Table 5). UV differs significantly among agro-ecological zones (ANOVA: $F = 87.92$; $df = 4$ and 1085; $p < 2 \times 10^{-16}$; Kruskal-Wallis: $\chi^2 = 305.06$; $df = 4$; $p < 2.2 \times 10^{-16}$), ethnic groups ($F = 31.57$; $df = 9$ and 1080; $p < 2 \times 10^{-16}$; $\chi^2 = 254.40$; $df = 9$; $p < 2.2 \times 10^{-16}$), sexes ($F = 13.68$; $df = 1$ and 1088; $p = 0.000228$; $\chi^2 = 18.88$; $df = 1$; $p = 1.39 \times 10^{-5}$) and organs ($F = 36.43$; $df = 6$ and 1083; $p < 2 \times 10^{-16}$; $\chi^2 = 192.93$; $df = 6$; $p < 2.2 \times 10^{-16}$).

Table 5. Comparison of use value (number of use categories cited) according to agro-ecological zone, ethnic group, sex and organ.

Factor	Test	Statistic	df	p
Agro-ecological zone	ANOVA (F)	87.92	4; 1085	$<2 \times 10^{-16}$
	Kruskal-Wallis (χ^2)	305.06	4	$<2.2 \times 10^{-16}$
Ethnic group	ANOVA (F)	31.57	9; 1080	$<2 \times 10^{-16}$
	Kruskal-Wallis (χ^2)	254.40	9	$<2.2 \times 10^{-16}$
Sex	ANOVA (F)	13.68	1; 1088	0.000228
	Kruskal-Wallis (χ^2)	18.88	1	1.39×10^{-5}
Organ	ANOVA (F)	36.43	6; 1083	$<2 \times 10^{-16}$
	Kruskal-Wallis (χ^2)	192.93	6	$<2.2 \times 10^{-16}$

UV: use value; df: degrees of freedom.

3.11. Explanatory Model of the Individual Use Value (Poisson GLM)

The Poisson GLM shows that several factors are significantly associated with the number of uses reported for *X. americana* (Table 6). For agro-ecological zones, AEZ 3 (estimate = 0.235; z = 2.477; p = 0.013) and AEZ 5 (estimate = 0.514; z = 4.710; p < 0.001) have positive and significant coefficients relative to the reference zone. For the level of education, only the high-school modality reaches the significance threshold, borderline (estimate = 0.284; z = 1.961; p = 0.050); lower sec-

ondary education has a marginal effect (estimate = 0.125; z = 1.716; p = 0.086). Among ethnic groups, Dendi and related (estimate = 0.908; z = 1.960; p = 0.050, borderline) and Yoa-Lokpa and related (estimate = 1.506; z = 3.259; p = 0.001) show significant effects, whereas Bariba (p = 0.074) and Fon (p = 0.100) show positive but non-significant effects at the 5% threshold. For organs, bark (estimate = 0.256; z = 2.390; p = 0.017), fruits (estimate = 0.431; z = 2.785; p = 0.005) and roots (estimate = 0.322; z = 3.419; p < 0.001) have significant positive effects, the effect of fruits being the largest, followed by roots and bark; leaves show a positive but only marginally significant effect (estimate = 0.144; z = 1.867; p = 0.062). The effects for fruits (n = 16) and for small ethnic groups (Dendi, n = 35; Yoa-Lokpa, n = 35) rest on small samples.

Table 6. Factors associated with the number of uses of *Ximenia americana* (Poisson GLM).

Factor	Modality	Estimate	z	p	Sig.
Agro-ecological zone	AEZ 3	0.235	2.477	0.013	
Agro-ecological zone	AEZ 5	0.514	4.710	<0.001	
Level of education	High school	0.284	1.961	0.050	
Level of education	Lower secondary	0.125	1.716	0.086	.
Ethnic group	Dendi and related	0.908	1.960	0.050	
Ethnic group	Yoa-Lokpa and related	1.506	3.259	0.001	
Ethnic group	Bariba and related	0.808	1.786	0.074	.
Ethnic group	Fon and related	0.744	1.647	0.100	
Organ	Bark	0.256	2.390	0.017	
Organ	Leaves	0.144	1.867	0.062	.
Organ	Fruit	0.431	2.785	0.005	
Organ	Root	0.322	3.419	< 0.001	

Null deviance = 563.21; residual deviance = 354.94 on 1061 df; AIC = 3098.8; 4 Fisher scoring iterations. Significance codes: p < 0.001; p < 0.01; p < 0.05; p < 0.10.

3.12. Multiple Correspondence Analysis of Uses, Ethnic Groups and Agro-Ecological Zones

The MCA was carried out on 1090 individuals described by eight categorical variables relating to the uses of *X. americana*, ethnic group, importance of uses and agro-ecological zone. The first two axes explain 13.8% and 8.9% of the inertia, respectively (**Figure 8**), which is usual for an MCA with many categorical modalities; the interpretation below is therefore descriptive. The factorial space is mainly determined by agro-ecological zone (η^2 = 0.817 on axis 1), importance of uses (η^2 = 0.702) and ethnic group (η^2 = 0.685). The second axis is mainly associated with ethnic group (η^2 = 0.788) and agro-ecological zone (η^2 = 0.702).

First axis. AEZ 5 is one of the modalities most strongly associated with this axis (contribution 13.99%; $\cos^2$ = 0.810; v-test = −29.34), whereas AEZ 2, AEZ 4

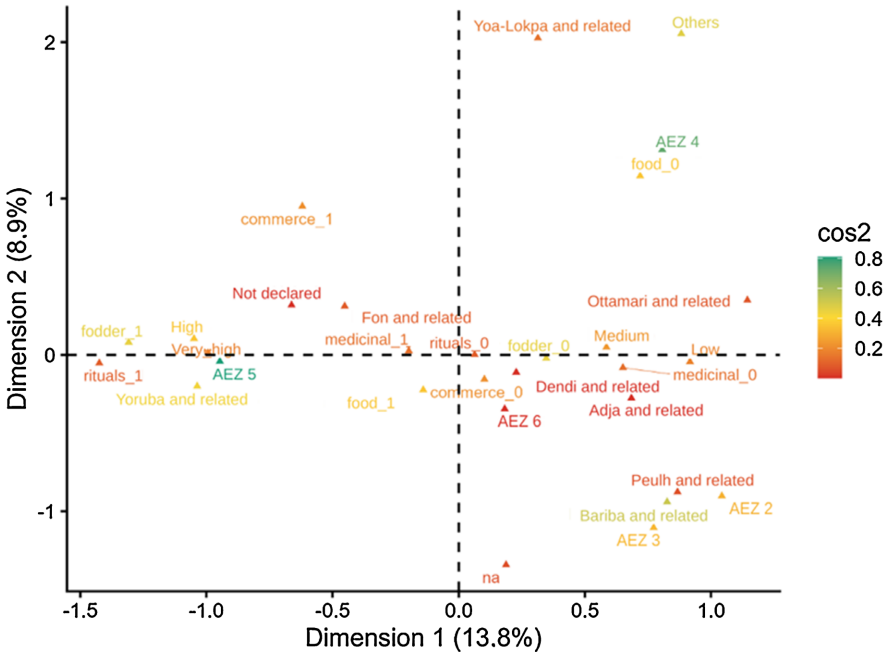


Figure 8. Factorial map of the categories (modalities) from the multiple correspondence analysis (MCA) of uses of *Ximenia americana*, ethnic groups, importance of uses and agro-ecological zones (AEZ). Dimensions 1 and 2 explain 13.8% and 8.9% of the total inertia, respectively. Colour indicates the quality of representation ($\cos^2$). Category labels ending in _1 or _0 indicate presence or absence of the use (food, medicinal, ritual, fodder, commerce).

and AEZ 3 lie on the positive side (coordinates 1.04, 0.81 and 0.77; contributions 4.91%, 5.05% and 2.93%). The axis opposes the Yoruba and related (coordinate = −1.04; contribution = 9.86%; v-test = −21.03) to the Bariba and related (coordinate = 0.83; contribution = 5.63%; v-test = 15.58), the Peulh (coordinate = 0.87; v-test = 5.66) and the Ottamari and related (coordinate = 1.14; v-test = 8.45). The High and Very high importance modalities are on the negative side (v-test = −19.35 and −13.58) and Low and Medium on the positive side (v-test = 13.84 and 15.66). Non-use of food (food_0) is on the positive side (coordinate = 0.72; v-test = 10.36) and food use on the negative side; an analogous opposition appears for medicinal, ritual, fodder and commercial uses. Fodder use contributes 11.79% to this axis (v-test = −21.96).

Second axis. The "Others" and Yoa-Lokpa groups are strongly distinguished on the positive side (coordinates 2.05 and 2.03; v-tests 20.61 and 12.00), together with AEZ 4 (coordinate = 1.31; contribution = 20.78%; v-test = 23.77), whereas AEZ 3 (coordinate = −1.11; v-test = −15.11) and AEZ 2 (v-test = −11.74) characterize the negative pole. The axis is also associated with food non-use (food_0: coordinate = 1.14; contribution = 10.96%; $\cos^2$ = 0.256; v-test = 16.50) and commercial use (commerce_1: coordinate = 0.95; v-test = 12.55).

Axes 3 to 5. The third axis is associated with ethnic group (η^2 = 0.551), medicinal use (η^2 = 0.541) and importance of uses (η^2 = 0.322); the non-medicinal modality (medicinal_0) contributes 23.82% (v-test = 23.99). The fourth axis is struc-

tured by ethnic group (η^2 = 0.472), importance of uses (η^2 = 0.436) and commercial use (η^2 = 0.329; trade contribution 17.79%), with Yoa-Lokpa (contribution 17.28%) on one side and Yoruba (v-test = −11.08) on the other. The fifth axis is dominated by ethnic group (η^2 = 0.693), mainly the Ottamari and related (contribution 33.47%; v-test = −22.09).

Overall, the MCA highlights a sociocultural and agro-ecological structuring of the use patterns of *X. americana*: agro-ecological zone is the main factor associated with the first axis, and ethnic group plays a transversal role, with the strongest associations on axes 2 and 5. Use patterns are therefore not randomly distributed but form differentiated profiles linked to sociocultural belonging, agro-ecological context and the importance given to the different uses.

4. Discussion

The results show that *X. americana* occupies an important place in the subsistence and health systems of the populations studied, in line with studies conducted in Cameroon [26] [27] and Ethiopia [28]. The high frequency of food and medicinal uses confirms the multifunctional nature of the species and is consistent with observations in several West African countries, where *X. americana* is considered both a nutritional and a therapeutic resource [8] [29]. The predominance of food use, mainly related to the fruit, highlights the interest of the species for local food security, particularly during the lean season, as reported for other wild fruit species of African savannas [30]-[33].

The functional specialization of organs is a particularly striking result. Fruits are mainly associated with food, while leaves, bark and roots are mainly used in medicinal practices [34]-[36]. This differentiation reflects a detailed knowledge of the properties attributed to each organ by local communities. Similar patterns have been reported for several African medicinal species, where leaves are often the preferred therapeutic organ because of their accessibility and the possibility of harvesting them without destroying the individual [37]. However, the high use of bark and especially roots suggests a potentially greater pressure on natural populations of *X. americana* [38].

The analysis of treated conditions shows a wide variety of ailments managed with the species, with a predominance of malaria, abdominal pain, ulcers and febrile states [39] [40]. The frequent citation of malaria probably reflects the epidemiological importance of this disease in rural Benin [41]. Leaves are particularly associated with malaria, whereas roots and bark are more often cited for abdominal pain, ulcers and certain chronic conditions. This therapeutic specialization could be linked to differences in the composition of secondary metabolites between organs [42], a hypothesis that deserves to be explored by phytochemical and pharmacological analyses.

In terms of the organs cited, leaves (69.53%) come first, followed by bark (62.5%) and roots (61.04%). From an ecological point of view, this hierarchy is important. Leaf harvesting is generally considered more compatible with sustainable man-

agement, whereas the removal of bark and especially roots can compromise the growth, survival and regeneration capacity of individuals, including through suckering [43]. Work on the vegetative propagation of *X. americana* in Cameroon [44] points to constraints on the regeneration of the species, which would reinforce this concern. However, harvesting intensity and regeneration were not measured here; that certain therapeutic uses constitute an additional vulnerability factor for the species therefore remains a hypothesis to be tested.

The differences observed between sociocultural groups and agro-ecological zones reflect a variability in endogenous knowledge. Some ethnic groups have higher use values, which may suggest a more active transmission of knowledge or a stronger dependence on local plant resources. Such cultural heterogeneity of ethnobotanical knowledge is frequently reported in studies conducted in Benin and in West African savannas [45] [46] and highlights the importance of considering sociocultural dimensions in strategies for valuing and conserving useful species [2]. The number of reported uses varies significantly with the agro-ecological zone, the ethnic group and the organ cited (and with sex in the univariate tests). The multivariate analysis shows that knowledge about *X. americana* is not homogeneously distributed within the population but organized around distinct cultural and functional profiles, an organization already described for other medicinal and food species in Benin [45] [46].

5. Limitations

Several limitations frame the interpretation of these results. (1) The uses are reported by respondents; they do not establish clinical efficacy or safety, and the therapeutic applications are presented as reported practices. (2) Harvesting pressure and regeneration were not measured, so the conservation concerns are potential risks rather than demonstrated effects. (3) Respondents were selected purposively (with snowball sampling) among resource persons, which limits generalization to the general population; women represented only 24% of respondents (261 of 1,090). (4) The sample was unbalanced among agro-ecological zones, with no quotas, and some strata contained very few respondents (AEZ 6, n = 3; Adja, n = 6; flower, n = 1; stem, n = 2), so comparisons involving them are descriptive. (v) Many tests were performed without correction for multiple testing, and some borderline p-values ($p = 0.050$) should be interpreted with caution.

6. Conclusion

Overall, this study shows that *Ximenia americana* L. is a major ethnobotanical resource in Benin, particularly important for food and traditional medicine. The reported use of roots and bark, combined with the regeneration constraints described in the literature, points to potential sustainability risks that should be verified by field assessments of harvesting pressure and population structure. These results argue for the promotion of less destructive harvesting practices (such as preferring leaves), community awareness of the conservation of adult individuals,

and the development of domestication or participatory management programmes aimed at reconciling the valorisation of endogenous knowledge with the preservation of natural populations of the species. Phytochemical, efficacy and toxicity studies are needed before any therapeutic promotion of the species.

Ethics Statement

See "Study design and ethical considerations".

Author Contributions

P. Tobada: conceptualization, investigation, methodology, data curation, formal analysis, writing—original draft. J.Z. Kpogniwe: resources, validation, writing—review and editing. F.Y. Assongba: funding acquisition, project administration, supervision, writing—review and editing. J. Djego: supervision, validation, writing—review and editing.

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Data Availability Statement

The anonymised dataset from the ethnobotanical interviews used in this study will be deposited in a publicly accessible data repository upon acceptance. Data are available upon reasonable request to the corresponding author.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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