An ethnobotanical survey of plants used against host-seeking mosquitoes by communities in Mazowe and Shamva districts, Zimbabwe

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Research

Abstract

Background: There is a dearth of information on plants used to repel mosquitoes in many rural malaria-endemic communities in Zimbabwe. The objective was to assess and document the knowledge and usage customs of mosquito-repellent plants among the people of Mazowe and Shamva districts.

Methods: Interviewer-administered questionnaires and key informant interviews were used to collect data on knowledge, perception, and practices concerning the use of mosquito-repellent plants against malaria-transmitting mosquitoes.

Results: A total of 144 key informants, selected using snowball sampling, were interviewed between April and June 2023. A total of 53 plant species from 29 families consisting of 33 (62%) native and 20 (38%) exotic plants were listed. The relative frequency of citation (RFC) values ranged from 0.01 to 0.97, the highest being for *Lippia javanica* (Burm.f.) Spreng (0.97) and *Ocimum incanum* L (0.71). Fabaceae (17%) and Asteraceae (11%) were the most represented families. Leaves (43%) were the most commonly utilized parts while burning plant parts to produce smoke (57%), hanging plants inside rooms (21%), and application of plant extracts on the skin (21%) were the most common methods of application. Amongst the plants with high RFC values, it appears five have not been ethnobotanically studied for mosquito repellency in the country.

Conclusion: The communities in Mazowe and Shamva districts have substantial ethnobotanical knowledge of mosquito-repellent plants. Ethnobotanical knowledge gathered in this study provides us with many new potential plants for follow-up research for the development of plant-based mosquito repellents.

Keywords: Ethnobotanical; Indigenous knowledge; Mosquito-repellent plants; Malaria-transmitting mosquitoes; Plant-based repellents.

Background

Malaria control involves the prevention of mosquito bites through the use of various methods including insecticide-treated bed nets (ITNs) and screening of houses to prevent mosquitoes from entering; killing of mosquitoes by reducing breeding sites and killing the aquatic stages, and adults using residual insecticides; and treatment of patients (WHO 2006; Wangai *et al*. 2020). According to the National Malaria Control Program (NMCP) (2020), Zimbabwe's agenda for malaria control and elimination is to be malaria-free by 2030, initially by reducing malaria incidence to 17 cases per 1000 population and malaria deaths by at least 90 percent by 2025 and eliminate malaria as a public health problem in areas where elimination is not possible with the current tools by 2030. Malaria control in Zimbabwe is based on vector control methods, especially the use of ITNs and indoor residual spraying (IRS), supplemented with larviciding and repellents (NMCP 2020).

Repellents in addition to ITNs/IRS are an effective way of preventing mosquito bites and malaria infection since they have the potential to minimize contact between humans and malaria vectors (Bekele 2018). Variations in repellent formulations ensure that they provide protection anytime, and in any locality particularly in areas where vector mosquitoes bite early in the evening and exhibit exophagic biting behaviour (Moore *et al*. 2006). Repellents also play a significant role in reducing malaria transmission in areas dominated by drug-resistant parasites and insecticide-resistant vectors (WHO 2017). Hence, the use of repellents to prevent systemic infections constitutes a fundamental public health effort (Nguyen *et al*. 2018).

Currently, the most commonly used repellent is broad-spectrum N-diethyl-3-methylbenzamide (DEET), which has proven to be efficacious (Nguyen *et al*. 2018). However, access to DEET and other synthetic repellent products in many rural malaria-endemic communities is often limited by scarcity and affordability (Karunamoorthi and Hailu 2014; Gou *et al*. 2020). Furthermore, synthetic repellents are reported to have reduced efficacy owing to sweating and allergic reactions (Leal 2014). In addition, the overuse of DEET has also been associated with safety issues related to neurotoxicity and dermatitis (Leal 2014; Diaz 2016). For instance, DEET was reported to harm synthetic clothes such as pigmented leather, spandex, and rayon and degrades vinyl and plastics (Osimitiz and Grothaus 1995; Brown and Hebert 1997; Leal 2014). Consequently, people across different cultures resort to several traditional practices including the use of native plants to repel mosquitoes (Pavela and Benelli 2016). The negative effects associated with DEET and other synthetic repellents have also led to increased research efforts in the development of alternative mosquito-repellent products.

Ethnobotany is the scientific study of interrelations between humans and plants and involves the study of indigenous or traditional knowledge of plants, their classification, cultivation, and use as food, medicine, and shelter (Iwu 2002; Okoh *et al*. 2021). Plants have been traditionally used as repellents for personal protection against different species of mosquitoes (Asadollahi *et al*. 2019). Many researchers have also reported on the effectiveness of plant extracts or essential oils against different mosquito species (Ansari *et al*. 2005; Rimando and Duke 2006; Lorenz *et al*. 2013; Asadollahi *et al*. 2019; Wangai *et al*. 2020). Thus, plants may provide an alternative source of compounds for the control of mosquitoes in integrated vector control since they constitute a rich source of bioactive chemicals that are target-specific and biodegradable (Elumalai *et al*. 2010). Plant-based repellents are generally considered inexpensive, easily available, safe, aromatic, easily degradable, locally known, and culturally acceptable (Kumar *et al*. 2011; Diaz 2016; Youmsi *et al*. 2017). However, knowledge of these repellent plants is vested in indigenous communities and is rarely documented.

Globally, rural communities utilize plant leaves, roots, bark, and flowers to repel mosquitoes (Kantheti and Padma, 2017). In Zimbabwe, rural communities also apply their local knowledge in utilizing mosquito repellent plants to prevent mosquito bites and protection from malaria infection (Lukwa 1999; Kazembe 2012). The country can leverage this indigenous knowledge of traditional medicine and its rich plant diversity to produce new, effective, and affordable mosquito control products for its population in rural malaria-endemic areas. However, there is limited information on plant species used for mosquito control in Zimbabwe in general and in Mashonaland Central Province in particular. The province, together with Manicaland and Mashonaland East is amongst the top three malaria-burdened provinces in the country (NMCP 2020, USAID PMI Vectorlink 2021).

The indigenous knowledge and use of plants as mosquito repellents in Mazowe and Shamva districts, Mashonaland Central Province, Zimbabwe lacked documentation and preservation as a cheap and sustainable way of preventing mosquito bites. Documentation will lead to research on efficacy and safety as well as the identification of single chemical entities that have mosquito-repellent activity and subsequently the development of new and standardized plant-based mosquito repellents in the country. This study aimed to comprehensively document the ethnobotanical information on mosquito-repellent plants from the communities in Mazowe and Shamva districts. A comprehensive database of plants traditionally used for repelling mosquitoes in the two districts increases the number of plants that are available for screening in the production of plant-based malaria vector control products thereby contributing significantly to Zimbabwe's national agenda to eliminate malaria by 2030.

Materials and Methods

Study area

The study was conducted in two wards, Bare (16.87°S; 31.12°E; average alt 1244m) and Mupfurudzi (16.97°S; 31.66°E; average alt 956m), located in the malaria-endemic districts of Mazowe and Shamva respectively, in Mashonaland Central province, Zimbabwe (Figure 1). Mazowe district is located about 50km north of the capital city, Harare (Chiweshe 2011) whilst Shamva is about 90km northeast of the capital city (Muchena *et al*. 2017). According to the NMCP (2020), Mazowe district is characterized by lower seasonal malaria transmission in comparison to other districts in the province whilst Shamva district is characterized by moderate to high seasonal malaria transmission. Both districts utilize vector control methods, malaria case management, surveillance, health promotion, epidemic preparedness, and response in efforts to reduce malaria transmission. The study was carried out in 12 villages - six from Bare (Ward 1) in Mazowe district and six from Mupfurudzi (Ward 14) in Shamva district. The villages from Bare ward are Chipfunde, Gendere, Timuri, Chawasarira, Goteka, and Chavhakaira whilst those from Mupfurudzi ward are Gato, Nyamhondoro, Kushinga, Tongogara, Mukwari, and Zvomanyanga. The 12 villages were selected based on high malaria transmission intensity, malaria outbreak trends over the past 10 years, accessibility, and ecological conditions that provide potential breeding habitats and survival of malaria vectors in the 2 wards.

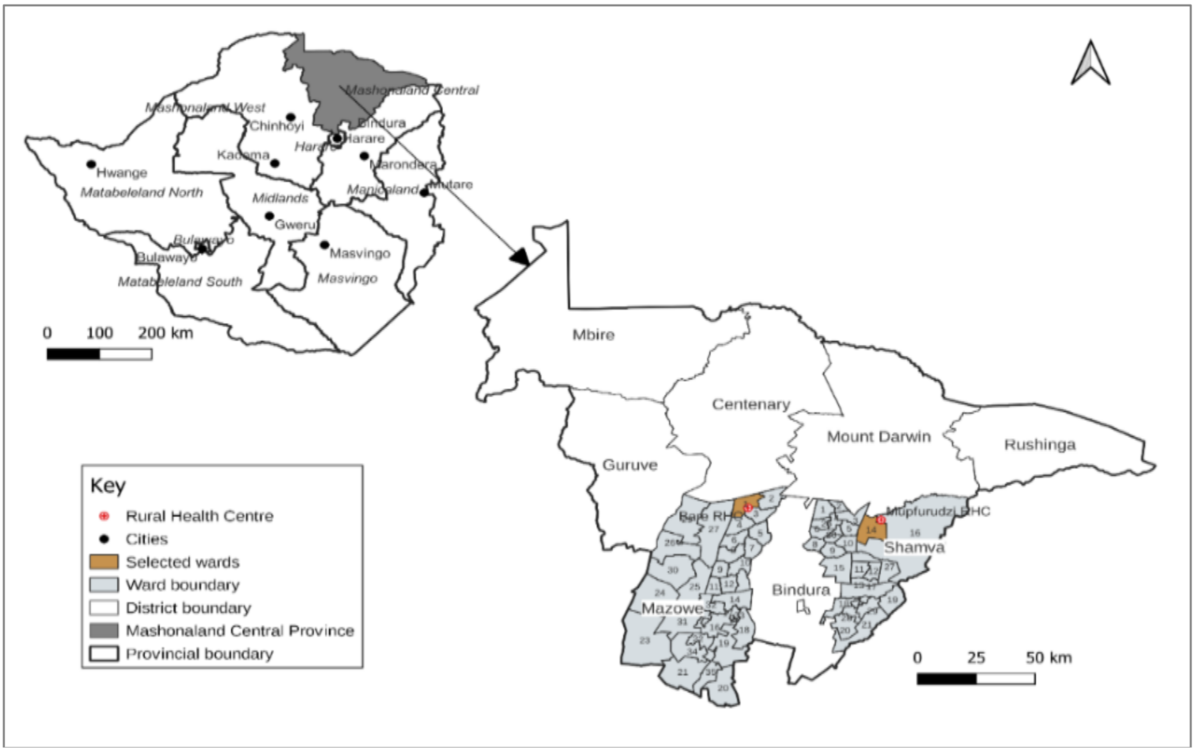

Figure 1. Study area map showing the locations of Bare and Mupfurudzi wards in Zimbabwe.

Questionnaire design and pre-testing

A questionnaire survey was designed to gather data from key informants about their knowledge, use, and perceptions regarding the use of plants for protection against mosquito bites and preventing malaria infection. The questionnaire was pre-tested for validity and reliability to ensure that questions were unambiguous and to catch errors and points of confusion before the actual study in March 2023 at Rudzimba village in Shamva district. Errors and ambiguous and open-ended questions were cleared and rectified before the actual survey. A clean pre-tested questionnaire was used for the survey.

Data collection

A total of 144 key informants were recruited by snowball sampling and interviewed using interviewer-administered questionnaires between April and June 2023. The key informants were selected based on their knowledge, experience, and functional role in their communities. The study was carried out following the recommendations of the International Society of Ethnobiology Code of Ethics. The research was authorized by the Department of Biological Sciences and Ecology at the University of Zimbabwe while permission to conduct the study in the two districts was granted by Dr. C. Tshuma, the Provincial Medical Director of Mashonaland Central Province. The local leadership (Village Heads, and Councilors) of the study areas were consulted before the survey and their agreement was obtained. Informed written consent was obtained from all key informants and accordingly, each key informant agreed to participate voluntarily, with confidentiality and anonymity maintained throughout the study. Information collected during the interviews included vernacular names of plants, specific parts used, method of application, availability of plants, other known uses of plants, reasons for using plants as mosquito repellents, and their source of knowledge.

Collection and identification of plant specimens
All plant specimens were collected following herbarium standards and identified using vernacular nomenclature with assistance from the key informants. The identified plants were presented to a taxonomist at the National Herbarium and Botanic Garden in Harare, Zimbabwe for species identification (ID) confirmation. Voucher specimens were deposited under specific identification numbers for records and future reference purposes at the National Herbarium in Harare, Zimbabwe.

Ethnobotanical indices and data analysis
Descriptive statistics such as frequency and percentage were used to summarise data on the socio-demographic characteristics of the key informants as well as on plant usage practices. The relative importance of the species was expressed as the relative frequency of citation (RFC) and was calculated based on the frequency of citation (FC) following the method by Tardio and Pardo-de-Santayana (2008) as follows:

RFC = FC/N where **RFC** is the relative frequency of citation; **FC** is the number of informants listing the species and **N** is the total number of informants participating in the survey.

Results

Socio-demographic characteristics of key informants
There was a 100% response rate for the questionnaire survey since all the selected key informants were interviewed. The socio-demographic characteristics of the key informants are shown in Table 1.

Table 1. Socio-demographic characteristics of key informants in Mazowe and Shamva districts, Zimbabwe.

Variable	**Socio-demographic characteristic**	**Mazowe district percentage of key informants (n = 72)**	**Shamva district percentage of key informants (n = 72)**	**Total percentage of key informants (n = 144)**
Gender	Male	36.11	50	43.06
	Female	63.89	50	56.94
Age	18-29 years	8.33)	6.94	7.64
	30-39 years	9.72	11.11	10.42
	40-49 years	25	18.06	21.53
	50 years and above	56.94	63.89	60.42
Marital status	Single	2.78	2.78	2.78
	Married	75	81.94	78.47
	Widowed	15.28	12.5	13.89
	Divorced	6.94	2.78	4.86
Religion	None	5.56	15.28	10.42
	African Traditional	12.5	38.89	25.69
	Christianity	79.17	45.83	62.5
	Islam	2.78	0	1.39
Educational status	None	0	4.17	2.08
	Primary	55.56	54.17	54.86
	Secondary/high	44.44	41.66	43.06
	Tertiary	0	0	0
Employment status	Formal	0	1.39	0.69
	None/Informal	100	98.61	99.31
Period staying in the district	Less than 10 years	8.33	2.78	5.56
	More than 10 years	91.67	97.22	94.44
Category of informants	Traditional Healer	12.5	22.22	17.36
	Community Health Worker	8.33	9.72	9.03
	Community Leader	23.61	13.89	18.75
	Elder in Community	55.55	54.17	54.86

Knowledge of malaria, personal preventive and environmental management practices
All the key informants in both districts indicated that mosquitoes were responsible for transmitting malaria. None of the informants listed the use of prophylactic drugs for protection against malaria infection. There were differences in the deployment of government/development partner-supported preventative measures between the two districts with the use of ITNs applied in Mazowe and IRS in Shamva. The National Malaria Control and Elimination Strategic Plan 2021-2025 policy is used to guide the deployment of malaria vector control interventions at the district/ward level in the country. Indoor residual spraying is implemented in districts/wards with moderate to high malaria transmission intensity while ITNs are

distributed in districts/wards with low to moderate malaria transmission intensity. The key informants in both districts also rely on practices such as keeping homesteads clean (41.5%), personal protective clothing (30.5%), and the use of synthetic repellents (15%) for protection against mosquito bites and preventing malaria infection. A low percentage of the usage of synthetic repellents for mosquito control was reported in the two districts. On further probing, respondents cited affordability (58.5%), limited availability (41.5%), strong smell (26%), skin irritation (17.5%), and respiratory problems (0.5%) as the reasons for the low usage of synthetic repellents.

Knowledge and perceptions on the use of plants and other traditional ways of repelling mosquitoes

In both districts, knowledge of the use of plants was limited to applications targeted at adult mosquitoes only. In addition, plants are mainly used for their repellent rather than insecticidal properties. Despite broad-based government and/or development partner-driven malaria control interventions, all key informants in Shamva district and 99% in Mazowe district indicated that they also use plants for repelling mosquitoes. Besides plants, the key informants also indicated the use of smoke produced from the burning of cattle droppings (76%), egg crates (67.5%), tissue paper (31%), and elephant droppings (1.5%) as other unconventional ways of repelling mosquitoes. They indicated getting knowledge through oral tradition, especially from family, neighbors, and the elderly in their communities. The key informants in this study indicated that they use plants for repelling mosquitoes because they perceive them as being easily accessible (89%), available for free (87%), effective (35.5%), and safe (7.5%).

Plant species and families, parts used, method of application, and other known uses

Among the plants listed in both districts are those of exotic origin. A total of 53 plant species from 29 families, consisting of 33 (62.26%) native and 20 (37.74%) exotic plants were listed as being known and used for repelling mosquitoes in Mazowe and Shamva districts. A total of 32 (60.37%) plants were mentioned in both districts while 12 (22.64%) and 9 (16.98%) plants were mentioned in Mazowe district only and Shamva district only respectively.

Nine plant families had 2 or more plants used for repelling mosquitoes in Mazowe and Shamva districts, with Fabaceae and Asteraceae having the greatest numbers (Table 2). Based on RFC values, the ten most relatively important species in Mazowe district were *Lippia javanica* (Burm.f.) Spreng (0.97), *Ocimum incanum* L. (0.71), *Eucalyptus grandis* Maiden (0.6), *Tagetes minuta* L. (0.5), *Chenopodium ambrosioides* L. (0.39), *Cupressus sempervirens* L. (0.35), *Cannabis sativa* L. (0.31), *Peltophorum africanum* Sond. (0.28), *Vitex payos* (Lour.) Merr. (0.26) and *Citrus limon* L.) Burm. F. (0.25) (Table 3). For Shamva district, based again on RFC values, the ten relatively most important species were *L. javanica* (Burm.f.) Spreng (0.58), *C. ambrosioides* L. (0.44), *O. incanum* L. (0.42), *E. grandis* Maiden (0.42), *Adansonia digitata* L. (0.4), *V. payos* (Lour.) Merr. (0.33), *Capsicum frutescens* L. (0.31), *P. africanum* Sond. (0.19), *Lantana camara* L. (0.18), and *Bidens pilosa* L. (0.17). Of these, five plants namely *A. digitata* L, *C. sempervirens* L., *C. sativa* L., *P. africanum* Sond., and *V. payos* (Lour.) Merr. have not been ethnobotanically studied for mosquito repellency in the country.

The dominant growth form of plants listed by key informants in this study for repelling mosquitoes were trees (38%) followed by herbs (30%), shrubs (24%), climbers (4%), grass (2%) and succulent (2%). Leaves (43%) were the most commonly used plant parts followed by whole plants (24%), fruits (13%), bark (6%), flowers (6%), twigs (4%), bulb (2%) and seeds (2%). Four methods of application were mentioned with burning of plant parts to produce smoke being the most common method for many plants (n=30), followed by hanging fresh plants inside the room (n=11), applying extract or residue on the skin (n=11) and sprinkling residue from boiled leaves on mosquito entry and resting surfaces (n=1).

Discussion

This study showed that communities in the malaria-endemic districts of Mazowe and Shamva make use of plants for protection against mosquito bites. This is a common practice in Africa where before the use of synthetic insecticides and repellents, people traditionally used plant and plant-derived materials to repel or kill mosquitoes (Curtis *et al*. 1990; Waka *et al*. 2004). Thus, the results of this study add to a growing base of knowledge on the diverse options and directions for the utilization of plants and plant-based compounds in the management of disease vectors, including mosquitoes. In addition, this documentation serves to preserve in written form the indigenous knowledge of plants used for repelling mosquitoes in the two districts and increases the number of plants that are available for screening in the production of plant-based malaria vector control products in the country. It also forms the basis of scientific research to confirm the claims by the key informants in the present study and provides a basis for future studies in the development of new, cost-effective, safe, and environmentally friendly plant-based mosquito repellent products in Zimbabwe.

There is a high level of awareness of malaria in the two districts since all key informants were highly knowledgeable on the subject. This is an indication of the effectiveness of the government's anti-malaria interventions and malaria information and education campaigns in the two districts. However, despite acknowledging government efforts that have resulted in over 90% coverage for both ITN distribution and IRS, key informants from both districts further utilize plants to repel mosquitoes. Thus, plants are perceived by these communities as an important supplement to government-driven interventions. This might also be related to the level of protection given by repellents in general. For instance, ITNs can only be used during sleep leaving individuals exposed during the other times necessitating the use of other measures to prevent mosquito bites during those times.

Table 2. Information on plants used for mosquito repellency in Mazowe and Shamva districts, Zimbabwe.

Family	Scientific name	Voucher specimen number	Local (Shona) name	Growth habit	Status	Habitat	Mazowe district FC (RFC)	Shamva district FC (RFC)	Plant part (s) used	State of use	Method of application	Other ethnomedicinal, ethnoveterinary, spiritual and ritual uses
Amacranthaeae	*Chenopodium ambrosioides* L	DSN 21	Munhuwenhuwe	Herb	Introduced	Weed in cultivated field	28 (0.39)	32 (0.44)	Whole plant	Fresh	1. Burning 2. Hanging fresh plants inside the room	Treat convulsions and ward off evil spirits
Anacardiaceae	*Lannea discolor* (Sond.) Engl.	DSN 01	Shambavazukuru*	Tree	Native	Termite mounds in open woodlands	1 (0.01)	0	Leaves and bark	Fresh	1. Burning leaves 2. Applying extract on skin	Remedy for menstrual cycle problems, convulsions, and malaria
	Mangifera indica L.	DSN 24	Mumango	Tree	Introduced	Cultivated in gardens, orchards, and homesteads for edible fruits	2 (0.03)	1 (0.01)	Flowers	Fresh	Burning	The bark is used as stomach pain medicine
	Ozoroa reticulata (Baker f.) R Fern. & A Fern	DSN 14	Mugaragunguwo	Tree	Native	Termite mounds and rocky places in woodlands	1 (0.01)	1 (0.01)	Leaves	Fresh or dry	Burning	-
Annonaceae	*Annona stenophyla* Engl. & Diels	DSN 15	Muroro	Shrub	Native	Grasslands and open woodlands	1 (0.01)	1 (0.01)	Leaves	Fresh	Burning	Snake repellent and treat sexually transmitted infections
Apocynaceae	*Catharanthus roseus* (L.) G. Don	DSN 19	No Shona name was given*	Herb	Introduced	Cultivated as a flower in gardens	1 (0.01)	0	Whole plant	Fresh or dry	Burning	Roots used to treat stomach pains
	Diplorhynchus condylocarpon (Mull. Arg.) Pichon	DSN 10	Mutowa	Tree	Native	Open woodlands and stony hillsides	3 (0.04)	3 (0.04)	Leaves	Fresh or dry	1. Burning 2. Hanging fresh leaves inside room	Treat dry cough and protection from evil attacks

Arecaceae	*Hyphaene petersiana* Klotzsch ex Mart.	DSN 52	Murara**	Tree	Native	Dry sandy soils	0	3 (0.04)	Leaves	Fresh	Sprinkling residues from boiled crushed leaves on windows, openings, and surfaces	Protection from lightning
Asparagaceae	*Asparagus falcatus* L. var *falcatus*	DSN 34	Katsvairachuru*	Climber	Native	Dense scrub and evergreen forests	1 (0.01)	0	Leaves	Dry	Burning	Treat respiratory infections
Asphodelaceae	*Aloe chabaudii* Schonland var.*chabaudii*	DSN 02	Gavakava	Succulen t	Native	Rocky outcrops and hillsides in wooded grasslands and woodlands	2 (0.03)	11 (0.15)	Leaves	Fresh	Applying extract on the skin	Treat constipation, diarrhea, and sick chickens
Asteraceae	*Ageratum conyzoides* L.	DSN 27	Kabarikire*	Herb	Introduced	Disturbed places, formerly cultivated areas, along rivers and streams and in open woodlands	5 (0.07)	0	Whole plant	Fresh or dry	Burning	Treat high blood pressure, convulsions, hyperglycemia, sick animals and sore eyes
	Bidens pilosa L.	DSN 33	Mutsine	Herb	Introduced	Weed in gardens, fallow lands, roadsides, and other disturbed habitats	15 (0.21)	12 (0.17)	Whole plant	Fresh	Burning	Treat high blood pressure
	Dicoma anomala Sond.	DSN 46	Chifumuro	Herb	Native	Grasslands and open woodlands	2 (0.03)	7 (0.1)	Whole plant	Fresh	Burning	Remove bad luck, ward off evil spirits, and remedy for stomach pains
	Geigeria africana Griess. (O. Hoffn.) Merxm	DSN 39	No Shona name was given**	Herb	Native	Sandy soils in pans, grasslands, and open woodlands	0	1 (0.01)	Leaves	Fresh	Burning	-

	Laggera decurrens (Vahl) Hepper & J. R. I. Wood	DSN 17	Chigoso**	Herb	Native	Sandy soils in disturbed or formerly cultivated areas, grassland, and open woodland	0	3 (0.04)	Whole plant	Fresh	Hanging	Ward off evil spirits
	Tagetes minuta L.	DSN 45	Mujerimani*	Herb	Introduced	Disturbed and cultivated areas	36 (0.5)	0	Leaves	Fresh	1. Burning 2. Applying extract on skin	Ward off evil spirits
Bignoniaceae	*Jacaranda mimosiflolia* D. Don	DSN 44	Mujakaranda*	Tree	Introduced	Cultivated in grasslands and woodlands	8 (0.11)	0	Flowers	Fresh	Burning	Asthma treatment
Cannabaceae Martinov-Hemp	*Cannabis sativa* L.	DSN 51	Mbanje	Shrub	Introduced	Cultivated in gardens and homesteads	22 (0.31)	1 (0.01)	Whole plant	Fresh or dry	Burning	Ward off evil spirits and treat respiratory infections
Caricaceae	*Carica papaya* L.	DSN 48	Mupopo**	Tree	Introduced	Cultivated in gardens, orchards, and homesteads	0	2 (0.03)	Leaves, fruits, and seeds	Fresh leaves and fruit and dry seeds	1. Burning 2. Applying leaf and fruit extract on the skin	-
Chrysobalanaceae	*Parinari curatellifolia* Benth.	DSN 05	Muhacha	Tree	Native	Grasslands and open woodlands	8 (0.11)	2 (0.03)	Leaves and fruits	Fresh leaves and fruits	Burning	Treat toothache, constipation discharging ears, and tanning hides
Clusiaceae	*Psorospermum febrifugum* Spach	DSN 13	Muminu*	Shrub	Native	Wooded grasslands, scrub, and open woodlands	1 (0.01)	0	Leaves	Fresh	Burning	Remedy for stomach pains
Cupressaceae	*Cupressus sempervirens* L.	DSN41	Musaipurasi*	Tree	Introduced	Cultivated in grassland and open woodlands	25 (0.35)	0	Leaves	Fresh or dry	Burning	Treat high blood pressure, cough, and toothache
Fabaceae	*Peltophorum africanum* Sond.	DSN 06	Muzeze	Tree	Native	Along vlei margin and wooded grasslands	20 (0.28)	14 (0.19)	Leaves	Fresh	Burning	Treating toothache, sore eyes, and sexually transmitted infections

	Albizia antunesiana Harms	DSN 07	Muriranyenze	Tree	Native	Mixed woodlands	1 (0.01)	1 (0.01)	Leaves	Fresh	Burning	Treat pneumonia, constipation, and infertility in women
	Bobgunia madagascariens is (Desv.) J. H. Kirkbr & Wiersama	DSN 03	Mucherekese	Tree	Native	Grasslands and open woodlands	1 (0.01)	1 (0.01)	Leaves and fruit	Fresh	Burning	-
	Cassia abbreviata Oliv.	DSN 36	Muremberembe	Tree	Native	Grasslands and open woodlands	3 (0.04)	6 (0.08)	Fruits	Dry	Burning	Remedy for diarrhea, constipation, and abdominal pains as well as an aphrodisiac and gonorrhea treatment
	Dichrostachys cinerea (L) Wight & Arn.	DSN 35	Mupangara	Shrub	Native	On poor and overgrazed soils in wooded grasslands and savannah areas	1 (0.01)	1 (0.01)	Leaves and fruits	Dry	Burning	Treat pneumonia and venereal diseases
	Piliostigma thonningii (Schumach.) Milne-Redh.	DSN 30	Musekesa	Tree	Native	Wooded grasslands and woodlands	3 (0.04)	2 (0.03)	Fruits	Dry	Burning	Cough medicine while fruit pods used as animal feed
	Pterocarpus angolensis DC.	DSN 09	Mubvamaropa**	Tree	Native	Well-drained soils in grasslands and open woodlands	0	2 (0.03)	Leaves	Fresh or dry	Burning	Earache medicine and treat infertility in women
	Rhynchosia resinosa (Hochst. Ex A. Rich.) Baker	DSN 50	Bunganyunyu	Climber	Native	Woodland, riverine fringes, and rocky places	5 (0.07)	10 (0.14)	Leaves	Fresh	Burning	Treat stomach pains
	Stylosanthes fruticosa (Retz.) Alston	DSN 32	No Shona name was given	Herb	Native	Sandy soils in Miombo woodlands	4 (0.06)	3 (0.04)	Whole plant	Fresh	Hanging	-
Flacourtiaceae	*Flacourtia indica* (Burm. F.) Merr	DSN 47	Munhunguru**	Shrub	Native	Woodlands	0	1 (0.01)	Leaves	Fresh or dry	Burning	Diarrhea and venereal disease medicine

Hyacinthaceae	*Drimia altissima* (L.f.) Ker Gawl	DSN 18	Chikukwa	Herb	Native	Scrub and open woodlands	1 (0.01)	2 (0.03)	Bulb	Fresh	Applying extract on the skin	Asthma treatment
Lamiaceae	*Mentha longifolia* (L.) Huds.	DSN 43	No Shona name was given	Herb	Introduced	Cultivated in gardens and homesteads	12 (0.17)	4 (0.06)	Whole plant	Fresh	Hanging plant inside the room	Treat colds and coughs
	Ocimum incanum L.	DSN38	Mbanda	Herb	Native	Weed in disturbed areas area as cultivated areas, gardens, and waste places near rivers on sandy soils	51 (0.71)	30 (0.42)	Whole plant	Fresh or dry	1. Burning 2. Hanging plants inside the room	Ward off evil spirits
	Orthosiphon schimperi Benth	DSN 53	Mbanda**	Herb	Native	Disturbed area around the homestead	0	10 (0.14)	Whole plant	Fresh	Burning	Ward off evil spirits
Malvaceae	*Adansonia digitata* L.	DSN 08	Muwuyu	Tree	Native	Woodlands in dry areas	10 (0.14)	29 (0.4)	Leaves, fruit shells, and bark	Fresh leaves and bark and dry fruit shells	1. Burning leaves and fruit shells 2. Applying bark extract on the skin	Cancer treatment
	Grewia flavescens Juss. var *flavescens*	DSN 12	Mugurumhanda **	Shrub	Native	Termite mounds, rocky outcrops along forest margins, and woodlands	0	1 (0.01)	Leaves and bark	Fresh	Burning	Remedy for pneumonia, snake bites, respiratory tract infections and malaria
	Thespesia garckeana F. Hoffm	DSN 28	Mutohwe*	Tree	Native	Rocky places in open woodlands and grasslands	1 (0.01)	0	Leaves	Fresh	Burning	Earache medicine

Moringaceae	*Moringa oleifera* Lour.	DSN 49	Moringa**	Shrub	Introduced	Cultivated in gardens and homesteads for edible roots and leaves	0	11 (0.15)	Leaves	Dry	Burning	Treat diarrhea and several ailments
Myrothamnaceae	*Myrothamnus flabellifolius* Welw	DSN 04	Mufandichimuk a	Shrub	Native	Rocky surfaces in grasslands and open woodland	2 (0.03)	2 (0.03)	Twigs	Dry	Burning	Remedy for colds, nose bleeds and fainting
Myrtaceae	*Eucalyptus grandis* Maiden	DSN 29	Mugamutiri	Tree	Introduced	Cultivated in grasslands and open woodlands	43 (0.6)	30 (0.42)	Leaves	Fresh or dry	Burning	Cough treatment, grain protectant, insect repellent and ward off evil spirits
	Psidium guajava L.	DSN 26	Mugwavha	Shrub	Introduced	Cultivated in gardens, fruit orchards, and homesteads. Also found along roadsides and riverine vegetation	4 (0.06)	6 (0.08)	Leaves and fruits	Fresh leaves and dry fruits	Burning	Treat coughs
	Syzigium guineense (Willd.) DC. subsp. *guineense*	DSN 25	Mukute	Tree	Native	Along streams and rivers and roadside banks and wooded grassland and woodlands	1 (0.01)	2 (0.03)	Leaves	Fresh	Burning	The bark is used as tuberculosis medicine
Poaceae	*Cymbopogon citratus* (DC) Stapf	DSN 42	Remonigirasi	Grass	Introduced	Cultivated around homesteads	3 (0.04)	2 (0.03)	Whole plant	Fresh	Hanging	Treat colds and coughs

Rubiaceae	*Vangueripsis lanciflora* (Hiern.) Robyns	DSN 16	Mutufu*	Shrub	Native	Rocky outcrop, sandy soils in open woodlands and grasslands	1 (0.01)	0	Leaves	Fresh	Burning	Cough treatment
Rutaceae	*Casimiroa edulis* La Llave	DSN 23	Muzhanje vechirungu *	Tree	Introduced	Cultivated in gardens, orchards, and homesteads for its edible fruits	1 (0.01)	0	Leaves	Fresh	1. Burning 2. Hanging fresh leaves inside the room	-
	Citrus limon (L.) Burm. F.	DSN20	Muremani	Shrub	Introduced	Cultivated in gardens and homesteads as a fruit tree	18 (0.25)	2 (0.03)	Leaves	Fresh	Applying leaf extract on the skin	Treat colds and coughs
Solanaceae	*Capsicum frutescens* L.	DSN 22	Mhiripiri	Herb	Introduced	Cultivated in gardens and homesteads	2 (0.03)	22 (0.31)	Whole plant	Fresh or dry	1. Burning 2. Hanging fresh plants inside the room	Scare away snakes and malaria treatment
	Solanum lycopersicum L.	DSN 40	Mudomasi*	Herb	Introduced	Cultivated in gardens and homesteads	1 (0.01)	0	Twigs	Fresh	Applying extract on the skin	-
Verbenaceae	*Lantana camara* L.	DSN 37	Mbarapati	Shrub	Introduced	Disturbed or formerly cultivated areas and woodlands	3 (0.04)	13 (0.18)	Leaves and flowers	Fresh or dry	1. Burning 2. Hanging fresh plants inside the room	Treat ringworm infections and eye treatment
	Lippia javanica (Burm.f.) Spreng	DSN31	Zumbani	Herb	Native	Stream banks, forest fringes, and hillsides on grasslands	70 (0.97)	43 (0.58)	Leaves	Fresh or dry	1. Burning 2. Hanging fresh leaves inside room	Treat colds and coughs, grain protectant, treat sick domestic animals, treat female reproductive systems, and ward off evil spirits

	Vitex payos (Lour.) Merr.	DSN 11	Mutsvubvu	Shrub	Native	Rocky slopes in open woodlands and wooded grasslands	19 (0.26)	24 (0.33)	Leaves	Fresh or dry	1. Burning 2. Applying extract on skin	Smoke from burning leaves is used as cough medicine

*Plant mentioned in Mazowe district only; ** Plant mentioned in Shamva district only

While individuals can apply topical and other synthetic repellents, this study showed that there are several reasons for their low adoption and utilization, ranging from costs to health concerns. This is also the case in other African countries, such as Guinea Bissau, and Kenya where the majority of villagers reportedly cannot afford synthetic repellents due to poverty (Odalo *et al*. 2005, Palsson and Jaenson 1999). Thus, communities perceive plant and plant-based repellents as viable alternatives that are cheap, safe, and effective. Some authors similarly cited accessibility, availability, and affordability as the major reasons for preference of plants over synthetics by indigenous people in Africa and other parts of the world (Palsson and Jaenson 1999; Kweka *et al*. 2008; Mavundza *et al*. 2011; Karunamoorthi and Hailu 2014; Iyamah and Idu 2015; Innocent *et al*. 2016; Bonkian *et al*. 2017; Kantheti and Padma 2017; Youmsi *et al*. 2017; Ejecta 2019; Gou *et al*. 2020). Besides being cheap and locally available homegrown natural plant repellents are locally known and generally culturally acceptable (Bekele 2018).

All the key informants acknowledged oral tradition as the source of their knowledge of plant species used for personal protection against mosquito bites. Several other studies reported that information on mosquito-repellent plants was verbally transmitted from one generation to another (Palsson and Jaenson 1999; Kweka *et al*. 2008; Karunamoorthi *et al*. 2009; Mavundza *et al*. 2011; Bonkian *et al*. 2017; Kantheti and Padma 2017; Youmsi *et al*. 2017; Ejecta 2019; Gou *et al*. 2020). Information on mosquito-repellent plants can be lost or distorted during the process and as argued by Bonkian *et al*. (2017), oral tradition can lead to the disappearance of local knowledge about resources since this knowledge is usually held by a few illiterate people in the communities. Hence, the preservation of this knowledge in written form through documentation is very important for future research purposes as it can be improved scientifically for better informed and rational use.

A diverse list of plants utilized by the communities in the present study showed huge similarities in the plant species used and utilization patterns despite the spatial separation of the two districts. Similarities and differences in traditional knowledge among different communities living within the same ecological region provide an understanding of how cultural reflection can change individual viewpoints about the environment and guide interactions between humans and resources in their ecosystems (Quave and Pieroni 2015). Sixty-two percent of the plants are native to the country and five of the ten most relatively important plants with mosquito-repellent activity mentioned in this study namely *L. javanica* (Burm.f.) Spreng., *O. incanum* L., *V. payos* (Lour.) Merr., *A. digitata* L., and *P. africanum* Sond. are native to Zimbabwe. This study therefore confirms that indigenous knowledge can provide valuable information on native plants with potential use in the production of mosquito control products. Native plants can be easily propagated for their utility without many ecological challenges. This study further showed that some plants of exotic origin are also utilized for mosquito control in the study areas, indicating the adventitious nature of these communities.

The RFC values in this study ranged from 0.01 to 0.97. The value of RFC directly correlates with the relative importance of the species as a mosquito-repellent plant since it indicates the significance and status of a particular plant species in the targeted community (Trotter and Logan 1986). Plants with high RFC values indicated their widespread knowledge and abundant use as well as the retention and smooth flow of traditional knowledge among local people (Tardio and Pardo-de-Santayana 2008). Except for *C. sempervirens* L., *C. sativa* L., and *A. digitata* L., all the plants with high RFC values are widely distributed in the study areas. The number of plants reported in this study was very high when compared to similar studies in other parts of Africa. This indicates the richness of indigenous knowledge amongst the communities in the study area and their heavy reliance on plants in the absence of synthetic repellents. Palsson and Jaenson (1999) reported eight plant species in Guinea Bissau whilst Kweka *et al*. (2008) reported five plant species belonging to four families in Tanzania. Karunamoorthi *et al*. (2009) reported nine plant species belonging to eight families in Ethiopia while in South Africa, Mavundza *et al*. (2011) reported 13 plant species belonging to nine families. Edwin-Wosu *et al*. (2013) reported 24 plant species used for protection against mosquitoes in South-Eastern Nigeria. *Lippia javanica* (Burm.f.) Spreng was the most mentioned plant in the present study. Lukwa *et al*. (1999) also reported that 50% of the study informants in Mutasa district in Manicaland Province, Zimbabwe, used *L. javanica* as a mosquito repellent by smoking and placing fresh plant parts in houses.

The lists of plants used for repelling mosquitoes in the present study were dominated by plants from the Fabaceae (17%) and Asteraceae (11%) families. In contrast, studies conducted in Ethiopia and Nigeria showed that the family Lamiaceae was the most reported in ethnobotanical studies on mosquito repellency (Karunamoorthi *et al*. 2009; Adelaja *et al*. 2021). This suggests that the utilization of plants for ethnobotanical purposes may be driven by local availability. The majority of plants listed by informants in this study for repelling mosquitoes were trees (38%), shrubs (24%), and herbs (30%) whilst leaves (43%), whole plants (24%), and fruits (13%) were the most used plant parts. Araya *et al*. (2015) and Maroyi (2011) noted that plant growth form and seasonal availability mediate utilization for medicinal purposes. The prominent application of leaves for most repellent plants was also reported in similar studies that were conducted in North Western Ethiopia (Karunamoorthi *et al*. 2009) and South Africa (Mavundza *et al*. 2011). Youmsi *et al*. (2017) assert that the prominent application of leaves for most repellent plants could be due to the readily available volatile (essential oils) compounds in leaves. The use of leaves of insecticidal plants for the control of hematophagous insects is a more sustainable option than whole plants, roots, and bark since the natural growth of the plant would not be disrupted (Karunamoorthi and Husen 2012). The local communities in the study areas also prefer to use whole plants but this is not recommended as the exploitation of whole plants has harmful effects on regeneration and may lead to species extinction (Giday *et al*. 2003).

The present study also revealed a high frequency of utilization of some plants that have no published or verified data on mosquito repellency against the main malaria vectors in the country. Amongst the relatively most important plant species in this study, only *L. javanica* (Burm.f.) Spreng (Lukwa 2009; Kazembe and Jere 2012), *O. incanum* L. (Kazembe *et al*. 2012), *E. grandis* Maiden (Lukwa *et al*. 2018), *C. ambrosioides* L. and *B. pilosa* L. (Kazembe and Nkomo 2012) and *T. minuta* L. (Lukwa *et al*. 2018) were evaluated and reported effective repellents against mosquitoes in Zimbabwe. Five plants namely *A. digitata* L., *C. sempervirens* L., *C. sativa* L., *P. africanum* Sond., and *V. payos* (Lour.) Merr. have not been ethnobotanically studied for mosquito repellency in the country. Experimental studies were conducted to confirm claims by informants in Tanzania (Kweka *et al*. 2008) and in South Africa (Mavundza *et al*. 2014). Consequently, there is a need to validate experimentally the repellent effect or insecticidal efficacy of plants documented in the present study against malaria-transmitting mosquitoes through conducting both laboratory and field research. The plants can be selected based on their folkloric use, and subjected to scientific evaluation studies to confirm the claim by the key informants in this study and justify their use in malaria vector control.

Burning of fresh or dry plant parts to produce smoke, hanging of plants inside rooms and the application of plant extract on skin were the most common methods used to repel mosquitoes in the two districts. The hanging of bruised plants in houses and the application of oil formulations to the skin are widely practiced in developing countries (Lee 2005) whilst smoke, plant extracts, oils, and mud have been traditionally used to repel mosquitoes (Seyoum *et al*. 2003). Smoking is a common method of repelling biting mosquitoes throughout the world (Moore *et al*. 2006). However, the use of smoke as a mosquito repellent is not desirable since it can lead to respiratory problems. Challenges associated with the direct burning of plants to produce smoke can be addressed using thermal expulsion (Lee *et al*. 2001; Seyoum *et al*. 2003; Bekele 2018).

All the plants mentioned and documented in the present study were used by the key informants as individual plants and not as combinations or mixtures of plants or plant parts. Previous laboratory studies conducted in Zimbabwe using mixtures of extracts derived from different plants showed that mixtures had higher repellency and protection periods than individual extracts (Kazembe and Jere 2012, Kazembe and Makusha 2012, Kazembe and Nkomo 2012, Kazembe *et al*. 2012). There is a general belief that mixtures enhance the repellency and insecticidal efficacy of repellent plants (Kazembe *et al*. 2012). The evaluation of the effect of mixtures of plants or plant parts used by the communities for repelling mosquitoes in Mazowe and Shamva districts in increasing the repellency efficacy of these plants under natural field conditions is required and significant.

The communities in Mazowe and Shamva districts possess valuable local plant knowledge on the use values of plants in their surroundings since the key informants reported that apart from their use in repelling mosquitoes, most of the plants listed in this study were also used for other ethnomedicinal, ethnoveterinary, spiritual and ritual purposes. The multiple functions of the plants in the surrounding areas play important roles in the daily lives of the local people and efforts should be directed towards the conservation and protection from abuse and extinction of the plants. Apart from the use of plants, smoke produced from burning cattle and elephant droppings, tissue paper, and egg crates were the other unconventional measures used for protection against mosquito bites and prevention of malaria infection in Mazowe and Shamva districts. These unconventional measures for protection against mosquito bites can also be scientifically evaluated as additional potential sources for the development of new strategies for malaria vector control in the country.

Conclusion

The present study has shown that communities in Mazowe and Shamva districts in Mashonaland Central province in Zimbabwe possess valuable knowledge on the use of plants for repelling mosquitoes. This knowledge was not documented and was passed on from one generation to another through oral tradition. This study documented plants used for repelling mosquitoes in the two districts. This documentation is important in preserving traditional knowledge of plants used for repelling mosquitoes in the country. Similar studies are recommended in other malaria-endemic parts of the country. The repellent efficacies of some of the plants listed in the present study are unknown. There is, therefore, a need for field-based scientific and experimental validation studies to confirm the claims of the key informants in this study so that the use of the documented plants can be promoted as a sustainable way of avoiding mosquito bites and controlling malaria transmission in rural malaria-endemic communities in the country. Future research should also consider investigating the larvicidal efficacy, phytochemistry, and safety of the documented mosquito-repellent plants. An evaluation of the conservation status of the plants that were documented in this study is also significant since some of the documented plants were reported to have multiple uses justifying the need for their proper conservation and protection from overuse and extinction. This study, therefore, opens up avenues for future research concerning plants used as mosquito repellents, contributing further to the exploration of plants as malaria vector control tools in Zimbabwe.

Declarations

***List of abbreviations*:** DEET: N, N-diethyl-3-methylbenzamide; FC: Frequency of citation; IRS: Indoor residual spraying; ITNs: Insecticide-treated bed nets; NMCP: National Malaria Control Program; RFC: Relative frequency of citation; WHO: World Health Organisation.

Ethics approval and consent to participate: The study was carried out following the recommendations of the International Society of Ethnobiology Code of Ethics. Informed written consent was obtained from all the study participants.

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