Ethnobotanical study of medicinal plants used for the treatment of urinary tract infections in the Haut-Sassandra region (Central-West, Côte d'Ivoire)

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Research

Abstract

Background: In Côte d'Ivoire, urinary tract infections (UTIs) pose a significant public health issue. The rising antibiotic resistance encountered in the treatment of these infections necessitates the search for alternative solutions. This study aims to inventory the medicinal plants used in the treatment of urinary tract infections in the Haut-Sassandra region.

Methods: This is a prospective study where ethnobotanical information was collected using semi-structured interviews and field walks with 349 respondents from October 2022 to January 2023. The study focused on socio-demographic and botanical characteristics.

Results: A total of 43 species belonging to 25 families were documented. The Fabaceae family was dominant (24%). Leaves (37%) and roots (33.8%) were the most preferred parts, as they are believed to contain more secondary metabolites. The most commonly used treatment methods were decoction (71.4%) and oral administration (67.8%). Knowledge of plants was significantly affected by age and ethnic group but not by sex, locality, or education level.

Conclusions: This study cataloged 43 plants and their modes of use in treating urinary tract infections. It helps bridge the information gap on the traditional treatment of urinary tract infections in the Haut-Sassandra region.

Keywords: Bacterial resistance, Fabaceae, Medicinal knowledge, Phytotherapy, prospective study, Public health

Background

Urinary tract infections (UTIs) are among the most prevalent bacterial infections worldwide, affecting various parts of the urinary system in both men and women. Indeed, UTIs are the most frequent infections, with a prevalence of 50 to 60% among adult women (Castillo-Pino & Medina 2019). They are one of the causes of morbidity in the general population and the second most common infectious disease after respiratory infections (Addis *et al.* 2021). In Africa, the prevalence of UTIs is significantly higher in women than in men. For example, in Nigeria, the prevalence of UTIs among women is 42.8%, compared to 10.2% in men (Oladeinde *et al.* 2011). Women are more susceptible due to their anatomical structures, sexual activities, use of certain contraceptive measures, and menopause (Dougnon *et al.* 2020). In Côte d'Ivoire, the prevalence of this infection remains notably high in specific localities, as highlighted by Kamara *et al.* (2017). For instance, in the Haut-Sassandra region, the overall prevalence between 2019 and 2022 was estimated at 16.25% (Gbégbé et al., 2023). These infections are typically managed with antibiotic treatment. However, recent years have seen a notable increase in antibiotic resistance among pathogens responsible for urinary infections (Rakotovao-Ravahatra *et al.* 2017). Globally, antibiotic resistance has now reached alarming levels, particularly with the emergence and spread of new resistance mechanisms, which compromise the ability to treat common infectious diseases (WHO 2021). According to the WHO, if no further action is taken, antimicrobial resistance could kill up to 10 million people per year by 2050. Additionally, the World Bank estimates that antimicrobial resistance could result in economic losses equivalent to 3.8% of the global gross domestic product by 2030, potentially pushing an additional 28 million people into extreme poverty by 2050 (Who 2021). Children up to 12 months old and adults aged 70 and older are more at risk of resistant infections (WHO 2019). In the face of this growing threat, medicinal plants represent a source of new, economically accessible antimicrobial molecules (Sanogo *et al.* 2006). Furthermore, globally, and especially in sub-Saharan Africa, over 80% of the population relies on plants for their medical needs (Jamila, 2018). The African flora is exceptionally rich in medicinal species, many of which are employed to treat urinary tract infections. Notable examples include *Herniaria hirsuta*, *Anastatica hierochuntica*, and *Apium graveolens* (Elhassan et al., 2019). In Côte d'Ivoire, the study of medicinal plants is well-established. For instance, *Cassia occidentalis* is known for its abortifacient, healing, diuretic, febrifuge, laxative, asthma, cataract, jaundice, and kwashiorkor properties (Aké-Assi et al., 1979). Additionally, *Euphorbia hirta* is commonly used to treat urinary tract infections in various regions. However, the role of traditional medicine in the lives of the populations in the Haut-Sassandra region remains underexplored. The people of this region face numerous recurrent diseases, including urinary infections. Due to the high cost of healthcare provided by modern health centers, the population has turned to traditional medicine (Sangaré 2003, Li & Shao 2008, Zihiri 1991). However, the plants used in the treatment of urinary infections are not well documented, highlighting the importance of this study. Therefore, the objective of this study is to inventory the medicinal plants used in the treatment of urinary tract infections in the Haut-Sassandra region.

Materials and Methods

Study area

This study was conducted in the Haut-Sassandra region of west-central Côte d'Ivoire, specifically across four localities: Daloa, Vavoua, Issia, and Gonaté. The Haut-Sassandra region is bordered to the south by the Gôh and Nawa regions, to the west by the Guémon and Tonkpi regions, to the north by the Worodougou and Béré regions, and to the east by the Marahoué region (Koffi-Bikpo and Kra, 2013). It has an area of 17,761 km² (Koffi-Bikpo & Kra 2013) and an estimated population of 1,430,960 inhabitants (INS 2014). The average annual temperature is 26°C, with an average rainfall of about 1,276 mm per year, and it is located at geographical coordinates 7°0′ 0′′N/6° 34′60′′W (Tra-Bi *et al.* 2015). This region comprises six departments, with the Daloa department being bordered to the north by Vavoua, to the south by Issia, to the east by Gonaté, Zuénoula, and Bouaflé, and to the west by Duékoué (Figure 1). The Haut-Sassandra region is the second main cocoa bean production area in Côte d'Ivoire, contributing more than 12% of the national production annually (N'guessan *et al.* 2014).

Ethnobotanical data collection

Between October 2022 and January 2023, a field survey was conducted with herbalists and traditional healers from the four mentioned localities. The study was based on an ethnopharmacological survey using a semi-structured questionnaire (Martin, 2010). Preliminary visits were conducted to establish a rapport with the participants. The interviews were conducted in French or the local language with the assistance of an interpreter when necessary. The questionnaire consisted of two parts: the first focused on the socio-demographic data of the respondents, while the second addressed the medicinal plants used, as well as the types of urinary infections treated. Each herbalist was interviewed individually to ensure the confidentiality of the process. The number of herbalists selected per market was based on this criterion. The markets chosen had at least two herbalists, known for the diversity of their medicinal plants. The surveys were conducted using the medicinal recipe triplet purchasing method (Klotoé et al., 2013). Regarding traditional healers, a list of practitioners in the study area was obtained from the Ministry of Health. Their selection was based on their local reputation. The study received ethical approval (No. 326-2022 /MESRS/UJLoG /PVURIT/SD/OZE) from the Université Jean Lorougnon Guédé. A total of 349 herbalists and traditional healers from the cities of Daloa, Vavoua, Issia, and Gonaté were interviewed after giving their informed consent. All mentioned plants were collected and identified with the help of botanists from the Université Jean Lorougnon Guédé. Voucher specimens were deposited in the herbarium of the Biology Department of the same university.

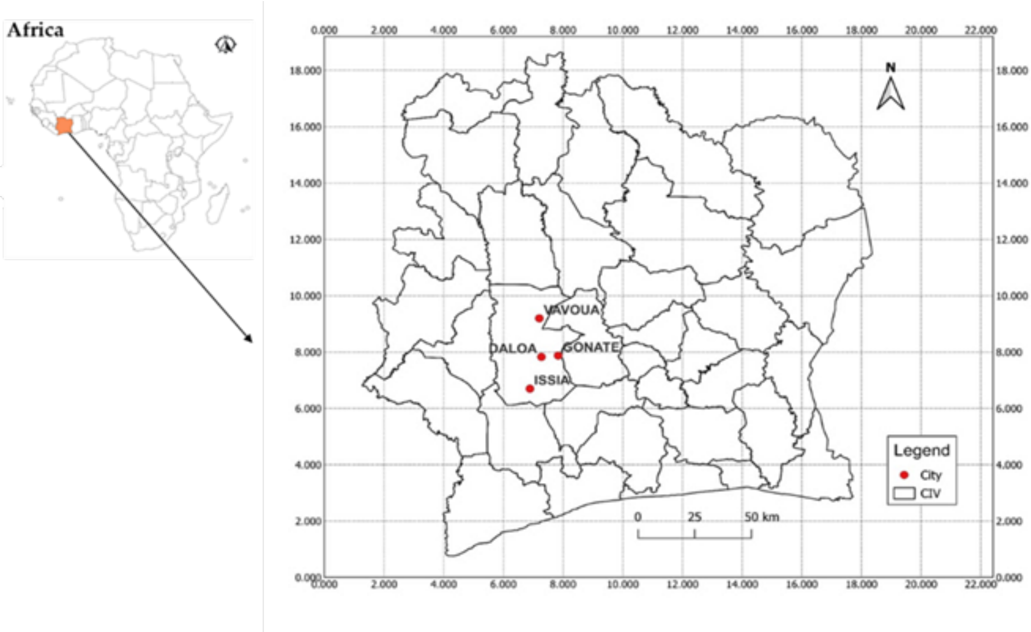

Figure 1. Map showing the location of the study area. CIV: Côte d'Ivoire

Data Analysis

Raw survey data were analyzed using Epi Info software version 7.2.5.0, exported to Excel spreadsheets (Microsoft Office 2021) for further analysis within the R 4.1.2 environment via RStudio. Various R packages such as questionr, gtsummary, ggplot2, and GGally were used to generate contingency tables. Independence tests between variables were conducted using the chi-square test ($\chi 2$), while Pearson's chi-square residuals were calculated to more accurately determine proportions affected by statistically significant differences (Angaman & Boko 2021). A Multiple Correspondence Analysis (MCA) was carried out to identify the socio-demographic factors (locality, gender, ethnic group,) that influence the use of plant species.

Ethnobotanical index Frequency of quotation (FC)

The frequency of quotation thus makes it possible to assess the credibility of the information received and the level of plant knowledge of the population surveyed (Betti 2003). The citation frequency (CF) of a species corresponds to the number of respondents who cited the species.

Relative frequency of citation (RFC)

The relative frequency of citation (RFC) is obtained by dividing the frequency of citation (FC) by the total number of informants in the survey (N=349). The RFC value for medicinal species is based on the percentage of informants citing each species. The RFC value was calculated using the following formula (Tardío & Pardo-de-Santayana 2008): RFC = FC/ N with ($0 < RFC < 1$). Species with a highly significant relative frequency of citation are those with a high level of use.

Ethnobotanical use value

The use value of each species or species with use value (UVs) can be calculated according to Albuquerque *et al.* (2006) formula: UVs = U/N where U represents the number of uses in which the species (s) is mentioned and N, the number of informants having mentioned the species (s).

Fidelity Level (FL)

Fidelity Level (FL) is the percentage of informants who mentioned the uses of certain plant species to treat a particular disease in the study area. The FL index is calculated using this formula (Friedman *et al.* 1986): FL (%) = Np/ N x 100. where Np is the number of informants who report the use of a plant species to treat a particular disease, and N is the number of informants who use these plants as medicine to treat a given disease.

Informant Consensus Factor (ICF)

This is an index that is often used for medicinal uses of plants. But its use can be extended to other categories of use, which can be subdivided into sub-categories of use. The Informant Consensus Factor (ICF) was derived to seek agreement between informants on the remedies reported for each disease group (Heinrich 2008): ICF = TNUQ -TNS - / TNUQ -1. Where TNUQ is the Total Number of Usage Quotes and TNS is the Total number of species. In practice, ICF values close to zero indicate that plants have been randomly selected, or that informants have not shared information about their use. Conversely, ICF values close to 1 suggest the existence of selection criteria or an exchange of information between informants on the use of plant species (Zivkovic *et al.* 2021).

Results

Sociodemographic characteristics of traditional Healers

The creation of pivot tables provided insights into the respondents (table1). The analysis highlights the knowledge of medicinal plants based on sex, locality, educational level, age, and ethnic group. A significant difference was observed in knowledge based on age (chi-square residual >3) (p-value = 1.663933e-46; X-squared = 220.2407; df :4). It was noted that the proportion of respondents aged between 20 and 30 who did not know medicinal plants was significantly higher than those who did. Specifically, among all the individuals surveyed in this age group, 72.7% did not know the medicinal plants used to treat urinary infections compared to 27.3% who did. Additionally, knowledge based on ethnic group was significant (p-value = 3.597144e-69 ; X-squared = 329.9628 ; df =5). It was revealed that the proportion of Baoulés who knew medicinal plants was significantly higher (85.7%) than those who did not (14.3%). However, this knowledge was not significantly influenced by the gender of the respondents, locality, or educational level (with chi-square residuals between -2 and 2).

Regarding age, these results indicate a knowledge gap between the older and younger generations, as reported in the Tabora region of Tanzania by some authors (Amir & Kacholi 2022) and Kagera (Coll & Kisangau 2007). The present study revealed that herbalists were generally older individuals. This is likely because knowledge of medicinal plants is usually passed down through generations and acquired through extensive experience (Nesrine 2022). Nowadays, many young people focus more on other hobbies and interests, which can lead to a disinterest in traditional medicine. Young people often believe that the income from selling medicinal plants is low, so they prefer to engage in higher-income activities. Consequently, this could lead to a decrease in the transmission of medicinal plant knowledge between generations. The modernization of life encourages younger generations to choose allopathic medicines over natural therapies, which is likely a contributing factor to the loss of knowledge (Sargin 2015). Another study revealed that 77% had acquired knowledge by observing family members (Jaradat *et al*.2017). The threat of loss of knowledge acquired from generation to generation through transmission between parents and younger generations is not always guaranteed (Anyinam 1995).

These results align with those obtained by other authors. This trend endangers the existence of indigenous knowledge, as it risks being lost after the older generation passes away if not well documented for future generations. This could also lead to the deterioration of traditional allopathic practices (Navaneethan *et al.* 2011). The high level of traditional knowledge among older individuals could be due to the accumulated knowledge from their long years of interaction with their environment (Usman *et al.* 2022). Furthermore, other authors have found in their studies that knowledge of medicinal plants was related to the age of informants. Most adults reported learning about medicinal plants during walks with their parents or grandparents to gather remedies in the forest when they were young. The lack of systematic documentation of medicinal plant knowledge can contribute to the loss of knowledge about medicinal plants, particularly those that are neglected or not prioritized. This situation seems to occur in many regions worldwide (Bussmann & Sharon 2006, Fekadu 2001). Thus, traditional medicine remains the most popular medicine for addressing health issues. Since traditional medical knowledge is transmitted orally through lifestyle, it is important to document and raise awareness of medicinal plant knowledge among younger generations to appreciate their traditional values and to conserve and sustainably use plants as well as maintain the traditional medical knowledge left in their community alive. In Burkina Faso, plant-based medical knowledge is also acquired through lived experiences as users of medicinal plants or by learning from the experiences of others (Skalli *et al.* 2009). Additionally, an ethnobotanical study conducted in eastern Indonesia revealed that 57% of traditional herbalists knew the medicinal plants used to treat urinary infections (Jazy 2017).

Moreover, the high knowledge rate observed among the Baoulés could be explained by the fact that they possess better knowledge of traditional medicine compared to other ethnic groups. Consequently, this knowledge would be transmitted from generation to generation through oral communication in the Haut-Sassandra region. However, elsewhere, interviews with informants revealed that the Hindko (34.12%) and Tanoli (29.41%) ethnic groups had better knowledge of medicinal plants, while the Gujjars and Pushtoons had less knowledge. Other researchers showed in their study in Togo that 39.9% of traditional herbalists were of the Ewe ethnic group and 33.6% were Ouatchi (Hoekou *et al.* 2016). Elsewhere in Benin, research showed that among the most represented ethnic groups, respondents were Fon (30%), followed by Goun (26.25%) and Yoruba (18.75%) (Funkè *et al.* 2023). These results contrast because the study areas were different. Furthermore, knowledge of traditional medicine did not vary significantly by gender, locality, or education level. This suggests that in the Haut-Sassandra region, herbalists and traditional healers used almost the same plants to treat urinary infections. Men and women had almost equal ethnomedical knowledge. A similar study conducted in the Urambo district of Tanzania by Amir and Kacholi (2022), in Nigeria by Kankara *et al.* (2018), and in Zambia by Chinsembu (2016), revealed that male healers enjoy high trust and dominate the traditional healing sector. Conversely, in many households, Kuria women were the central authority for home-based herbal therapies (Charwi *et al.* 2023). Similar supremacy was also reported among the Bambaras in Mali (Imperato 1981). Moreover, other studies, such as Mkabela and Zabolo (2006), reported women and girls as the primary guardians of indigenous plant knowledge in South Africa. A similar study was conducted by Funkè *et al.* (2023). Indeed, the predominance of women among respondents could be justified by the essential role women play in therapy and nutrition within households as mothers (N'Diaye *et al.* 2003). In Morocco, a study showed that gender, education level, and age are factors that influence the transmission of knowledge about the therapeutic uses of medicinal plants (Elhassan *et al.* 2019). Some researchers found similar results in national ethnobotanical studies (Benkhnigue *et al.* 2014, Tahraoui *et al.* 2007). These results differ from those obtained by these authors.

Regarding localities, plant knowledge (medicinal plants) is homogeneous across the studied region (Haut-Sassandra). Healers in the four localities (Daloa, Vavoua, Issia, and Gonaté) have the same level of knowledge of medicinal plants used to treat UTIs. This could be explained by the fact that healers share common traditional health practices (Herrick 1995). However, Voeks (2007) revealed in his study that traditional knowledge regarding medicinal taxa differed by sex, age, and ethnic origin. These similarities and variations in knowledge are due to ecological (Ladio 2007) and historical (Moerman 1994) factors. Additionally, some authors revealed in their work a negative correlation between the level of education and knowledge of plants (Charwi *et al.* 2023, Girma *et al.* 2022). However, other researchers indicated that knowledge was linked to the level of education. This may be because educated individuals prefer the contemporary healthcare system (Jan *et al.* 2022, Heera *et al.* 2023). Conversely, Funkè *et al.* (2023) revealed in their work that most respondents had a secondary education level (45%). Furthermore, Hélé *et al.* (2014) noted in their study that most respondents had a university level education. Other researchers also observed similar results (Bhatia *et al.* 2014, Jan *et al.* 2021). This contradicts the common belief that selling medicinal plants is a job reserved for poor and illiterate individuals. These results differ here because the study areas were different.

Table 1. Knowledge of medicinal plants according to gender, location, education level and ethnic group

	Knowledge: No	Knowledge: Yes	
Women	28.5%	71.5%	Sex
Men	35.5%	64.5%	Sex
Vavoua	25.8%	74.2%	Locality
Issia	22.6%	77.4%	Locality
Gonaté	30.4%	69.6%	Locality
Daloa	33.6%	66.4%	Locality
University	0.0%	100.0%	Study level
Secondary school	30.8%	69.2%	Study level
Primary school	33.3%	66.7%	Study level
Illiterate	30.3%	69.7%	Study level
More than 60	20.0%	80.0%	Age
[51-60]	30.2%	69.8%	Age
[41-50]	32.2%	67.8%	Age
[31-40]	26.0%	74.0%	Age
[20-30]	72.7%	27.3%	Age
Yacouba	33.3%	66.7%	Ethnicity
Senoufo	35.2%	64.8%	Ethnicity
Malinké	29.1%	70.9%	Ethnicity
Foreigners	41.7%	58.3%	Ethnicity
Bété	23.5%	76.5%	Ethnicity
Baoulé	14.3%	85.7%	Ethnicity

Chi2 Residuals: 3, 2, -2, -3

Botanical characteristics

Diversity of medicinal plants used to treat urinary tract infections

As a result of this ethnobotanical survey, 43 plant species were identified, spanning 25 families and 40 genera. This study showed that informants in the Haut-Sassandra region use a wide range of medicinal plants to treat various types of urinary tract infections. The scientific name, vernacular name, part of the plant used, preparation methods, and therapeutic uses of each plant are compiled in Table 2 The most frequently cited plants by respondents were *Securidaca longepedunculata*, *Anthocleista nobilis*, and *Khaya senegalensis*, while other species were less commonly mentioned. The versatility of these plants likely contributes to their widespread use, as they are rich in secondary metabolites that may act against pathogens responsible for urinary tract infections (Lassa et al., 2022). For example, a study in Morocco identified *Herniaria hirsuta* and *Anastatica hierochuntica* as the most cited species for treating these infections (Elhassan *et al.* 2019). Similarly, other studies have highlighted *Khaya senegalensis* and *Ocimum americanum* (Funkè *et al.* 2023), *Zea mays* and *Lavandula vera* in Morocco (Hseini et al., 2007), and *Ocimum gratissimum* in another region (Koudokpon *et al.* 2017). Additionally, *Salvia fruticosa* and *Matricaria chamomilla* have been noted in the treatment of urinary infections (Jaradat *et al.* 2016). Another study carried out in N'Djamena showed that the main plants used to treat urinary tract infections were Ziziphus spina-christi with a rate of 50%, Cassia obovata with a rate of 16.67% and Euphorbia hirta with a rate of 15% (mahamat *et al.* 2024). Several of the species mentioned here have been the subject of pharmacological trials against urinary tract infections. This could reinforce their use in the treatment of this pathology.These variations in findings are likely due to differences in study areas and local medicinal practices.

R*elative Frequency of Citations (RFC) and Ethnobotanical Use Value (EUV)*

Securidaca longepedunculata Fres has the highest RFC and VU values (table 2). It is therefore the plant most widely used by the populations interviewed. This could be explained by the fact that this species is very well known (Aké *et al.* 2015). The low RFC AND UV values could be explained by the fact that these species are less used in traditional medicine. Informants often mention the best-known and most effective uses of medicinal plants. The high EUV value of each plant indicates its significant importance in the in the traditional practices of the population studied, thus designating it as the most being the most recommended, used and known by the population, which may reflect the recognition of its medicinal properties.

Fidelity Level (FL)

The fidelity level (FL) value is an important way of determining for which condition a particular species is more effective, it may suggest that a specific species is used to treat a particular disease (Ahmad *et al.* 2018). In the present study, LF values ranged from 2.3% to 97.6% (Table 2). The results show that *Securidaca longepedunculata* Fres has the highest level of fidelity. The first thing that follows from a high FL value is that the plant in question is widely recognized and used within the population studied to treat urinary tract infections. High values also reflect the community's confidence in a particular plant to treat these problems, based on empirical knowledge handed down from generation to generation, allowing it to be considered effective, safe or appropriate. This explains the high FL values for urinary problems, particularly cystitis. This information means that informants in this region tended to use one specific species to treat a given disease rather than several diseases. Plant species with the highest FL values indicate good healing potential against a specific disease mentioned (Asnake *et al.* 2016). In addition, plants with low LF values should not be abandoned instead of being pointed out to future generations that they could increase the risk of knowledge being phased out (Chaudhary *et al.* 2006).

Table 2. Ethnobotanical data on all plants recorded for the treatment of urinary tract infections

Family	Voucher specimens references	Scientific names (Vouchers no)	Vernacular name	Part used	Preparation method	Route of administration	Number of citations	Types of urinary infections	Relative frequency of quotations	Use value	Fidelity level (%)
Liliaceae											
	(Mohamed et al.2014)	*Allium sativum* L. NKA002	Ail	Bub	Decoction, Kneading	Oral	2	Cystitis	0.005	1	4.6
Anacardiaceae											
	(Ross 1999)	*Mangifera indica* L. NKA010	Manguier	Leaf	Decoction	Oral, Anal	1	Cystitis,Others	0.002	1	2.3
Annonaceae											
	(Emmanuel *et al.* 2024)	*Annona senegalensis* Pers. NKA003	Sidjan	Leaf, Root	Decoction	Oral	10	Pyelonephritis	0.028	5	23.2
Apiaceae											
	(Mohamed et al.2014)	*Daucus carota* L. NKA001	Carotte	Tuber	Decoction	Oral	1	Cystitis	0.002	1	2.3
Apocynaceae											
		Secamone myrtifolia Benth. NKA009	Korosingié	Leaf	Infusion	Oral	1	Cystitis, Urethritis	0.002	1	2.3
		Strophanthus sarmentosus DC. NKA004	Kounankala	Leaf, Root	Decoction	Oral, Anal	2	Cystitis	0.005	2	4.6
Asteraceae											
		Ageratum conyzoides L. NKA020	N'kokolon	Whole	Decoction	Oral	1	Cystitis	0.002	1	2.3
Bignoniaceae											
		Kigelia africana (Lam.) Benth. NKA005	Blimo	Leaf	Decoction	Oral	2	Cystitis	0.005	1	4.6

Caricaceae											
	Naive, M.A.K. (2021) (Naive *et al.* 2021)	*Carica papaya* L. NKA019	Oflè	Leaf,Root	Decoction	Anal	3	Cystitis,Pyelonephritis, Others	0.008	1.5	6.9
Combretaceae											
	*(*Monila *et al.* 2017)	*Terminalia leiocarpa* (DC.) Baill NKA007	Krékété	Leaf,Root, Bark	Decoction, Maceration		5	*Cystitis, 0.*014 Pyelonephritis, Others	2.5	11.6	
		Terminalia macroptera Guill. & Perr. NKA018	wôlô	Root	Decoction, Infusion	Oral	3	yelonephritis	0.008	1.5	6.9
Euphorbiaceae											
	(Siwe-Noundo *et al.* 2019)	*Alchornea cordifolia* Müll. Arg. NKA006	Djéka	Leaf, Root	Decoction, Infusion	Oral,Anal	6	Cystitis,Pyelonephritis, Others	0.017	3	13.9
	Balinado, L.O. (2017) (Balinado and Chan, 2017)	*Euphorbia hirta* (L) NKA016	Akododo	Whole	Decoction	Oral, Anal	2	Cystitis,Pyelonephritis, Others	0.005	1	4.6
		Sapium ellipticum (Hochst) NKA008	Tomi	Leaf, Root	Decoction	Oral, Anal	2	Pyelonephritis, Others	0.005	1	4.6
	*(*Omoregie EH *et al.* 2013)	*Jatropha curcas* L. NKA017	Aploplo	Leaf, Root	Decoction	Oral, Anal	2	Cystitis	0.005	2	4.6
Fabaceae											
		Peiricopsis laxiflora (Benth.) NKA011	Kolokolo	Root	Decoction	Oral	3	Cystitis	0.008	1	6.9

		Glycine max (L) Merr. NKA021	Soja	Seed	Decoction	Oral	2	Prostatitis	0.005	1	4.6
	Eldeen *et al.* 2015) (Funkè *et al.* 2023)	*Acacia nilotica* (L.)Willd.Ex Benth. NKA043	Acacia	Leaf,Root	Decoction, Infusion	Oral, Anal	1	Pyelonephritis, Others	0.002	1	2.3
		Cassia occidentalis Linn. NKA015	Sangozrè	Leaf, Root	Decoction, Infusion	Oral, Anal	1	Cystitis	0.002	1	2.3
		Parkia biglobosa(Jacq) R.Br NKA022	Nèrè	Leaf, Root	Décoction	Oral	7	Cystitis,Pyelonephritis,Urethritis,Others	0.020	2.33	16.2
	*(*Funkè *et al.* 2023))	*Tetrapleura tetraptera*Taub NKA014	4 Cotés	Seed	Decoction	Oral	1	Cystitis, Others	0.002	1	2.3
Loganiaceae											
		Anthocleista nobilis G.Don. NKA013	Wô	Leaf, Root, Bark	Decoction	Oral,Anal	35	Cystitis, Prostatitis, Others	0.100	8.75	81.3
		Strychnos dinklagei Gilg NKA042	Coulé-Coulé	Leaf, Root	Decoction	Oral	5	Urethritis, Others	0.014	2.5	11.6
Malvaceae											
		Cola cordifolia (Cav.) R.Br. NKA023	Cola	Leaf	Decoction	Oral	1	Cystitis	0.002	1	2.3
Meliaceae											
	(Funkè *et al.* 2023)	*Khaya senegalensis* (Desr.)A.Juss NKA030	Diala	Leaf, Root, Bark	Decoction, Maceration	Oral, Anal	27	Cystitis,Pyelonephritis	0.077	6.75	62.7
		Khaya grandifoliola C.DC. NKA040	Acajou	Bark	Decoction	Anal	1	Cystitis	0.002	1	2.3

		Turraea heterophylla Sm. NKA024	Cure-Dent Gouro	Whole	Decoction	Oral	5	Cystitis,Pyelonephritis, Others	0.014	1.66	11.6
Moraceae											
		Ficus mucuso Welw. ex Ficalho NKA041	Goman	Leaf	Decoction	Oral	3	Cystitis ,Urethritis, Others	0.008	1.5	6.9
Moringaceae											
	Lopez Z F (2019) (Lopez and Solis 2019)	*Moringa oleifera* Lam NKA025	Moringa	Leaf,Root, Bark	Decoction	Oral	3	Cystitis ,Urethritis, Others	0.008	1	6.9
Myrtaceae											
	*(*Elhassan et al 2019)	*Syzygium aromaticum*(L.) Merr. NKA039	clou de girofle	Seed	Decoction	Oral	4	yelonephritis, Others	0.011	2	9.3
Piperaceae											
	(Mohamed *et al.* 2024)	*Piper longum* L. NKA026	Poivre long	Seed	Decoction	Oral	5	Cystitis	0.014	2.5	11.6
Polygalaceae											
		Carpolobia lutea D.Don NKA027	Ngbémi	Leaf	Decoction, Infusion	Oral, Anal	3	Cystitis	0.008	1	6.9
		Securidaca longepedunculata Fres NKA032	Dioro	Leaf,Root, Bark	Decoction	Oral, Anal	42	Cystitis,Pyelonephritis,Prostatitis,Others	0.120	4.2	97.6
Phyllantaceae											
		Antidesma venosumE.Mey. ex Tul. NKA038	Kéri	Leaf, Root	Decoction	Oral, Anal	8	Pyelonephritis, Others	0.022	2.6	18.6
	(Phénix *et al.* 2021)	*Bridelia ferruginea Benth. NKA031*	Sagba	Root	Decoction	Anal	5	Cystitis,Pyelonephritis	0.014	2.5	11.6

	Dapar M (2020) (Dapar *et al.* 2020)	*Phyllanthus amarus* SchumThonn NKA028	Mille maladies	Whole	Decoction, Maceration	Oral	4	Cystitis, Urethritis, Others	0.011	2	9.3
		Uapaca togoensis Pax NKA033	Sômon	Leaf, Root	Decoction, Maceration	Oral,Anal	4	Cystitis, Others	0.014	1	9.3
Rubiaceae											
		Sarcocephalus esculentus Afzel. Ex NKA034	Bâti	Leaf, Root	Decoction, Maceration	Oral,Anal	3	Cystitis,Pyelonephritis, Others	0.008	1.5	6.9
Rutaceae											
	(Mohamed *et al.* 2014)	*Citrus limon* Burn. f. NKA029	Citronnier	Root	Decoction, Maceration	Oral, Anal	10	Cystitis,Pyelonephritis,Prostatitis,Others	0.028	2	23.2
		Citrus sinsensis (L.) NK028	Oranger	Leaf	Decoction	Oral	1	Pyelonephritis	0.002	1	2.3
Sapindaceae											
		Blighia sapida (K.Koenig) NKA037	Kaa	Leaf	Decoction	Oral	2	Pyelonephritis	0.005	2	4.6
Xanthorrhoeaceae											
	(Aserne M M *et al.* 2022)	*Aloe vera* Linn. *NKA036*	Aloes	Leaf	Decoction	Oral	3	Cystitis, Others	0.008	1.5	6.9
Zingiberaceae											
	Olowa, L. (2015) (Olowa and Demayo 2015)	*Zingiber officinale* Roscoe *NKA035*	Zingembre	Rhizome	Kneading	Oral	2	Cystitis	0.005	1	4.6

NKA: N'GUESSAN Kouamé Abraham

Relationships between plants, humans, and their environment

A Multiple Correspondence Analysis (MCA) was conducted to better understand the use of medicinal flora in the Haut-Sassandra region. This method provides a comprehensive graphical representation of the relationships between variables related to the traditional use of indigenous medicinal species and their different modalities. It also identifies associations between species (individuals) and connects groups of species with specific variables and their modalities. Factorial designs in MCA allow, through the simultaneous projection of modalities and individuals, the evaluation of similarities between individuals and the identification of distinct profiles (Palm 2007).

The MCA, applied to analyze the relationships between ethnobotanical indices (RFC, UV, and FL) and factors such as gender, ethnicity, locality, and plants used, reveals that the first factorial plane is formed by axes 1 and 2 (Figure 2). Together, these axes explain 9.8% of the total variance, with the first axis contributing 5% and the second 4.8%.

The horizontal axis (Dim1) primarily differentiates plant species and ethnic categories. For instance, certain plants (*Ks, Alc, Sl*) are positioned on one side, while others (*Pb, Av*) appear on the opposite side. The vertical axis (Dim2) contrasts specific plants with UV and FL indices. Modalities such as UV_2.6 and FL_18.6 are located towards the upper part of the graph, whereas others (*Alc, Sénoufo, Pel*) are closer to the center. Additionally, two closely positioned and well-represented variables exhibit a positive correlation, while opposing variables indicate a negative correlation. Orthogonality between two variables suggests the absence of linear correlation (Bilodeau & Faye 2009).
In the upper left quadrant, the modalities Av (plant), FL_18.6, and UV_2.6 are associated with specific individuals (numbered in red), indicating a higher frequency of use of this plant among them. In the lower left quadrant, Ks, FL_62.7, and UV_6.75 appear to be linked to another subset of individuals, likely reflecting a specific preference for this plant. The central area contains modalities such as Daloa, Malinké, Female, and Issia, suggesting that these categories are prevalent but do not necessarily provide a strong discriminatory factor among groups. On the right side, modalities like TII, PI, Sénoufo, and Th form an associated cluster, indicating a potential link between these elements.

The association between Sénoufo and Th suggests that individuals from the Sénoufo ethnic group utilize Th more frequently than other plants. This aligns with previous findings indicating a diverse range of traditional medicinal applications for Th. Despite the growing interest in this plant, it remains a wild-harvested species, emphasizing the need for its domestication to support economic development. Existing pharmacological data (Masunda et al., 2020) highlight its potential as a raw material for the formulation of new medicinal products.

Moreover, the grouping of Malinké, Female, Issia, and Daloa indicates shared characteristics in responses. This phenomenon can be attributed to socio-cultural mixing driven by social mobility, where diverse ethnic groups increasingly exchange traditional knowledge, values, and rituals (Lougbegnon et al., 2015). Consequently, knowledge related to medicinal plant use appears to be evenly distributed across ethnic communities (Ngbolua 2020).

Additionally, the similarity between Alc and PEL suggests that these plants are used in comparable contexts, possibly due to their availability in the region (Zon *et al.* 2022) or similar therapeutic properties. The differentiation of FL and UV indices further indicates that the perceived importance of medicinal plants varies significantly. This observation reinforces the idea that each individual holds a distinct perception regarding the utilization and significance of the studied plant species.

Floristic analysis

The analysis of information collected during this ethnobotanical study also enriched the regional floristic data of Haut-Sassandra. A total of forty-three medicinal plants belonging to twenty-cinq families were documented in the four localities studied for the management of urinary infections (Figure 3). The Fabaceae family was dominant, with 24% of medicinal plants documented, followed by Euphorbiaceae and Phyllantaceae (16% each), then Meliaceae (12%) and Combretaceae, Rutaceae and Apocynaceae and Polygalaceae (8% each). Finally, the remaining seventeen families were represented by a single species each (4% each) (Figure 2). The high proportion of Fabaceae could be explained by their significant representation in the flora of Haut-Sassandra due to ecological factors that favor the development and adaptation of many species in this family. Thus, the predominance of Fabaceae in this survey aligns with the assertion that the more common a plant taxon is in an area, the greater its likelihood of popular use. A similar documentary study shows that the Fabaceae family is the most abundant in the East Midnapore district (31 species) and Purba Medinipur of West Bengal (21 species) (Bhakat & Sen 2020). This also indicates that healers use a diversity of medicinal plants to treat UTIs. These results are consistent with those obtained by these authors but differ from those obtained by Erasto *et al.* (2005) in South Africa and

Etuk *et al.* (2010) in Nigeria. For each author, the most represented family varied from one study to another. This disparity in results is influenced by the geographical differences of the study areas and the variations in populations and flora studied from one country to another (Etuk *et al.* 2010).

Furthermore, healers are generally more experienced in treating cystitis than pyelonephritis. Also, prostatitis is treated by the Annonaceae family (1 species, 4%), while urethritis is more commonly treated by the Fabaceae family (2 species, 4.6%). The predominance of the Fabaceae familie could be due to their characteristic presence in African savannas (Nacoulma 2012) and their bioactive substances involved in the management of genital infections (Tsobou *et al.* 2016). It has also been reported in Burkina Faso that the Fabaceae and Euphorbiaceae families are the most used in the treatment of urinary infections (Sami *et al.* 2020). These results are identical to those obtained by these researchers. Ivorian and Burkinabe healers use almost the same medicinal plants to treat urinary tract infections. However, elsewhere, the Asparagaceae, Rutaceae, and Lamiaceae families were well represented, with eight, six, and six species used to treat urinary infections (Ian *et al.* 2021). Species from these families are primarily used because they are easy to collect and commonly used in medicine due to their rich bioactive compounds and associated pharmacological activities (Jan *et al.* 2021). According to the collected information,these species are effective and have no side effects. Numerous ethnomedical studies suggest that the most cited family could be considered the most useful. Additionally, other authors revealed in their work that Asteraceae (31.6%), Lamiaceae (26.3%), and Fabaceae (15.8%) were commonly used as therapies against urinary infections in Burkina Faso (Kam *et al.* 2018). The work of Elhassan *et al.* (2019) also revealed that the most represented families were Apiaceae (5 species), Lamiaceae (3 species), Leguminosae (3 species), and Poaceae (3 species). Legumes were also commonly used as therapies against urinary infections, with fourteen plant species reported (Hutchings *et al.* 1996).

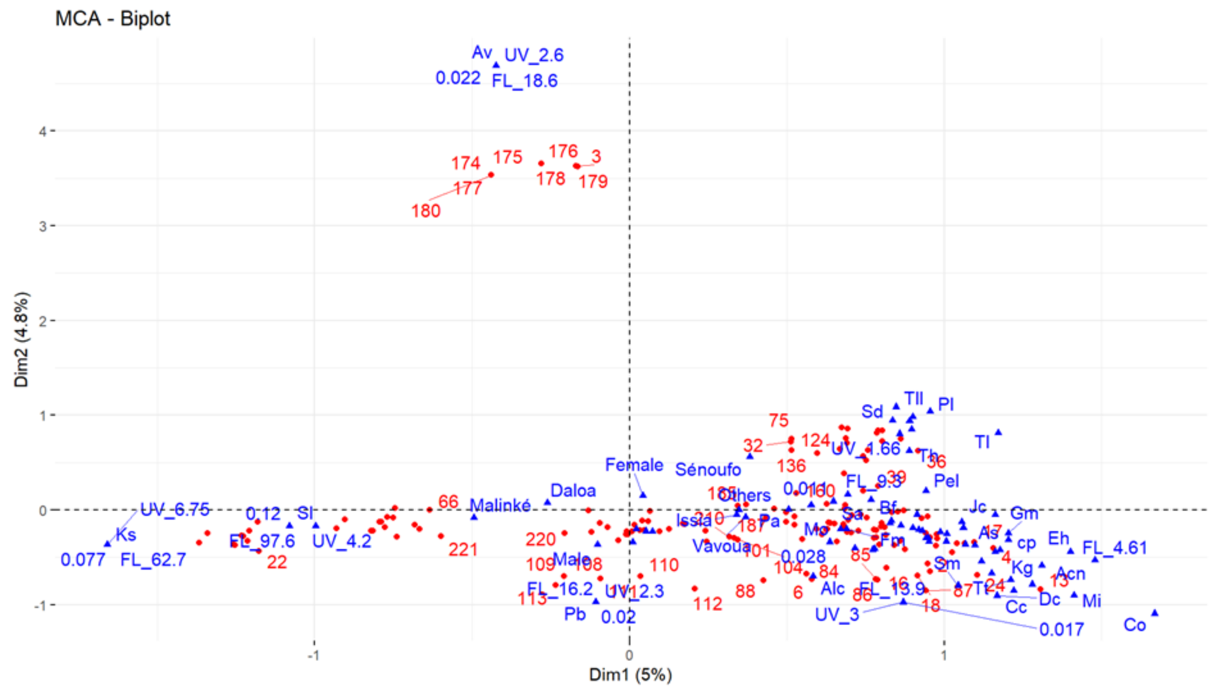

Figure 2. Multiple Correspondence Analysis (MCA) of the variables: ethnobotanical indices (RFC, UV, and FL), gender, ethnicity, locality, and plants used

An :*Anthocleista nobilis* ; Av :*Antidesma venosum* ; Ac :*Ageratum conyzoides* ; Acn :*Acacia nilotica* ; Alc : *Alchornea cordifolia*; As :*Allium sativum* ; Alv :*Aloe vera* ; Ans :*Annona senegalensis* ; Bs :*Blighia sapida* ; Bf :*Bridelia ferruginea* ; Cp :*Carica papaya* ; Cl :*Carpolobia lutea* ; Co :*Cassia occidentalis* ; Cl :*Citrus limon* ; Cs : *Citrus sinsensis* ; Cc :*Cola cordifolia* ; Eh :*Euphorbia hirta* ; Dc :*Daucus carota* ; Gm :*Glycine max* ; Fm :*Ficus mucuso* ; Kg :*Khaya grandifoliola* ;Ks :*Khaya senegalensis* ; Ka :*Kigelia africana* ; Mi :*Mangifera indica* ;Mo : *Moringa oleifera* ; Pb :*Parkia biglobosa* ; Pa :*Phyllanthus amarus* ; Pl :*Piper longum* ; Pel :*Peiricopsis laxiflora* ; Se :*Sapium ellipticum* ; Sae :*Sarcocephalus esculentus* ; Sm :*Secamone myrtifolia* ; Sl :*Securidaca longepedunculata* ; Sd :*Strychnos dinklagei* ; Sa : *Syzygium aromaticum* ; Ss :*Strophanthus sarmentosus* ; Tm :*Terminalia macroptera* ;Tll : *Terminalia leiocarpa* ; Tt :*Tetrapleura tetraptera* ; Th :*Turraea heterophylla* ; Ut :*Uapaca togoensis* ; Jc :*Jatropha curcas* ; Zo :*Zingiber officinale.*

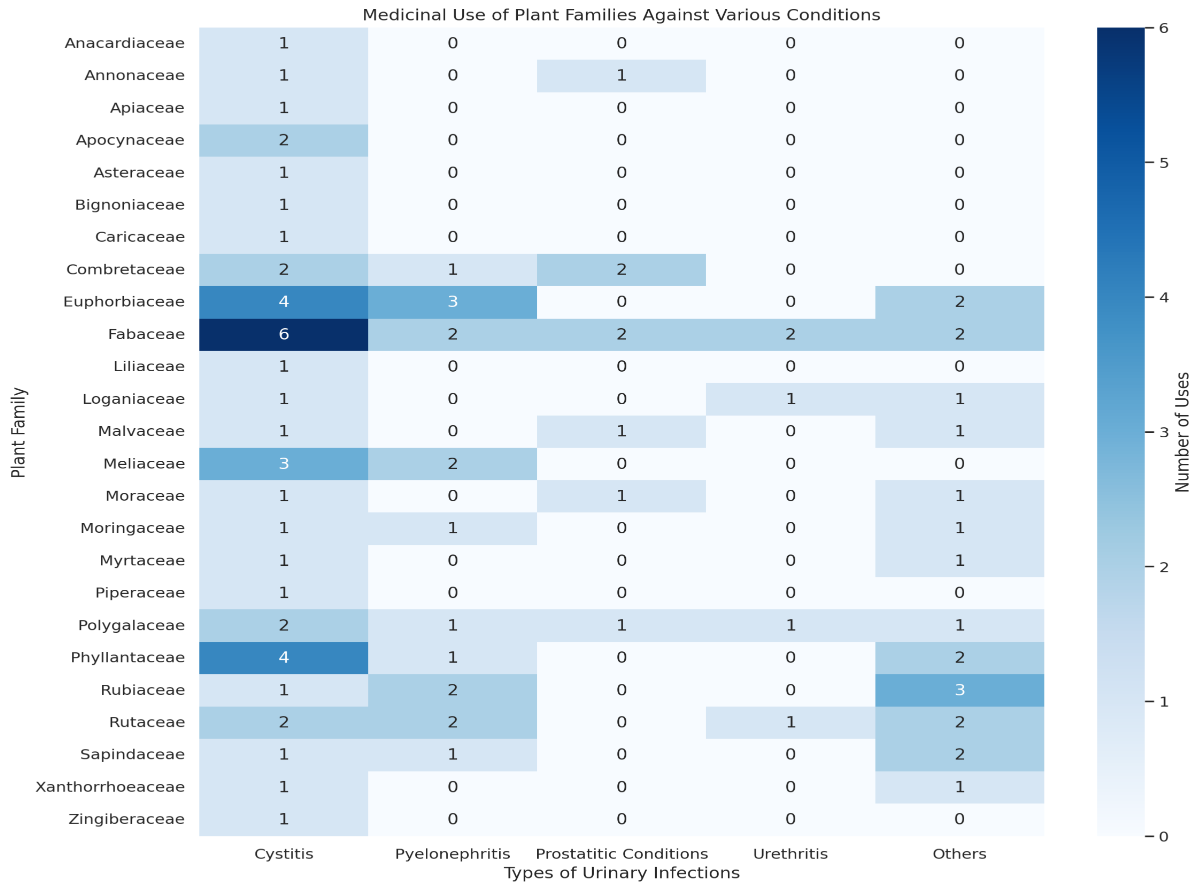

Figure 3. Medicinal use of plant families against various conditions.

Informant Consensus Factor (ICF)

Overall, the results show that the category with the highest level of informant agreement (ICF) was cystitis (0.965). The ICF results showed that diseases common in the Haut-Sassandra region had the highest consensus of agreement among informants (values between 0.772 and 0.984), (Table 3). These high GSI values indicated reasonable informant reliability on the use of plant species (Lin *et al.* 2002). Informant consensus values also indicated that informants shared knowledge of medicinal plants, the most important for treating the diseases most frequently encountered in the study area. And given that this index represents a coefficient of cultural importance for locally known species it is possible to conclude that these results reflect a homogeneity of information between the different people interviewed. High ICF values indicate reasonable reliability of informants and consistency of their knowledge regarding the use of plant species to treat a category of diseases (Orch *et al.* 2021). The low value of the ICF suggests that there is a lower degree of consensus on the use of a certain medicinal plant to treat a particular disease category.

Table 3.

Disease categories treated	TNS	TNUQ	ICF
Cystitis	34	194	0.984
Pyelenephritis	22	146	0.855
Prostatitis	4	20	0.842
Urethretis	6	23	0.772

TNS : Total Number of Species, TNUQ : Total Number of Usage Quotes

Parts used

The survey revealed that leaves are the most commonly cited plant part for treating urinary tract infections, accounting for 37%, followed closely by roots at 33.8%. Other plant organs were less frequently mentioned (Figure 4). These results corroborate those found by Effoe *et al.* (2020), Ladoh-Yemeda *et al.* (2016), Gbekley *et al.* (2015), and Koudouvo *et al.* (2011), who also found that leaves were the most used plant parts. Other authors noted that most respondents (83%) used leaves (Khalumba *et al.* 2005). Ethnobotanical studies by Lakouéténé *et al.* (2009) and Zerbo *et al.* (2011) showed that leaves were the most commonly used parts in various therapeutic preparations, with respective proportions of 67% and 41%. Sami *et al.* (2020) revealed that leaves and roots were the most cited parts, with proportions of 40% and 32%, respectively.

There might be concerns about the excessive use of medicinal plant leaves, but studies by Poffenberger *et al.* (1992) showed that harvesting 50% of a tree's leaves does not significantly affect its survival. Additionally, Coll and Giday (2003) and Srithi *et al.* (2009) found that leaf harvesting was generally more sustainable for most plants than harvesting underground parts. Thus, the dominance of leaves is mainly due to their accessibility and their role in photosynthesis, which makes them prime sites for the accumulation of active principles (Mukaila et al., 2023). The frequent use of leaves can be attributed to their abundance of various types of metabolites (Ullah *et al.* 2021). Moreover, leaves are produced in large quantities and are easy to collect (Ahmad et al., 2021). Therefore, using leaves is sustainable and safe for plant life from a conservation perspective (Jan *et al.* 2020). The ease of collection, accessibility, and variety of biochemical substances contribute to the use of whole plants in phytotherapy (Hassan *et al.* 2020).

Leaves have been widely used in the preparation of medicinal plants due to the presence of active secondary metabolites (Bano *et al.* 2014, Ghorbani 2005). Leaves are also useful in preparing various herbal products in many communities worldwide (Ahmad *et al.* 2017). Leaves are the most common and preferred components in medical preparations due to their ease of handling and stability (Rodrigues *et al.* 2020). Additionally, leaves are the main photosynthetic organs of plants and are considered natural pharmacies for synthesizing many active principles that are pharmacologically more effective against certain diseases (Passalacqua *et al.* 2007). The use of leaves could be linked to their role as the site of photosynthesis and preferential accumulation sites for active substances (Ragunathan *et al.* 2009). Leaf exploitation is beneficial for plant survival (Sadeghi *et al.* 2014). According to Chamouleau (1979), leaves are the most used because they are the site of photochemical and metabolic reactions and reservoirs of organic matter derived from them. Several previous ethnobotanical studies have shown that seeds and leaves are the most used parts in preparing various herbal remedies (Barkaoui *et al.* 2017, Eddouks *et al.* 2017). However, harvesting plant roots poses a threat to species sustainability (Ragunathan et al., 2009).

The study also revealed that roots are the second most used part for treating urinary tract infections. As in previous studies, roots were frequently used in the second position after leaves (Ragunathan *et al.* 2009, Scherrer *et al.* 2005). Roots are known to be rich in bioactive compounds (Alebie *et al.* 2017). They are preferred after leaves because they are rich in terpenes (Silva *et al.* 2021). Roots serve as storage sites for various secondary metabolites with diverse therapeutic properties due to their underground position, which favors the preservation of active substances from other plant parts (Bashige *et al.* 2020, Dongock *et al.* 2018, Houmenou *et al.* 2017). However, their removal affects the plant's nutrient supply, impacting its vegetative aspect and physiology. Harvesting plant roots or bark can have more detrimental ecological consequences than harvesting leaves (Dongock *et al.* 2018). These results are close to those of N'guessan *et al.* (2009), indicating 51.22% leaf use in their studies. However, these results are very different from those of Yapi (2013) regarding the percentage of roots (10%). Furthermore, bark harvesting often leaves large scars through which plants are later attacked by fungi, birds, and infesting caterpillars. Uprooting, branch cutting, bark harvesting, and felling are dangerous methods for the plant (Ouattara 2006).

Methods of preparation and routes of administration of recipes

The study identified four preparation methods for recipes, with decoction being the most predominant (71.4%), followed by maceration (14.3%), infusion (10.7%), and kneading (3.7%), (figure5). These recipes are administered orally and anally, with oral administration being predominant (67.8%) compared to anal administration (32.2%). All four preparation methods are administered orally, with decoction being the most predominant (78.4%), followed by maceration (11.8%), infusion (9.8%), and kneading (3.9%). However, for anal administration, three preparation methods were used, with decoction again being the most predominant (66.6%), followed by maceration and infusion (16.6% each).

According to literature, infusion and decoction are the most commonly used methods to prepare medicinal plants. This survey also revealed the same finding. These results are consistent with those obtained in the Elkantara region (Khanfer 2019). This technique allows the extraction of active principles in water (Ladoh-Yemeda 2016). Thus, the population of Haut-Sassandra mainly uses decoction as a preparation method for medicinal recipes to treat urinary tract infections. These results are in agreement with those obtained by Dongock *et al.* (2018), who showed that decoction was the most used method with a rate of 62%. According to Lahsissène *et al.* (2010), the interest in using decoction lies in its ability to increase body temperature. Salhi *et al.* (2010) stated that decoction is the best preparation method to maximize the active ingredients of medicinal plants, allowing for the collection of the most active principles and mitigating or nullifying the toxic effects of some recipes. The best use of a plant is the one that preserves all its properties while allowing for the extraction and assimilation of active principles (Dextreit 1984). Similarly, ethnobotanical studies conducted in the Blouberg region of South Africa (Mathibela *et al.* 2019), Burkina Faso (Kam *et al.* 2018), and the city of Shiraz in Iran (Bahmani *et al.* 2016) reported decoction as the most dominant technique in preparing remedies for urinary tract infections. This traditional practice is widespread because the local population believes it is suitable for body warming and disinfecting the plant (Koman *et al.* 2019, Ngbolua *et al.* 2016).

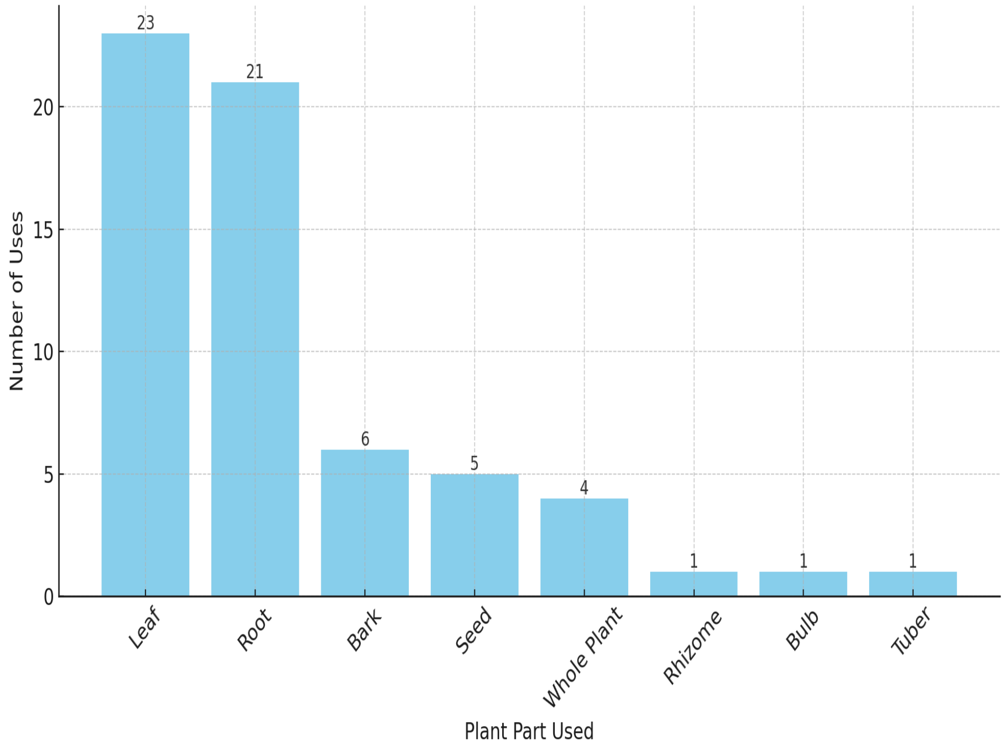

Figure 4. Number of uses by plant part.

Medicinal plants can have adverse effects when used without precaution by patients. Therefore, gentle medicine must be practiced carefully and within well-defined parameters and measures (Benlamdini *et al.* 2014). Water is the best and most widespread solvent for extracting the most active principles (Koman *et al.* 2019).

The routes of administration were mainly oral, as most respondents revealed that oral administration was the most practiced by informants to treat urinary infections. These results are compatible with those obtained in an ethnobotanical study by El Hafian *et al.* (2014) in Morocco. This can be explained partly by the ease of this method and partly by the fact that the disease affects deep organs. To reach these organs, any compound must pass through the digestive system to facilitate its assimilation. These results align with those of N'Guessan *et al.* (2009), who indicated that drinking accounted for 46.98% and Bla *et al.* (2015) 57.69%. They stated that ingesting bio-active principle-containing decoctions via oral administration involves a much faster and more effective metabolic process than other techniques. Traditional healers explained that by drinking the decoction, the probability of neutralizing the parasite is higher, and it would be eliminated through urine. Studies conducted elsewhere by Kam *et al.* (2018), Nisa *et al.* (2021), and Elhassan *et al.* (2019) also reported that oral administration was the only method for administering drugs to treat urinary infections. According to Bi *et al.* (2008), this method helps molecules to be absorbed more effectively. Chakale *et al.* (2021) indicated that the oral route is preferred over topical because it allows rapid and efficient distribution and interaction of drugs with the target site inside the body. Phytotherapy is a reasoned and thoughtful use of medicinal plants, requiring the most effective preparation method to ensure the preservation of all properties while allowing for the extraction and assimilation of active principles (Benlamdini *et al.* 2014, Rhattas *et al.* 2016). This study highlights the common knowledge of plant species used to treat urinary tract infections.

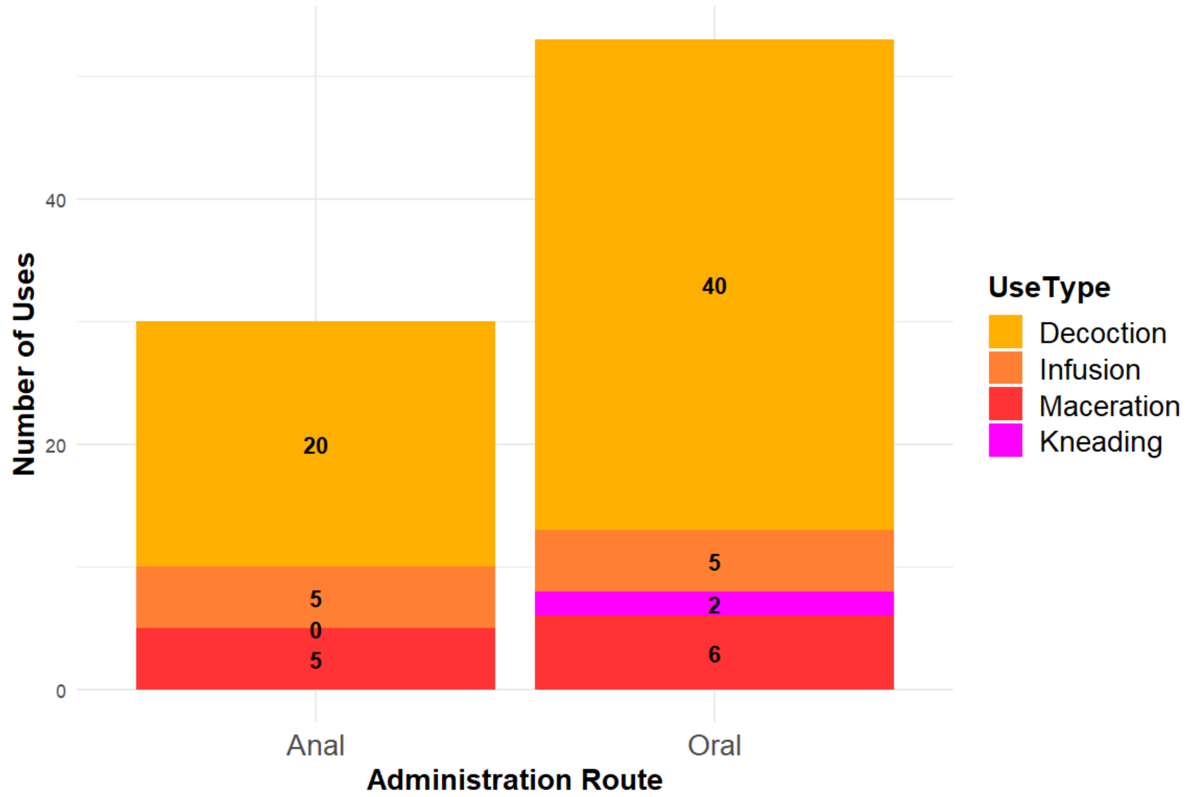

Figure 5. Number of uses by administration route and preparation method.

Conclusion

The study conducted in the four localities of the Haut-Sassandra region identified forty-three species. Some species and families were more frequently cited than others, as were the plant parts used. Most of the recipes from these plant species were prepared using leaves. The most commonly adopted preparation method was decoction, et almost all products were administered orally. The diversity of recipes and plant parts used, along with the various preparation and administration methods, indicate that traditional healers in these regions have extensive knowledge of plants used to treat urinary infections. The results obtained provide a database for future research related to phytochemistry and pharmacobiology. For better valorization and conservation of this medicinal heritage, effective collaborations should be established between traditional health practitioners and scientific actors.

Declarations

List of abbreviations: MP - Medicinal Plants; UTI - Urinary Tract Infections; p.c - percentage

Ethics approval and consent to participate: All informants involved provided their prior informed consent before the interviews.

Consent for publication: Oral consent from respondents and local authorities was obtained

Availability of data and materials: Voucher specimens have been deposited in the herbarium of the Biology Department, Jean Lorougnon Guédé University, Daloa, Côte d'Ivoire. The rest of the details are available within this article.

Competing interests: The authors declare no competing interests.

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Author contributions: DMA and KNA conceptualized and designed the overall strategy of the study. KNA conducted fieldwork and collected plant materials for identification. KNA, SK, NPN, DAG and DMA processed, interpreted the surveyed data, drafted the manuscript, and All authors read, reviewed, and approved the final manuscript for publication consideration.

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