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Research Article

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Abstract

Background: Folk medicine is crucial to healthcare delivery in the underdeveloped countries. It is frequently used as a primary treatment option or as a complementary therapy for malaria treatment. Malaria is a deadly disease which greatly threatens global public health, claiming incredible number of lives yearly. The study was aimed at documenting the medicinal plants used for malaria treatment in folk medicine in Kwara State, Nigeria.

Methods: Ethnobotanical information was collected from selected consenting registered traditional medicine practitioners (TMPs) through oral face-to-face interviews using in-depth, semi-structured questionnaires. Data were analysed and discussed in relation to published literature on the documented plants.

Results: Sixty-two indigenous medicinal plants including 13 new plants used for malaria treatment were identified in this study. The TMPs preferred decoction in aqueous solvent (34%) and steeping in decaffeinated soft drink (19%) for herbal preparations. Oral administration (74%) was the main route of administration, while leaves (40%) and stem barks (32%) were the most dominant plant parts used in herbal preparations. The most cited families were Fabaceae (15%) and Rutaceae (6%), while *Mangifera indica* (77.14%), *Enantia chlorantha* (65.71%), *Alstonia boonei* (57.14%) followed by *Cymbopogon citratus* (54.29%) were the most used plants. Besides, the antimalarial activities of many of the plants recorded and their isolated phytocompounds have been demonstrated. Furthermore, the conservation status of 4 identified plants were Vulnerable.

Conclusion: The study showed strong ethnobotanical knowledge shared by the TMPs in the State and provides preliminary information that could be explored for discovery of more potent antimalarial compounds.

Background

Malaria is a deadly disease which has continued to plague global health for many centuries now, leading to an unimaginable loss of life annually. The malaria scourge is evolving, dynamic and diverse, and currently, it is concentrated in some of the poorest nations in the world [1]. In particular, the World Health Organization (WHO) African Region is affected the most where it causes huge economic setbacks, and mostly afflicts children below age 5; an outcome that is largely attributed primarily to *Plasmodium falciparum*, the most virulent of the five human malaria parasite species [2-4]. In 2021, an estimated 247 million malaria cases were reported in 84 malaria endemic countries worldwide and Africa, with 234 million cases, accounted for approximately 95% of all malaria cases globally. Death due to malaria in 2021 was estimated to be 619, 000 and the largest mortality was recorded in Nigeria [4]. The rapid spread of resistance of the malaria parasites to recommended drugs including artemisinin-based compounds [4-8], in addition to the high cost of procurement of antimalarial drugs and counterfeiting have made the treatment and control of the disease very challenging and almost impossible [9] hence, necessitate urgent need for more potent and safer alternative therapeutic agents with novel mode of action.

Since time immemorial, humans have relied upon medicinal plants for the prevention and cure of myriad of diseases and pathological disorders including malaria [10]. The application of the knowledge of medicinal plants for the treatment of various diseases has attracted attention of researchers and formed the basis for modern pharmacology leading to the discovery and development of different therapeutic agents with plant origin [11, 12]. Today, the application of medicinal plants in folk medicine is still accepted as a preferred source of primary health care delivery in many nations including Nigeria and other parts of Africa [13-16] in spite of the paucity of pharmacological elucidation of their mechanisms of action and standard clinical trials. About

80% of the world's population is reported to depend on the use of medicinal plants as essential sources of pharmaceutical and therapeutic needs largely because they are accessible and affordable [17-19].

Nigeria has a rich heritage in folk medicine in which herbal preparations comprising different medicinal plant parts are used as an alternative or to complement orthodox medicine in the prevention or treatment of many diseases and health disorders [18, 20, 21]. Till date, many Nigerians, especially those in rural and peri-urban areas, still depend on folk medicine as a major source of healthcare because it is readily available, conventional medicine is expensive, there is lack of adequate healthcare facilities, and also due to their limited access to allopathic medicine [13, 22]. Yet, others use herbal formulations most of the time simply because they trust them and their ancestors have been using them over the years.

A large number of medicinal plants that are used for malaria treatment in Nigeria, either singly or as polyherbal recipes, have been reported in previous studies [23-26] and many of them have been demonstrated to possess antimalarial properties [27-30] and could serve as new leads for the discovery, design and development of more potent antimalarial agents [27]. This is predicated on the fact that the two most successful antimalarial drugs -quinine and artemisinin- were synthesized from plants [31, 32]. In the light of the above, exploration of the rich biodiversity of indigenous medicinal plant taxa through ethnobotanical and pharmacological studies becomes very important.

Ethnobotanical studies concentrate on the intricate relationship between indigenous people and local plants, including customs and cultural beliefs connected to various uses [33]. These studies help to collect vital ethnobotanical information from indigenous people including herbal practitioners in order to preserve the indigenous knowledge on the diagnosis of diseases, plant

species used for treatment of diseases, their modes of preparation and administration used in folk medicine, as well as the socio-cultural heritage of indigenous people for succeeding generations [34, 35]. In addition, ethnobotanical surveys are of great socio-economic importance to researchers as they are acknowledged as one of the most efficient ways of finding and documenting new medicinal plants with novel therapeutic properties and uses, and therefore enhance drug discovery and development approaches [36, 37]. This knowledge could be eroded and eventually lost to future generations without prompt and proper documentation since they are often passed through verbal communication and inappropriately documented [38, 39]. Besides, many of these plants are being destroyed due to industrialization, urbanization and expansion of housing programmes while some taxa are becoming endangered or threatened as a result of the loss of their natural habitats [40, 41].

The current study is premised on the observations of the historic application of medicinal plants in traditional medicine for the treatment of various human diseases among traditional medicine practitioners (TMPs) in the study area. We hypothesized that the TMPs that provide treatment for different human diseases and health disorders in the study area have valuable knowledge about the medicinal plants used for malaria treatment. Hence, this ethnobotanical survey was designed to identify and coherently document the indigenous medicinal plant taxa that are used in folk medicine for malaria treatment in Kwara State, Nigeria. Although, ethnobotanical studies of medicinal plants used in the treatment of malaria in north-eastern [42], south-western [25, 43-46], and south-eastern [23, 47, 48] regions of Nigeria have been reported, to the best of our knowledge, this is the first comprehensive account of the ethnobotanical resource of indigenous medicinal plants used for malaria treatment in the region. The current survey was carried out as a preliminary to a larger study, the aim of which is to collect the five most used

plants by the TMPs in the State for malaria treatment, evaluate them for antimalarial activity and isolate the bioactive principles in an effort to discovering new lead structures.

Methods

Description of the study area

Kwara State is located in the North-Central region of the Federal Republic of Nigeria and lies between latitudes 7°45′ N and 9°30′ N and longitudes 2°30′ E and 6°25′ E. The state consists mostly of wooded savannah with forested regions in the south. It has a tropical wet and dry climate with a mean annual precipitation of about 1200 mm [49]. The distribution of rain is bimodal with long rains between April and September and short rains from October to November annually. The dry season is usually between November and March. Its average annual temperature is about 26.2 °C and peaks at about 30 °C in March. Kwara State is divided into three Senatorial Districts: Kwara North, Kwara Central and Kwara South, and 16 Local Government Areas (LGAs) (Fig. 1).

The inhabitants of the State are predominantly of Yoruba-speaking ethnic group comprising Christians, Muslims and African Traditional worshippers. Others include Nupe, Bariba, Busa and Fulani minorities. They are dominated with farmers, traders, wage earners as well as those engaged in commercial services.
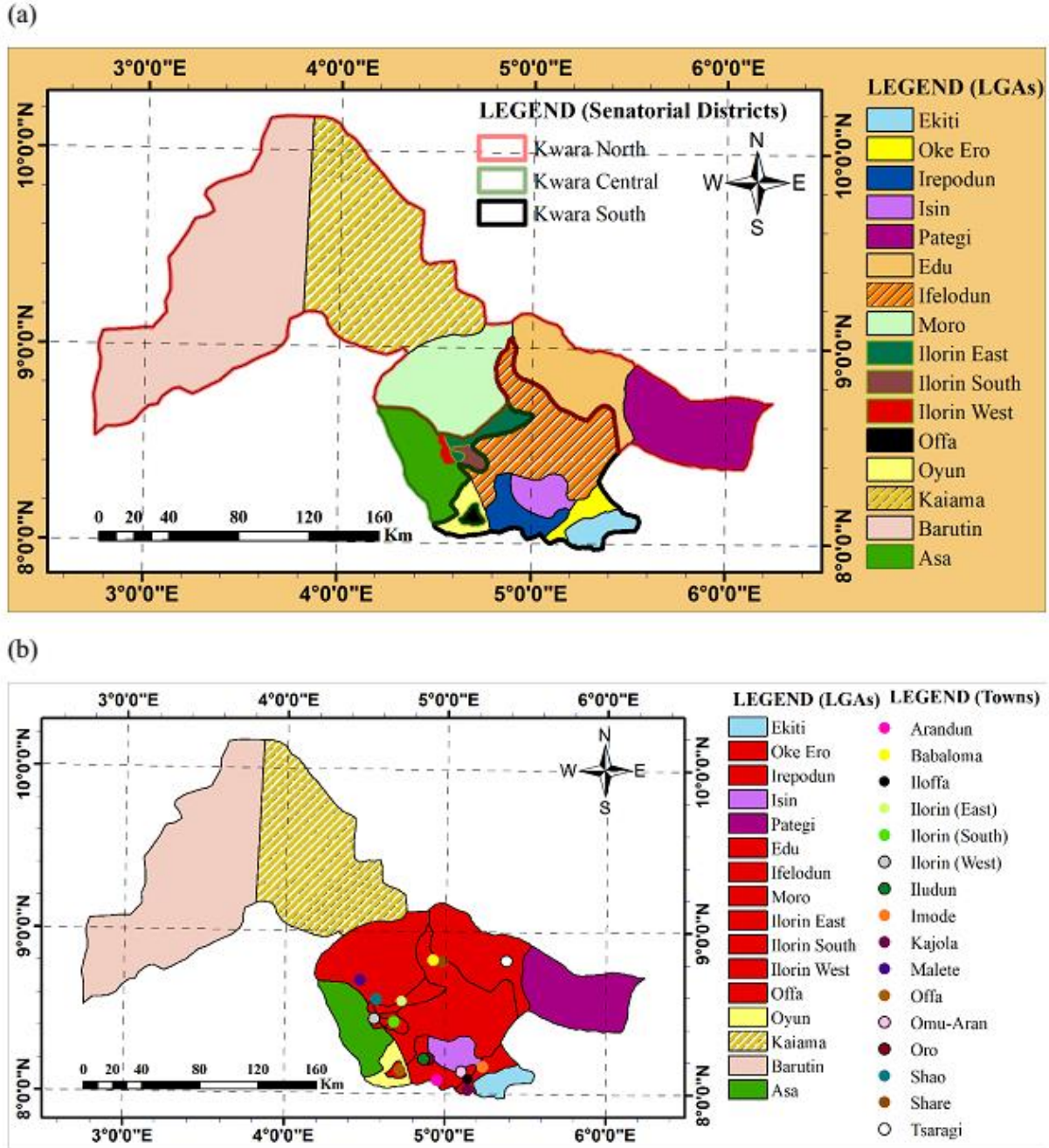
Fig. 1 Map of Kwara State showing (a) the Senatorial Districts and LGAs, and (b) the LGAs (red) with the Towns/Villages visited

Selection of study participants and exclusion criteria

The respondents (Traditional medicine practitioners, TMPs) were purposively selected from the study area adopting the method of Vasileiou et al. [50]. Purposeful sampling is utilized to select respondents who are most likely to provide relevant and useful information, and is a way to identify and select cases that will make efficient use of limited research resources available [51]. In each location, approval from the highest-ranking TMP was sought who later granted permission for the study and provided a list and locations of other TMPs in the village/town. They were giving essential information regarding the concept of the study in order to seek their consent and willingness to participate in the survey. All the TMPs willing to participate in the study were included in the survey. They were questioned individually on their knowledge of malaria and indigenous medicinal plant species used for malaria treatment.

Hawkers of medicinal plants used for malaria treatment as well as indigenes and dwellers with some form of knowledge about medicinal plants used for malaria treatment but are not TMPs were excluded from the survey.

Ethnobotanical data collection and plant identification

The participants were questioned individually in their homes and workplaces on the knowledge of using medicinal plants for malaria treatment. Data on socio-demographic characteristic of the TMPs, diagnosis/symptoms of malaria and ethnobotanical uses of the indigenous medicinal plants were collected through oral face-to-face interviews by the use of in-depth, standardized semi-structured questionnaires (Supplementary 1) [52]. The survey was conducted between November and December, 2021. Ethnobotanical information including the vernacular names of commonly used plants for malaria treatment, frequently used plant parts, methods of herbal preparation, mode of administration, dosage, duration of malaria treatment and possible side effects were obtained from the participants and recorded using a recorder. They were later translated and properly

documented. The bio-data of the participants including age, gender, town or village, religious affiliation, level of education and years of experience were also recorded. Three Yoruba-speaking field assistants, who are familiar with some of the medicinal plants used by the indigenous people of the State for malaria treatment, were engaged to administer and interpret the questions to the participants in their local languages, including Yoruba and Nupe, so as to facilitate efficient communication.

Photographs of the plants reported were taken to verify the taxonomic identification. Several plant identification guides were used to identify the family and species names of the medicinal plants obtained from the informants [53-55]. The scientific names of the plant species were checked with the "Plant List database" (www.theplantlist.org) [56] for accuracy. Thereafter, the voucher specimens were prepared and authenticated by experts, and deposited at the Forestry Research Institute of Nigeria (FRIN), Ibadan, National Institute of Pharmaceutical Research and Development (NIPRD), Abuja and University of Benin Herbarium (UBH), Benin City, Nigeria.

Data analysis

Data were computed and analysed using the Statistical Packages for the Social Sciences (IBM SPSS) Statistics software v25. Descriptive statistical method (percentage and/or frequency) was employed to summarize the ethnobotanical data. Results were reported as charts and tables.

Conservation status of the medicinal plants

The conservation status of the indigenous medicinal plants was collected and recorded for different conservation attributes, and classified according to the International Union for Conservation of Nature [57].

Results and Discussion

Sociodemographic data of the informants

For the survey interview, a total of 35 indigenous TMPs comprising 10 (28.57%) males and 25 (71.43%) females (Supplementary Table S1) were randomly selected from 16 Towns/Villages across 9 Local Government Areas (LGAs) in the 3 Senatorial Districts of Kwara State. The educational background of the informants showed that 17 (48.6%), had no formal education. Seven of the informants had secondary (20%) and 6 had primary education (17.1%) respectively. Others attended Polytechnic (8.6%) and College of Education (5.7%).

The higher number of female respondents involved in herbalism could be attributed to the unique role women play both in the family and society. A similar trend was also observed in earlier reports [45, 58, 59]. The largest age group of the informants was 48-69 years old (51.43%); this was followed by those above or equal to 70 years old (25.71%) and 25-47 years old (20%) while the smallest age group was less than 21 years old (2.86%). This corroborates earlier studies by Tchicaillat-Landou et al. [59] and Raimi et al. [60]. They reported that the majority of traditional healers who served as respondents in their ethnobotanical study was 40 and above. Also, our findings substantiate the report of Mudau et al. [61]. which showed that most of the traditional healers in their survey were 41 years and above with adults between 21 and 40 years constituting the least.

Put together, the data support the concept that older generations are the main custodians of the knowledge of folk medicine and are more interested in traditional medicine practice compared with the younger generations. This development presents an enormous threat to the sustainable retention, transfer and enhancement of existing knowledge about the use of indigenous plants for folk medicine since it may eventually be lost following the demise of older generation. A possible reason for lower knowledge among young informants could be as a result of their limited interest

in herbalism due to changes in lifestyle influenced by rapid sociocultural transformation, marked by industrialization and modernization. Also, due to the increasing literacy level, traditional medicine practice is becoming unpopular and unattractive to younger generations as such, they do not pay attention to the knowledge of using medicinal plants as sources of therapy.

Eleven (31.43%) of the informants had over 40 years' experience as TMPs. This is followed by 13 (37.14%), 7 (11.25%) and 4 (11.43%), for 26–40, 11–25, and less than 10 years of experience, respectively. Regarding religious affiliation, most of the informants were Muslims (77%), others were Christians (17%) and Traditionalist (6%). When we asked our informants how they gathered knowledge about plants and became TMPs, 48.6% stated that they were taught folk use of medicinal plants by their mother. Others received their education about herbal medicine from their father (25.7%), maternal grandparents (17.1%), maternal aunts (5.7%), and 2.9% was self-taught. This shows that transition of knowledge about the use of medicinal plants as sources of therapy is usually ancestral; passed down from one generation to another, supporting earlier findings [62, 63].

Documented medicinal plant species used for malaria treatment in Kwara State and their taxonomy

The ethnobotanical information inventoried in this survey is presented in Table 2. The vernacular/indigenous, common and scientific names of the plants, plant family, plant habit, plant parts used, use reports and citation frequency (%) are shown in the table. In this ethnobotanical investigation, a total of 62 indigenous medicinal plant species belonging to 58 genera distributed across 36 families were revealed by the TMPs to be used in traditional health care system for malaria treatment (Table 1).

Many of the medicinal plants identified in this study are also utilized for malaria treatment in other parts of Nigeria [24,43,64]; and several other nations in Africa including Benin Republic [65]; Cameroon, Kenya and Namibia [66]; Ethiopia [67, 68]; Togo [69] and Zimbabwe [70]. Additionally, they have also been reported to be used for the treatment and management of a wide range of ailments and health disorders such as chronic diarrhoea, jaundice, insomnia and rheumatism [71, 72]; asthma, warts, cancer, chicken pox and gonorrhoea [23, 73]; fever, hepatitis, tuberculosis and urinary tract infections [74, 75]; cough, bronchitis, laryngitis and hoarseness of voice [76-78]; nasopharyngeal, heamorrhoids, skin infections and infertility [79]; bronchitis, stomach ache, monorrhagia, high blood pressure and diabetes [80, 81].

When compared to similar ethnobotanical surveys carried out in north-eastern [42], south-western [9, 43-45, 64] and south-eastern Nigeria [23], this present study recorded a higher number of plant taxa used for malaria treatment. Nevertheless, it recorded fewer number of plants in comparison to Oyeyemi et al. [24] in south-western Nigeria. Noteworthily, 13 new plants which have not been reported before in previous ethnobotanical surveys of plants used for malaria treatment in Nigeria were identified in this study (*Acanthus montanus*, *Calliandra haematocephala*, *Pseudocedrela kotschyi*, *Vitellaria paradoxa*, *Ancistrophyllum secundiflorum*, *Waltheria indica*, *Byrsocarpus coccineus*, *Piliostigma thonningii*, *Cussonia barteri*, *Senna occidentalis*, *Tetracera potatoria*, *Ficus platyphylla* and *Entada africana*). Altogether, the data obtained in this study contribute to the concerted effort globally to record local plants and their accompanying indigenous knowledge for the benefit of the present and succeeding generations [26, 82]. Additionally, the present study adds to the existing collection of medicinal plants in Nigeria [26, 43, 45, 73, 78, 83, 84].

Our results showed that a total of 36 medicinal plant families were used as traditional antimalarial medicine (Table 1). Regarding the number of identified species, the family Fabaceae was the most dominant plant family, represented with 9 species (15%) used as medicine for malaria treatment. This was followed by Rutaceae 4 species (6%), Poaceae, Meliaceae, Malvaceae and Moraceae with 3 species (5%) each. Twenty-three (63.89%) other families were represented with a single species (2%) each. The dominance of Fabaceae as the most represented family has been reported in previous ethnobotanical surveys in Nigeria [45, 73, 78, 85, 86], as well as in other African countries including Ghana [87], South Africa [88], the Democratic Republic of Congo [89], and Uganda [90]. These data suggest a richness of their local flora species and affirm the popularity of Fabaceae for their curative effectiveness.

Habit of plants utilized for malaria treatment among the informants

The inventory of 62 indigenous medicinal plants was represented by different plant habits which were dominated by woody species (81%) comprising trees (57%) and shrubs (24%) (Fig. 2). The remaining 20% of the plants were distributed among herb (6%), climber (6%), grass (5%) and weed (2%). The strong connection between the predominant local plants corresponds to the dominance of plant habit used for medicine among the traditional medical practitioners [87, 91]. In comparison with herbaceous plant species, the preponderance of trees and shrubs in folk medicine is linked to their comparatively longer accessibility and persistence of the various plant parts used [92].
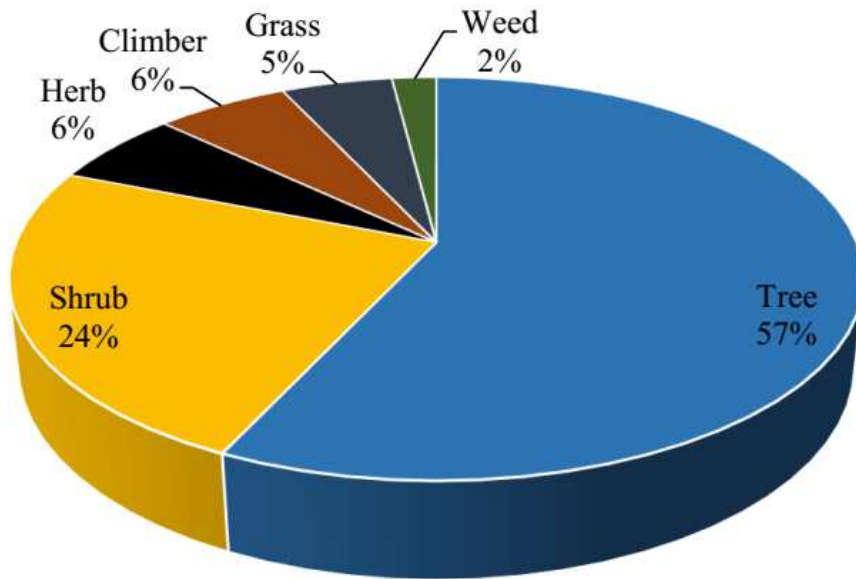
Fig. 2 Percentage distribution of habit of medicinal plants used for malaria treatment

Table 1 Ethnobotanical data including use reports, citation frequency and conservation status of the identified indigenous medicinal plants

S/n	Local names	Common names	Scientific names Voucher number	Plant family	Habit of plant	Plant parts used	Use value	Citation frequency (%)	Conservation status
1.	Mongoro	Common Indian mango	*Mangifera indica* Linn. (FHI 109451)	Anacardiaceae	Tree	Stem bark, root, leaves	27	77.14	DD
2.	Awopa or Dokita igbo	African yellow wood	*Enantia chlorantha* Oliv. (FHI 109950)	Annonaceae	Tree	Stem bark, root, leaves	23	65.71	NE
3.	Ahun	Stool wood, Pattern wood	*Alstonia boonei* De Wild (FHI 107254)	Apocynaceae	Tree	Stem bark, root	20	57.14	LC
4.	Ewe tii	Lemon grass	*Cymbopogon citratus* (DC.) Stapf (FHI 605214)	Poaceae	Grass	Leaves	19	54.29	NE

5.	Egbesi	African peach	*Nauclea latifolia* Sm. (FHI 112779)	Rubiaceae	Tree	Stem bark, root, leaves	15	42.86	LC
6.	Oruwo	Brimstone tree	*Morinda lucida* Benth. (FHI 106992)	Rubiaceae	Tree	Stem bark, root, leaves	10	28.57	LC
7.	Ibepe	Pawpaw	*Carica papaya* Linn. (FHI 109462)	Caricaceae	Tree	Leaves, Unripe fruit	9	25.71	DD
8.	Kasu	Cashew	*Anacardium occidentale* Linn. (FHI 109858)	Anacardiaceae	Tree	Stem bark, root, leaves	9	25.71	LC
9.	Aganwo or Oganwo	African mahogany	*Khaya ivorensis* A. Chev. (FHI 56845)	Meliaceae	Tree	Stem bark	9	25.71	VU
10.	Boonii	Gum Arabic tree	*Acacia nilotica* (L.) Delile	Fabaceae	Tree	Stem bark, leaves	8	22.86	LC

			(FHI 108425)						
11.	Amuje wewe or Kanti-kanti	Crimson thyme	*Byrsocarpus coccineus* Schum. & Thonn. (FHI 112950)	Connaraceae	Shrub	Stem bark	6	17.14	LC
12.	Epoara	Sleeping morning	*Waltheria indica* Linn. (FHI 92465)	Malvaceae	Shrub	Stem bark, leaves	6	17.14	NE
13.	Koko	Cocoa	*Theobroma cacao* Linn. (FHI 700314)	Sterculiaceae	Tree	Stem bark	6	17.14	NE
14.	Laali (Yoruba), Lăli (Nupe)	Henna tree	*Lawsonia inermis* Linn. (FHI 702616)	Lythraceae	Shrub	Leaves	5	14.29	LC
15.	Akerejupon or Ajo	Sphenocentrum	*Sphenocentrum jollyanum* Pierre (FHI 108283)	Menispermaceae	Shrub	Root, leaves	5	14.29	NE

16.	Osan wewe	Lime	*Citrus aurantifolia* (Christm.) Swingle (FHI 110009)	Rutaceae	Tree	Stem bark, leaves	5	14.29	NE
17.	Ayin	African birch	*Anogeissus leiocarpus* (DC.) Guill. & Perr. (FHI 107122)	Combretaceae	Tree	Stem bark, root, leaves	4	11.43	NE
18.	Idi	Tropical carpet grass	*Axonopus compressus* (Sw.) P.Beauv. (FHI 109977)	Poaceae	Grass	Leaves	4	11.43	LC
19.	Osan-laimu or Osan agan	Lemon	*Citrus limon* (L.) Osbeck (FHI 110008)	Rutaceae	Tree	Fruit	4	11.43	LC
20.	Ponhan	Red iron wood	*Lophira alata* Banks *ex* Gaertn. (FHI 109820)	Ochnaceae	Tree	Stem bark	4	11.43	VU

21.	Dongoyaro	Neem	*Azadirachta indica* A.Juss. (FHI 112927)	Meliaceae	Tree	Root, leaves	4	11.43	LC
22.	Owu or Owu akese (Yoruba), Lulu fùkà (Nupe)	Cotton plant	*Gossypium barbadense* Linn. (FHI 107327)	Malvaceae	Shrub	Leaves	4	11.43	NE
23.	Karandafi or Poroporo	Red sorghum	*Sorghum bicolor* (L.) Moench (FHI 109659)	Poaceae	Grass	Leaves, root	4	11.43	LC
24.	Okuuku	Giant rattan	*Ancistrophyllum secundiflorum* (P.Beauv.) G.Mann & H.Wendl. (FHI 50908)	Arecaceae	Climber	Stem bark	3	8.57	NE

25.	June 12	Tree marigold or Mexican sunflower	*Tithonia diversifolia* (Hemsl.) A. Gray (FHI 108055)	Asteraceae	Shrub	Leaves	3	8.57	NE
26.	Emi	Shea tree	*Vitellaria paradoxa* C.F. Gaertn. (FHI 107924)	Sapotaceae	Tree	Root, leaves	3	8.57	VU
27.	Ataile	Ginger	*Zingiber officinale* Roscoe (FHI 107935)	Zingiberaceae	Herb	Rhizome	3	8.57	DD
28.	Pandoro	Sausage tree	*Kigelia africana* (Lam.) Benth. (FHI 107654)	Bignoniaceae	Tree	Stem bark, fruits	3	8.57	LC

29.	Arunje	Dragon's blood tree	*Harungana madagascariensis* Lam. ex Poir. (FHI 107392)	Hypericaceae	Tree	Stem bark, leaves	2	5.71	LC
30.	Gilofa or Gurofa	Guava	*Psidium guajava* Linn. (FHI 110937)	Myrtaceae	Shrub	Leaves	2	5.71	LC
31.	Emi gbegiri or Akodinrin	Dry-zone cedar	*Pseudocedrela kotschyi* (Schweinf.) Harms (FHI 106873)	Meliaceae	Tree	Stem bark	2	5.71	LC
32.	Ọpẹ oyinbo	Pineapple	*Ananas comosus* (L.) Merr. (FHI 58509)	Bromeliaceae	Shrub	Peel	2	5.71	NE
33.	Tude	Powder puff	*Calliandra haematocephala* Hassk.	Fabaceae	Shrub	Root	2	5.71	NE

			(FHI 45788)					
34.	Efirin	Scent basil	*Ocimum gratissimum* Linn. (FHI 111995)	Lamiaceae	Herb	Leaves	2	5.71	NE
35.	Ewuro	Bitter leaf	*Vernonia amygdalina* Delile (FHI 112924)	Asteraceae	Shrub	Leaves	2	5.71	NE
36.	Ayan	African mesquite	*Prosopis africana* (Guill. & Perr.) Taub. (FHI 112370)	Fabaceae	Tree	Leaves, root	2	5.71	LC
37.	Mafowokan omomi or Ahon ekun	Mountain Thistle	*Acanthus montanus* (Nees) T. Anderson (FHI 107529)	Acanthaceae	Shrub	Leaves	1	2.86	LC

38.	Akogun (Yoruba), Kwagǔgi (Nupe)	Dutchman's pipe	*Aristolochia ringens* Vahl (FHI 112929)	Aristolochiaceae	Climber	Root	1	2.86	NE
39.	Gbere (Nupe)	Breadfruit	*Artocarpus altilis* (Parkinson) Fosberg (FHI 110483)	Moraceae	Tree	Root	1	2.86	NE
40.	Orombo	Sweet orange	*Citrus sinensis* (L.) Osbeck (FHI 108811)	Rutaceae	Tree	Stem bark, leaves	1	2.86	NE
41.	Agbon	Coconut palm	*Cocos nucifera* Linn. (FHI 109665)	Arecaceae	Tree	Husk	1	2.86	NE
42.	Ataile pupa	Turmeric	*Curcuma longa* Linn. (FHI 106920)	Zingiberaceae	Herb	Rhizome	1	2.86	DD

43.	Iya	African copaiba balsam tree	*Daniellia oliveri* (Rolfe) Hutch. & Dalziel (FHI 36952)	Fabaceae	Tree	Stem bark	1	2.86	LC
44.	Igbaluwere or Ogurobe	Splinter bean	*Entada africana* Guill. & Perr. (NIPRD/H/6412)	Fabaceae	Tree	Stem bark	1	2.86	LC
45.	Ipin	Sandpaper	*Ficus exasperata* Vahl (FHI 109550)	Moraceae	Tree	Leaves	1	2.86	LC
46.	Obo	Gutta percha tree	*Ficus platyphylla* Del. Holl (FHI 78251)	Moraceae	Tree	Stem bark	1	2.86	LC
47.	Orogbo	Bitter kola	*Garcinia kola* Heckel (FHI 109481)	Clusiaceae	Tree	Stem bark	1	2.86	VU

48.	Lapalapa funfun	Bubble bush	*Jatropha curcas* Linn. (FHI 109020)	Euphorbiaceae	Shrub	Leaves	1	2.86	LC
49.	Ogbesi	Pheasant-berry	*Margaritaria discoidea* (Baill.) G.L. Webster (FHI 43971)	Phyllanthaceae	Tree	Root	1	2.86	LC
50.	Ogede agbagba	Banana	*Musa paradisiaca* Linn. (FHI 110122)	Musaceae	Herb	Leaves	1	2.86	NE
51.	Ogbo	African Parquetina	*Parquetina nigrescens* (Afzel.) Bullock (FHI 110044)	Apocynaceae	Shrub	Leaves	1	2.86	NE
52.	Nla	Avocado	*Persea americana* Mill. (FHI 109444)	Lauraceae	Tree	Stem bark	1	2.86	LC

53.	Abafe	Wild bauhinia	*Piliostigma thonningii* (Schum.) Milne-Redh. (FHI 107815)	Fabaceae	Tree	Stem bark	1	2.86	NE
54.	Iyere	Climbing black pepper	*Piper guineense* Schum. & Thonn. (FHI 112922)	Piperaceae	Climber	Fruit	1	2.86	LC
55.	Sigo	Elephant's sugarcane	*Cussonia barteri* Hochst. Ex A. Rich. (UBHdt/SN/173)	Araliaceae	Tree	Leaves	1	2.86	LC
56.	Jelenubenu (Yoruba), Gayà ebá (Nupe)	Coffee senna or septic weed	*Senna occidentalis* (L.) Link (FHI 109866)	Fabaceae	Shrub	Leaves	1	2.86	LC
57.	Ajarere	Podocarpa leaf	*Senna podocarpa* (Guill. & Perr.) Lock	Fabaceae	Shrub	Leaves	1	2.86	NE

			(FHI 109903)							
58.	Isekotu (Yoruba), Sàngi yèkó (Nupe)	Common wireweed	*Sida acuta* Burm.f. (FHI 112276)	Malvaceae	Weed	Leaves	1	2.86	NE	
59.	Opon	Cup of water	*Tetracera potatoria* Afzel. ex G. Don. (FHI 105782)	Dilleniaceae	Climber	Stem bark	1	2.86	NE	
60.	Aridan/Aidan	Soup perfume	*Tetrapleura tetraptera* (Schum. & Thonn.) Taub. (FHI 110141)	Fabaceae	Tree	Fruit	1	2.86	LC	
61.	Eeru alamo	Ethiopian or Negro pepper	*Xylopia aethiopica* (Dunal) A. Rich. (FHI 108978)	Annonaceae	Tree	Stem bark	1	2.86	LC	

| 62. | Orin ata | Senegal prickly-ash | *Zanthoxylum zanthoxyloides* (Lam.) Zepern. & Timler (NIPRD/H/7101) | Rutaceae | Tree | Stem bark | 1 | 2.86 | LC |

Abbreviations: DD – Data Deficient; NE – Not Evaluated; LC – Least Concern; VU – Vulnerable; NT – Near Threatened; EN – Endangered; CR – Critically Endangered; EW – Extinct in the Wild; EX – Extinct

Parts of the medicinal plants used for preparation of herbal medicine for malaria treatment

Our results showed that leaves (40%) were the most utilized medicinal plant parts for preparation of herbal medicine for malaria treatment, solely or in combination with other plant parts; closely followed by stem bark (32%), root (18%) and fruit (6%) while the least commonly used parts were rhizome (2%), husk (1%) and peel (1%) as shown in Fig. 3.

Plant parts are capable of accumulating different important natural phytocompounds, which offer significant pharmaceutical potentials [93]. The dominance of leaves over other plant parts in preparing herbal remedies could be linked to their being the primary site of photosynthetic and other biosynthetic activities in plants, leading to the production and accumulation of photosynthates which contain higher concentrations of bioactive molecules including alkaloids and tannins with rich medicinal properties [94-96]. Another reason could be because of the ease of handling them [97]. Again, leaves are more readily available hence, they are easily accessible and harvested in large quantities for use when compared to other parts of the plant. Harvesting leaves does not exert much strain on plant regeneration and also does not extensively harm the plants compared to the use of stem barks, roots, and/or the whole plant [98, 99]. Furthermore, from a conservation and sustainability point of view, leaves are preferred over stem barks and roots since they are not as closely linked to the survival rate of plants. So, collecting the leaves biomass within acceptable limits does not cause serious interference with the plant life.
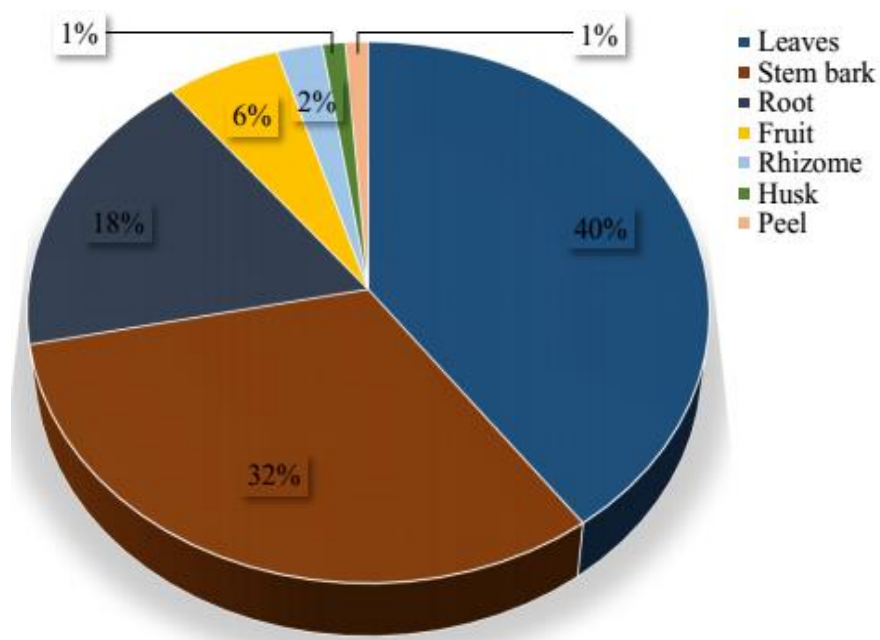
Fig. 3 Percentage of different plant parts utilized for herbal preparation

Traditional malaria medicine recipes, modes of preparation, routes of administration and duration of treatment

The TMPs revealed different recipes for preparing herbal medicine for malaria treatment, modes of preparation and administration, and duration of administration with possible side effects. Overall, 35 different polyherbal recipes were obtained from the informants. The recipes contain various plant parts including leaves, stem bark and roots, and ranged from 3 to 13 different plants used together. Although some of the plants can be used singly, earlier reports have claimed that the use of plant mixture in herbal preparation may enhance the synergism of phytochemicals of the different plants so as to elicit maximum therapeutic efficacy and also cure several malaria-associated dysfunctions in the body [43, 90, 100].

Of the 11 different traditional methods reported to be used for preparation of malaria therapy by the TMPs, decoction in water (34%) was the most preferred method of extracting the

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bioactive ingredients from the plants (Fig. 4). The different components of the recipes are uniquely arranged with the stem bark and/or root usually cut into smaller pieces and placed at the bottom of the pots followed by the leaves, fruits and other plant parts. Other modes of preparation included steeping (infusion) in non-caffeinated soft drink (7up) (19%), steeping in alcohol "*ogogoro*" (11%) and steeping in water from fermented maize "*omi ogi*" or "*omi idun*" (10%). The least preferred methods were squeezing of leaves in lime juice (1%), steeping in coconut water (1%) and pulverization into powder (1%). The choice of decoction and steeping as the best or most preferred traditional methods of preparing malaria herbal remedies is consistent with earlier reports [101-104]. The main reason why these modes of preparation are widely utilized by the TMPs could be because they are simple, easy to handle and cheap [78]. In addition, decoction enhances extraction of bioactive ingredients from the plant parts much more in comparison to cold extraction. However, several factors including boiling duration, amount of solvent and plant material used may differ which could possibly affect the potency of the herbal preparations [61]. Also, both decoction and steeping do not provide long shelf life for the herbal preparations and as a result, the medicinal plants would need to be continuously harvested thereby putting them under considerable pressure that may lead to overexploitation.
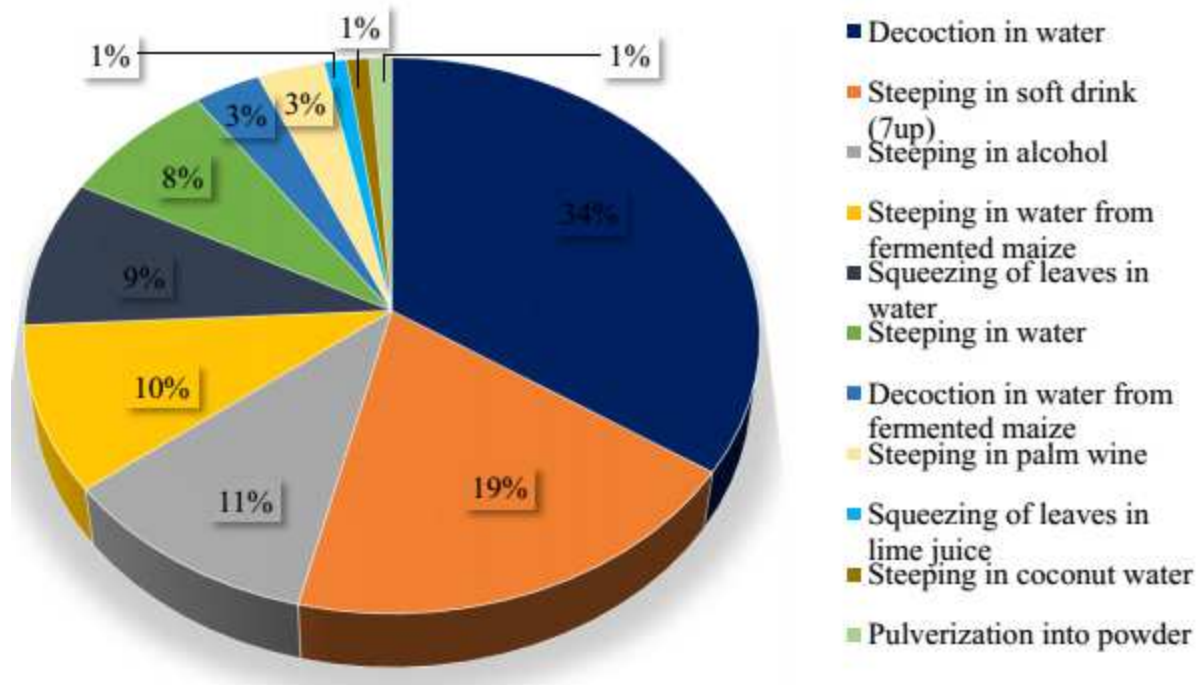
Fig. 4 Distribution of traditional modes of preparation of herbal medicine

Regarding administration of herbal preparation, oral administration (74%), bathing with water from decoction (15%), steam inhalation (9%) and pulverized form of plant parts taken with cornmeal (2%) were reported to be the routes of administration (Fig. 5). In this report, oral administration was considered to be the main route of administering herbal preparations, consistent with previous investigations [63, 105-107]. Oral administration ensures quick absorbability and strongest action of herbal preparations [60]. These factors make it preferable to other routes of administration by the TMPs.
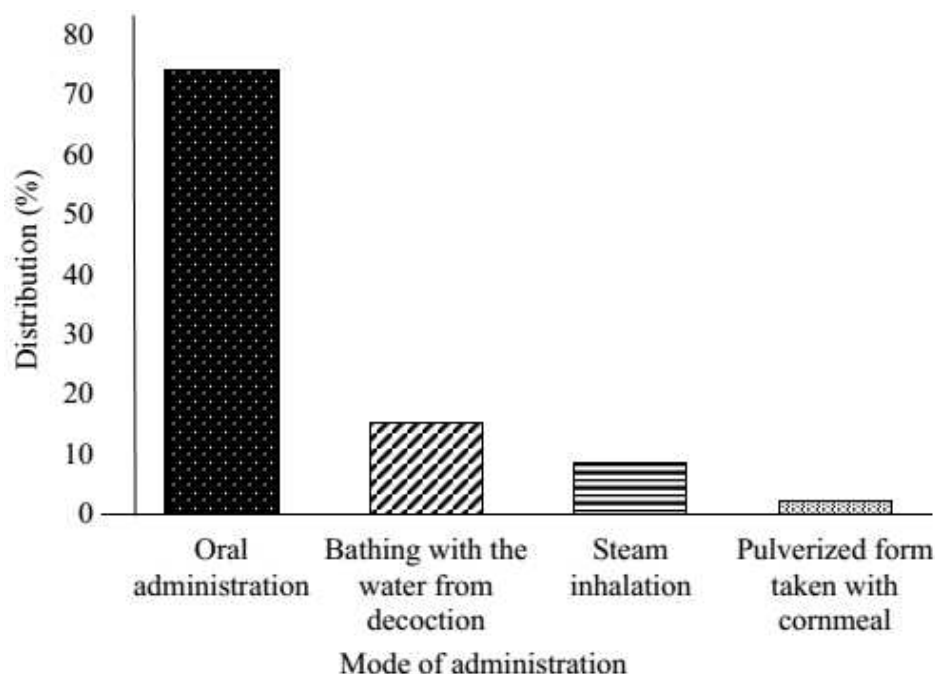
Fig. 5 Distribution of different modes of administration of herbal preparation

Pharmacological relevance of the extracts and phytocompounds isolated from the identified plants

As a result of the growing interest in phytoremediation as an alternative therapeutic strategy for combating malaria, many bioactive compounds have been extracted, isolated and characterized from medicinal plants using different methods including chromatographic and spectrophotometric techniques [108-111]. Interestingly, most of the medicinal plants recorded in this study have been demonstrated through *in vitro* and/or *in vivo* approaches to possess antimalarial activity (Table 2), supporting the traditional use of these plants for malaria treatment in the region. Over 50 compounds (Table 3), with varying antimalarial activities, have been isolated from some of the plants documented in this study including *E. chlorantha*, *V. amygdalina*, *M. lucida*, *A. occidentale*, *H. madagascariensis*, *K. africana*, *G. kola*, *A. indica*, *X. aethiopica*, *C. papaya* and *P. americana*.

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Following is a brief description of some of the medicinal plants and their constituents previously investigated for their antimalarial property.

Alstonia boonei De Wild is an evergreen tree, that is widely distributed in the tropical and rain forests zones of West and Central Africa. The plant is listed in African pharmacopoeia and is commonly applied in Nigeria for the treatment of a variety of ailments including malaria, chronic diarrhoea, insomnia, jaundice and rheumatic pains [72, 112]. Herbal tincture and decoction of the stem bark of the plant is also used as an effective antidote against scorpion or snake poison, as well as for inducing lactation and expelling retained products of afterbirth when administered to women [113]. Infected mice with the chloroquine-sensitive *Plasmodium berghei* NK65 parasite were used to study the *in vivo* anti-plasmodial effects (suppressive, curative and prophylactic) of the ethanolic extract of the stem bark of the plant. The extract demonstrated significant ($p < 0.05$) suppressive (46.43-75%), curative (61.02-81.36%) and prophylactic (34.83-60.67%) antiplasmodial effects against the parasite in a dose-dependent (100, 200 and 400 mg/kg) manner [114]. Also, Agbedahunsi et al. [115] investigated the *in vivo* chemosuppressive effect of the ethanolic leaf extract of the plant in *P. berghei*–infected mice and their results revealed a chemosuppression of 0.2–74.8%, dose-dependently (12.5-400 mg/kg).

Anacardium occidentale L. is a nut tree crop widely cultivated in tropical regions of the world including Nigeria. Decoction of the leaves and stem bark have been reported to be used in ethnomedicine for malaria treatment and management of severe diarrhoea in Nigeria [64, 71]. The *in vitro* antiplasmodial investigation of ethanol extract of cashew apple demonstrated significant activity with an IC_{50} of 0.577 g/ml [116]. Besides, the phytocompounds cardol triene 1 (IC_{50} = 5.69 M) and 2-methylcardol triene 4 (IC_{50} = 5.39 M) isolated from the plant showed significant antimalarial activity *in vitro* when evaluated against *P. falciparum* D6 strain [116]. Additionally,

anacardic acid, another phytocompound from *A. occidentale*, was demonstrated to possess antiplasmodial effect [117]. The compound interrupted the parasite's transcription process by inhibiting *P. falciparum* histone acetyltransferase (PfGCN5) activity.

Azadirachta indica A. Juss. is a tropical and subtropical plant which is utilized for various medicinal purposes. In the tropics, the plant is used as traditional remedies for the treatment of malaria [43, 46]. Several studies have shown the seed kernel, leaf and stem bark extracts to possess antimalarial properties [118-120]. In an *in vitro* study, Hout et al. [121] reported a good activity (4.7 µg/ml IC_{50}) of dichloromethane stem bark extract of *A. indica* against chloroquine resistant *P. falciparum* W2 strain. Tepongning et al. [122] reported that *P. berghei*-infected BALB/c mice treated with hydroethanolic leaf extract of the plant showed a significant ($p \leq 0.001$) reduction of parasitaemia ranging from 49.75±3.64 to 69.28±1.36% in a dose-dependently. The antimalarial efficacy of tablet suspension of the leaf and bark of the plant were assessed on *P. yoelli nigeriensis*-infected mice. The tablet suspensions demonstrated high preventive to moderate suppressive and weak curative schizonticidal effects, respectively [123]. Furthermore, the *in vitro* antimalarial activities of various phytocompounds such as nimbolide, gedunin and azadirachtin isolated from *A. indica* have been reported [124-126].

Carica papaya L. is commonly administered in traditional settings for the treatment of malaria and various other maladies including cancer, asthma, warts, jaundice and malaria [23]. Using bioassay-guided fractions and dichloromethane extract, Teng et al. [127] evaluated the antimalarial activity of *C. papaya* leaf extracts *in vitro* against *P. falciparum* 3D7 and Dd2 strains. The hexane extract was the most potent of the extracts obtained from *C. papaya* leaves; it had an IC_{50} of 3.43±0.41 and 1.52±0.003 g/ml against the 3D7 and Dd2 strains, respectively. This was followed by dichloromethane leaf extract which had an IC_{50} of 7.67±1.9 and 4.50±0.17 g/ml

against the 3D7 and Dd2 strains, respectively. The ethyl acetate leaf extract was moderately potent against the *P. falciparum* 3D7 strain, with an IC_{50} of 20.32±3.5 g/mL, while the leaf juice at a dilution of 1/64 inhibited its development by 50%. In another study, Melariri et al. [128] demonstrated the antiplasmodial activity *in vitro* of the leaf extract of the plant. Their result showed that ethyl acetate crude extract had a very good activity with an IC_{50} of 2.96 µg/ml against *P. falciparum* D10 strain. The phytocompound carpaine isolated from *C. papaya* exhibited very good activity against *P. falciparum* 3D7 and Dd2 strains with IC_{50} of 2.01±0.18 µg/ml (4.21 µM) and 2.19±0.60 µg/ml (4.57 µM) against 3D7 and Dd2 strains, respectively [127]. Furthermore, both linoleic and linolenic acids isolated from the ethyl acetate leaf fraction of the plant showed good activity with IC_{50} of 6.88 µg/ml and 3.58 µg/ml against *P. falciparum* chloroquine-sensitive D10 and chloroquine-resistant DD2 strains, respectively [128].

Daniella oliveri (Rolfe) Hutch. & Dalziel grows predominantly in some parts of South America and Africa. In Nigeria, the plant is used in traditional medicine for the treatment of breast tumours, abscesses, and vestibule vagina fistula [129]. Also, herbal preparations with the leaves and stem bark are used for the treatment of gastrointestinal disorders, diabetes and diarrhoea, as well as malaria [130, 131]. The antiplasmodial effect of the methanol, aqueous, butanol and ethyl acetate stem bark extract revealed weak activity (IC_{50} of 23.14-32.97 µg/ml) against *P. falciparum* 3D7 and K1 strains [132]. But a suppression effect of 87% against *P. berghei* was recorded, though at a higher dose of 700 mg/kg [133].

Enantia chlorantha Oliv. is widely distributed along the coastal regions of West and Central Africa including Nigeria where it is utilized in traditional medicine for the treatment and management of several health disorders including urinary tract infections, jaundice, malaria, fever, tuberculosis and hepatitis [74, 75]. A decoction of 500 g of stem bark of the plant in 3 L of water

for 20 min, taken orally, has been reported to treat malaria symptoms, aches, wounds, fever and chills [134]. Boyom et al. [135] investigated the *in vitro* antiplasmodial activity of solvent fractions and ethanolic crude extract of *E. chlorantha* stem bark against *P. falciparum* W2 strain, and they reported a good activity at IC_{50} of 0.68 to 14.72 µg/ml. Also, the antimalarial activities of the protoberberine alkaloids compounds – jatrorrhizine, berberine and palmatine isolated from *E. chlorantha* have been tested both *in vitro* against *P. falciparum* and *in vivo* against *P. berghei*. They showed potency similar to that of quinine *in vitro* however, none of the compounds was active *in vivo* [136].

Ficus platyphylla Del. Holl is a deciduous heavily branched tree that is distributed widely throughout the savannah region of West African coast. In folk medicine, decoction of the seeds, leaves and stem bark of *F. platyphylla* is taken as fertility enhancement in Nigeria [137]. It is also used for the management of epilepsy and psychosis [138], and tuberculosis [139]. In Burkina Faso, the stem bark of the plant is used traditionally for malaria treatment [140]. *In vivo* antiplasmodial activity of the ethanolic stem bark extract of the plant suppressed malaria dose-dependently in *P. berghei*-infected mice, by 43.50% at the highest dose of 300 mg/kg [141]. Additionally, treatment with the plant extract prevented severe reduction in packed-cell volume in the infected mice revealing its capacity to remedy anaemic conditions.

Garcinia kola Heckel is a flowering plant widely distributed in the tropical rain forest region of West and Central Africa, and it is largely valued for its nuts. The seeds, commonly known as "bitter kola", are edible and are usually chewed as an adjuvant to the true kola (*Cola nitida* and *C. accuminata*). In traditional medicine, preparations with different parts of the plant including the seeds, leaves and stem bark are used extensively as purgatives, aphrodisiac, as well as for the treatment of diarrhoea, liver diseases, cough, hoarseness of voice, laryngitis and bronchitis [76,

77, 142]. *In vitro* and *in vivo* antimalarial studies have been carried out on the plant. The results from Tona et al. [143] revealed that the ethanolic extract of the stem bark and its petroleum ether fraction showed very good antiplasmodial activities with IC_{50} values of <3 µg/ml *in vitro*. In another study by Ujomu et al. [144] it was observed that n-hexane, dichloromethane and methanol extracts of the seeds of *G. kola* were active *in vitro* against chloroquine sensitive *P. falciparum* D10 strain (10.59-26 µg/mL IC_{50}). They also reported that the n-hexane extract reduced parasitaemia in *P. berghei*-infected mice by 70% at 400 mg/kg, prolonging survival of the animals. Three biflavanones (I-4′,II-4′,I-5,II-5,I-7,II-7-hexahydroxy-I-3,II-8-biflavanone, II-3,I-4′,II-4',I-5,II-5,I-7,II-7-heptahydroxy-I-3,II8-biflavanone and II-3, 3′,I-4′,II-4′,I-5,II-5,I-7, II-7-octahydroxy-I-3,II-8-biflavanone) isolated from *G. kola* demonstrated potent inhibitory activity *in vitro* against *P. falciparum* proliferation and against *P. berghei in vivo* [145]. I-4′,II-4′,I-5,II-5,I-7,II-7-hexahydroxy-I-3,II-8-biflavanone exhibited the strongest *in vitro* antimalarial potency on *P. falciparum* with an IC_{50} of 0.16 μM. In the *in vivo* antimalarial assay in *P. berghei*-infection in mice, I-4′,II-4′,I-5,II-5,I-7,II-7-hexahydroxy-I-3,II-8-biflavanone was found to exhibit antimalarial effect with an ED_{50} of about 100 mg/kg following oral treatment. I-4′,II-4′,I-5,II-5,I-7,II-7-hexahydroxy-I-3,II-8-biflavanone was also found to increase the average life span of the infected mice significantly when compared to that of the control ($p<0.01$).

Harungana madagascariensis Lam. ex Poir. is found in tropical Africa with wide distribution in areas where annual rainfall is above 1300 mm. In traditional medicine, preparations from different parts of the plant including the stem bark and leaves are used in the treatment of urogenital infections, chest pain, river blindness, hepatitis, toothache, dysmenorrhea, asthma and malaria [146]. Iwalewa et al. [147] evaluated the *in vitro* and *in vivo* antimalarial activity of the stem bark extract of *H. madagascariensis*. The IC_{50} of the ethanolic extract of the plant on *P.*

falciparum was between 0.052 and 0.517 µg/ml as against the standard drugs artemether (0.021

g/ml) and chloroquine (0.0412 g/ml). The activities of the extract in an *in vivo* study on *P. yoelii*

nigeriensis were between 28.6–44.8 and 30.2–78.2% at 20-80 mg/kg in both suppressive and

prophylactic assays, respectively, in comparison to chloroquine (70.6%) and pyrimethamine

(43.3%). However, in the curative test, only 80 mg/kg of the extract decreased the level of

parasitaemia in comparison to the standard drug chloroquine. In a similar report, the methanolic

leaf extract of the plant showed weak *in vitro* activity (39.07 ± 1.57 µg/ml) against *P. falciparum*

D6 strain and moderate chemosuppression of parasitaemia (53.13%) [148]. The aqueous leaf

extract was inactive *in vitro* but showed high chemosuppression of parasitaemia (88.04%). Lenta

et al. [149] evaluated the antiplasmodial activity of compounds harunganin, harunganol A,

harunganol B, feruginin and bazouanthrone isolated from *H. madagascariensis* against *P.*

falciparum W2 strain. All the compounds showed varying activities against the malaria parasite

with bazouanthrone being the most potent (IC_{50} = 1.80µM).

Jatropha curcas Linn. is a semi-evergreen shrub found in abundance in Mexico,

northeastern part of South America as well as in some tropical and sub-tropical regions in Asia

and Africa. Herbal preparations of the stem, leaves and seeds are widely used for various medicinal

purposes in traditional settings in Africa. Decoction of the leaves is utilized to treat cough while

the seed oil is used for treating several skin diseases and soothing rheumatic pain. Decoction of

the leaves is also applied as an antiseptic after child delivery [150]. Moreover, the seeds are used

as purgative and laxative, and for the treatment of helminthic infections, paralysis, ascites and

gouts [151]. Furthermore, drops of diluted twig-sap are administered orally to babies affected by

tetanus [152]. An *in vitro* study of the ethyl acetate, hexane and methanol leaf extract of the plant

leaves demonstrated good to moderate antiplasmodial activity (2.39±0.54- 31.09±4.36 µg/ml IC_{50}) against *P. falciparum* K1 and NF54 strains [153].

Kigelia africana (Lam.) Benth. is a monospecific genus under the family Bignoniaceae which grows along watercourses and in riverine areas in West, Central and South Africa [154]. Different parts of the plant are utilized in traditional medicine for the treatment of various ailments including rheumatism, heamorrhoids, nasopharyngeal, skin infections, malaria as well as for fertility enhancement [79, 155]. Imran et al. [9] evaluated the extracts of the leaf, stem bark, fruit and root of *K. africana* in a 4-day antiplasmodial test in *P. berghei*-infected mice, they all showed dose-dependent chemosuppressive activity at the three administered doses of 125, 250 and 500 mg/kg, respectively. The stem bark extract exhibited the highest chemosuppressive activity of 84.73%, followed by the root with 78.06% and then the leaf (72.94%) while the fruit had the least chemosuppressive activity of 70.33% at the maximum dose of 500 mg/kg compared to the standard drug chloroquine with 93.99% chemosuppression of parasitaemia. They also evaluated the antiplasmodial effect of different solvent fractions of the extract: the chemosuppressive activity of the ethyl acetate, n-butanol and methanol fractions were 42.61, 56.05 and 69.94%, respectively in comparison with the positive control (chloroquine) which had chemosuppression of 86.17%. Zofou et al. [156] isolated the phytocompounds *p*-hydroxycinnamic acid, specicoside, 2β,3β,19α-trihydroxy-urs-12-en28-oic acid and atranorin from the stem bark of the plant and evaluated them against the multidrug-resistant W2mef strain of *P. falciparum*. Three of the four compounds tested showed significant activity against W2mef: specicoside (IC_{50} = 1.02±0.17 µM), 2β,3β,19α-trihydroxy-urs-12-en28-oic acid (IC_{50} = 1.86±0.15 µM) and atranorin (IC_{50} = 1.78±0.18 µM) while on the other hand, *p*-hydroxycinnamic acid showed a moderate activity (IC_{50} = 12.89±0.87 µM).

Margaritaria discoidea (Baill.) G.L. Webster is a tree that can grow up to 30 m in height. The plant abounds in Senegal, Cameroun and other parts of tropical Africa. The stem bark of the plant is used in folk medicine to treat malaria and helminthic infections in Cote d'Ivoire [157]. It is also utilized for the treatment of onchocerciasis in Cameroon [158]. Additionally, the decoction of the stem bark is used in the Republic of the Congo to relieve stomach discomfort, and facilitate delivery during parturition [159]. The aqueous, ethanol and methanol leaf extracts of *M. discoidea* were assessed for their *in vitro* antiplasmodial activity against chloroquine sensitive (NF54) and multi-resistant (K1) strains of *P. falciparum* [160]. Moderate to weak activity (13.60 ± 1.80-43.61 ± 0.92 µg/ml IC_{50}) against the K1 and NF54 strains was reported.

Morinda lucida Benth is a small to medium-sized tree which grows in grassland, forests and occasionally in regularly flooded areas. Decoctions and infusions of the leaves, stem bark and root of the plant are utilized as remedies in traditional settings against trypanosomiasis, feverish condition during child delivery, yellow fever and malaria [161]. The antimalarial effects of extracts of different parts of *M. lucida* have been demonstrated. Olasehinde et al. [162] reported the antiplasmodial effect *in vitro* of the methanolic extract of *M. lucida* leaf. An excellent activity against *P. falciparum* was recorded at IC_{50} of 25 nM. Treatment of *P. berghei*-infected mice with 200 and 400 mg/kg hydroethanolic (50:50) leaf extract of the plant significantly ($p>0.05$) reduced the level of parasitaemia (96.24%), but was however slightly lower than that recorded in infected mice treated with the standard compound chloroquine (100%) [163]. In a similar manner, decoction of *M. lucida* root in distilled water demonstrated significant ($p<0.05$) chemosuppressive ($60.9 \pm 0.01\%$), curative ($85.1 \pm 0.04\%$) and prophylactic ($74.6 \pm 0.03\%$) activities in *P. berghei* NK65-infected mice at 1200 mg/kg [164] Additionally, the activity of three anthraquinone compounds – digitolutein, rubiadin 1-methyl ether and damnacanthal isolated from the stem bark

and the root of the plant against *P. falciparum* have been demonstrated *in vitro*. The number of parasites significantly decreased dose-dependently, and 100% inhibition was recorded with 30–40 µg of each compound [165]. In a similar manner, the two triterpenic acids – ursolic and oleanolic acids isolated from the plant showed very good to moderate antiplasmodial activity with IC_{50} values of 3.1±1.3 and 15.2±3.4 µg/ml, respectively [166].

Persea americana Mill. is a tropical plant that produces an edible fruit called avocado. The plant is used in ethnomedicine in Nigeria and other parts of Africa for the treatment of different health conditions including monorrhagia, rheumatism, stomach ache, high blood pressure, diarrhoea, bronchitis, diabetes and malaria [23, 80, 81]. The curative and suppressive antimalarial activities of extract and fractions of *P. americana* leaf have been demonstrated *in vivo* [167]. In the curative model, the extract produced inhibition ($p<0.05$) of parasitaemia in a dose-dependent manner. The inhibition produced by 400 mg/kg of the extract (methanol in water) was 52.16±2.77%, similar to that of the standard drug artemisinin-combination therapy (ACT) with 69.04±3.02% inhibition. The extract produced significant ($p<0.05$) chemosuppression (55.00±0.06%) in parasitemia. Similarly, the ethyl acetate, hexane and aqueous fractions produced significant ($p<0.05$) chemosuppressive effect by 40.00±0.05, 56.03±0.07 and 64.01±0.08%, respectively at 200-400 mg/kg. However, the effects of the fractions were lower than the standard drug ACT (70.00±0.06%) with only the aqueous fraction (64.01±0.08%) producing a similar activity. The avocadenols, 1, 2, 4-trihydroxyheptadec-16-ene and 1, 2, 4, 15-tetrahydroxyheptadecane-6, 16-diene isolated from *P. americana* seeds showed promising antiplasmodial activity when investigated for their antiplasmodial effect *in vitro* [168].

Vernonia amygdalina Delile is a perennial rainforest herb which is commonly used as a vegetable in preparation of the popular bitter leaf soup as well as for other medicinal purposes in

folk medicine in Nigeria [169]. Extracts of the herb have been utilized in ethnomedicines for the treatment of fevers, hiccups, stomach disorders, kidney problems and malaria [170, 171]. The antimalarial effects of *V. amygdalina* have been reported. Omoregie et al. [172] demonstrated the *in vitro* and *in vivo* activities of the ethanolic, aqueous and hydroethanolic (50:50) leaf extracts of the plant. In the *in vitro* study, the ethanolic extract produced the highest (*p*<0.05) antiplasmodial activity (IC_{50} = 9.83 µg/ml) against *P. falciparum* 3D7 strain. Also, the ethanolic extract was significantly active *in vivo* against *P. berghei*, dose-dependently, with maximum activity observed at 1,000 mg/kg (82.3 % % inhibition). In a 4-day chemosuppression test, a parasitaemia suppression of 67% in *P. berghei*-infected mice was demonstrated following oral administration of methanolic extract of the plant at a dose of 1,000 mg/kg [173]. Also, an aqueous extract of the plant administered orally to *P. berghei*-infected mice at 125 mg/kg reduced the parasitaemia by 63% [174]. Various compounds including steroidal saponins vernoniosides A1, A2, A3, A4 and B1, as well as sesquiterpenes vernodalin, vernodalol, vernolide and hydroxyvernolide isolated from the leaves of the plant have been shown to possess varying degrees of antimalarial effects *in vitro*. The compounds had antiplasmodial activities with IC_{50} between 4.0 and 46.1 µg/ml and vernodalin was observed to be the most potent (IC_{50} = 4.0 µg/ml) [175].

Xylopia aethiopica (Dunal) A. Rich is a sweet-smelling evergreen medicinal plant usually found in the forest-Savannah zone and the rainforest region of Africa [176]. Various parts of the plant including fruit, leaves, stem, stem bark and root are utilized in folk medicine for the treatment of different diseases and health disorders such as rheumatism, asthma, infertility, dysentery, epilepsy, candidiasis, fever and malaria [177-179]. The *in vitro* antimalarial effect of the volatile oil of *X. aethiopica* seed was evaluated against *P. falciparum* 3D7 strain, a moderate activity against the malaria parasite was observed with an IC_{50} of 14 µg/ml [180]. In a similar vein, the

antimalarial potential of the kaurene diterpene compound xylopic acid isolated from the fruit of the plant was assessed in *P. berghei*-infected mice and it showed promising activity ($p<0.05$) comparable to that of the standard drug artemether/lumefantrine [181].

In addition to the plants above, the antiplasmodial activity of the underlisted plants have been evaluated *in vitro* and/or *in vivo* and are summarized in Table 2: *M. indica*, *C. limon*, *C. citratus*, *L. inermis*, *N. latifolia*, *A. altilis*, *C. longa*, *T. cacao*, *L. alata*, *C. nucifera*, *S. acuta*, *Z. zanthoxyloides*, *C. aurantifolia*, *P. guajava*, *K. ivorensis*, *A. nilotica*, *B. coccineus*, *W. indica*, *A. leiocarpus*, *A. compressus*, *V. paradoxa*, *Z. officinale*, *P. kotschyi*, *A. comosus*, *O. gratissimum*, *P. africana*, *A. altilis*, *C. sinensis*, *F. exasperata*, *P. nigrescens*, *P. thonningii* and *P. guineense*.

Table 2 Scientific evaluation of the antimalarial properties of the identified medicinal plants and their phytocompounds

S/n	Name of plant	Parts of plant used	Extraction solvent	Antimalarial activity of extracts and parasite suppression rate	IC_{50}	Isolated compounds with antimalarial activity
1.	*E. chlorantha*	Stem bark	Ethanol, water, methanol, dichloromethane, hexane	*In vitro* Boyom et al. [135] Very good to moderate activity *P. falciparum* W2 strain	0.68–14.72 µg/ml IC_{50}	Jatrorrhizine, palmatine and berberine *in vitro* and *in vivo* [136]
2.	*A. indica*	Leaf	Hydroethanol	*In vivo* [122] Suppression of 49.75±3.64 to 69.28±1.36% against *P. berghei* NK65 at 75-300 mg/kg		Nimbolide *In vitro* and *in vivo* [124] Gedunin *In vitro* [125] Azadirachtin *In vitro* [126]
				In vitro [160]		
		Stem bark	Dichloromethane	Very good activity against *P. falciparum* W2 strain	4.7 µg/ml IC_{50}	
3.	*M. indica*	Stem bark	Ethanol	*In vivo* [164]		

#	Species	Part	Solvent	Activity	IC50	Compounds
				Suppression of 76.9 ± 0.02% against *P. berghei* NK65 strain at 1,000 mg/kg		
4.	*M. lucida*	Leaf	Hydroethanol (50:50)	*In vivo* [163] Suppression of 96.24% at 200 and 400 mg/kg *In vivo* [164]		Digitolutein, rubiadin 1-methyl ether and damnacanthal *In* vitro [165]
		Root	Aqueous	Suppression of 60.9±0.01% against *P. berghei* NK65 strain at 1,200 mg/kg *In vitro* [162]	25 nM IC$_{50}$	Ursolic acid and Oleanolic acid *In vitro* and *in vivo* [166]
		Leaf	Methanol	Excellent activity against *P. falciparum*		
5.	*X. aethiopica*	Seed	Aqueous	*In vitro* [180] Moderate activity against *P. falciparum* 3D7 strain	14 µg/ml IC$_{50}$	Xylopic acid *In vivo* [181]

6.	*A. occidentale*	Apple	Ethanol	*In vitro* [116] Poor activity against *P. falciparum* D6 strain	0.577 g/ml IC$_{50}$	Anacardic acid *In vitro* [117] Cardol triene 1 and 2-methylcardol triene 4 *In vitro* [116]
7.	*C. limon*	Leaf	Dichloromethane	*In vitro* [182] Good activity against *P. falciparum* D10 strain	5.0 µg/ml IC$_{50}$	
8.	*C. citratus*	Leaf	Dried and ground into powder	*In vivo* [183] Suppression effect of 99.89% at 1,600 mg/kg against *P. berghei* ANKA		
9.	*L. inermis*	Leaf	Dichloromethane:methanol (1:1)	*In vivo* [84] Suppression effect of 68.20% at 250 mg/kg against *P. berghei* ANKA strain		

10.	*A. boonei*	Leaf	Ethanol	*In vivo* [115]	
				Suppression effect of 74.9% at	
				400 mg/kg against *P. berghei*	
				NK65 strain	
		Stem bark	Ethanol	*In vivo* [114]	
				Suppression effect of 75% at	
				400 mg/kg against *P. berghei*	
				NK65 strain	
11.	*N. latifolia*	Leaf	Ethanol	*In vivo* [184]	
				Suppression effect of 60.63% at	
				500 mg/kg against *P. berghei*	
12.	*A. altilis*	Leaf and stem bark	Ethanol	*In vivo* and *in vitro* [185] Very active against *P. berghei* ANKA at ED_{50} value of 0.82 mg/kg	1-(2,4-dihydroxy phenyl)-3-[8-hydroxy-2-methyl-2-(4-methyl-3-pentenyl)-2H-1-benzopyran-5-yl]-1-propanone

				Very good activity against *P. falciparum* 3D7 strain	1.32 µg/ml IC$_{50}$	*In vitro* [186]
13.	*C. papaya*	Leaf	n-Hexane, ethyl acetate and dichloromethane	*In vitro* [127] Very good to moderate activity against *P. falciparum* 3D7 and Dd2 strains	1.52-20.32 g/ml IC$_{50}$	Carpaine *In vitro* [127] Linoleic and linolenic acids *In vitro* [128]
		Leaf	Ethyl acetate	*In vitro* [128] Very good activity against *P. falciparum* D10 strain	2.96 µg/ml IC$_{50}$	
14.	*C. longa*	Leaf	Ethanol	*In vivo* [115] Suppression effect of 78.4% at 400 mg/kg against *P. berghei* NK65 strain		
15.	*V. amygdalina*	Leaf	Ethanol	*In vitro* and *in vivo* [172]	9.83 µg/ml IC$_{50}$	Vernonioside A1, A2, A3, A4, B1, vernodalin,

50

				Good activity against *P. falciparum* 3D7	vernodalol, vernolide and hydroxyvernolide
					In vitro [175]
				Suppression of 82.3% at 1,000 mg/kg against *P. berghei* ANKA	
	Leaf	Ethanol		*In vivo* [173]	
				Suppression of 67% at 1,000 mg/kg against *P. berghei*	
	Leaf	Aqueous		*In vivo* [174]	
				Suppression of 63% at 125 mg/kg against *P. berghei* ANKA	
16.	*T. cacao*	Leaf	Aqueous	*In vivo* [187]	
				Suppression effect of 79.19% at 400 mg/kg against *P. berghei* ANKA strain	

No.	Species	Part	Extract	Activity	IC$_{50}$	Compounds
17.	*L. alata*	Leaf	Hexane	*In vitro* and *in vivo* [188] Very good activity against *P. falciparum* NF54 and K1 strains Suppression effect of 74.45% at 500 mg/kg against *P. berghei* NK65	2.5 µg/ml IC$_{50}$	
18.	*C. nucifera*	Husk fibre	Ethyl acetate	*In vitro* and *in vivo* [189] Good activity against *P. falciparum* W2 strain Suppression effect of 98.6% at 125 mg/Kg against *P. berghei* NK65	10.94 µg/ml IC$_{50}$	
19.	*H. madagascariensis*	Leaf	Methanol	*In vitro* [148] Weak activity against *P. falciparum* D6 strain	39.07±1.57 µg/ml	Bazouanthrone, feruginin, harunganin, harunganol A and harunganol B

		Stem bark	Ethanol	*In vitro* and *in vivo* [147] Poor activity against *P. falciparum*	0.052-0.517 g/ml53 IC$_{50}$	*In vitro* [149]
				Suppression of 28.6–44.8% at 20-80 mg/kg against *P. yoelii nigeriensis* N67 strain		
20.	*K. africana*	Leaf, root, stem bark and fruit	n-Hexane, dichloromethane, ethyl acetate, n-butanol and methanol	*In vivo* [9] Suppression effect of 70.33-84.73% at 500 mg/kg against *P. berghei* NK65		*p*-hydroxycinnamic acid, specicoside, 2β,3β,19α-trihydroxy-urs-12-en28-oic acid and atranorin
		Stem bark	Ethyl Acetate	*In vitro* [190] Moderate activity against *P. falciparum* W2 strain	11.15 μg/ml IC$_{50}$	*In vitro* [156]
21.	*S. acuta*	Leaf	Methanol	*In vivo* [191]		Cryptolepine *In vitro* [192]

				Suppression effect of 64.64% at 600 mg/kg against *P. berghei* NK 65 strain			
		Leaf	Ethanol	*In vivo* [193] Suppression effect of 97.38% at 600 mg/kg against *P. berghei* ANKA-65 strain			
22.	*Z. zanthoxyloides*	Leaf	Methanol	*In vivo* [194] Suppression effect of 95.95% at 600 mg/kg against *P. berghei* ANKA-65 strain			Fagaronine *In vitro* [195,196]
		Root	Aqueous	*In vitro* [195] Very good activity against *P. falciparum* strain 3D7	4.9 IC$_{50}$	μg/mL	
23.	*T. diversifolia*	Aerial part	Ethanol	*In vivo* [197]			Tagitinin C *In vitro* [198]

				Suppression effect of 82.55% at 400 mg/kg against *P. berghei var Anka 1* strain		
24.	*G. kola*	Stem bark	Ethanol and petroleum ether	*In vitro* [143] Very good activity against *P. falciparum*	<3 µg/ml IC$_{50}$	Kolaviron *In vivo* [199] I-4′,II-4′,I-5,II-5,I-7,II-7-hexahydroxy-I-3,II-8-biflavanone, II-3,I-4′,II-4',I-5,II-5,I-7,II-7-heptahydroxy-I-3,II8-biflavanone and II-3, 3′,I-4′,II-4′,I-5,II-5,I-7, II-7-octahydroxy-I-3,II-8-biflavanone *In vitro* and *in vivo* [145]
		Seed	n-Hexane, dichloromethane and methanol	*In vivo* and *in vitro* [144] Moderate activity against *P. falciparum* D10 strain	10.59-25.65 µg/mL IC$_{50}$	
25.	*C. aurantifolia*	Leaf	Methanol	*In vivo* [200]		

				Suppression effect of 75.66% at 320 mg/kg against *P. berghei* NK65 strain	
26.	*P. guajava*	Leaf	Ethanol	*In vivo* [201] Suppression effect of 58.9 and 67.4% at 600 mg/kg against *P. berghei* ANKA strain and *P. chabaudi chabaudi*	
		Leaf	Aqueous	*In vitro* [202] Good activity against *P. falciparum* K1 strain	5.46 µg/ml IC$_{50}$
27.	*K. ivorensis*	Stem bark	Aqueous	*In vivo* [203] Suppression effect of 35.5% at 400 mg/kg against *P. berghei* ANKA strain	

No.	Species	Part	Solvent	Study type [ref] / Activity	Result	Compounds
28.	*A. nilotica*	Leaf, pods and bark	Hydroethanol	*In vitro* [204] Very good activity against *P. falciparum* 3D7 strain	1.29, 4.16 and 4.28 µg/ml IC_{50}	
		Twigs	Dichloromethane/ methanol	*In vitro* [205] Moderate activity against *P. falciparum* D10 strain	13 µg/ml IC_{50}	
29.	*B. coccineus*	Leaf	Ethanol	*In vivo* [206] Suppression effect of 92.3% at 400 mg/kg against *P. berghei berghei*		
30.	*W. indica*	Aerial parts	Aqueous and dichloromethanol:methanol (1:1)	*In vitro* [205] Poor activity against *P. falciparum* D10 strain	>100 µg/ml IC_{50}	
31.	*A. leiocarpus*	Stem bark	Methanol, water, butanol and ethyl acetate	*In vitro* [132]	10.94–13.77 µg/ml IC_{50}	Castalagin, ellagic acid, flavogallonic acid and punicalagin

No.	Species	Part	Solvent	Activity	IC$_{50}$	Study
				Good to moderate activity against *P. falciparum* 3D7 and K1		*In vitro* [132]
32.	*A. compressus*	Leaf	Aqueous	*In vivo* [207] Suppression effect of 85.7% at 62.5mg/kg against *P. berghei* NK65		
33.	*V. paradoxa*	Leaves and stem bark	70% aqueous methanol	*In vitro* [208] Weak to very weak activity against *P. falciparum* 3D7 strain	39 and 66 µg/ml IC$_{50}$	
		Stem bark	Dichloromethane	*In vitro* [209] Weak activity against *P. falciparum* 3D7 strain	43.94±13.44 µg/ml IC$_{50}$	
34.	*Z. officinale*	Root	Hydromethanol	*In vivo* [210]		

			Suppression effect of 32.83±1.03% at 1000 mg/kg against *P. berghei* ANKA strain		
35.	*P. kotschyi*	Leaf	Ethanol	*In vivo* [211] Suppression effect of 90% at 400 mg/kg against *P. berghei* NK65 strain	Kotschyins A-C, 7-deacetylgedunin and 7-deacetyl-7-oxogedunin *In vitro* [212]
36.	*A. comosus*	Leaf	Ethanol	*In vitro* [213] Very weak activity against *P. falciparum* 3D7 and INDO strains	>100 µg/ml IC_{50}
37.	*P. americana*	Leaf	Methanol, n-hexane, ethyl acetate, methanol and aqueous	*In vivo* [167] Suppression effect of 55.00±0.06 to 64.01±0.08% at	1, 2, 4-trihydroxyheptadec-16-ene and 1, 2, 4, 15-tetrahydroxyheptadecane-6, 16-diene

No.	Species	Plant part	Solvent	Activity	IC$_{50}$	
				200-400 mg/kg against *P. berghei*		*In vitro* [168]
38.	*O. gratissimum*	Fresh leaf	Aqueous (Hydrodistillation)	*In vivo* [214] Suppression effect of 77.8% at 500 mg/kg against *P. berghei* ANKA strain		
		Leaf	Aqueous	*In vitro* [202] Good activity against *P. falciparum* K1 strain	7.25 µg/ml IC$_{50}$	
		Leaf and twig	Dichloromethane	*In vitro* [215] Good activity against *P. falciparum* D6 and W2 strains	8.616 µg/ml IC$_{50}$	
		Leaf	Methanol	*In vitro* [216] Good activity against *P. falciparum* D6 and W2 strains	5.9 µg/ml IC$_{50}$	

39.	*P. africana*	Stem bark	Methanol, aqueous, butanol and ethyl acetate	*In vitro* [132] Moderate activity against *P. falciparum* 3D7 and K1	14.97–15.28 µg/ml IC$_{50}$
40.	*C. sinensis*	Stem	Ethanol	*In vivo* [217] Suppression effect of 53.27% at 700 mg/kg against *P. berghei* ANKA strain	
		Rind of ripe fruit	Petroleum ether and methanol	*In vitro* [218] Very weak activity against *P. falciparum* FCK 2 strain	51.06-53.61 µg/ml IC$_{50}$
41.	*D. oliveri*	Leaf	Methanol	*In vivo* [133] Suppression effect of 87% at 700 mg/kg against *P. berghei*	
		Stem bark	Methanol, aqueous, butanol and ethyl acetate	*In vitro* [132] Weak activity against *P. falciparum* 3D7 and K1 strains	23.14-32.97 µg/ml IC$_{50}$

42.	*F. exasperata*	Leaf	Ethanol	*In vivo* [219]	
				Suppression effect of 82% at	
				400 mg/kg against *P. berghei*	
				NK65 strain	
43.	*F. platyphylla*	Stem bark	Ethanol	*In vivo* [141]	
				Suppression effect of 43.50% at	
				300 mg/kg against *P. berghei*	
44.	*J. curcas*	Leaf	Ethyl acetate, hexane and methanol	*In vitro* [144] Good to moderate activity against *P. falciparum* K1 and NF54 strains	2.39±0.54- 31.09±4.36 µg/ml IC$_{50}$
45.	*M. discoidea*	Leaf	Aqueous, ethanol and methanol	*In vitro* [160] Moderate to weak activity against *P. falciparum* K1 and NF54 strains	13.60±1.80- 43.61±0.92 µg/ml IC$_{50}$
46.	*P. nigrescens*	Leaf	Aqueous	*In vivo* [220]	

| | | | | Suppression effect of 86% at 150 mg/kg against *P. berghei* NK65 |

47.	*P. thonningii*	Leaf	Ethanol	*In vivo* [221]
				Suppression effect of 91.94% at 400 mg/kg against *P. berghei* NK65
48.	*P. guineense*	Leaf	Ethanol	*In vivo* [222]
				Suppression effect of 62.69% at 600 mg/kg against *P. berghei*

Table 3 Phytocompounds with antimalarial activities isolated from some of the indigenous medicinal plants used for malaria treatment

S/n	Name of plant	Isolated phytocompounds with antimalarial activity	Structure

1.	*A. occidentale*	Anacardic acid [117]	
		Cardol triene 1 [116]	
		2-methylcardol triene 4 [116]	
2.	*A. indica*	Gedunin [125]	
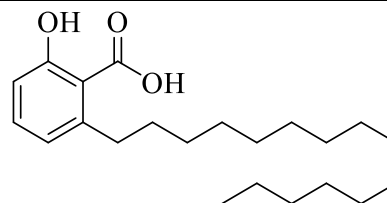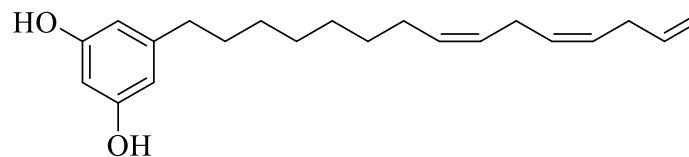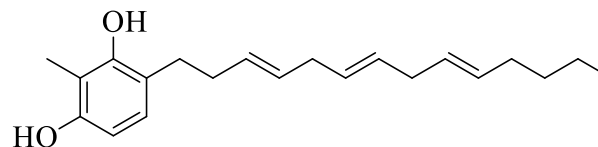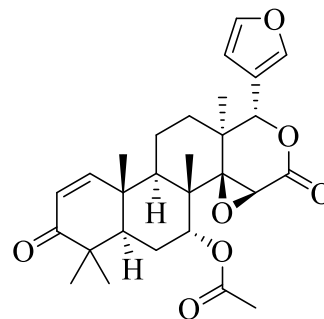
Nimbolide [124]
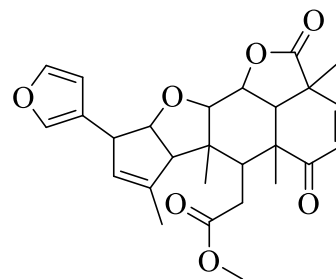
Azadirachtin [126]
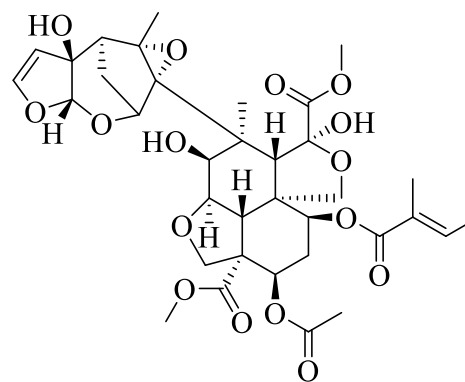
| 3. | *C. papaya* | Carpaine [127] |

| Linoleic acid [128] | |
| Linolenic acid [128] | |
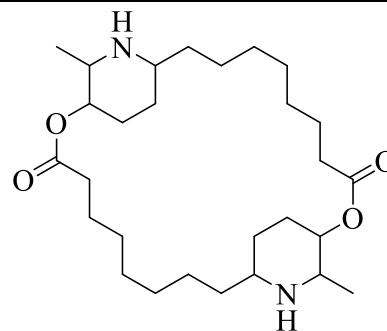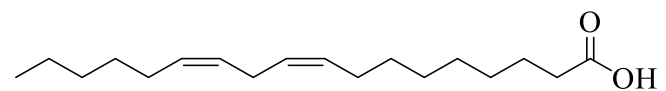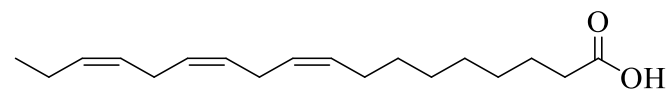
4.	*E. chlorantha*	Jatrorrhizine [136]	
		Berberine [136]	
		Palmatine [136]	
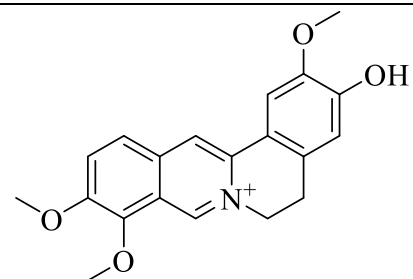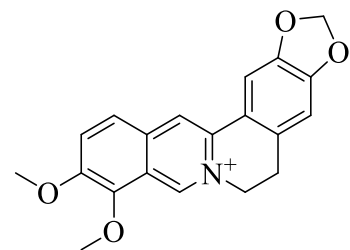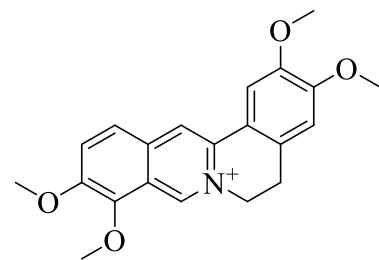
5.	*M. lucida*	Digitolutein [165]	
		Rubiadin 1-methyl ether [165]	
		Damnacanthal [165]	
		Ursolic acid [166]	
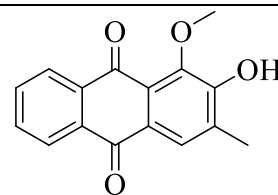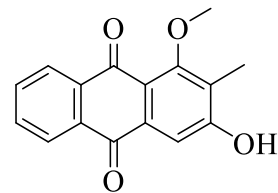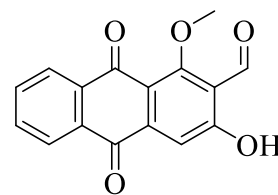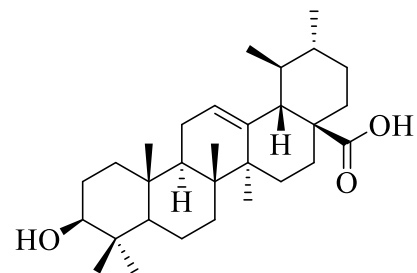
Oleanolic acid [166]
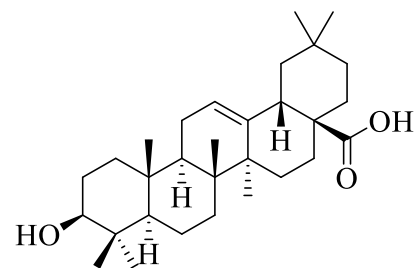
| 6. | *P. americana* | 1, 2, 4-trihydroxyheptadec-16-ene [168] | |
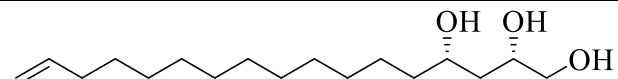
1, 2, 4, 15-tetrahydroxyheptadecane-6, 16-diene [168]
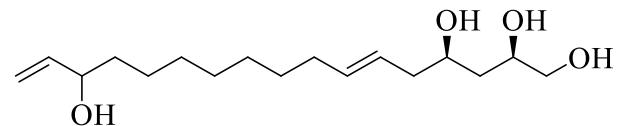
| 7. | *V. amygdalina* | Vernonioside A1: R_1 = beta-OH, R_2 = H [175] |

Vernonioside A2: R_1 = alpha-OH, R_2 = H [175]

Vernonioside A3: R_1 = O, R_2 = H [175]

Vernonioside B1: R_1 = H, R_2 = OH [175]

Glc
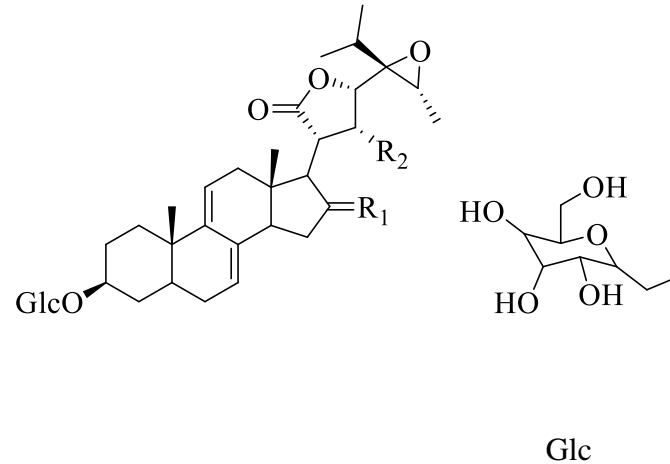
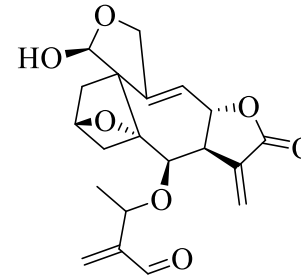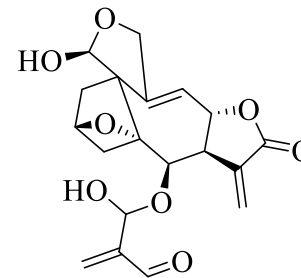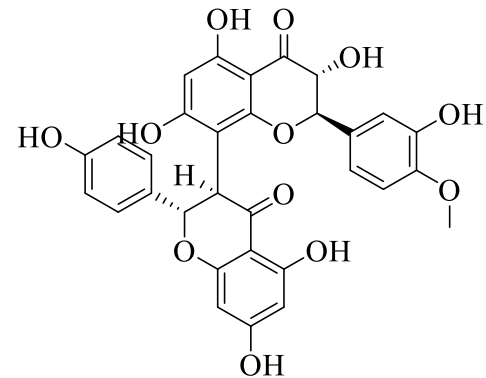Vernonioside A4 [175]
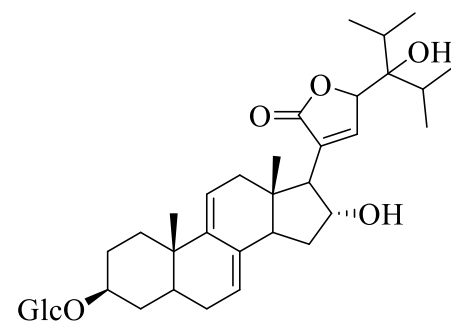
Vernodalin [175]
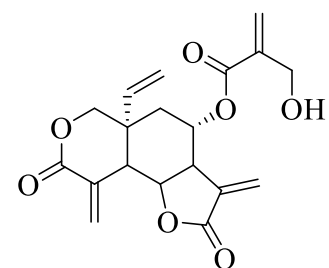
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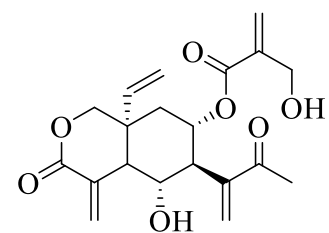
Vernolide [175]

Hydroxyvernolide [175]

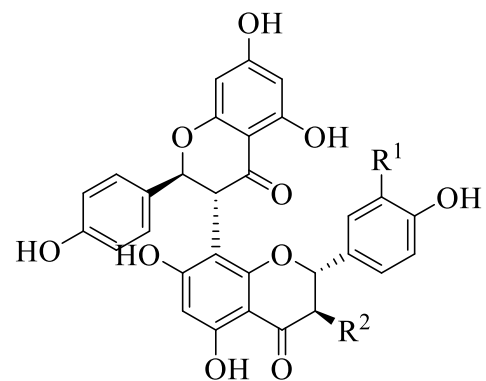| 8. | *G. kola* | Kolaviron [199] | |

I-4′,II-4′,I-5,II-5,I-7,II-7-hexahydroxy-I-3,II-8-biflavanone:

R^1 = H, R^2 = H [145]

II-3,I-4′,II-4',I-5,II-5,I-7,II-7-heptahydroxy-I-3,II8-

biflavanone: R^1 = H, R^2 = OH [145]

II-3,   3′,I-4′,II-4′,I-5,II-5,I-7,   II-7-octahydroxy-I-3,II-8-

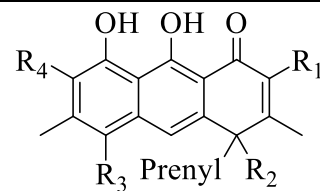biflavanone: R^1 = OH, R^2 = OH [145]

9.	*H. madagascariensis*	Bazouanthrone: R_1 = Prenyl, R_2 = Prenyl, R_3 = OH, R_4 = H [149]	

Feruginin: R_1 = H, R_2 = Prenyl, R_3 = H, R_4 = Prenyl [149]

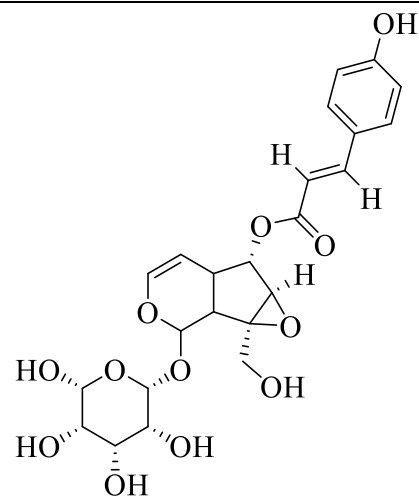Harunganin: R_1 = H, R_2 = Prenyl, R_3 = Prenyl, R_4 = H [149]

Harunganol A: R_1 = H, R_2 = H, R_3 = Prenyl, R_4 = Prenyl [149]

Harunganol B: R_1 = H, R_2 = H, R_3 = Prenyl, R_4 = H [149]
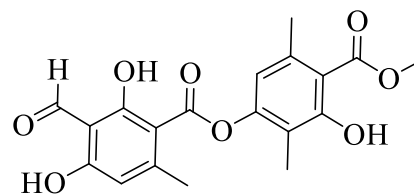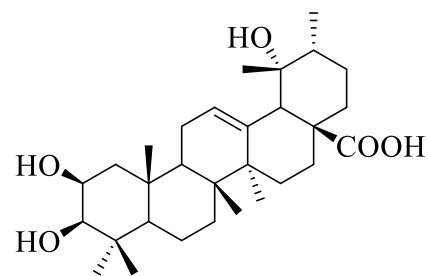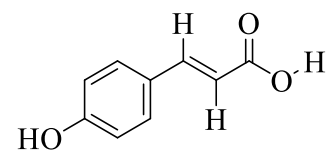
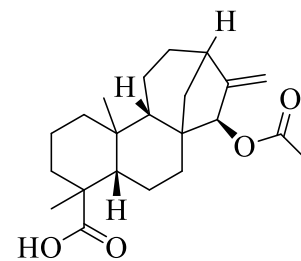| 10. | *K. africana* | Specicoside [156] | |
| | | Atranorin [156] | |
| | | 2β,3β,19α-trihydroxy-urs-12-en28-oic acid [156] | |

p-Hydroxycinnamic acid [156]

| 11. | *X. aethiopica* | Xylopic acid [181] |

Conservation status of the medicinal plants

The conservation status of the 62 medicinal plant species reported in this study showed that 30 were found to be Least Concern (LC), data for 24 were Not Evaluated (NE), 4 each were both Data Deficient (DD) and Vulnerable (VU). Findings from this present study showed that none of the documented indigenous medicinal plant species was found to be Near Threatened (NT), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW) and Extinct (EX) suggesting that they have not been overexploited. However, conservation strategies should be intensified to preserve and prevent the plants, especially the Vulnerable (*K. ivorensis*, *L. alata*, *V. paradoxa* and *G. kola*), from becoming Endangered or Extinct so as to ensure their sustainable availability and biodiversity. This can be achieved by planting these trees through afforestation and forestation programmes to guarantee the sustainable use of the exploited plant taxa [223, 224].

Conclusion

This is the first comprehensive ethnobotanical study carried out in the region revealing important medicinal plant taxa diversity and ethnomedicinal knowledge held by the TMPs. The current study highlighted the use of indigenous medicinal plants for malaria treatment and fills a gap in our ethnomedicinal knowledge about Kwara State and Nigeria in general. We showed that folk medicine is still being practiced in Kwara State which harbours a wide variety of ethnoflora. A total of 62 medicinal plant species including 13 new plants used for malaria treatment in the State were identified. Although, these medicinal plants are usually combined as recipes for herbal preparations, many of them and their isolated phytocompounds have shown *in vitro* and/or *in vivo* antiplasmodial activities against *P. falciparum* and *P. berghei* while some are yet to be evaluated.

Due to their high percentage citation frequency, *M. indica*, *E. chlorantha*, *A. boonei*, *C. citratus* and *N. latifolia* were identified as the most widely used medicinal plants for malaria treatment in folk medicine among the TMPs thus, have great potential to be used in further ethnopharmacological research. This could help contribute to the provision of "*Good Health and Well-being*", Goal 3 of the United Nations Sustainable Development Goals (UN SDGs), for the hundreds of millions of people infected with the human malaria parasites, and the achievement of the WHO Global Technical Strategy for Malaria goal – "*reduction of global malaria burden by 90% in 2030*".

In the immediate past, environmental issues, and various health disorders and diseases including malaria have diversified the reason people utilize plants for medicinal purposes and these have increased the level at which these plants are used. This heightened consumption of medicinal plants carries with it overuse and abuse. Hence, people should be educated on the correct usage and dose of medicinal plants and, most importantly, to create the awareness that these resources are limited and could be exhausted if not properly managed. This awareness must be raised, particularly among younger generations, with a view to ensuring the sustainable use of medicinal ethnoflora and preservation of traditional knowledge.

Altogether, the data in this current study contributes to both national and international efforts aimed at documenting the local use of indigenous medicinal plants with antimalarial potentials and provides preliminary information for future pharmacological, toxicological and conservation studies.

Guidelines for human and plant study

It is imperative for researchers to obtain official written approval before embarking and collecting plant specimens in indigenous communities. To be able to do this, researchers must be affiliated with a research institution or a university and be ready to prepare and deposit the voucher specimens in a recognized herbarium. Also, researchers and fieldworkers should get an approval from the community head(s) or leader(s) of the group under study as well as obtain an informed consent from the participants, either verbally or in writing. The community leaders and participants may have suggestions that could enhance the study and add more value to the indigenous community, so researchers need to establish trust by being open and honest in addition to discussing the aim, study methodology, and possible implications and consequences of the study in clear and unambiguous terms.

Abbreviations

CR: Critically Endangered

DD: Data Deficient

EN: Endangered

EW: Extinct in the Wild

EX: Extinct

FRIN: Forestry Research Institute of Nigeria

IC_{50}: Half maximal inhibitory concentration

LC: Least Concern

LGA: Local Government Area

LUCRID: Landmark University Centre for Research, Innovation and Discoveries

NE: Not Evaluated

NIPRD: National Institute of Pharmaceutical Research and Development

NT: Near Threatened

TMP: Traditional medicine practitioner

UBH: University of Benin Herbarium

VU: Vulnerable

Declarations

Ethics approval and consent to participate

The study was carried out in strict compliance with the Declaration of Helsinki. The plant study also complied with the IUCN Policy Statement and institutional legislation and regulations on Research Involving Species at Risk of Extinction and the Convention on the Trade in Endangered Species of Wild Fauna and Flora. Ethical approval to carry out the research was granted by the Landmark University Centre for Research, Innovation and Discoveries (LUCRID) and the Research Ethical Committee for Landmark University (LUAC/2021/0067C). Informed consent to participate in the study was obtained from the participants.

Consent for publication

Not applicable.

Availability of data and materials

The data generated or analysed during this study are included in this article.

Authors' contributions

IOE, OSA, OMO: Methodology, Conceptualization, Project administration, Investigation, Writing–original draft, Writing—review & editing. IOE, OSA: Funding acquisition. OSA, OMO: Supervision. All the authors listed in this paper have read and approved the final version of the submitted manuscript, and agreed to be accountable for the content of the work.

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