Antimalarial and mosquito repellent plants: insights from Burundi

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Research

Abstract
Background: The present ethnobotanical study was conducted to identify plant species used by Burundians to treat malaria and to repel mosquitoes, to compare this with existing literature, identify species which could be further investigated and discuss potential future promotion or cultivation.

Methods: Surveys were conducted between April and October 2018 in seven provinces representing the five ecological zones of Burundi. A semi-structured questionnaire was administered to 341 randomly selected respondents (between 25 and 50 household heads in each province).

Results: A total of 44 plant species were reported in this study: 32 as antimalarial, two as mosquito repellents and 10 for both purposes. For antimalarial plants (84%) and mosquito repellent plants (88%), leaves were the most commonly used plant part. According to the respondents, 28 plant species were being cultivated and 16 were mostly collected from the wild. An examination of the literature on some of the plant species mentioned in this study revealed that eight of them had never been studied before.

Conclusions: The use of antimalarial and mosquito repellent plants in Burundi was highlighted in this study. Its goal is to create a database of antimalarial and mosquito repellent plants. This will aid decision-making in the development of traditional medicine and the conservation of medicinal plants.

Keywords: Ethnobotany; antimalarial activity; mosquito repellents; plants cultivation; Eco-climatic zones.

Background
Malaria is the world's deadliest disease with, approximately 229 million malaria cases and 409 thousand deaths reported worldwide in 2019, with the African region accounting for 94% of these deaths (WHO 2020). Burundi is

one of the countries most affected by this disease, which has been identified as the country's leading cause of morbidity and mortality (République du Burundi 2018). In 2017, for example, the annual cumulative number of malaria deaths was 815 per 1,000 (Sinzinkayo 2018). Surprisingly, the treatment of malaria is still not subsidized in Burundi. Ndayizeye *et al.* (2020) reported that the low-income population (e.g. Twa hunter-gather community of Pygmy origin) considers access to western medicine to be limited due to its prohibitively high cost, despite the fact that malaria treatment is subsidized in some countries (e.g. Kenya) (Delbanco *et al.* 2017). In this context, the use of medicinal plants in the treatment of malaria becomes an important contribution to the health of people who cannot afford the pharmaceutical products from conventional medicine.

Natural plant recipes are commonly used to treat malaria in Africa (for example, Ghana and Burkina Faso) (Ankrah *et al.* 2003; Bonkian *et al.* 2017). Furthermore, recent research indicates that the malaria parasite and its vector are becoming increasingly resistant to conventional drug molecules developed by industrialists (Lutgen *et al.* 2018; WHO 2018). Nonetheless, new tools and products for the detection, treatment and prevention of malaria are constantly being developed (Hemingway *et al.* 2016; Othman *et al.* 2018). As a result, research on malaria alternatives remains current and is expected to mobilize scientists in a variety of fields. Several studies have been conducted to determine which plant species are used as antimalarials. For example, in northeast India, (Namsa *et al.* 2011) investigated anti-malarial herbal remedies and (Odoh *et al.* 2018) identified medicinal plants used by the people of Nsukka to the treat malaria in south-eastern Nigeria.

Furthermore, because prevention is better than cure, the role of plants in avoiding mosquito's bites has been investigated. Some studies have focused on malaria vector control using plants, for example. in the endemic regions of Cameroon (Youmsi *et al.* 2017), the north-eastern Tanzania (Kweka *et al.* 2008), in Dai people of Xishuangbanna in China (Gou *et al.* 2020) and the uMkhanyakude district, KwaZulu-Natal in South Africa (Mavundza *et al.* 2011).

Two recent studies from Burundi focused on the characteristics of traditional healers (Falisse *et al.* 2018) and traditional healers' use of plants to treat microbial diseases (Ngezahayo *et al.* 2015). Malaria was overlooked in both studies. In general, traditional healers are not visited to treat malaria because it is a common disease and people in Burundi, particularly the poor, prefer to self-medicate. Apart from understanding which species is used, it is also important to understand (i) plant part utilized, (ii) habitat and (iii) perceived abundance in the wild (if not cultivated). These three aspects can work in favor of actions to manage and conserve species and ecosystems. In fact, harvesting the wood, bark or entire medicinal plant is more destructive and may result in the death of the individual plant, whereas the fruits and the leaves pose less of a threat to the species (Delbanco *et al.* 2017). Similarly, harvesting habitat (for example, the forest versus fallow) of medicinal plants influences the potential threat on the ecosystem. The perception of abundance or scarcity is relevant for conservation policy-making and/or may inspire seedling production and population dissemination programs.

This study focused on plant species used by Burundians to treat malaria and repel mosquitoes. The objectives of this study are: (i) to identify plant species used by Burundians to treat malaria and repel mosquitoes, (ii) to compare this with the literature to identify species whose usage has not been reported and which could be further investigated, (iii) to identify part (s) used, habitat, and perceived abundance in the wild to discuss potential future promotion/cultivation of some species.

Material and Methods

Study area

Burundi has a population of nearly 12 million people and a population density of 422 inhabitants per km^2 (PopulationData.net - Burundi). The altitude ranges from 774 m on the shores of Lake Tanganyika to 2680 m on the mountain ranges, gradually decreasing to 1100 m in the east of the country (Nzigidahera 2012).

This study was conducted in seven of the 18 provinces of Burundi (Fig. 1). The selected provinces represent the five eco-climatic zones of Burundi as described by Martens and Sauttiaux (1979) in (Nzigidahera 2012): (i) the Imbo plain, with elevations ranging from 800 to 1100 m and mean annual temperature exceeding 23 °C, (ii) the Mirwa foothills, with elevations ranging from 1000 to 1700 m and mean annual temperature ranging from 18 to 28 °C, (iii) Congo-Nile ridge with elevations ranging from 1700 to 2684 m and mean annual temperatures ranging from 14 to 15 °C, (iv) the central highlands with elevations ranging from 1350 to 2000 m and mean annual temperature ranging from 17 to 20 °C; and (v) the northern and eastern lowlands with elevations ranging from 1100 to 1400 m and mean annual temperatures ranging from 20 to 23 °C. The Imbo plain and Mirwa foothills are represented by Bubanza, Bujumbura Mairie and Rumonge while in the Congo-Nile ridge, Bubanza and Muramvya were selected. The Central highlands was represented by Muramvya, Ngozi and Cankuzo; and the Northern and eastern lowlands were represented by Cankuzo and Kirundo. Burundi's population is made up of three major ethnic groups: Twa (hunter-gatherers of Pygmy origin), Tutsi, and Hutu (both farmers of Bantu origin). We only interviewed the last two groups in this study.

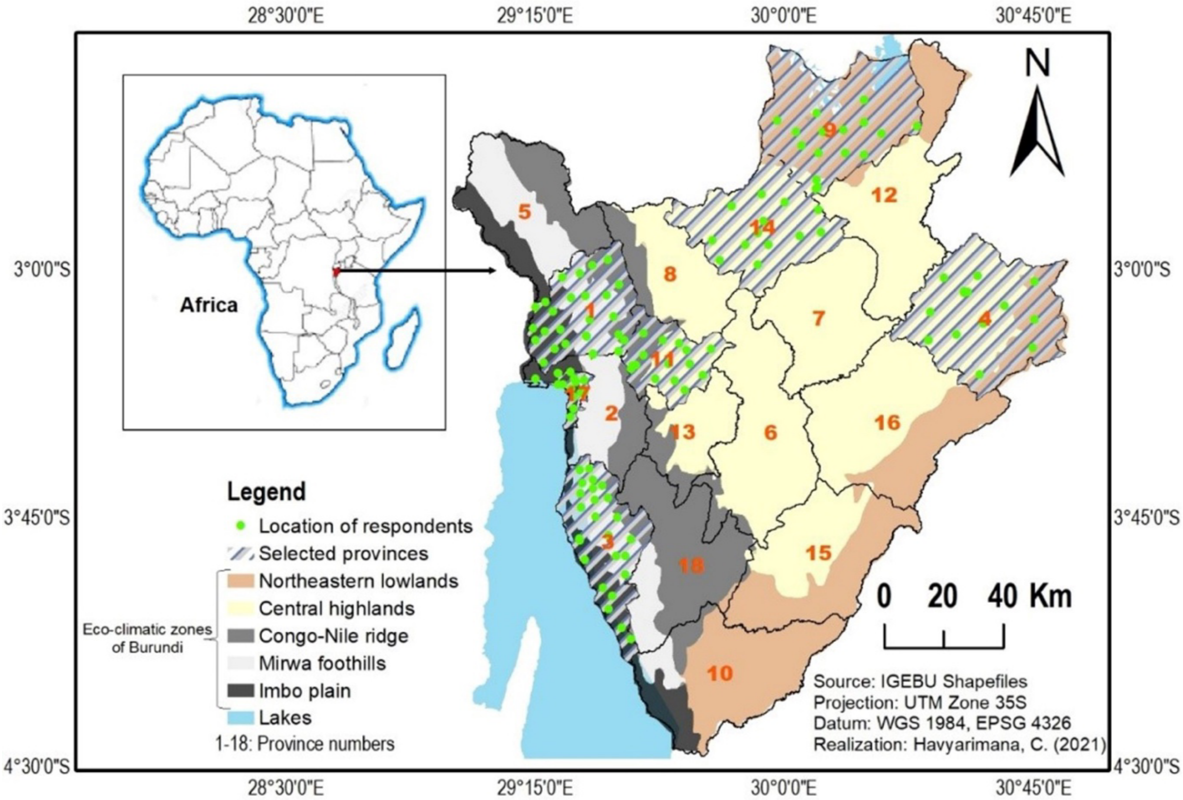


Figure 1. Eco-climatic zones of Burundi and the selected provinces: Bubanza (1), Rumonge (3), Cankuzo (4), Kirundo (9), Muramvya (11), Ngozi (14) and Bujumbura municipality (17).

Ethnobotanical data collection

Semi-structured questionnaires were administered to 341 respondents between April and October 2018. We targeted one village (rural) and one urban center in each province, and we randomly selected between 25 and 50 household heads (aged above 18 years) who admitted to using at least one plant as natural mosquito repellent or as antimalarial.

Respondents were first informed that the aim of the study was to better understand the importance of natural mosquito repellent and antimalarial plants, and that their responses would be kept anonymous and confidential. The questionnaire was given to them if they agreed to participate in the study. The semi-structured questionnaire addressed: (i) respondents' socioeconomic characteristics (e.g. gender, age, urban or rural residence); (ii) species' used, plant part, and type of usage; and (iii) the ecology and availability of the species mentioned. The first author facilitated all questionnaires, which were done in Kirundi. Smap Server Version 19.04 installed in an android phone was used to collect data before being exported to Microsoft Excel 2016 software. To conduct this research, we obtained a research permit and permission from local authorities in each village. We informed all informants of our intentions and obtained their verbal consent.

Plant samples were collected around the villages and deposited at the Herbarium of the University of Burundi (BJA) for identification and authentication by a plant taxonomist. Plant species' scientific names mentioned during the interviews were verified from the collected plant specimens. Several resources (Troupin 1982; Reekmans and Niyongere 1983; Troupin 1983; Troupin 1985; Troupin 1988; Lebrun and Stork 1991) were used for plant identification. Voucher specimen numbers for 35 out of the 44 species listed in this study are indicated in Table 1. The nine species with no herbarium samples are commonly cultivated plants in Burundi.

Ethnobotanical indices

The relative importance of the species cited was expressed as the percentage of respondents who cited that species as following: $F = \frac{S}{N} * 100$ (Ndiaye *et al.* 2017) with F: species citation frequency; S: number of species citations and N: total number of interviewees.

Finally, based on the plant species here inventoried, a literature review was conducted to highlight the overview knowledge of their anti-malaria and anti-mosquito's properties.

In order to determine if respondents were using plant species of conservation concern, the conservation status of all the species mentioned in the study was checked using the IUCN Red List (IUCN 2019). A literature review was also conducted to check the mosquito repellent or antimalarial uses, ecology and distribution of the species mentioned by study participants. Plant nomenclature follows the African Plant Database (version 3.4.0, African Plant Database, 2020).

Statistical analysis

We investigated if there were differences in the number of species cited across genders (male or female), age groups (<35 years, 35 to 59 years, > 60 years) or domicile (urban or rural). We used Chi-square (χ^2) test, with significance level α=0.05. Overall, we interviewed 136 males and 205 females, 132 urban residents and 209 rural residents and 102, 127 and 112 respondents of <35 years, 35 to 59 years, > 60 years respectively.

Results and Discussion

Species cited

Respondents identified 44 plant species in total, 32 of which were used as antimalarial, two as mosquito repellents and ten for both purposes (Table 1). Other studies reported 107 species used as antimalarial in Uganda (Okello and Kang 2019), 35 in Rwanda (Muganga *et al.* 2010) and 139 in Kenya (Omara 2020). Most species were also mentioned by participants in other studies in 12 other tropical African countries, namely: Tanzania in the Kagera and Lindi regions (Nondo *et al.* 2015), Uganda around the Mabira Forest Reserve (Tugume *et al.* 2016), Benin in the Allada Plateau (Yetein *et al.* 2013), Nigeria in the States of Ondo, Ogbomoso and Ogun (Idowu *et al.* 2010; Olorunnisola *et al.* 2013; Oyeyemi *et al.* 2019), Namibia in the Oshikoto region (Cheikhyoussef *et al.* 2011), the Democratic Republic of Congo in the Mbanza-Ngungu region (Nzuki 2016), Ethiopia in the districts of Hawassa Zuria and Shinile (Mesfin *et al.* 2012; Tefera and Kim 2019), Mali in the district of Bamako (Dénou *et al.* 2017), Burkina Faso in the Sahel region (Bonkian *et al.* 2017), Togo in the maritime region (Koudouvo *et al.* 2011), Morocco in the Talassemtane National Park (Rhattas *et al.* 2016) and Ivory Coast in the Zanzan District (Kouadio *et al.* 2016).

The most commonly cited antimalarial species were: *Gymnanthemum amygdalinum* (Delile) Sch. Bip. ex Walp (F=57.48), *Eucalyptus globulus* subsp. *maidenii* (F. Muell.) Kirkp. (F=14.96*), Cinchona officinalis* L. (F=10.56), *Cajanus cajan* (L.) Huth (F=9.38) and *Tetradenia urticifolia* (Hochst.) Codd (F=9.09).

Cymbopogon citratus (DC.) Stapf (F=6.16) was the most frequently mentioned mosquito repellent species. Mosquito repellent species were mentioned by fewer people than antimalarial species. Thirty-six active compounds were also reported to have antimalarial or mosquito repellent properties. These excluded eight species: *Markhamia lutea* (Benth.) K. Schum*.*, *Chenopodium ugandae* (Aellen) Aellen, *Euphorbia grantii* Oliv., *Plectranthus esculentus* N.E.Br*.*, *Eucalyptus globulus* subsp. *maidenii* (F. Muell.), *Cencrhus purpureum* (Schumach.) Morrone, *Digitaria abyssinica* (Hochst. ex A.Rich.) Stapf and *Solanum terminale* Forssk*,* for which we recommend further work to validate their usages.

Male respondents identified 44 species, while women identified 40. Urban respondents identified 39 species, while rural respondents identified 42. In terms of age groups, 112 respondents of <35 years, 35 to 59 years, > 60 years named 31, 39, and 44 species, respectively. The calculated Khi-deux value is less than the critical Khi-deux value in terms of age and residence. However, when gender is considered, the calculated Khi-deux value is greater than the critical Khi-deux value (Table 2).

In this study, gender and residence (urban/rural) had no significant effects on the knowledge of anti-malarial plants. A study from autonomous district of Abidjan (Ivory Coast) showed that women identified more medicinal plants than men (Manouan *et al.* 2014), another study from the Edough peninsula (north-east Algeria) also showed that women hold greater traditional phytotherapeutic knowledge than men (Hamel *et al.* 2018). A study from Quebradas del Norte (Uruguay) showed that rural residents identified more medicinal plants than urban residents, but the differences were not statistically significant (Latorre *et al.* 2018).

Table 1. Antimalarial and mosquito repellent plants used in Burundi: Taxonomy position, local name, frequency of citation

Family	**Plant species**	**Local name**	**Voucher specimen number**	**F (%) Respondents anti-malaria**	**F (%) Respondents mosquito repellent**	**Mentioned by respondents elsewhere**	**Anti-malaria or mosquito repellent property reported in literature**
Anacardiaceae	*Mangifera indica* L.	Umwembe	-	2,64	0	(Nondo *et al.* 2015; Yetein *et al.* 2013; Oyeyemi *et al.* 2019)	(Cudjoe *et al.* 2020)
Asphodelaceae	*Aloe sp.*	Igikakarubamba, Impfizi y'umusozi	-	2,35	0	(Teka *et al.* 2016; Amir *et al.* 2019; Mesfin *et al.* 2012; Kasali 2014; Dibessa et al. 2020; Geremedhin, Bisrat, and Asres 2014; Michayewicz 2013)	(Geremedhin, Bisrat, and Asres 2014; Dibessa *et al.* 2020; Teka *et al.* 2016)
Asteraceae	*Artemisia annua* L.	Aritemiziya	-	1,17	0	(Manya et al. 2020; Feng *et al.* 2020; Chiribagula *et al.* 2020)	(Alesaeidi and Miraj 2016; Czechowski *et al.* 2019; Elfawal *et al.* 2012; Liu *et al.* 1992)
Asteraceae	*Baccharoides lasiopus* (O. Hoffm.) H. Rob	Umuvuma	HC&NK023	1,76	0	(Amuka *et al.* 2014; Mulei, Otieno, and Onkware 2014; Maroyi 2020)	(Muregi *et al.* 2007)
Asteraceae	*Bidens pilosa* L.	Icanda	HC&NK040	2,05	0,29	(Clement *et al.* 2020)	(Nadia *et al.* 2020)
Asteraceae	*Erigeron sumatrensis* (S.F. Blake) Pruski & G.Sancho	Umururasase	HC&NK027	4,69	0	(Manya *et al.* 2020)	(Boniface *et al.* 2015)
Asteraceae	*Guizotia scabra* (Vis.) Chiov.	Ikizimyamuriro	HC&NK031	0,88	0	(Nondo *et al.* 2015)	(Nondo *et al.* 2015)
Asteraceae	*Gutenbergia cordifolia* Benth. ex Oliv.	Umweza	HC&NK004	1,47	0	(Koch *et al.* 2005)	(Koch *et al.* 2005)
Asteraceae	*Gymnanthemum amygdalinum* (Delile) Sch. Bip. ex Walp	Umubirizi, Umufumya	HC&NK009, HC&NK010, HC&NK011	57,48	0	(Nondo *et al.* 2015; Yetein *et al.* 2013; Oladeji *et al.* 2020)	(Bihonegn *et al.* 2019)

Family	Plant species	Local name	Voucher specimen number	F (%) Respondents anti-malaria	F (%) Respondents mosquito repellent	Mentioned by respondents elsewhere	Anti-malaria or mosquito repellent property reported in literature
Asteraceae	*Solanecio mannii* (Hook.f.) C.Jeffrey	Umutagari, Umugango	HC&NK017, HC&NK018, HC&NK019	4,11	0	(Manya *et al.* 2020)	(Muganga *et al.* 2010)
Asteraceae	*Tithonia diversifolia* (Hemsl.) A. Gray	Ikinyamuhora, Banyakuyumye, Kivyeyi	HC&NK026	7,91	0,29	(Odugbemi *et al.* 2011)	(Afolayan, Oladokun, and Fasoranti 2020)
Bignoniaceae	*Markhamia lutea* (Benth.) K. Schum.	Umusave	HC&NK001, HC&NK002, HC&NK003	2,64	0	(Nondo *et al.* 2015; Tugume *et al.* 2016)	-
Caricaceae	*Carica papaya* L.	Igipapayi	-	1,17	0	(Olorunnisola *et al.* 2013; Dike, Obembe, and Adebiyi 2012)	(Abdillah *et al.* 2015; Priyadarshi and Ram 2018)
Casuarinaceae	*Casuarina equisetifolia* L.	Akajwari	HC&NK032	0	0,88	-	(Malann *et al.* 2015)
Chenopodiaceae	*Chenopodium ambrosioides* L.	Akavunjahoma, Umusuzi w'ingona	NK&BU011	3,82	0	(Yetein *et al.* 2013; Frausin *et al.* 2015)	(Cysne *et al.* 2016)
Chenopodiaceae	*Chenopodium ugandae* (Aellen) Aellen	Umugombe	HC&NK033	1,47	0	(Chiribagula *et al.* 2020)	-
Cupressaceae	*Cupressus sp.*	Isederi	HC&NK016	0	2,64	(Kasali 2014)	(Saad *et al.* 2017)
Euphorbiaceae	*Euphorbia grantii* Oliv.	Imambura	HC&NK015	0,29	0,88	-	-
Fabaceae	*Cajanus cajan* (L.) Huth	Intengwa, Umukunde, Incaruzo	HC&NK022	9,38	0	(Idowu *et al.* 2010; Oyeyemi *et al.* 2019)	(Ajaiyeoba *et al.* 2013; Olusi, Ibukunoluwa, and Dada 2016)
Fabacea	*Senna didymobotrya* (Fresen.) H. S. Irwin & Barneby	Umubagabaga	HC&NK013	4,11	0	(Njoroge and Bussmann 2006)	(Waiganjo *et al.* 2020)
Fabaceae	*Sesbania sesban* (L.) Merr.	Umunyegenyege	HC&NK005	2,93	0	(Shah and Rahim 2017)	(El-Emam, Mahmoud, and Bayaumy 2015)
Lamiaceae	*Ocimum gratissimum* L. var. *gratissimum*	Kabugagwe, Simama nikwambiye	HC&NK007, HC&NK008	1,73	1,76	(Oyeyemi *et al.* 2019; Oladeji *et al.* 2020;	(Zirihi *et al.* 2005)

Family	**Plant species**	**Local name**	**Voucher specimen number**	**F (%) Respondents anti-malaria**	**F (%) Respondents mosquito repellent**	**Mentioned by respondents elsewhere**	**Anti-malaria or mosquito repellent property reported in literature**
						Odugbemi *et al.* 2011)	
Lamiaceae	*Plectranthus barbatus*	Igicuncu	HC&NK035, HC&NK036	2,05	0	(Kiraithe *et al.* 2016; Philip *et al.* 2017)	(Owuor *et al.* 2012)
Lamiaceae	*Plectranthus esculentus* N.E.Br.	Inumpu	-	1,76	0	(Frausin *et al.* 2015)	-
Lamiaceae	*Tetradenia urticifolia* **(Hochst.) Codd**	Umuravumba	HC&NK006	9,09	0,29	(Bahekar and Kale 2013)	(Bickii *et al.* 2007; Noronha *et al.* 2020)
Lauraceae	*Persea americana* Mill.	Ivoka	-	1,76	0	(Philip *et al.* 2017; Idowu *et al.* 2010)	(Adesina *et al.* 2016)
Meliaceae	*Azadirachta indica* A. Juss.	Arobayine	HC&NK039	5,57	0,59	(Dike, Obembe, and Adebiyi 2012; Noronha *et al.* 2020; Bodeker *et al.* 2001; Iyamah and Idu 2015)	(Akpuaka *et al.* 2013; Deshpande, Gothalwal, and Pathak 2014; Murugan *et al.* 2016)
Moringaceae	*Moringa oleifera* Lam.	Moringa	-	1,76	0	(Oladeji *et al.* 2020; Nondo *et al.* 2015)	(Cudjoe *et al.* 2020)
Myrtaceae	*Eucalyptus globulus* subsp. *Maidenii* (F. Muell.)	Umukaratusi wera	HC&NK028	14,96	2,35	(Tefera and Kim 2019)	-
Myrtaceae	*Psidium guajava*	Ipera	HC&NK020	2,05	0	(Odugbemi *et al.* 2011; Nondo *et al.* 2015)	(Kaushik *et al.* 2015)
Phytolaccaceae	*Phytolacca dodecandra* L. Hér.	Umwokora	HC&NK029, HC&NK030	2,93	0,59	(Bahekar and Kale 2013; Gurmu *et al.* 2018)	(Adinew 2014)
Poaceae	*Cencrhus purpureum* (Schumach.) Morrone	Urubingo	HC&NK021	1,17	0	(Nondo *et al.* 2015; Oladeji *et al.* 2020)	-
Poaceae	*Cymbopogon citratus* (DC.) Stapf	Cayicayi	-	0,58	6,16	(Nondo *et al.* 2015; Oladeji *et al.* 2020)	(Melariri *et al.* 2011)

Family	Plant species	Local name	Voucher specimen number	F (%) Respondents anti-malaria	F (%) Respondents mosquito repellent	Mentioned by respondents elsewhere	Anti-malaria or mosquito repellent property reported in literature
Poaceae	*Digitaria abyssinica* (Hochst. ex A.Rich.) Stapf	Urwiri	HC&NK043, HC&NK044	1,47	0	-	-
Poaceae	*Zea mays* L.	Ikigori	-	7,04	0	(Betti *et al.* 2013; Koudouvo *et al.* 2011)	(Okokon *et al.* 2017, 2019)
Polygalaceae	*Securidaca longipedunculata* Fresen.	Umunyagasozi	NK019	2,05	0	(Bonkian *et al.* 2017)	(Bah *et al.* 2007; Ancolio *et al.* 2002)
Rubiaceae	*Cinchona officinalis* L.	Ikinini	HC&NK034	10,56	0	(Süntar 2020; Selvam and Durai 2018; Chiribagula *et al.* 2020)	(Karle and Bhattacharjee 1999)
Rubiaceae	*Rubia cordifolia* L. subsp. *conotricha* (Gand.) Verdc.	Umukararambwa	HC&NK012	0,88	0	(Dwivedi *et al.* 2020)	(Nyambati *et al.* 2013)
Rutaceae	*Citrus limon* (L.) Osbeck	Indimu	-	1,76	0,88	(Youmsi *et al.* 2017)	(Bonkian *et al.* 2019)
Sapindaceae	*Dodonea viscosa* Jacq.	Umusasa	HC&NK025	3,23	0	(Tefera and Kim 2019)	(Clarkson *et al.* 2004)
Solanaceae	*Physalis angulata* L.	Intumbaswa, Amahwibiri, Agaperi	HC&NK024	2,35	0	(Odugbemi *et al.* 2011; Frausin *et al.* 2015)	(Lusakibanza *et al.* 2010)
Solanaceae	*Solanum terminale* Forssk.	Umuhanurankuba	HC&NK037	0,88	0	-	-
Verbenaceae	*Lantana camara* L.	Mavyi ya kuku	HC&NK038	1,17	0	(Selvam and Durai 2018; Yetein *et al.* 2013; Nondo *et al.* 2015)	(Ved *et al.* 2018)
Verbenaceae	*Lantana trifolia* L.	Umuhengerihengeri	HC&NK014	1,17	0	(Mukungu *et al.* 2016)	(Seyfe *et al.* 2017)

Table 2. Significance of age, gender and residence variables on knowledge of antimalarial and mosquito repellent plants listed in Burundi

Variable	Anti-malarial	Anti-mosquito	DF	χ^2 (α=0,05)	χ^2	P-value	Decision
Age							
> 35 years	164	12	2	5,991	11,117	0,021	$\chi^2 > \chi^2$ (α=0,05) and P-value < α; H_0 accepted
35 to 59 years	344	32					
> 60 years	212	13					
Gender							
Female	276	29	1	3,841	1,636	0,079	$\chi^2 < \chi^2$ (α=0,05) and P-value > α; H_0 rejected
Male	444	28					
Residence							
Rural	496	27	1	3,841	3,485	0,125	$\chi^2 < \chi^2$ (α=0,05) and P-value > α; H_0 rejected
Urban	224	30					

However, in this study, age had a significant impact on the knowledge of anti-malarial plants. A study from of the East Douala (Cameroon) showed that knowledge of the properties and uses of medicinal plants are generally acquired after a long experience (Latreche and Sadoudi 2017). Another study from Nyong department (Cameroon) showed that young people are mostly in school and lose interest in traditional medicine (Mpondo *et al.* 2017). Therefore, this study shows that age can be recognized as a determining factor in the knowledge of medicinal plants, which consideration may lead to reliable results in ethnobotanical studies.

Plant parts and preparations

The leaves of antimalarial plants were the most commonly used plant part (84%). Bark (7%), entire plants (5%), roots (2%) and sap (2%) were less frequently mentioned. Preparation modes of antimalarial plants included maceration (60%), decoction (37%) and infusion (3%). Leaves were also the most commonly used plant part (88%) in mosquito repellent plants. Entire plants (12%) were mentioned less frequently. Mosquito repellent plants are either burned (58%), hung in the house (25%), or even planted near residential areas (17%).

The results of this study agree with other studies that reported that leaves were the most commonly used plant part (Yetein *et al.* 2013; Kalonda *et al.* 2014; Bla *et al.* 2015; Sylla *et al.* 2018). In this study, maceration and decoction were the most used mode of preparation. According to other studies, maceration and decoction are the most frequently used modes of preparation (Yetein *et al.* 2013; Nzuki 2016; Sylla *et al.* 2018). The use of decoction may be justified by the fact that it promotes extraction and the release of volatile toxicants.

Species' habitats and relative abundance

Respondents reported that 28 antimalarial plants were cultivated (farms or planted forests) and 16 were mostly collected from the wild: 7 species were mostly found in semi-natural forests, 7 in savannahs, 14 mostly in fallows, and 11 in cultivated fields (Table 3). Seven of the species collected in the wild were identified as scarce by more than 70 % of those who used that species (Table 3). The available literature revealed that species perceived as scarce were, in fact, scarce in the wild. According to the IUCN Red list, none of the species cited in this study are of international conservation concern. The majority of plant species identified in this study were cultivated, with only a few collected in the wild. A study conducted on Batan Island (Philippines) showed that medicinal plants were cultivated, but the majority were found growing wild in fields, backyards, or forests (Abe and Ohtani 2013).

This study identified species which were scarce in some localities in terms of relative abundance. This is consistent with the study conducted in India, which showed that medicinal plants are becoming increasingly scarce as a result of overexploitation and unscientific harvesting practices (Akhilraj *et al.* 2021).

Literature review on some plant species mentioned in this study and their antimalarial or mosquito repellent compounds

Some plants species (nine out of 11) included in this chapter are among the most cited by traditional healers during the ethnobotanical survey. Others (*Artemisia annua* and *Azadirachta indica*), have not been widely cited (probably because they were introduced recently in Burundi, and therefore are not known in the country), but are recorded in literature as sources of potent antimalarials that have played a major role in the fight against malaria (Manya et al. 2020; Feng *et al.* 2020; Chiribagula *et al.* 2020; Dike, Obembe, and Adebiyi 2012; Noronha *et al.* 2020; Bodeker *et al.* 2001; Iyamah and Idu 2015). The structures of active molecules isolated from these different plants are presented in Table 4.

***Artemisia annua* L.**

Artemisia annua L. (Asteraceae) is a mugwort of Chinese origin known as Qinghao and traditionally used in Chinese medicine against malarial fevers for a very long time. The structure of the active molecule (artemisinin, **1**) was elucidated in the 1970s (Collaboration Research Group for Qinghaosu 1977) after several years of research on antimalarials (large-scale phytochemical screening in animals infected with malaria). Known in China as *qinghaosu*, this molecule is a sesquiterpene lactone (carrying a peroxide group which is essential for its therapeutic efficacy), with an extremely effective anti-malarial effect and capable of inducing oxidative stress in *Plasmodium*, the causative agent of malaria. In particular, it makes it possible to treat strains resistant to chloroquine, with practically no side effects. Its discovery earned Youyou Tu (a Chinese scientist) the Nobel Prize in Physiology or Medicine in 2015 (Liu *et al.* 2015). Other types of molecules (non-terpene) have been isolated from this species; thus, flavonoids (**2-7**) have shown an antimalarial activity, as well as a potential synergistic effect with artemisinin *in vitro* (Cao *et al.* 2020; Gruessner *et al.* 2021, Zhou *et al.* 2021).

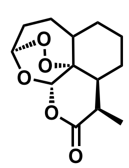
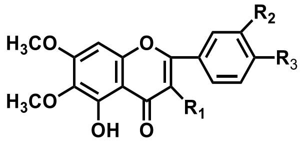
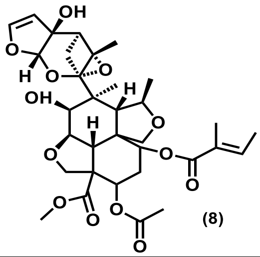
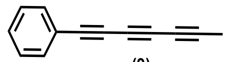
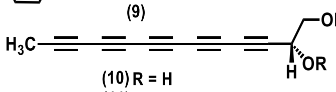
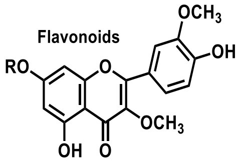
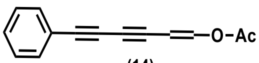
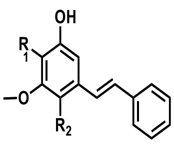
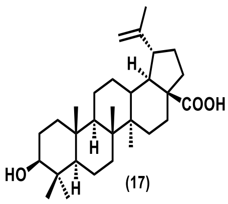
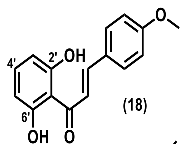
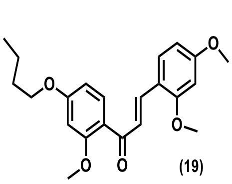
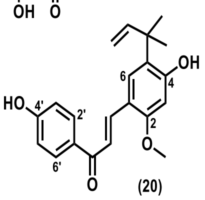
Table 3. Perception of respondents on availability of anti-malaria and anti-mosquito plants in Burundi

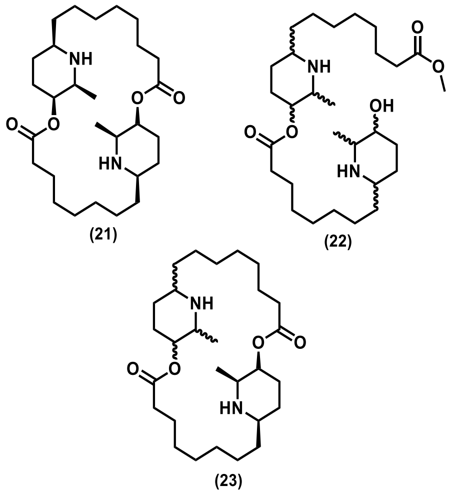
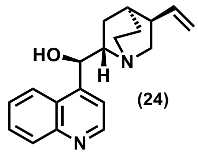
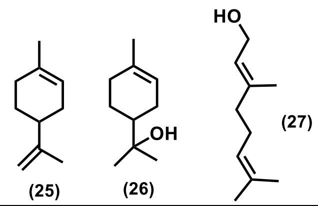
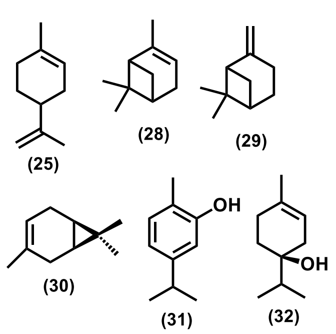
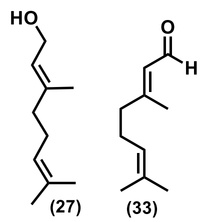
Species	Part used	Habitat	Perceptions of respondents on Abundance according to the survey (% of respondents)	Literature for the plants perceived as scarce
Collected from the wild				
Bidens pilosa L.	Lf	Fallow, Cultivated fields	Abundant (100 %)	-
Erigeron sumatrensis (S.F. Blake) Pruski & G.Sancho	Lf	Cultivated fields, Savannahs	Abundant (100 %)	-
Digitaria abyssinica (Hochst. ex A. Rich.) Stapf	Lf	Cultivated fields, Savannahs, Fallow	Scarce (10 %), Less abundant (20 %), Abundant (75 %)	-
Dodonea viscosa Jacq.	Lf	Fallow, Cultivated fields	Scarce (70 %), Less abundant (25 %), Abundant (5 %)	(Ng *et al.* 2021)
Guizotia scabra (Vis.) Chiov.	Lf	Semi-natural forest, Cultivated fields, Fallow, Savannahs	Scarce (30 %), Less abundant (20 %), Abundant (50 %)	-
Gutenbergia cordifolia Benth. ex Oliv.	Lf	Fallow, Savannahs	Scarce (70 %), Less abundant (25 %)	(Kavana *et al.* 2019)
Lantana camara L.	Lf	Semi-natural forest, Savannahs, Fallow	Less abundant (5 %), Abundant (95 %)	-
Lantana trifolia L.	Lf, Rt, Ec	Cultivated fields, Savannahs, Fallow	Scarce (70 %), Less abundant (15 %), Abundant (15 %)	(Adomou 2005)
Ocimum gratissimum L. var. *gratissimum*	Wp	Cultivated fields, Fallow	Scarce (30 %), Less abundant (15 %), Abundant (55 %)	-
Physalis angulata L.	Lf	Semi-natural forest, Cultivated fields, Fallow	Scarce (30 %), Less abundant (15 %), Abundant (55 %)	-
Phytolacca dodecandra L. Hér.	Lf	Cultivated fields, Fallow, Natural forest	Scarce (70 %), Less abundant (25 %), Abundant (5 %)	(MINEAGRIE 2014)
Rubia cordifolia L. subsp. *conotricha* (Gand.) Verdc.	Lf	Natural forest, Fallow	Scarce (80 %), Less abundant (15 %), Abundant (5 %)	(Masharabu *et al.* 2010)
Securidaca longipedunculata Fresen.	Lf	Savannahs	Scarce (10 %), Less abundant (15 %), Abundant (75 %)	-
Sesbania sesban (L.) Merr.	Lf	Semi-natural forest, Cultivated fields, Fallow	Scarce (70 %), Less abundant (30 %)	(Orwa *et al.* 2009)

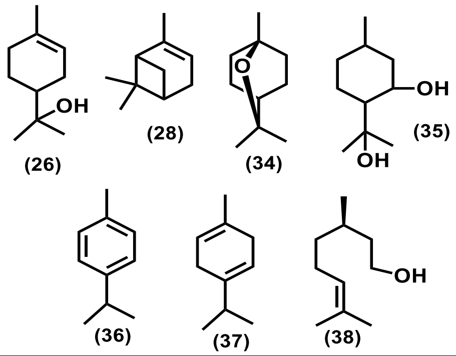
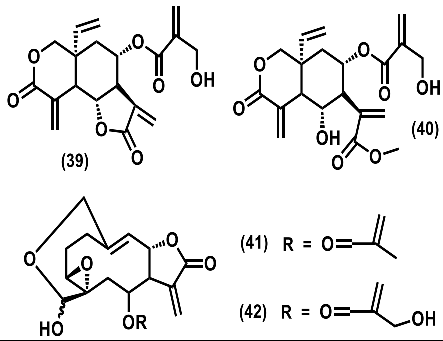
Species	Part used	Habitat	Perceptions of respondents on Abundance according to the survey (% of respondents)	Literature for the plants perceived as scarce
Solanum terminale Forssk.	Lf	Semi-natural forest, Fallow	Scarce (95 %), Less abundant (5 %)	(Schmelzer and Gurib-Fakim 2008)
Tithonia diversifolia (Hemsl.) A. Gray	Lf	Fallow, Cultivated fields	Less abundant (15 %), Abundant (85 %)	-
Cultivated				
Aloe sp.	Lf	Gardens, Cultivated fields	Less abundant (25 %), Almost untraceable (75 %)	-
Artemisia annua L.	Lf	Gardens, Cultivated fields	Scarce (50 %), Less abundant (25 %), Abundant (25 %)	-
Azadirachta indica A. Juss.	Lf, Ec	Gardens, Cultivated fields	Scarce (50 %), Less abundant (25 %), Abundant (25 %)	-
Baccharoides lasiopus (O. Hoffm.) H. Rob	Lf	Savannahs, Gardens, Cultivated fields	Scarce (60 %), Less abundant (25 %), Abundant (10 %)	-
Cajanus cajan (L.) Huth	Lf	Gardens, Cultivated fields	Scarce (60 %), Less abundant (25 %), Abundant (15 %)	-
Carica papaya L.	Lf	Gardens, Cultivated fields	Scarce (65 %), Less abundant (15 %), Abundant (20 %)	-
Casuarina equisetifolia L.	Lf	Artificial afforestation	Scarce (30 %), Less abundant (35 %), Abundant (35 %)	-
Cencrhus purpureum (Schumach.) Morrone	Lf	Little disturbed forests, Gardens, Cultivated fields	Scarce (50 %), Less abundant (25 %), Abundant (25 %)	-
Chenopodium ambrosioides L.	Wp	Cultivated fields, Gardens, Fallow	Scarce (50 %), Less abundant (25 %), Abundant (25 %)	-
Chenopodium ugandae (Aellen) Aellen	Lf	Fallow, Gardens, Cultivated fields	Scarce (70 %), Less abundant (12 %), Abundant (18 %)	-
Cinchona officinalis L.	Lf, Ec	Artificial afforestation, Cultivated fields, Gardens	Scarce (80 %), Less abundant (15 %), Abundant (5 %)	-
Citrus limon (L.) Osbeck	Lf	Gardens, Cultivated fields	Scarce (60 %), Less abundant (20 %), Abundant (20 %)	-
Cupressus sp.	Lf	Gardens, Cultivated fields	Scarce (50 %), Less abundant (25 %), Abundant (25 %)	-
Cymbopogon citratus (DC.) Stapf	Wp	Cultivated fields, Fallow, Swamp, Gardens	Scarce (40 %), Less abundant (35 %), Abundant (25 %)	-
Eucalyptus globulus subsp. *maidenii* (F. Muell.)	Lf, Ec	Artificial afforestation, Fallow	Scarce (50 %), Less abundant (35 %), Abundant (15 %)	-
Euphorbia grantii Oliv.	Lf, Latex	Cultivated fields, Gardens	Scarce (65 %), Less abundant (30 %), Abundant (5 %)	-

Species	Part used	Habitat	Perceptions of respondents on Abundance according to the survey (% of respondents)	Literature for the plants perceived as scarce
Gymnanthemum amygdalinum (Delile) Sch. Bip. ex Walp	Lf	Cultivated fields, Gardens, Fallow	Scarce (60 %), Less abundant (25 %), Abundant (15 %)	-
Mangifera indica L.	Lf	Gardens, Fallow, Cultivated fields	Less abundant (35 %), Abundant (65 %)	-
Markhamia lutea (Benth.) K. Schum.	Lf	Semi-natural forest, Cultivated fields	Scarce (70 %), Less abundant (25 %), Abundant (5 %)	-
Cultivated				
Moringa oleifera Lam.	Lf	Gardens, Cultivated fields, Fallow	Scarce (60 %), Less abundant (25 %), Abundant (15 %)	-
Persea americana Mill.	Lf	Fallow, Gardens, Cultivated fields	Less abundant (5 %), Abundant (95 %)	-
Plectranthus barbatus Andrews	Lf	Little disturbed forests, Cultivated fields, Fallow	Scarce (50 %), Less abundant (25 %), Abundant (25 %)	-
Plectranthus esculentus N.E.Br.	Lf	Savannahs	Scarce (80 %), Less abundant (15 %), Abundant (5 %)	-
Psidium guajava L.	Lf	Little disturbed forests, Cultivated fields, Gardens, Savannahs	Less abundant (10 %), Abundant (90 %)	-
Senna didymobotrya (Fresen.) H. S. Irwin & Barneby	Lf	Cultivated fields, Little disturbed forests, Fallow	Scarce (80 %), Less abundant (20 %)	-
Solanecio mannii (Hook.f.) C. Jeffrey	Lf	Cultivated fields, Fallow, Gardens	Scarce (40 %), Less abundant (25 %), Abundant (35 %)	-
Tetradenia urticifolia (Hochst.) Codd	Lf	Cultivated fields, Fallow, Gardens	Scarce (20 %), Less abundant (45 %), Abundant (35 %)	-
Zea mays L.	Lf	Cultivated fields, Swamp	Less abundant (5 %), Abundant (95 %)	-

Table 4. Chemical structures of antimalarial and mosquito repellent compounds isolated from some of the plant species listed in Burundi

Plant species	Structures	Effect	References
Artemisia annua L.	 (1)  (2) $R_1 = R_2 = R_3 = OCH_3$ (3) $R_1 = R_3 = OCH_3$, $R_2 = OH$ (4) $R_1 = R_3 = OCH_3$, $R_3 = OH$ (5) $R_1 = OCH_3$, $R_2 = R_3 = OH$ (6) $R_1 = H$, $R_2 = OCH_3$, $R_3 = OH$ (7) $R_1 = H$, $R_2 = OH$, $R_3 = OCH_3$	Antimalarial	Artemisinin **(1)** (Kohler *et al.* 1997; Willcox 2009); Artemetin **(2),** casticin **(3),** chrysoplenetin (**4),** chrysosplsrtol-D **(5),** cirsilmeol **(6),** eupatorin (**7)** (Cao *et al.* 2020; Gruessner *et al.* 2021, Zhou *et al.* 2021)
Azadirachta indica A. Juss.	 (8)	Antimalarial	Azadirachtin (**8**) (Pohlit *et al.* 2011).
Bidens pilosa L.	 (9)  (10) R = H (11) R = Glucose Flavonoids  (12) R = Alpha-L-rhamnopyranosyl-(1-6)-beta-D-glucopyrose (13) R = Beta-D-glucopyranose  (14)	Antimalarial	Phenylheptatriyne (**9**), (R)-1,2-dihydroxytrideca-3,5,7,9,11-pentayne (**10**), 2-β-D-glycopyrasyloxy-1-hydroxytrideca-3,5,7,9,11-pentayne (**11**) ; flavonoids (**12, 13**), Phenylacetylene (**14**) (Nogueira and Lopes 2011; Tobinaga *et al.* 2009; Antoniana U Krettli *et al.* 2001).
Cajanus cajan (L.) Huth	 (15) $R_1 = CH_2CHC(CH_3)$, $R_2 = H$ (16) $R_1 = H$, $R_2 = CH_2CHC(CH_3)_2$  (17)  (18)  (19)  (20)	Antimalarial	Longistylin A **(15)** & C **(16)**, and betulinic acid **(17)** (Duker-Eshun *et al.* 2004). Cajachalcone 2',6'-dihydroxy-4-methoxy chalcone **(18)**; 2,4-dimethoxy-4'-butoxy chalcone **(19);** Licochalcone (**20)** (Ajaiyeoba *et al.* 2013).

Plant species	Structures	Effect	References
Carica papaya L.		Antimalarial	(1S-11R-13S–14S-24R–26S)-13,26-dimethyl-2,15-dioxa-12,25-dia- zatricyclo [22.2.2.211,14] triacontane-3,16-dione ((þ)-carpaine (**21**); 6-(8-Methoxy-8-oxooctyl)-2-methylpiperidin-3-yl8-(5-hydroxy-6-methylpiperidin-2-yl) octanoate (**22**); 13,26-dimethyl-2,15-dioxa-12,25-diazatricyclo [22.2.2.2 11,14] triacontane-3,16-dione (**23**) (Julianti *et al.* 2014)
Cinchona officinalis L.		Antimalarial	Quinine **(24)** (Cragg and Newman 2005)
Citrus limon (L.) Osbeck		Insect repellent	Limonene (**25**), α-terpineol (**26**) and myrcene (**27**) (Pohlit *et al.* 2011)
Cupressus sp.		Insect repellent	Limonene (**25**), α & β-pinene (**28** & **29**), 3-carene (**30**), carvacrol (**31**) and terpinen-4-ol **(32)** (Pohlit *et al.* 2011).
Cymbopogon citratus (DC.) Stapf		Insect repellent	Myrcene (**27**) and geranial (**33**) (Pohlit *et al.* 2011).

Plant species	Structures	Effect	References
Eucalyptus sp. (including E. globulus subsp. *Maidenii)* (F. Muell.) Kirkp.		Insect repellent	α-terpineol (**26**); α-pinene (**28**); 1,8-cineole (**34**), p-menthane-3,8-diol (**35**), p-cymene (**36**), γ-terpinene (**37**) and citronellol (**38**) (Batish *et al.* 2008).
Gymnanthemum amygdalinum (Delile) Sch. Bip. ex Walp		Antimalarial	Vernodalin (**39**), and vernodalol (**40**) vernolide (**41**), hydroxyvernolide (**42**) (Ohigashi *et al.* 1994)

***Azadirachta indica* A. Juss.**

Azadirachta indica A. Juss. (Meliaceae) is a species native to India and is known as Neem. It has become naturalized in Burundi where it primarily serves as an insecticidal plant. It is also one of the main insecticidal plants (also mosquito repellent) recommended to farmers by INADES Formation Burundi to farmers as alternatives to chemical pesticides, some of which are classified as dangerous and toxic (INADES Formation Burundi 2022). Additionally, it is used primarily as a mosquito repellent in many parts of the world. The species has been reported to repel the female mosquito (*Anopheles stephensi*), which is the main vector of malaria in urban India (Pohlit *et al.* 2011). *Azadirachta indica* is widely marketed around the world in the form of vegetable oil with insecticidal properties because of the main component (azadirachtin, **2**) of the leaves, flowers and fruits (Isman 2006). The molecule acts as an anti-appetizing, repellent and loathsome agent. It also induces growth retardation, inhibition of moulting and malformations, sterility in insects (by preventing egg-laying and interrupting sperm production in men). It is a very interesting insecticide with a much lower environmental impact than synthetic pesticides (Chaudhary *et al.* 2017). Finally, this oil derived from the seeds of this species is one of the patented essential vegetable oils used in mosquito repellent inventions (Pohlit *et al.* 2011).

***Bidens pilosa* L.**

Bidens pilosa L. (Asteraceae) is commonly known as **icanda** in Burundi. It is used in both traditional human and veterinary medicine to treat a variety of pathologies, including microbial infections (Ngezahayo *et al.* 2015). In addition, phytochemical screenings for antimalarial agents were performed on several plant species (including *B. pilosa*) in Brazil and showed that the plant possessed significant antimalarial activity both *in vivo* and *in vitro* (Krettli *et al.* 2001). Similar studies have also been conducted by other groups of researchers, and all have confirmed this effect of the plant, by testing its extracts *in vitro* (Clarkson et al. 2004; Oliveira *et al.* 2004; Lacroix *et al.* 2011), and *in vivo* (Brandão *et al.* 1997; Andrade-neto *et al.* 2004; Krettli 2009). In addition, compounds with potent antimalarial effects (Table 4, structures **9-14**) have been isolated and identified in extracts of the species (Krettli *et al.* 2001; Tobinaga *et al.* 2009; Nogueira and Lopes 2011).

***Cajanus cajan* (L.) Huth**

Cajanus cajan (L.) Huth (Fabaceae) is a perennial seed legume grown in tropical regions. In addition to its reported use as a febrifuge in traditional medicine (Duke and Martinez 1994), antimalarial activity of the leaf extracts of this plant has also been reported (Ajaiyeoba *et al.* 2005). Antiplasmodial agents have also been isolated and characterized from the plant material. Thus, two stilbenes (longistylin A**, 15** and C, **16)**, and betulinic acid **(17)**, isolated from the extracts of the roots and leaves of the plant, were tested for their antimalarial effects, and showed moderately high in vitro activity against chloroquine-sensitive *Plasmodium falciparum* strain 3D7 (Duker-eshun *et* *al.* 2004). Three charcones (**18-20**) were also isolated from *C. cajan* leaf extract and a test on a strain of *Plasmodium falciparum* (multi-resistant strain K1) gave very good results (Ajaiyeoba *et al.* 2013).

***Carica papaya* L.**

Carica papaya L. (Caricaceae) is a well-known fruit tree in tropical regions. It is also known for its several medicinal uses (Krishna *et al.* 2008). It is used in particular against fever in traditional Burundian medicine (Ngezahayo *et al.* 2015), and its leaves are used against malaria (Tor-anyiin *et al.* 2003; Bertani *et al.* 2005; Ellena *et al.* 2012; Suleman *et al.* 2018). In 2018, Woon-Chien Teng and his collegues isolated one of the plant's active components. They discovered that it was an alkaloid (carpaine, **21**) with good activity against two strains of *Plasmodium falciparum* 3D7 and Dd2 (Teng *et al.* 2019). Furthermore, this alkaloid had already been characterized in the plant in 2014. The antiplasmodial test revealed that carpain had high antiplasmodial activity and low cytotoxicity when compared to two other alkaloids (**22, 23**) isolated from the same plant extract. A synergistic effect between *C. papaya* extract and artesunate has also been reported. Indeed, short-term co-administration of the methanolic extract of the plant and artesunate in mice infected with *Plasmodium berghei* showed an increase in antimalarial efficacy (Oraebosi and Good 2021).

***Cinchona officinalis* L.**

Cinchona officinalis L. (Rubiaceae) is known in Burundi under the vernacular name **ikinini,** which means quinine (name of the active substance of the plant against malaria). It is a native of South America where species of the genus *Cinchona* (including *C. officinalis*) were known for their febrifuge properties. The first generation of antimalarial drugs used in the world was, quinine **(24)**, a quinoline alkaloid isolated from the bark of these plants for the first time by Pelletier and Caventou (French chemists and pharmacists) in 1820.

***Citrus limon* (L.) Osbeckn**

Citrus limon (L.) Osbeckn(Rutaceae) is an evergreen tree whose main raw material is the yellow fruit (edible), essential oil (insect repellent) and juice (most often used as a condiment) (Klimek-Szczykutowicz *et al.* 2020). The plant is cited in several patents on mosquito repellent inventions (Pohlit *et al.* 2011). The repellent properties of the plant against mosquitoes have been reported, particularly in *Anopheles stephensi* (main vector mosquito of malaria in urban areas in India), *Aedes aegypti* (main vector mosquito of dengue fever, Zika virus infection, chikungunya and yellow fever) and *Culex quinquefasciatus* (mosquito vector of various diseases including Nile fever, Saint Louis encephalitis, avian malaria) (Oshaghi *et al.* 2003; Amer and Mehlhorn 2006). Among the components of the essential oil of the plant (β-pinene, γ-terpinene, limonene **(25)**, α-terpineol **(26)**, myrcene **(27)**, D-dihydrocarvone, only those bearing numbers have proven mosquito repellent and deterrent properties (Pohlit *et al.* 2011).

Cupressus sp.

Cupressus is a genus of trees in the Cupressaceae family with over 25 species. Essential oils from these species have been scientifically proven to repel a range of mosquitoes including *Anopheles stephensi*, *Aedes aegypti* and *Culex quinquefasciatus* (Pohlit *et al.* 2011). As with other essential oil plants mentioned in this work, species of this genus are cited in many patents on mosquito repellent inventions. Their chemical composition is very diverse; it contains in particular thujopsene, eudesmol, E-(+)-α-atlantone; α,β & γ-himachalenes; α- & β-cedrenes; limonene **(26)**, β-phellandrene, α & β-pinene **(28** & **29)**, 3-carene **(30)**; p-methyl-Δ-3-tetrahydro & p-methyl acetophenones; hinokitiol, carvacrol **(31)**, terpinen-4-ol **(32),** sabinene (Burfield 2002). It should be noted that only molecules with numbers after their names (corresponding to the structures in Table 4) have proven to be anti-mosquito and deterrent (Pohlit *et al.* 2011).

***Cymbopogon citratus* (DC.) Stapf**

Cymbopogon citratus (DC.) Stapf (Poaceae) is a perennial herb with large leafy clumps that grow 30-50 cm tall. It is a plant species native to Asia, but it is currently cultivated in all the intertropical regions (Troupin 1988). This plant species is known for its properties to repel mosquitoes such as *Aedes aegypti, Aedes atlanticus, Aedes mitchellae, Anopheles stephensi, Anopheles darlingi*, and *Culex quinquefasciatus*). The chemical composition of *C. citratus* essential oils used in patented mosquito repellent inventions includes geranial **(33)**, neral, myricene **(27)**. However, only geranial and myricene mosquito repellent properties (Pohlit *et al.* 2011).

***Eucalyptus globulus* subsp. *maidenii* (F. Muell.) Kirkp.**

Eucalyptus globulus subsp. *maidenii* (F. Muell.) Kirkp. (Myrtaceae) is an introduced species in Burundi. It is used in particular against fever and cough in Burundian traditional medicine (Ngezahayo *et al.* 2015). During the COVID-

19 pandemic it was also very coveted and commercialized in this country: the decoction of its leaves was used as fumigants. This plant is used as both an antimalarial and a mosquito repellent. A large number of patents containing the genus *Eucalyptus* have already been registered for this last property (Pohlit *et al.* 2011). Additionally, it has been reported that essential oils of *Eucalyptus* spp. are widely used to repel mosquitoes and other insects and contain several mosquito repellents compounds such as 1,8-cineole **(34)**, p-menthane-3,8-diol **(35)**, α -pinene **(28)**, **p**-cymene **(36)**, γ-terpinene **(37)**, citronellol **(38)** and α-terpineol **(26)** (Batish *et al.* 2008).

Gymnanthemum amygdalinum **(Delile) Sch. Bip. ex Walp**

Gymnanthemum amygdalinum (Delile) Sch. Bip. ex Walp (Asteraceae) is a synonym of *Vernonia amygdalina* Delile; it is used in the fight against insects harmful to humans (including mosquitoes) (Ahishakiye *et al.* 2022), and microbial infections (including malarial fever) in traditional Burundian medicine (Ngezahayo *et al.* 2015). Extracts of the species have already shown antimalarial activity *in vitro* (Muthaura *et al.* 2015) and *in vivo* (Abosi and Raseroka 2003; Okpe *et al.* 2016). Four sesquiterpene lactones (vernodalin, **39**; vernodalol, **40**; vemolide, **41**, hydroxyvemolide, **42**) have been isolated from the plant, and exhibited antimalarial activity *in vivo* in chempanzees (Ohigashi *et al.* 1994).

Conclusion

This study highlighted the use of more antimalarial plants than mosquito repellent plants in Burundi. Some plants species reported in this study were not reported in previous studies and require further investigation before they are recommended for use.

The study also showed that traditional knowledge is primarily held by older people, highlighting the importance of investing more in this sector to prevent the disappearance of traditional medicine knowledge. The parts used and the preparation modes are not limiting factors in plants conservation. The exploitation of these species is practically not a problem because most of them are found in degraded forests, artificial afforestation, fallow land, gardens and cultivated fields; but rarely in natural forests. However, conservation efforts are recommended for species that are not yet cultivated by the people, although they are scarce in some localities according to respondents.

Limitations

This study had some limitations: the number of respondents was not the same in each region due to the environment's accessibility and the study did not sufficiently document the availability of the species identified in the study area because the results were mostly based on respondent's information.

Declarations

List of abbreviations: F: Frequency; MINEAGRIE: Ministere de l'Environnement, de l'Agriculture et de l'Elevage (Ministry of the Environment, Agriculture and Livestock in Burundi).

Consent for publication: Not applicable.

Availability of data and materials: All the data are presented in figures, tables and appendix in the manuscript and are available with the corresponding author.

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Authors' contributions:

Célestin Havyarimana: Conducting field surveys, Drafting the work, Analysis and interpretation of data for the work, Corresponding author and submission; **Jacques Nkengurutse:** Participated in the drafting of work**,** Revising botanical aspect of plants, Analysis and interpretation of data for the work; **Jérémie Ngezahayo:** Participated in the drafting of work**,** Drawing of the chemical molecules, Analysis and interpretation of data for the work; **Aida Cuni-Sanchez:** Critical review of the content; **Tatien Masharabu:** Revising of the content and final approval of the version to be published.

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