Ethnobotanical knowledge of *Prunus africana* (Hook. f.) Kalkman (*Rosaceae*) by people living in community forests in North Kivu, Eastern Democratic Republic of Congo

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Research

Abstract

Background: *Prunus africana* (Hook. f) Kalkman (*Rosaceae*) is a multi-purpose species with important utility value for the populations that depend on it. Indeed, local populations living in community forests use *P. africana*. The objective of this study is to document the different uses of *P. africana* by local populations in traditional medicine for a better vulgarization for a sustainable management of the resource.

Methods: Ethnobotanical surveys were conducted in four *P. africana* distribution areas in North Kivu. Data were collected on the basis of a survey from 221 informants. Statistical analysis and calculation of ethnobotanical indices were performed using R 4.1.2 software.

Results: Results of the investigations show that *P. africana* is by far used in medical practices (96.83%). It is also used as wood energy (60.18 %), charcoal (40.27 %), in handicrafts (7.24 %), construction (6.79 %), food (2.26 %) and traditional rites (0.45 %). In traditional pharmacopoeia, the characterization of the uses allowed us to identify 23 diseases for which *P. africana* extracts are used to treat them. The bark and leaves are the most used organs in the recipes. The decoction (99.5%), the

macerated (10.41%) and the powders (7.69%) are the galenic or pharmaceutical forms in which the local populations prepare the remedies. The potions prepared are mainly administered orally (99.5%).

Conclusion: The multiple forms of use of *P. africana* by the populations of North Kivu, both in medicine and in other categories of use, constitute a threat to its survival. For a sustainable management, the results of this study reveal that it is possible to substitute the species *P. africana* with other plant species with similar potential in order to limit its overexploitation.

Keywords: *Prunus africana*, community forests, multiple uses, traditional medicine, sustainable management, DR Congo

Background

Medicinal plant use in the world is very old, there is a modern revival in the use of these plants. In all ancient civilizations and on all continents, there are traces of the use of medicinal plants and their bioactive constituents in the treatment of various diseases (Islam *et al*. 2020; Nanjala *et al*. 2022; Islam *et al*. 2022). Worldwide, more than 50,000 plant species are documented for their clinical benefits and pharmacological effects on humans and domestic animals (Sharma *et al*. 2022). Studies show that 80% of the world's population uses medicinal plants or their bioactive compounds for the prevention, cure or treatment of several diseases (Macía *et al*. 2005; Ajibesin *et al*. 2012; Chiribagula *et al*. 2020; Mlilo and Sibanda 2022; Ugbogu *et al*. 2022; Delices *et al*. 2023). In developing countries, the use of herbal medicines as an alternative to modern medicine is very common (Nath and Puzari 2022). Indeed, the World Health Organization (WHO) reported that between 70-90% of the population in developing countries used herbal medicines in primary health care (Costa *et al*. 2023).

In addition, the increase in the use of traditional medicine in both developing (such as DR Congo) and developed countries can be explained by several factors. The first factor is related to the discovery in plants of secondary metabolites that have different pharmacological potentials (Delices *et al*. 2023). The second factor is the low cost of treatment (in terms of consultation and consumption of medicinal plants) compared to conventional medicine which is based on overpriced commercial pharmaceuticals (Macía *et al*. 2005; Kasika *et al*. 2015; Kasika *et al*. 2016; Basak *et al*. 2022; Ginko *et al*. 2023). The third factor is the financial capacity of the patients or his family and the difficulties in accessing modern health care (Amuri *et al*. 2018; Cakupewa *et al*. 2022). In this sense, medicinal plants are the most accessible form of health care resource, especially for populations living in rural areas (Mlilo and Sibanda 2022; Ginko *et al*. 2023). The fourth factor is related to the changing needs, diseases, and beliefs of the populations (Ginko *et al*. 2023) on the one hand, faith in ancestral culture healing practices on the other (Amuri *et al*. 2018; Cakupewa *et al*. 2022). These healing practices of ethnic populations have been socially recognized at all stages of anthropological, cultural, and environmental evolution (Islam *et al*. 2022).

Democratic Republic of Congo (DRC) is a reservoir of biodiversity in terms of both flora and fauna. Its flora abounds in medicinal plants of biopharmaceutical interest and capable of supplying new molecules (Masunda *et al*. 2019). Given the country's socio-economic realities, which prevent a large proportion of the population from accessing modern healthcare, the use of medicinal plants to solve health problems is an alternative (Cakupewa *et al*. 2022; Iragi *et al*. 2021). Indeed, traditional medicine is a highly credible alternative against diseases such as malaria, which is endemic throughout the Congolese territory (Chiribagula *et al*. 2020). In the Beni and Lubero territories, traditional medicine is widely used due to the rising cost of conventional medicines, which are becoming inaccessible to many populations, particularly in rural areas (Kasika *et al*. 2015; Kasika *et al*. 2016).

In these territories, traditional medicine is used to treat over 50 diseases, including malaria, diarrhea, colic, internal candidiasis, yellow fever, migraine, rheumatism, otitis, abscesses, gastritis, intestinal worms, panariasis, wounds, ulcers, haemorrhoids, hernias, dysentery, nasal haemorrhage, gastroenteritis, sprains, atherosclerosis, urogenital infections, furunculosis, ringworm, scabies, coughs, asthma, poison, etc. (Kasika *et al*. 2016; Ndavaro *et al*. 2023; Saa-Sita *et al*. 2022). Among these medicinal plants is *Prunus africana*, distributed in the Afromontane forests of North and South Kivu provinces (Cunningham *et al*., 2016; Muhesi and Mate, 2018; Muhesi *et al*. 2023). In 1995, due to its ever-increasing international demand for bark, it was listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Betti *et al*. 2003). Furthermore, the importance of *P. africana* lies in the medicinal virtues of its bark extracts, which are used in the manufacture of over 19 medicines sold on the European and American markets (Cunningham *et al*. 2016; Muhesi *et al*. 2023). *P. africana* bark extracts are used medicinally to treat benign prostate adenoma and benign prostate hyperplasia, which are common in older men (Betti and Ambara 2013; Betti *et al*. 2014). Demand for *Prunus africana* bark and wood from other species worries scientists, given that several authors such as Muhesi and Mate (2018) and Cunningham *et al*. (2016) have already reported the lack of natural regeneration and low levels of recruitment under dense canopies in forests across its range.

Studies carried out to date in the region have focused, for example, on the natural regeneration of *P. africana* (Muhesi and Mate 2018) or its post-barking response under various ecological zones (Muhesi *et al*. 2023). However, studies on the ethnobotanical uses of this species among local and indigenous communities in eastern DR Congo are fragmentary. Yet simple observation shows that indigenous communities living around forests where *P. africana* specimens are found, and lacking access to health systems due to their remoteness, use this species to treat various illnesses. In a context characterized by the need to reconcile the sustainable use of *P. africana* by these local and indigenous communities with its conservation, ethnobotanical studies on this species in North Kivu are necessary.

There are several reasons why ethnobotanical studies of endangered species like *P. africana* are important. First, these studies could lead to the discovery of effective medicines of health importance. In this sense, ethnobotanical studies have become increasingly valuable for the development of health care programs (Shil *et al*. 2014). Second, documenting indigenous knowledge of medicinal plants can also contribute to the conservation of these species (Mahwasane *et al*. 2013; Adil *et al*. 2022) and the cultural heritage of associated indigenous people for future generations (Mahwasane *et al*. 2013). Indeed, the link between ecosystem services, resource ecology, and people is exploited, which is essential for sustainable resource use (Chen and Sun 2018; Ncube *et al*. 2022). This importance is further justified as recent research has shown that increasing demand for medicinal plants is leading to overexploitation of wild populations for commercial purposes, resulting in habitat degradation and possible extinction of these species (Shopo *et al*. 2022). Third, with the impacts of urbanization, industrialization, migration from rural to urban areas, rapid loss of natural habitats, and lifestyle changes, the wealth of ethnomedicinal plant knowledge in many cultures is gradually decreasing (Pradhan *et al*. 2022). This decline in traditional knowledge due to a breakdown in oral transmission between current and future generations needs to be restored (Pradhan *et al*. 2022).

Taking into regard the above-mentioned considerations, this article is of particular interest because it will allow to understand the relationships between the riparian populations of the community forests and the species *P. africana* in order to put in the following management and conservation strategies. This study will also help fill gaps in traditional knowledge about the uses of this species and the sustainability of biocultural links. Indeed, the documentation and prioritization of ethnomedicinal plants associated with *P. africana* in the preparation of traditional remedies in this paper will also provide a baseline for studies on bioactive components and local and national drug discovery programs based on these plants.

This paper has 2 objectives:
1. To identify the different uses of *P. africana* by people living in community forests in four zones in North Kivu; and
2. To characterize the traditional uses of *P. africana* in the local pharmacopoeia, considering the plant parts used, the pharmaceutical forms, the ways of administration and the associations with other plants.

Materials and Methods

Study area

Ethnobotanical investigations were conducted in four forest sites in the province of North Kivu (Lubero, Mangurejipa, Walikale and Ruwenzori) in the northeast of the Democratic Republic of Congo (Figure 1). Lubero and Mangurejipa sites are located in Lubero territory in the Bamate Chiefdom and in the Bapère sector, respectively. Walikale site is located in Walikale territory, specifically in the Wanianga sector, while the Ruwenzori site is located in Beni territory in the Ruwenzori sector. These four zones have fairly similar agroclimatic characteristics. The climate belongs to the equatorial zone. In the highlands, there is a decrease in temperature as the altitude increases (Kapiri *et al*. 2023a). This explains the presence of two climates: the equatorial climate of altitude in the highlands and the classic equatorial climate in the lowlands (Kapiri *et al*. 2023b; Muhesi *et al*. 2023). Populations in the areas studied are divided into two categories: indigenous communities (Pygmies) and non-indigenous communities. Indigenous communities are more dependent on forests than others. Cultural diversity characterizes the population of the study areas. Ethnic groups found in the different zones include the Nande, who predominate, and the Nyanga, Piri, Kovo, Rega and Pygmy (Mbuti), who are in the minority. In the four study zones, the majority of people make their living from agriculture, livestock breeding, gold panning, logging and petty trading. As the areas are heavily landlocked, access to modern healthcare is a problem for most of the population.

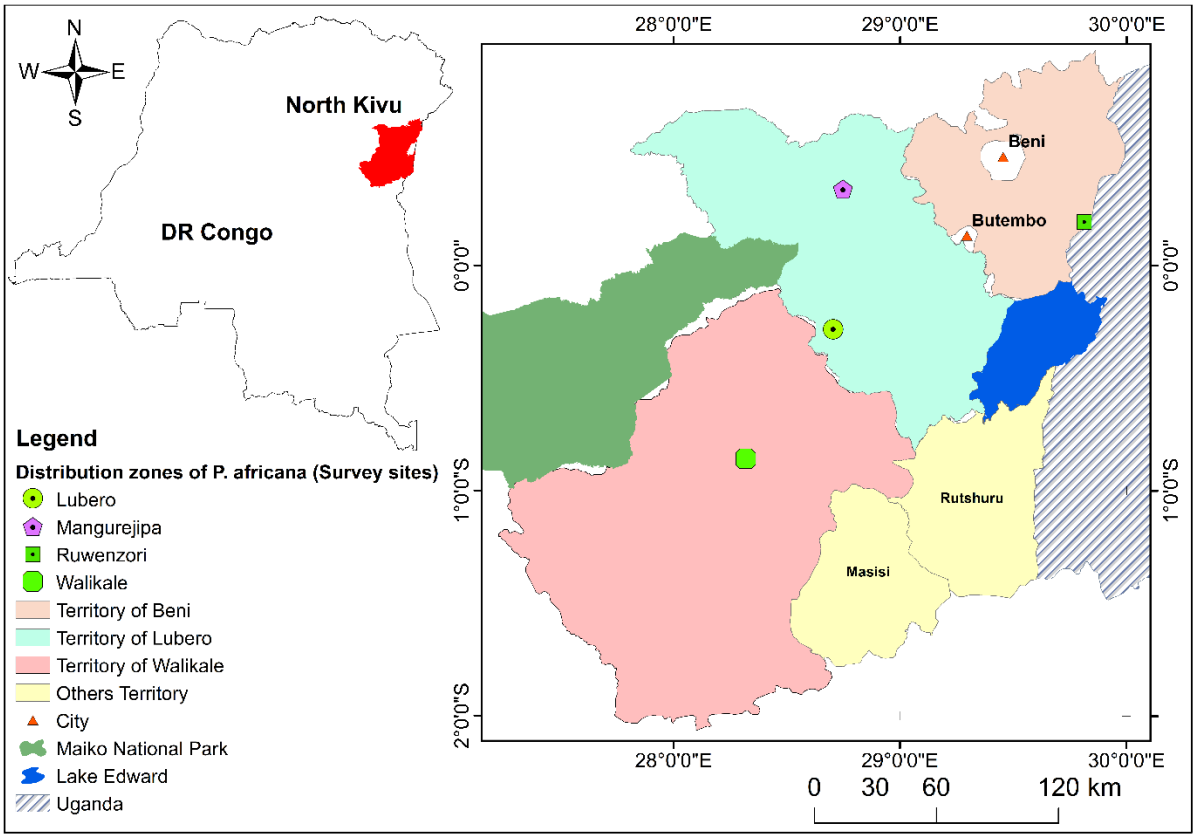

Figure 1. Study sites, North Kivu, eastern Democratic Republic of Congo

Materials and Methods

Sample size

We selected a sample of individuals with knowledge of the species *P. africana*. Informants were selected randomly and consisted of interviews with individuals available to participate in the study based on criteria. Given that the plurality of people to be interviewed always reveals a diversity of viewpoints (Ndavaro *et al*. 2023) and that the diversification of sources of ethnobotanical data allows us to consider the societal realities specific to each environment (Sambiéni *et al*. 2015, Ndavaro *et al*. 2023), the sample size (*n*) was calculated by the normal approximation of the binomial distribution (Padonou *et al*. 2014; Agbo *et al*. 2017; Ndavaro *et al*. 2023):

$$n = \frac{\left(U_{1-\frac{\alpha}{2}}\right)^2 * p\,(1-p)}{\delta^2} \qquad (1)$$

With n the sample size, p the proportion of people with the characteristic i.e. the proportion of people who claimed to have ever used *P. africana*. Based on a pre-survey, where 82.7% of the 50 people randomly selected in the four zones had already used *P. africana* in traditional medicine or in other forms, the value of p is then equal to 0.827 for this investigation. In Equation 1, the quantity $U_{1-\frac{\alpha}{2}}$ is the value of the normal random variable for a risk α (α=0.05; $U_{1-\frac{\alpha}{2}} = 1.96$) and δ is the expected margin of error of any parameter to be calculated and is set to 5%. By substituting the value of each parameter in equation 1, a sample consisting of 219 informants was obtained. To simplify matters, this sample was rounded up to 221 informants.

Selection of villages and informants

Two criteria were used to select villages in the four study areas: the presence of a forest with *Prunus africana* trees and indicators of *Prunus africana* use. A pre-survey phase verified these indicators and ensured the medicinal and socio-cultural importance of the study for the local communities. Thus, ethnobotanical investigations were organized in 9 villages (notably Rusamambo, Bukumbirwa, Misinga in Walikale, Mwenda, Ibathama, Rughetsi in Ruwenzori, Mbuavinywa in Lubero and Njiapanda and Mangurejipa in the Bapère sector). Informants were selected using a simple random sampling method, based

primarily on criteria such as age and length of time in the village. However, some informants were chosen for convenience (traditherapists) as they had sufficient knowledge of the different uses of *P. africana*.

Data collection and botanical identifications

Ethnobotanical surveys in the four zones were conducted between July 15 and December 13, 2022. Informants were interviewed using a well-structured questionnaire with four sections. The first section presented the socio-demographic characteristics of the informant (gender, ethnicity, age, seniority, level of education, profession, origin, marital status, etc.). In the second section, the different uses of *P. africana* in their community (medicinal, construction, charcoal, fuelwood, handicrafts, magico-religious, etc.) were noted. The third section dealt with questions related to the characterization of medicinal uses only. Here, informants were asked about the plant parts used in the preparation of the recipes, the methods of preparation, the routes of administration, the materials used in the formulation of the extracts, the units of measurement used to estimate the dose (posology) and the duration of treatment. In the fourth section, informants were asked to name five diseases treated by *P. africana* according to the order of priority of the disease. Combination of plants in the medicinal recipes was also discussed. Thus, the informants provided information on the vernacular name, the organs used, the modes of preparation, the forms of administration, the dosage, the duration of treatment and the morphological type of the associated species. Transposition of the vernacular names into scientific names and the identification of the plants were carried out with the expertise of a specialized botanist. Families of these species were determined according to the APG (Angiosperm Phylogeny Group) III classification (Bremer *et al*. 2009).

Data processing and statistical analysis

Due to the complexity of the questionnaire linked to the different conditionality's, the survey questionnaire was formalized in the *KoboCollect* v1.25 application to limit errors and to allow the prioritization of variables during the analysis. This application automatically generated a file in Excel format via the online tool *KoboToolbox*. Statistical analyses were performed using R 4.1.2 (R Core Team 2021). Descriptive statistics focused on the calculation of proportions between different modalities of socio-demographic characteristics. These proportions were compared using Pearson's chi-square test of independence. Comparison of informants' means according to study areas was done using an analysis of variance (ANOVA). We compared the importance of each species associated with *P. africana* during the preparation of remedies using the four indices which are: Use Report (UR) of organs of the species (equation 2), Frequency of Citation (FC) per species (equation 3), the number of organs solicited per species (NU) (equation 4) and the Relative Importance Index (RI) of the species (equation 5). Use Report (UR) and Relative Importance Index (RI) were also used to calculate the importance informants place on *Prunus africana* in relation to disease treatment (prioritization of diseases based on importance).

Use Report (UR) per species

With this index, the total uses of species organs by all informants ($^{i}1$ to ^{i}N) in each organ category for that species (s) were calculated. It is a count of the number of informants mentioning each organ used of the species *NC* and the sum of all organs in each category ($^{u}1$ to ^{u}NC) (Prance *et al*. 1987; Tardío and Pardo-De-Santayana 2008):

$$UR_S = \sum_{u=u_1}^{^{u}NC} \sum_{i=i_1}^{^{i}N} UR_{ui} \qquad (2)$$

Frequency of Citation (FC) per species

It is the sum of informants citing a use of the species (Prance *et al*. 1987):

$$FC_s = \sum_{i=i_1}^{^{i}N} UR_i \qquad (3)$$

Number of organs used (NU) per species

$$NU_s = \sum_{u=u_1}^{^{u}NC} \qquad (4)$$

NC are the number of organ categories and *NU*s is the sum of all organ categories for which a species is considered useful (Prance *et al*. 1987).

Relative Importance Index (RI)

It calculates the Relative Importance Index (RI) for each species in the database.

$$RI_s = \frac{RFC_{s(max)} + RNU_{s(\max)}}{2} \qquad (5)$$

$RFC_{s(max)}$ is the relative frequency of citation of the species over the maximum, $RNU_{s(\max)}$ is the relative number of solicited organs of the species over the maximum (Tardío and Pardo-De-Santayana 2008). These indices were implemented in R software using the *ethnobotanyR* package (Whitney 2022). Chord diagrams between diseases, *P. africana*-associated species, and solicited organs and/or preparation modes were obtained by the *circlize* package (Gu *et al*. 2014). A Multiple Correspondence Analysis (MCA) was performed between, on the one hand, the diseases and the informants' socio-demographic characteristics and, on the other hand, between the species associated with *P. africana* and the informants' socio-demographic characteristics. MCA was performed using the packages *FactoMineR* (Lê *et al*. 2008), *factoextra* (Kassambara and Mundt 2020) and *ggplot2* (Wickham 2016).

Results

Informants' Characteristics

A Total of 221 people were interviewed in all sites, including 55 informants in Lubero, 42 informants in Mangurejipa, 78 informants in Ruwenzori and 46 informants in Walikale. Males were predominantly represented compared to females. The gender ratio of informants differs between the different study areas (p-value=0.026). Regarding the level of education in the sample, informants with no education or with a primary level of education are more represented (Table 1). The analyses show that there is a significant difference in the proportion of the different levels of education according to the study areas (p-value=0.002)

A majority of the respondents (more than 80% for each study area) were couples. Chi-square test shows that there is no significant difference between the marital status categories and the study areas. With regard to the activities practiced in the four study zones, the proportion of farmers and traditional practitioners is much higher than the other professional categories. Most informants have been living in the areas for a long time (more than 15 years). Large majority of informants were indigenous (Table 1). The proportion of people who were native to the area (indigenous) and those who had migrated (non-indigenous) showed a significant difference (p-value =0.022). The most represented ethnic group in the four zones is the *Nande*. The average age of informants in all four study zones is high. Indeed, the informants in Lubero ranged in age from 19 to 70 years with an average of 47.51 ± 13.76 years, while in Mangurejipa, the age ranged from 21 to 75 years with an average of 47.31 ± 14.25 years. Finally, the informants in Ruwenzori ranged in age from 23 to 69 years with an average of 42.33 ±12.47 years, while those in Walikale ranged in age from 22 to 71 years with an average of 43.78 ±13.44 years. Nevertheless, the analysis of variance shows that the average ages of informants in the areas of interest in this study are similar (p-value=0.0862 > 0.05).

Table 1. Socio-demographic characteristics of informants according to study sites

Variable	Modalities	Lubero	Mangurejipa	Ruwenzori	Walikale	p
Gender	Female (F)	13 (23.6)	15 (35.7)	18 (23.1)	4 (8.7)	0.026
	Male (M)	42 (76.4)	27 (64.3)	60 (76.9)	42 (91.3)	
Education level	Agricultural literacy (A. literacy)	2 (3.6)	0 (0.0)	10 (12.8)	0 (0.0)	0.002
	Primary (Pri.)	13 (23.6)	16 (38.1)	21 (26.9)	17 (37.0)	
	No education (No. edu)	11 (20.0)	18 (42.9)	24 (30.8)	12 (26.1)	
	Secondary (Sec.)	24 (43.6)	8 (19.0)	18 (23.1)	15 (32.6)	
	High schooling (H. schooling)	5 (9.1)	0 (0.0)	5 (6.4)	2 (4.3)	
Civil State	Celibates (Cel.)	5 (9.1)	0 (0.0)	6 (7.7)	1 (2.2)	0.506
	Divorced (Div.)	1 (1.8)	0 (0.0)	2 (2.6)	0 (0.0)	
	Married (Mar.)	44 (80.0)	37 (88.1)	63 (80.8)	39 (84.8)	
	Widow/Widower (Wid.)	5 (9.1)	5 (11.9)	7 (9.0)	6 (13.0)	
Occupation	Farmers (Farm.)	24 (43.6)	20 (47.6)	45 (57.7)	23 (50.0)	0.029
	State agents (S.agents)	2 (3.6)	0 (0.0)	0 (0.0)	5 (10.9)	

	Breeders (Breed.)	6 (10.9)	1 (2.4)	5 (6.4)	0 (0.0)	
	Teachers (Teach)	3 (5.5)	1 (2.4)	3 (3.8)	3 (6.5)	
	Forest operators (F. operators)	3 (5.5)	2 (4.8)	3 (3.8)	0 (0.0)	
	Doctors & nurses (Doc & Nu)	1 (1.8)	1 (2.4)	0 (0.0)	3 (6.5)	
	Traditherapists (Tradi)	16 (29.1)	17 (40.5)	22 (28.2)	12 (26.1)	
Seniority	1-5 years (1-5)	1 (1.8)	0 (0.0)	16 (20.5)	0 (0.0)	<0.001
	11-15 years (11-15)	1 (1.8)	6 (14.3)	6 (7.7)	11 (23.9)	
	6-10 years (6-10)	1 (1.8)	0 (0.0)	14 (17.9)	4 (8.7)	
	Over 15 years (> 15)	52 (94.5)	36 (85.7)	42 (53.8)	31 (67.4)	
Origin	Migrant (Migr)	7 (12.7)	10 (23.8)	28 (35.9)	10 (21.7)	0.022
	Native (Nat)	48 (87.3)	32 (76.2)	50 (64.1)	36 (78.3)	
Informant categories	Old women (Old_w)	5 (9.1)	8 (19.0)	2 (2.6)	1 (2.2)	<0.001
	Adult women (Adult_w)	4 (7.3)	3 (7.1)	11 (14.1)	2 (4.3)	
	Adult man (Adult_m)	22 (40.0)	10 (23.8)	15 (19.2)	17 (37.0)	
	Young women (Young_w)	2 (3.6)	5 (11.9)	7 (9.0)	2 (4.3)	
	Young man (Young_m)	8 (14.5)	4 (9.5)	40 (51.3)	12 (26.1)	
	Old man (Old)	14 (25.5)	12 (28.6)	3 (3.8)	12 (26.1)	
Age groups (years)	[18,25]	5 (9.1)	3 (7.1)	2 (2.6)	2 (4.3)	0.166
	[25,35]	7 (12.7)	7 (16.7)	28 (35.9)	13 (28.3)	
	[35,45]	13 (23.6)	10 (23.8)	20 (25.6)	13 (28.3)	
	[45,55]	14 (25.5)	12 (28.6)	12 (15.4)	8 (17.4)	
	[55,65]	12 (21.8)	4 (9.5)	12 (15.4)	6 (13.0)	
	[65,75]	4 (7.3)	6 (14.3)	4 (5.1)	4 (8.7)	
Ethnicity	Kovo	0 (0.0)	0 (0.0)	0 (0.0)	35 (76.1)	<0.001
	Mbuti (Pygmies)	0 (0.0)	6 (14.3)	0 (0.0)	0 (0.0)	
	Nande	52 (94.5)	4 (9.5)	78 (100.0)	3 (6.5)	
	Nyanga	2 (3.6)	0 (0.0)	0 (0.0)	5 (10.9)	
	Piri	0 (0.0)	30 (71.4)	0 (0.0)	1 (2.2)	
	Rega	1 (1.8)	2 (4.8)	0 (0.0)	2 (4.3)	

***Note**: In the "modalities" column in table 1, the names in parentheses represent the variable names that will be on the graphs of the MCA analysis to avoid overlapping labels.*

Uses of *Prunus africana*, plant parts used, modes of preparation and modes of administration

Uses of *Prunus africana* are of the medicinal, service, and artistic type. Communities living along the banks of community forests mainly use *Prunus africana* for traditional medicine (96.83% of informants). Some communities use this species as a source of energy: fuelwood and charcoal (Figure 2a). Bark and other organs (leaves) used as remedies for diseases are generally prepared in the form of decoction (99.5% of informants) (Figure 2b). The potions are administered orally (95.5% of informants) or by simply chewing the fresh bark or by anal way (purgation). Fresh extracts of *Prunus africana* bark can also be administered to the sick by the skin (local application) to treat specific diseases (Figure 2c). Communities use one glass (98.19%) as a unit of measurement for dosage because it is difficult for these communities to determine the amount of active ingredient in decoctions or infusions (Figure 2d). Depending on the zone and the ethnicity that determines people's beliefs and perceptions, *Prunus africana*-based remedies are prepared in a pan (96.38% of informants) or are only ground on a mortar (66.52% of informants).

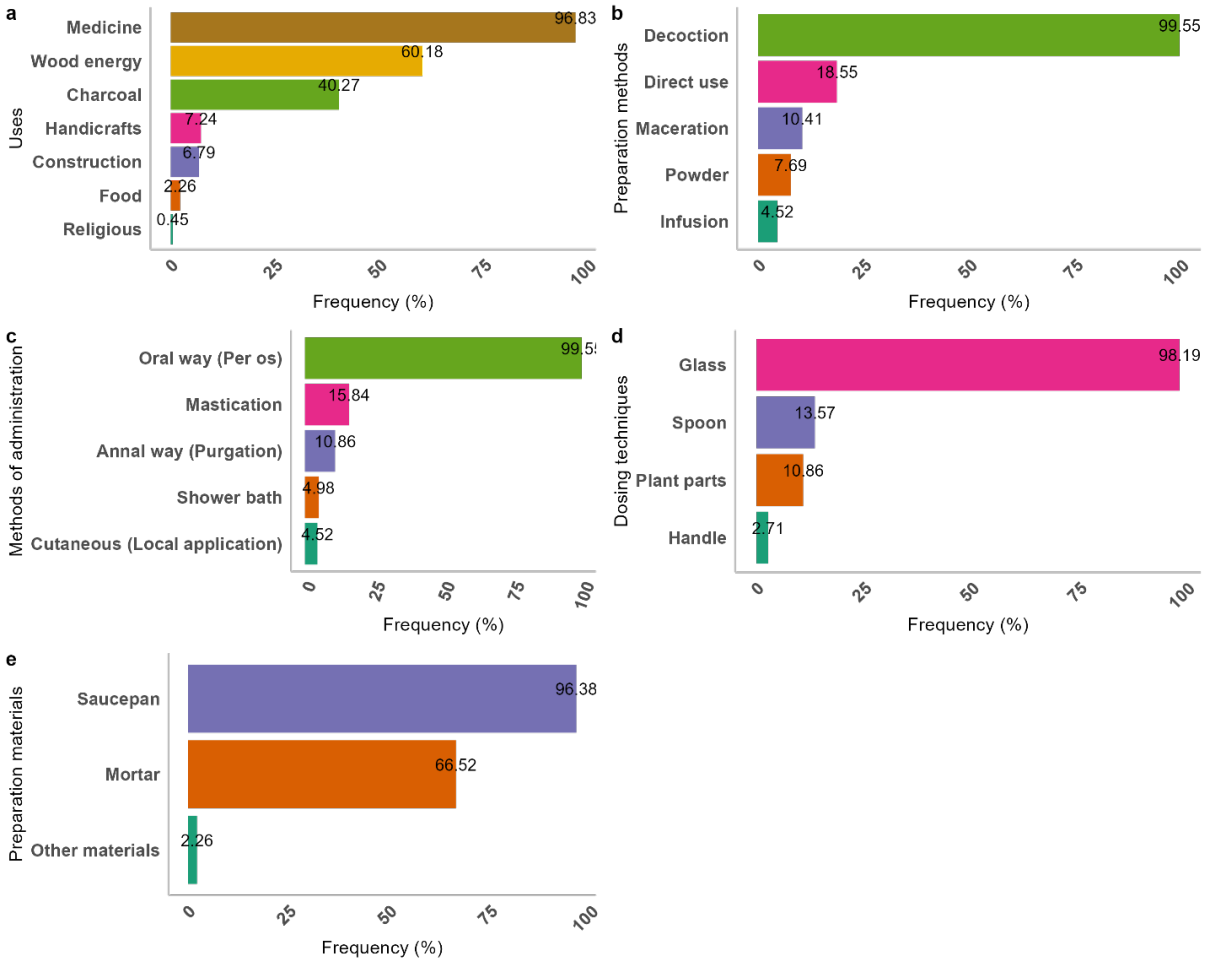

Figure 2. *Prunus africana* in traditional medicine: organs used, preparation, and administration methods

Diseases treated by *Prunus africana* extracts

Extracts from the bark and other organs of *Prunus africana* are used to treat various diseases. Informants interviewed stated that they use this species in the treatment of prostate (UR=174), malaria (UR=101), urogenital infections (UR=69), sexual weakness/impotence (UR=68) and digestive disorders (UR=41) (Table 2). Great importance is given to the prostate (IR=1) when riparian communities use *Prunus africana* in traditional medicine (Table 2). Depending on the diseases targeted, the methods of preparing the organs and the methods of administering the remedies are not always the same. For the majority of diseases, decocted forms (Figure 3) administered orally are the most commonly used (Figure 4). Through an MCA, we found that there is a relationship between the diseases treated by *P. africana* and the socio-demographic characteristics of individuals. For example, adult and old females solicit potions from this species for diseases such as cancer, amoeba cyst, nocturia, and malaria while young females mainly struggle with ovarian cyst. In contrast, young men and singles use extracts of *P. africana* organs for diseases such as hernia, diarrhea, and typhoid fever. In addition, the use of *P. africana* associated with herbaceous and woody species among young and adult males is directly related to sexual problems (male sterility, sexual weakness, prostate) common in the communities (Figure 5).

Table 2. Diseases identified by *Prunus africana* and their importance according to the informants

Id	**Disease treated**	**UR**	**RI**
1	Prostate	174	1
2	Malaria	101	0.66
3	Urogenital infections	69	0.59
4	Sexual weakness	68	0.58
5	Lumbago	61	0.56
6	Digestive disorders	41	0.61
7	Nocturia	29	0.35

8	Hernia	23	0.43
9	Muscle pain	14	0.28
10	Ovarian cyst	10	0.27
11	Curvature	8	0.27
12	Asthma	7	0.26
13	Cancers	6	0.26
14	Diarrhea	6	0.26
15	Fatigues	4	0.26
16	Apendiseptonia	1	0.25
17	Amoeba cyst	1	0.12
18	Heart attack	1	0.12
19	Male sterility	1	0.12
20	Rheumatism	1	0.12
21	Threats of abortion	1	0.12
22	Tooth decay	1	0.12
23	Typhoid fever	1	0.12

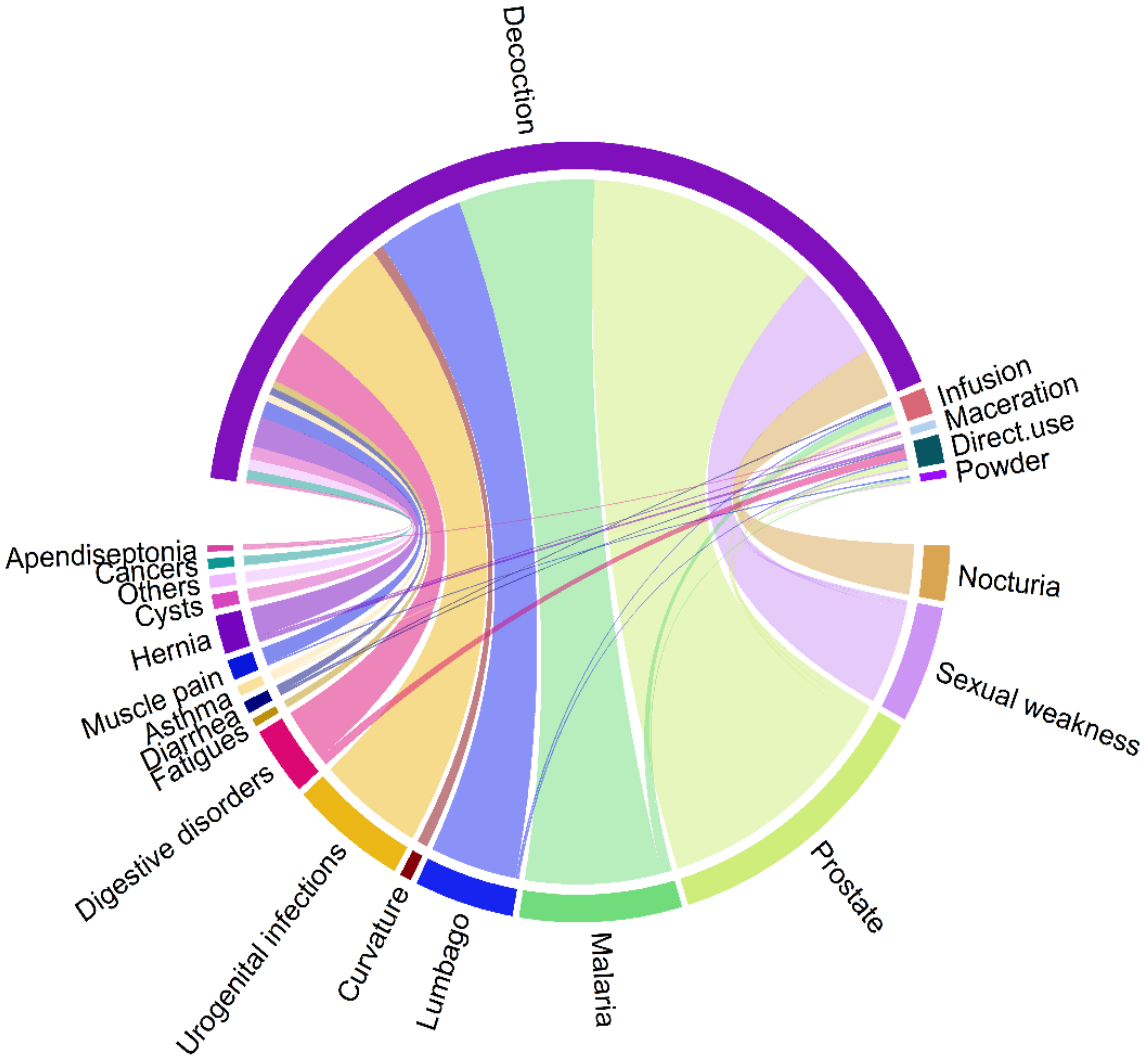

Figure 3. Links between diseases and organ preparation methods

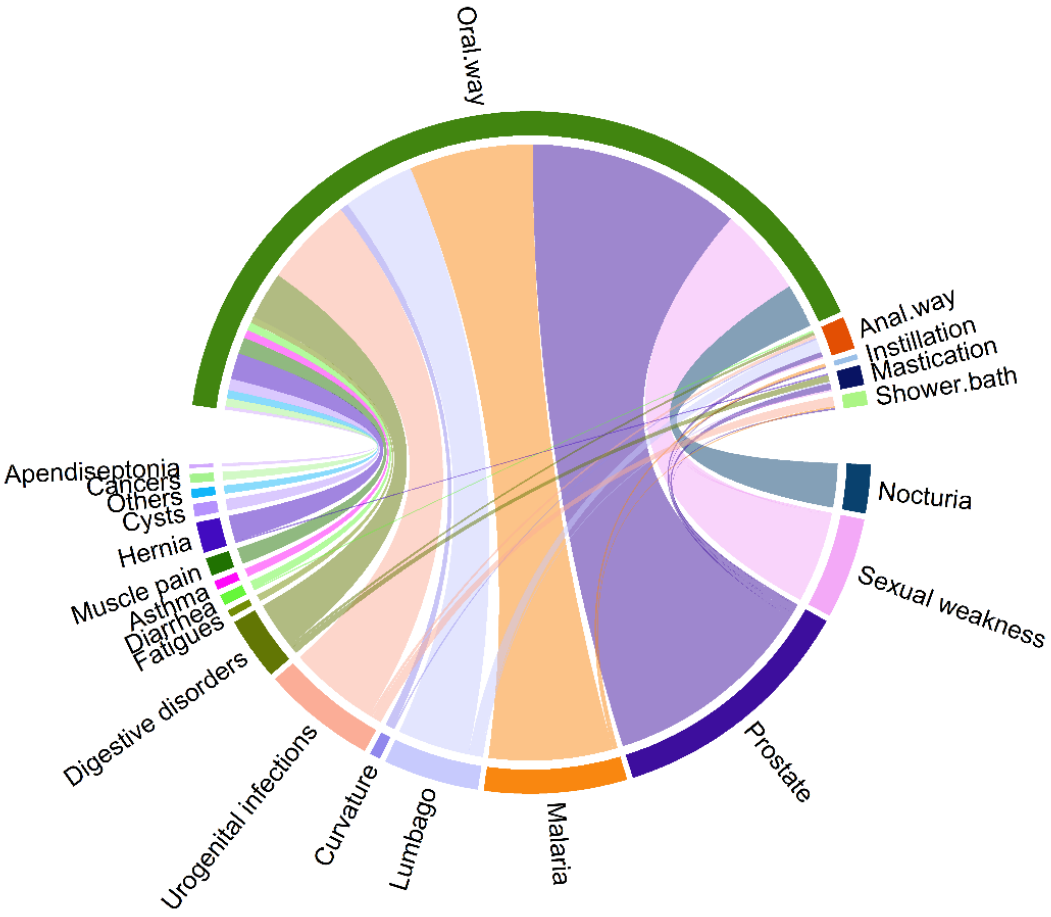

Figure 4. Links between diseases and modes of administration of remedies (cures)

Figure 5. MCA showing the influence between disease occurrence, community characteristics, and solicitation of *P. africana*-based cures.

Plants associated with *P. africana* in the preparation of cures

Informants reported that they combine *Prunus africana*-based extracts with other herbaceous and woody species to increase the effectiveness of remedies against the targeted disease(s). Trunk bark, leaves, fruits and roots are the main organs used for these species (Figure 6). Extracts from these organs of the different species are prepared following the same preparation methods as *P. africana* and are administered mainly orally. Other species require their remedies to be administered to sick people by the anal way (purgation), by the cutaneous way (local application), by the auricular way, by a simple chewing in the mouth or by a shower bath to be effective (Figure 6 and 7).

However, the species associated with *Prunus africana* during the preparation of the remedies vary according to the socio-demographic characteristics of each individual (living zone, ethnicity, gender, education level, marital status, age groups, and seniority). Multiple correspondence factor analysis (MCA) (Figure 8) shows, for example, that people from the *Piri* ethnic group associate *P. africana* more with native forest species such as *Anthochleista grandifolia*, *Bridelia micrantha*, *Piper nigrum*, *Garcinia kola* and *Azadiracha indica*. In contrast, Pygmies (*Mbuti*) preferentially use the forest species *Zanthoxylum gilletii* and *Piptadeniatrum africanum*. With the exception of *Tabernaemontana johnstonii*, the populations of Lubero territory largely associate *P. africana* with herbaceous species that grow in the climatic conditions of this zone (*Cymbopogon citratus*, *Bidens pilosa*, *Conyza sumatrensis*, *Ricinus communis*, *Camellia sinensis*, etc.) MCA also shows that adult males associate more in *P. africana* potions with aphrodisiac species such as *Zingiber officinale* (Fig. 8). Chi-square test shows that species use varies by zone (X^2=365.25, df=120, p-value< 0.001), gender (X^2=83.14, df=40, p-value< 0.001), seniority in the locality (X^2=317. 05, df=120, p-value< 0.001), level of education (X^2=255.87, df=160, p-value< 0.001), marital status (X^2=186.83, df=120, p-value< 0.001) and age group (X^2=381.05, df=200, p-value< 0.001) of the respondents. Venn diagram shows the similarities and dissimilarities between the uses of species associated with *Prunus africana* according to the areas surveyed. For example, it can be seen that the populations of Ruwenzori use 17 species that the populations of other zones (Lubero, Mangurejipa, Walikale) do not use (Figure 9a and Table 3).

Table 3. Synthesis of ethnobotanical knowledge of local and indigenous communities on *Prunus africana* in North Kivu: herbaceous and woody species associated with the preparation of cures.

Species name	Local/ Vernacular name	Family	Life form	Parts used	Modes of preparation	Modes of administration	Disease treated	UR	FC	NU	RI	Ethnicity	Zones
Aloe vera (L) Burm.f	Ngaka	*Xanthorrhoeaceae*	Herb	Leaves, Young shoots	Decoction, Infusion	Oral way	Digestive disorders, Hernia, Malaria	5	4	2	0.28	Nande	Lubero, Ruwenzori
Anthochleista grandifolia L.	Mukuvokuvo/Kipoku	*Sapotaceae*	Tree	Trunk bark	Decoction	Oral way	Prostate, Digestive disorders, Urogenital infections	5	5	1	0.17	Nande, Piri	Lubero, Mangurejipa
Artemisia annua L.	Artemisia	*Asteraceae*	Herb	Leaves, Young shoots, Trunk bark, Whole plant	Decoction, Infusion, Maceration, Direct use	Oral way, Mastication	Prostate, Malaria	23	18	4	0.66	Nande, Kovo, Piri	Lubero, Mangurejipa, Ruwenzori, Walikale
Azadirachta indica A.Juss.	Neem, Murubaini, Dira	*Meliaceae*	Tree	Leaves	Decoction	Oral way	Nocturia	1	1	1	0.13	Nande	Ruwenzori
Bidens pilosa L.	Vukuto	*Asteraceae*	Herb	Whole Plant	Decoction	Oral way	Sexual weakness	1	1	1	0.13	Nande	Ruwenzori
Bridelia micrantha (Hochst.) Baill	Mughanza	*Phyllanthaceae*	Tree	Trunk bark	Decoction	Oral way	Nocturia, Prostate, Lumbago, Curvature, Urogenital infections	20	20	1	0.30	Kovo, Nande, Nyanga, Piri	Lubero, Mangurejipa, Ruwenzori, Walikale
Camellia sinensis (L.) Kuntze	Chai, Thé	*Theaceae*	Shrub, Small tree	Leaves	Decoction	Oral way	Prostate	2	2	1	0.14	Nande	Ruwenzori
Canarium schweinifurthi Engl.	Canarium	*Burseraceae*	Tree	Exudates	Local application	Cutaneous way	Digestive disorders, Hernia, Malaria	2	2	1	0.14	Kovo, Nyanga	Walikale
Carica papaya L.	Papaye	*Caricaceae*	Herb	Leaves, Fruits, Flowers, Young shoots	Decoction	Oral way	Malaria, Digestive disorders, Lumbago	9	6	4	0.55	Kovo, Nande	Ruwenzori, Walikale
Cinchona legderiana L.	Kingina	*Rubiaceae*	Tree, shrub	Leaves, Trunk bark, Young shoots, Roots bark	Decoction	Oral way	Prostate, Malaria, Lumbago, Curvature, Urogenital infections, Sexual weakness	31	23	4	0.70	Nande, Piri, Rega	Lubero, Mangurejipa, Ruwenzori, Walikale

Coffea sp	Kawa	*Rubiaceae*	Tree, shrub	Fruits	Decoction	Oral way	Sexual weakness, Muscle pain, Malaria, Prostate, Hernia	18	18	1	0.28	Nande	Lubero, Ruwenzori
Cola acuminata Schott & Endl.	Ngongolio	*Malvaceae*	Tree	Fruits	Decoction, Direct use	Oral way, Mastication	Sexual weakness, Urogenital infections	5	5	1	0.17	Kovo, Nande, Piri	Lubero, Mangurejipa, Walikale
Conyza sumatrensis (*syn. Erigeron sumatrensis* Retz.)	Kavingande	*Asteraceae*	Herb	Leaves, Flowers, Exudates	Decoction,	Oral way	Malaria	3	1	3	0.38	Nande	Lubero, Ruwenzori
Cymbopogon citratus (DC.) Stapf	Citronnelle	*Poaceae*	Herb	Leaves	Decoction	Oral way	Malaria, Fatigues, Sexual weakness, Prostate, Lumbago, Hernia	16	16	1	0.27	Kovo, Nande	Ruwenzori
Dracaena sp	Mughathi	*Asparagaceae*	Shrub	Leaves, Trunk bark, Young shoots	Decoction, Direct use	Oral way, Mastication	Prostate, Curvature, Malaria, Urogenital infections	22	20	3	0.55	Kovo, Mbuti, Nande, Nyanga, Piri, Rega	Lubero, Mangurejipa, Walikale
Drypetes aubrevillei Leandri	Mulabe	*Putranjivaceae*	Tree	Trunk bark, Fruits, Exudates	Decoction, Maceration, Direct use	Oral way, Anal way, Shower bath	Prostate, Sexual weakness, Curvature, Lumbago, Digestive disorders, Urogenital infections, Cancers	56	55	3	0.87	Kovo, Mbuti, Nande, Nyanga, Piri, Rega	Lubero, Mangurejipa, Ruwenzori, Walikale
Eucalyptus globulus subsp. Maidenii (F.Muell.) J.B.Kirkp.	Muratusi	*Myrtaceae*	Tree	Leaves	Decoction	Oral way	Malaria, Muscle pain	9	9	1	0.33	Kovo, Nande, Piri	Lubero, Mangurejipa, Ruwenzori, Walikale
Garcinia kola Heckel	Kadika	*Clusiaceae*	Tree	Trunk bark	Decoction, Direct use, Powder	Oral way, Mastication, Shower bath	Prostate, Malaria	2	2	1	0.14	Nande, Piri	Lubero, Mangurejipa
Harungana madagascariensis Lam. ex Poir.	Musombo	*Hypericaceae*	Tree	Trunk bark	Decoction, Maceration	Anal way	Diarrhea, Digestive disorders	2	2	1	0.14	Nande	Ruwenzori

Hibiscus malvacearum L. (*syn. H. vitifolius* L.)	-	*Malvaceae*	Herb, Shrub	Leaves	Decoction	Oral way	Male sterility	1	1	1	0.13	Nande	Ruwenzori
Mangifera indica L.	Muhembe	*Anacardiaceae*	Tree	Leaves, Trunk bark	Decoction	Oral way	Lumbago	5	3	2	0.27	Nande	Ruwenzori
Markhamia lutea (Benth.) K.Schum	Musavu/Muchafu	*Bignoniaceae*	Tree	Trunk bark	Decoction	Oral way	Ovarian cyst	2	2	1	0.14	Nande	Lubero, Ruwenzori
Mondia withei (Hook.f.) Skeels	Murondo	*Apocynaceae*	Perennial herb, Woody climber	Roots, Trunk bark, Fruits	Decoction, Direct use	Oral way, Mastication	Prostate, Nocturia, Sexual weakness, Fatigues	8	8	3	0.44	Kovo, Nande, Nyanga	Lubero, Ruwenzori, Walikale
Moringa oleifera Lam.	Muringa	*Moringaceae*	Tree	Fruits	Decoction	Oral way	Hernia, Apendiseptonia	2	2	1	0.14	Nande	Ruwenzori
Nicotiana tabacum L.	Tabac	*Solanaceae*	Herb	Leaves	Decoction	Oral way	Prostate	2	2	1	0.14	Nande	Ruwenzori
Ocimum gratissimum L.	Mujaja	*Lamiaceae*	Herb	Leaves	Decoction	Oral way	Asthma, Malaria, Diarrhea, Hernia	6	6	1	0.18	Nande	Ruwenzori
Piper guineense Schum and Thonn	Ketchu	*Piperaceae*	Herb, Liane	Roots, Fruits	Decoction, Direct use, Powder	Oral way, Mastication	Prostate, Digestive disorders, Sexual weakness, Malaria	18	12	2	0.35	Kovo, Nande	Ruwenzori, Walikale, Mangurejipa
Piper nigrum L.		*Piperaceae*	Perennial woody wine	Roots, Fruits	Decoction, Direct use	Oral way	Lumbago	2	1	2	0.25	Piri	Mangurejipa
Piptadeniastrum africanum (Hook.f.) Brenan	Dabema/Mukundusevere	*Fabaceae*	Tree	Roots, Trunk bark, Roots bark	Decoction	Oral way	Nocturia, Tooth decay, Sexual weakness	12	9	3	0.45	Kovo, Nande, Piri, Rega	Lubero, Mangurejipa, Ruwenzori, Walikale
Psidium guayava L.	Mabela, Mapera	*Myrtaceae*	Shrub, Small tree	Leaves	Decoction	Oral way	Prostate	1	1	1	0.13	Nande	Lubero
Rauvolfia vomitoria L.	Katongwe/Kathongo	*Apocynaceae*	Shrub, Small tree	Trunk bark, Roots bark	Decoction	Oral way	Malaria, Digestive disorders, Diarrhea, Hernia, Lumbago	14	11	2	0.35	Kovo, Mbuti, Nande, Nyanga	Mangurejipa, Ruwenzori, Walikale
Ricinus communis L.	Mbono	*Euphorbiaceae*	Shrub, Herb	Leaves, Fruits	Decoction, Direct use	Anal way, Cutaneous way	Rheumatism, Lumbago	3	3	2	0.35	Nande	Ruwenzori
Rosmarinus officinalis L. (*syn.*	Romarin	*Lamiaceae*	Shrub	Leaves	Decoction	Oral way	Hernia, Fatigues	1	1	1	0.13	Nande	Ruwenzori

Salvia rosmarinus Spenn.)													
Sorghum vulgare L.	Mughemba	*Poaceae*	Shrub	Fruits	Decoction	Oral way	Digestive disorders, Hernia, Malaria	5	4	1	0.16	Nande	Ruwenzori
Spathodea campanulata P.Beauv	Aro (Kilur)rruu (Kilendu)	*Bignoniaceae*	Tree	Trunk bark	Decoction	Oral way	Urogenital infections	1	1	1	0.13	Nande	Ruwenzori
Tabernaemontana jonhstonii (Stapf) Pichon		*Apocynaceae*	Tree	Trunk bark	Decoction	Oral way, Anal way	Urogenital infections, Prostate, Sexual weakness	4	4	1	0.16	Kovo, Nande, Rega	Lubero, Mangurejipa, Ruwenzori, Walikale
Tetradenia riparia (Hochst.) Codd	Mutuvya	*Lamiaceae*	Shrub	Leaves	Decoction	Oral way	Typhoid fever, Heart attack	2	2	1	0.14	Nande	Ruwenzori
Triticum sativum L.	Engano	*Poaceae*	Herb	Fruits	Decoction	Oral way	Malaria	2	2	1	0.14	Nande	Ruwenzori
Zanthoxylum gilletii (De Wild.) P.G.Waterman	Sia/Rwese	*Rutaceae*	Tree	Leaves, Roots, Trunk bark	Decoction, Maceration	Auricular way, Oral way	Nocturia, Prostate, Urogenital infections, Lumbago, Malaria, Sexual weakness, Curvature	39	38	3	0.72	Kovo, Nande, Piri, Rega, Nyanga, Mbuti	Lubero, Mangurejipa
Zea mays L.	Etsikussa (Maïs)	*Poaceae*	Herb	Fruits, Flowers	Decoction	Oral way	Prostate	10	10	1	0.34	Kovo, Nande	Lubero, Ruwenzori, Walikale
Zingiber officinale Roscoe	Tangawisi	*Zingiberaceae*	Perennial herb	Roots, Fruits	Decoction, Direct use	Oral, Mastication	Prostate, Lumbago, Sexual weakness, Digestive disorders	6	6	2	0.30	Mbuti, Nande, Nyanga, Piri	Mangurejipa, Ruwenzori, Walikale

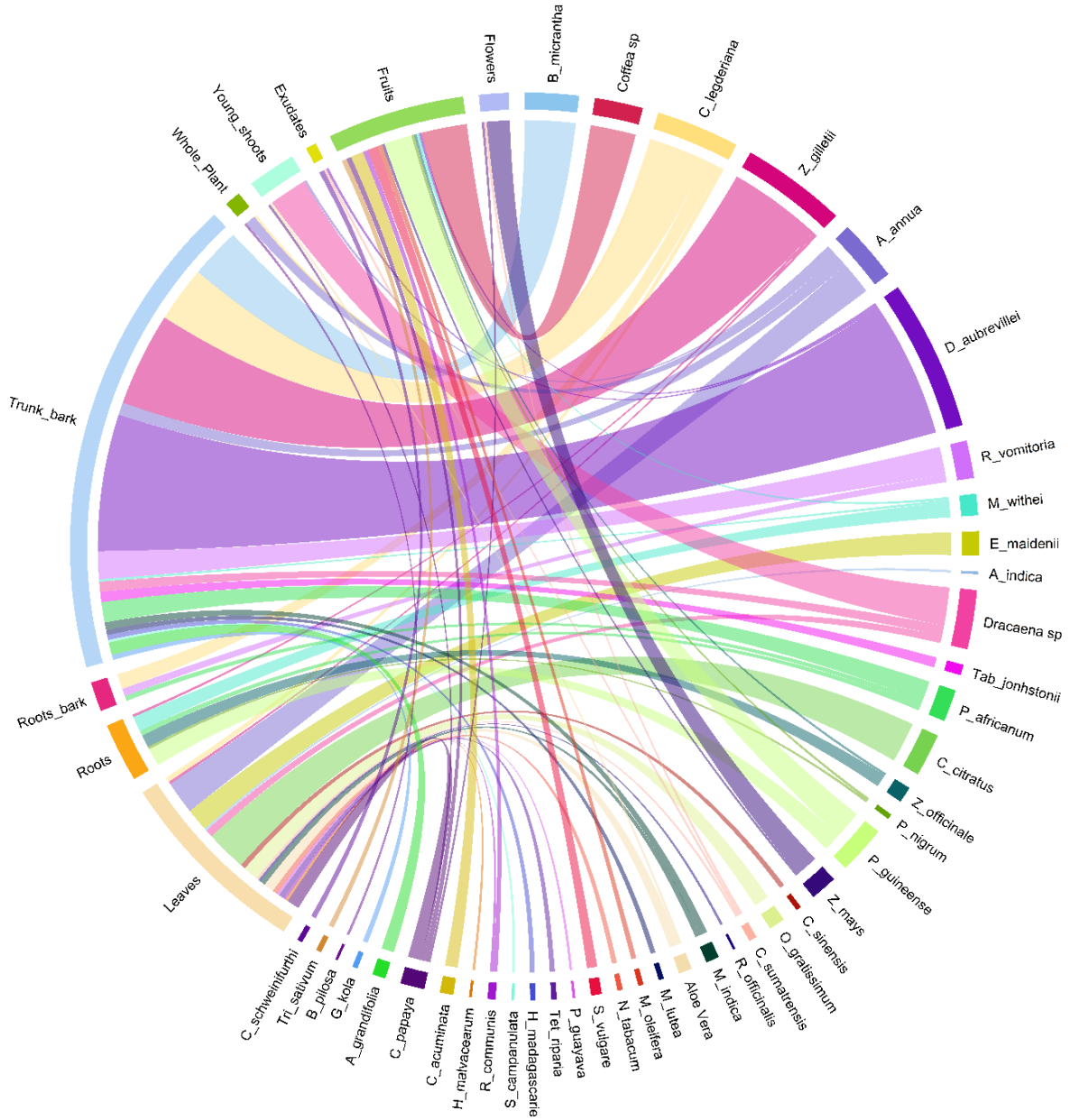

Figure 6. Relationship between species associated with *P. africana* in traditional disease treatment and organs used (Chord diagramm species-organ used)

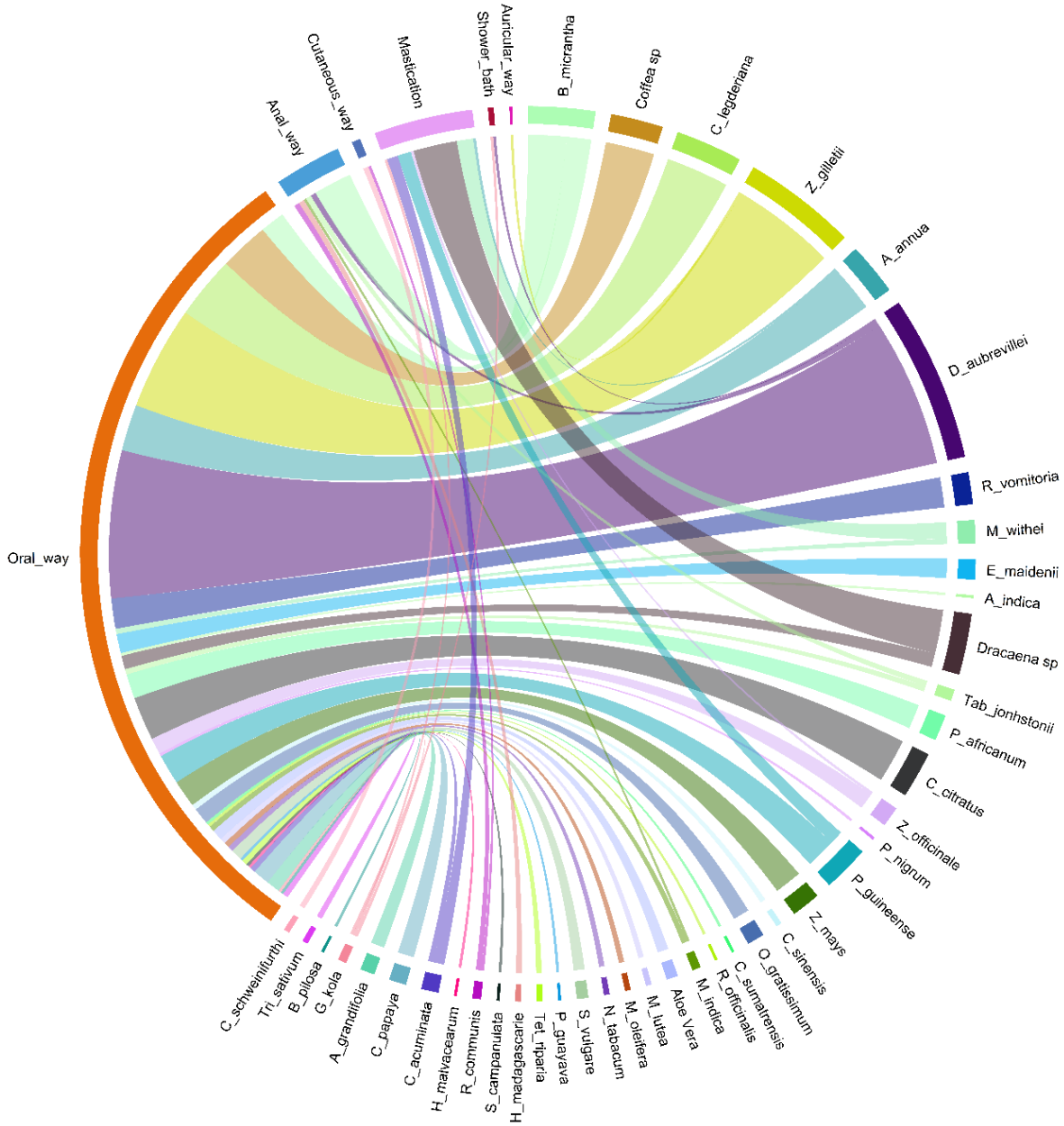

Figure 7. Relationship between species associated with *P. africana* and methods of administration of drugs (Chord diagramm species-modes of administration)

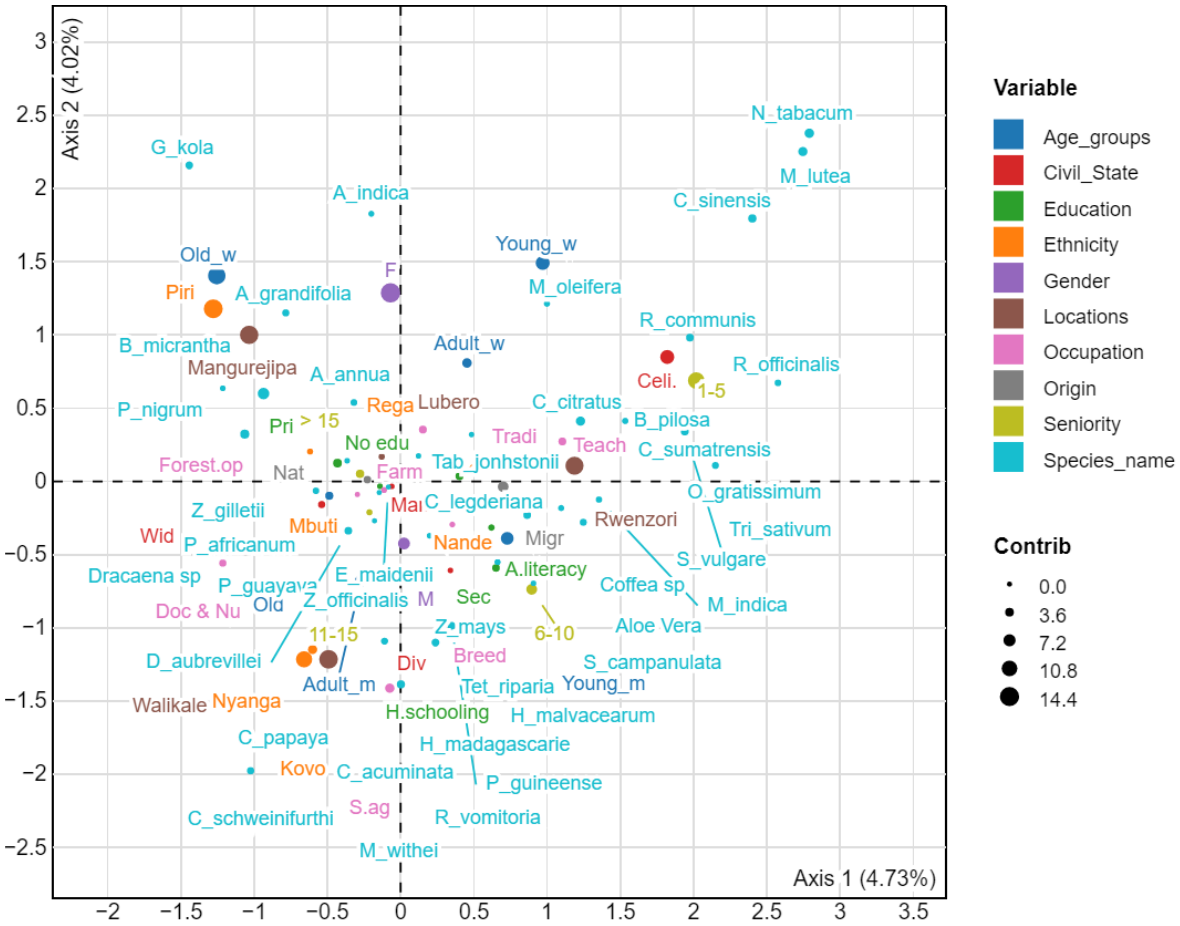

Figure 8. MCA between socio-demographic characteristics of informants and species associated with *P. africana* during cure preparation

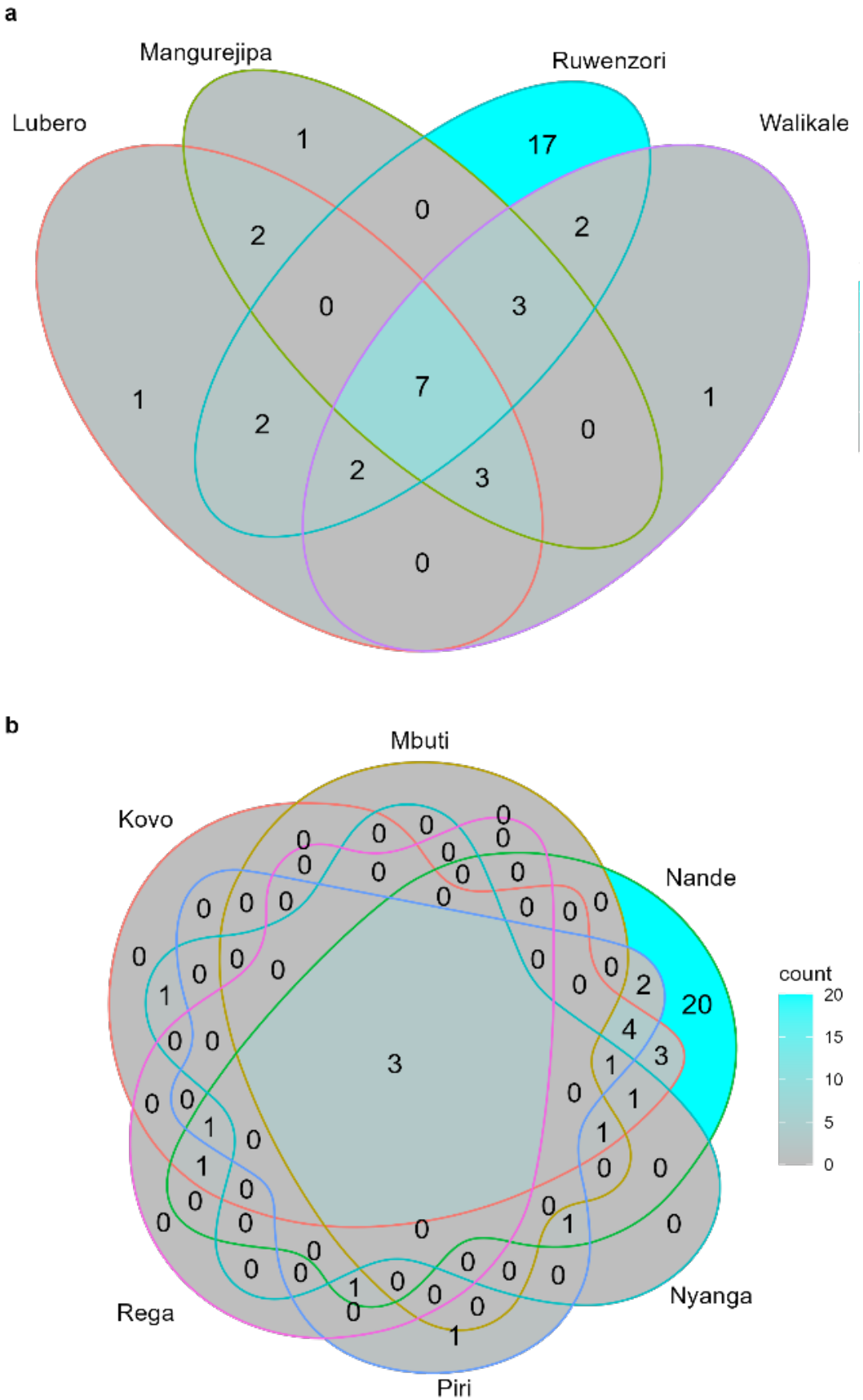

Figure 9. Venn diagram: similarities of zones (a) and ethnic groups (b) on species associated with *P. africana* in traditional disease treatment

Diversity of species families associated with *P. africana* in the treatment of diseases

Analysis of the ethnobotanical data provided by the informant's shows that the species of the *Putranjivaceae* family is are most cited. It is followed by *Rubiaceae*, *Rutaceae*, *Poaceae*, *Apocynaceae*, *Asparagaceae*, *Asteraceae* and *Phyllanthaceae* (Figure 10). However, the *Poaceae* family remains the most diverse in terms of species associated with *P. africana* during disease treatment (4 species out of a total of 41 species cited by informants). This is followed by the *Apocynaceae*, *Asteraceae,* and *Lamiaceae* families, each with 3 different species (Figure 11).

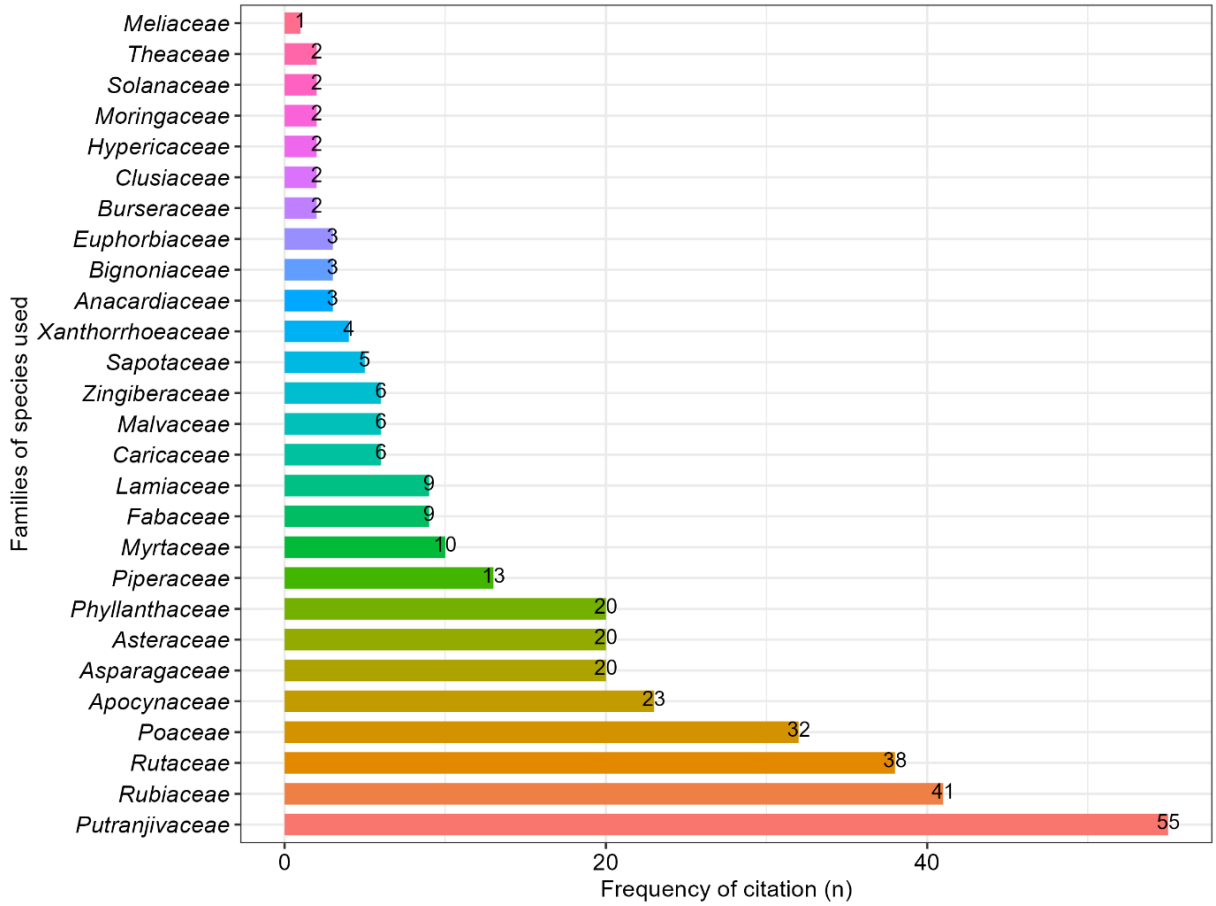

Figure. 10 Families of species used in association with *Prunus africana*

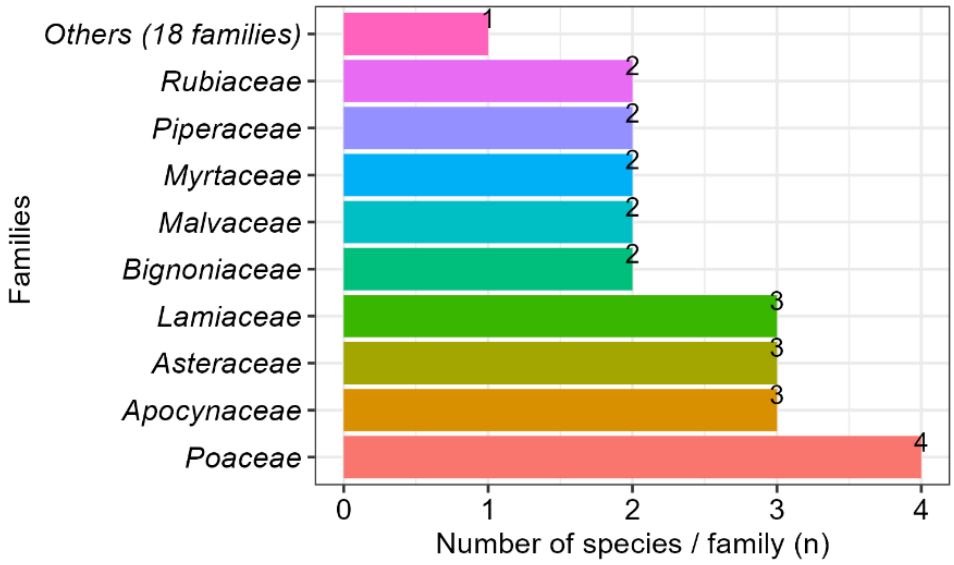

Figure. 11 Diversity of medicinal species families

Discussion

Ethnobotanical uses of *P. africana*

According to our study, people living near community forests in the four study areas use *P. africana* for a variety of uses. Use in traditional medicine is the most sought-after, given that local and forest-dwelling communities have no access to the modern health system. Beyond medicinal use, the results of our study show that the species is used as a source of energy in households (fuelwood and charcoal), produces building materials for homes (poles, rafters, etc.) and is used in handicrafts (manufacture of wooden chairs, beds, furniture, mortar, etc.). These results are similar to those obtained in various countries (DR Congo, Cameroon, Kenya, Uganda, Burundi, South Africa, and West Africa) where climatic conditions are favorable to the growth of this species (Stewart, 2003). For all these countries except DR Congo and Burundi, Stewart (2003) reports that *P. africana* produces firewood, construction wood (truck bodies, beer boats, bridges, cupboards and furniture, roof supports, window and door frames, cutting blocks, beehive supports, etc.) and is used in handicrafts (mortar and pestle manufacture, …).

In the same vein, Zocchi *et al*. (2020) found that the wood of *P. africana* is highly valued by local people in the manufacture of beehives. The wood of this species results in a highly valued hive in terms of its durability. In addition to medicinal use and the production of wood for various purposes, Stewart (2003) reports that some indigenous populations in countries where this species is found use it in traditional rituals and ceremonies (ceremonial spear handles, wainscoting on sculptures). *P. africana* also has agricultural importance in that the young stems (1.5-5 cm in diameter) are also used as stakes for the cultivation of voluble beans in many populations.

Types of parts used and diseases treated by *P. africana* extracts

A majority of local populations living in the *P. africana* range use extracts from the bark and leaves of this species to treat a wide range of illnesses. This tendency is linked to the fact that ethnobotanical knowledge is passed on from person to person by word of mouth, and some people restrict themselves to what is known to all (for example, some people believe that only *P. africana* bark extracts are effective against disease, as this knowledge was passed on to them by their elders). In general, Stewart (2003) reports that *P. africana* extracts are effective in the traditional treatment of over 45 human and 11 animal diseases based on ethnobotanical studies in Cameroon alone.

For example, in the province of North Kivu where we conducted ethnobotanical surveys, people living in community forests with specimens of *P. africana* treat 23 human diseases with extracts from the bark and leaves of this woody species. When asked what diseases local people target when using *P. africana*, 174 of 221 informants in the sample cited prostate, or 78.7%. These local populations attach great importance to the prostate (IR=1). After the prostate, the other most cited diseases were malaria (101 informants), urogenital diseases (69 informants), sexual weakness and/or impotence in men (68 informants) and digestive disorders (41 informants). These results are similar to those obtained by Kasika *et al*. (2016). Indeed, in a study on the use of plant species in traditional medicine among two ethnic groups (Bantu and Pygmies), Kasika *et al*. (2016) identified 63 diseases that are treated by plants. The most cited diseases in their study are: malaria (15 species for treatment), diarrhea (11 species), colic (7 species), internal candidiasis and yellow fever (12 species), migraine (3 species) and rheumatism (4 species). Four species identified in this study were previously reported by Kasika *et al*. (2016): *Ricinus communis* (15 diseases), *Bidens pilosa* (13 diseases), *Conyza sumatrensis* (13 diseases), and *Canarium schweinfurthii* (12 diseases).

If we compare the diseases identified in this study with those reported by previous research, we can observe a great similarity with local populations using *P. africana* in other countries. Indeed, a number of ethnobotanical studies have found that not only local populations but also the scientific community are attracted to this species because of its effective active ingredients against benign prostatic hyperplasia and prostate hypertrophy (Abera 2014; Ibrahim *et al*. 2016; Jared Misonge *et al*. 2019; Qureshi *et al*. 2009; Tugume *et al*. 2016; Komakech and Kang 2019; Komakech *et al*. 2020; Komakech *et al*. 2022), an increasingly common problem in older men. Beyond the prostate, our ethnobotanical surveys showed that local people also use *P. africana* in the treatment of other diseases. Diseases reported are similar to those mentioned in previous research. Without being exhaustive, *P. africana* extracts treat the following diseases: malaria (Jiofack *et al*. 2008; Jiofack *et al*. 2010; Ibrahim *et al*. 2016; Syamasamba *et al*. 2022), gastralgia (i.e., stomach pain) (Mwaura *et al*. 2020), digestive disorders, chest pain, heartburn, madness (Jiofack *et al*. 2008; Jiofack *et al*. 2010), cough, flu, chest congestion, abdominal and back pain (low back pain), analgesic cancer, blood purification, muscle pain, joint pain (Gakuya *et al*. 2013), ear infections, toothache and tooth decay (Giday *et al*. 2009), diarrhea, fever, kidney disease, inflammation, complaints and allergies (Ibrahim *et al*. 2016), breast cancer (Jared Misonge *et al*. 2019), jaundice (Kassa *et al*. 2020) and fainting (Tugume *et al*. 2016). Besides these aforementioned diseases, Gail *et al*. (2015) report that some populations living in or around forests use the leaves and ground

powder of *P. africana* bark as a remedy for HIV as well as HIV-TB co-infection. According to these same authors, traditional *P. africana*-based formulations are a source of blood purification, a universal tonic, an antidepressant, and a remedy for TB-related respiratory conditions such as asthma, bronchitis, influenza, and weight loss (Gail *et al*. 2015).

Analysis of previous ethnobotanical research results from around the world shows that medicinal plants are never used alone to treat a given disease. Whether among traditional healers (traditherapists) or among individuals with little knowledge of traditional medicine, the tendency is always to mix several species to constitute a remedy. We made similar observations for populations in four study areas in North Kivu where the majority of informants stated that they mix *P. africana* with other woody and herbaceous species when preparing remedies. Studies have shown, however, that mixing species in traditional medicine is a source of many side effects and intoxications. According to Kamau (2021), the main toxic effects resulting from the mixing of medicinal plants include headache, diarrhea, and stomachache. In interviewing traditional healers, Kamau (2021) found that the majority mix extracts of *P. africana* with those of other species in order to increase the effectiveness of the treatment on the targeted disease(s). In this study, we identified 41 woody and herbaceous species associated with *P. africana* in the preparation of potions in the four study areas. Among the top 10 species most cited by informants were: *Drypetes aubrevillei* (FC=55), *Zanthoxylum gilletii* (FC=38), *Cinchona legderiana* (FC=23), *Bridelia micrantha* (FC=20), *Dracaena* sp. (FC=20), *Artemisia annua* (FC=18), *Coffea* spp. (*C. arabica* and *C. canephora*) (FC=18), *Cymbopogon citratus* (FC=16), *Piper guineense* (FC=12) and *Rauvolfia vomitoria* (FC=11). Some species listed in Table 3 had already been mentioned by Kasika *et al*. (2014) as likely to treat 10 different diseases among the *Nande* (the majority in our sample). These species are: *Aloe Vera*, *Bidens pilosa*, *Carica papaya*, *Conyza sumatrensis* and *Ricinus communis* (Kasika *et al*. 2014).

Effects of informants' socio-demographic characteristics on the use of *P. africana* and other species

Results of this paper revealed that the use of medicinal plants associated with *P. africana* in the preparation of cures varied according to the individual's place of residence, his/her gender, his/her seniority in the locality, his/her level of education, his/her marital status and his/her age group (p-value< 0.05). Residence's influence on plant use is due to two factors: (i) each area is characterized by populations with different ancestral practices, customs and even perceptions; (ii) ethnobotanical knowledge is highly dependent on the species available in each study area, despite the similarities we observed. Considering gender, we found that men are most often concerned by erectile dysfunction and tend to associate plants with aphrodisiac properties (*Zingiber officinale*, *Cola acuminata*) with *P. africana* to increase sexual strength, unlike women.

In contrast, the chi-square test of independence showed that ethnic group and occupation did not have a significant influence on the preference for species used in the traditional treatment of illnesses. This statistical insignificance of belonging to an ethnic group on the use of species may be linked to the fact that, in our sample, the majority of informants were from the Nande ethnic group. Thus, the fact that individuals belonging to the same ethnic group share the same culture, practices and, by extension, lifestyles explains this trend. In addition, each ethnic group transmits ethnobotanical knowledge in its own way from one generation to the next (oral transmission). Our results are contrary to those obtained by Kasika *et al*. (2015), who found that Bantu (Nande) phytotherapy was different from that of the Pygmies (Mbuti). Their study showed that 97 recipes from 182 plant species were used by the ethnic group versus 78 recipes from 83 species among the pygmies (Kasika *et al*. 2015).

In another study, Kasika *et al*. (2016) showed that Bantus and Pygmies living in the same village in the Beni and Lubero territories used different plant species as traditional medicines to treat the same illnesses. If we consider seniority in the village, our results show a difference in the use of species linked to the fact that the most senior know more medicinal species than the least senior, due to their great experience. Level of education influences species use, because people with a high level of education (high school, university) have more knowledge of plant virtues acquired at school than people with a low level of education. People with a low level of education have endogenous knowledge, but in some cases are limited to what their ancestors, parents, relatives or friends pass on to them orally. With regard to age group and marital status, we believe that the significant effect on species use is linked to the fact that the diseases and plants used to treat them are different for young people, adults and the elderly/old ladies, and for married, single, widowed and divorced people. So, for example, married people of all ages will be more interested in aphrodisiac plants. Similarly, older people will be more interested in species that treat recurrent diseases of the elderly (rheumatism, for example).

Implications of the study results for *P. africana* conservation

Results of our study could have implications for the conservation of *P. africana* in the region if local and indigenous communities are supported in substituting or reducing the extraction of bark from this species. Indeed, we found that the leaves are also used by informants to prepare cures, so replacing bark with leaves would reduce the pressure on *P. africana*

in the region. In addition, we have shown that local and indigenous communities mix extracts of *P. africana* with extracts of other woody and herbaceous species. As these herbaceous and woody species can treat the same diseases as *P. africana*, it is possible to reduce the pressure on this species in North Kivu. Furthermore, previous literature shows that certain herbaceous and woody species can be substituted for *P. africana* in the treatment of certain diseases. Based on some recent previous research, we present a non-exhaustive list of species found in forests or agricultural landscapes that could play the same role as *P. africana* in traditional medicine, in order to limit pressure on this endangered species in North Kivu.

A recent study shows the species *Catharanthus roseus* (L.) G. Don to possess anticarcinogenic properties quite similar to those of *P. africana*, as several antitumor drugs are already produced there (Omara *et al*. 2020). Besides *Catharanthus roseus*, *Zingiber officinale* has active principles that are effective in the traditional treatment of influenza, internal parasitosis (Abera 2014) and rheumatism (Jiofack *et al*. 2008). Another example is that of species of the *Coffea* genus, which can be substituted for *P. africana* in the treatment of diarrhoea (Abera 2014). Another recent study shows that *Carica papaya* leaf and fruit extracts are effective against gastritis, malaria, diarrhea (Amsalu and Regassa 2022), cervical cancer, prostate cancer and breast cancer (Omara *et al*. 2020). *Carica papaya* seeds also have antivermifuge properties (Focho *et al*. 2009). So, as *Carica papaya* grows spontaneously or can easily be cultivated, it offers an alternative for reducing pressure on *P. africana*.

Other woody species of the *Bridelia* genus, easily found in the community forests of North Kivu, can also be used in place of *P. africana* to treat certain diseases. Indeed, leaf extracts from *Bridelia spinosa* and *Bridelia micrantha* are effective in the traditional treatment of diabetes. Extracts from the roots and bark of *Rauvolfia vomitoria* are used to calm the mentally ill (Focho *et al*. 2009), as well as treating typhoid fever, helminths and cardiac pain (Jiofack *et al*. 2008). In view of the diversity of diseases that *Rauvolfia vomitoria* treats, and its availability in forest ecosystems, it also represents an alternative to *P. africana*. Jiofack *et al*. (2008) show that extracts of guava leaves (*Psidium guayava* L.) cure diarrhoea and wounds. Same authors report that extracts of maize (*Zea mays* L.) are an excellent worm extractor and limit bladder problems (nocturia) in adults (Jiofack *et al*. 2008). In addition to guava and maize, Jiofack *et al*. (2008) have also shown that extracts of *Spathodea campanulata* (a species also found in community forests and other ecosystems in North Kivu province) have an effect on hooked eye disease, while the use of castor oil (*Ricinis communis*) is part of the traditional treatment of infertility in women. On the basis of the species presented in Table 3 and the diseases they treat, they can easily be substituted for *P. africana*, which could enable this species to be conserved on a long-term basis in its areas of distribution in DR Congo. Research into medicinal species that can be substituted for *P. africana* to treat diseases must be a priority in the region, as numerous studies (e.g. Betti and Ambara 2013) have already warned of the overexploitation of *P. africana* linked to the increase in its demand for prostate bark since the 1990s.

In this context, the possibility of extinction of *P. africana* would become high in view of the organs used not only in traditional but also modern medicine, as well as other uses such as energy wood, handicrafts and construction timber. This extinction would be further accelerated by the fact that numerous studies have found that the repetitive harvesting of medicinal plants from their roots, stems or bark has a serious effect on the survival of many species (Abera 2014). Using other organs such as leaves to prepare recipes in association with other woody or herbaceous species we have identified (Table 3) may contribute in some small way to the survival of the species in its range in North Kivu province. Debarked or uprooted species have a low regenerative capacity. This observation was noted for the species *P. africana*.

Conclusion

This study investigated the ethnobotanical knowledge of *P. africana* in four areas of distribution in North Kivu. Results show that this species is used for a wide range of uses, although local people living in community forests mainly exploit its bark and leaves for traditional medicine. This often-uncontrolled exploitation exposes the species to extinction if sustainable management strategies are not implemented. However, people do not use this species alone; they combine it with other herbaceous and woody species to prepare remedies against various diseases. As these herbaceous and woody species have similar virtues in the treatment of certain diseases, we suggest that local and indigenous communities use them to reduce the pressure on *P. africana*. In the meantime, further in-depth research should be carried out with the aim of identifying new species based on phytochemical analyses that could constitute an alternative or be substituted for *P. africana* in local traditional medicine. Indeed, knowledge of these alternative medicinal plants will reduce the pressure on this species and ensure its conservation for present and future generations. However, the results of our investigations lay the foundations for further reflection on how to raise community awareness of the fact that other species can be used instead of *P. africana* to treat a number of illnesses. Such awareness-raising is essential if we are to achieve sustainable management and use of *P. africana* in eastern DR Congo.

Declarations

Ethical considerations: No informants from either local or indigenous communities were forced to respond without their free consent. All informants who voluntarily refused to participate in the study were excluded.
Data Availability: Data used in this article are available for any requests from the Editorial Board of *Ethnobotany Research & Applications*.
Conflicts of interest: All authors of the article declare that there are no conflicts of interest between them or other authors.
Authors' contributions: **EKM**: Conceptualization, Methodology, Data collection, validation, writing of the original manuscript, revision and editing of the manuscript; **JLB**: Conceptualization, Methodology, revision and editing, validation, supervision; **ND**: Conceptualization, Methodology, revision and editing, validation, supervision; **MMK**: Conceptualization, Methodology, Data analysis, revision and editing; **HNNA**: Validation, Revision and editing; **PBF**: Validation, Revision and editing.

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