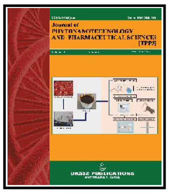
Journal of Phytonanotechnology and Pharmaceutical Sciences 4(4): 39-46, 2024

Online ISSN:2583-0376

http://jpps.ukaazpublications.com

DOI: http://dx.doi.org/10.54085/jpps.2024.4.4.6

Journal of Phytonanotechnology and Pharmaceutical Sciences



Review Article : Open Access

Understanding the epidemiology of Malaria: Insights into plant-based prevention and control strategies

Shruti Vyas and Fatima Umaira Saeed

Department of Pharmacology, RBVRR Women's College of Pharmacy, Affiliated to Osmania University, Hyderabad-500027, Telangana State, India

Article Info

Article history
Received 10 November 2024
Revised 12 December 2024
Accepted 13 December 2024
Published Online 30 December 2024

Keywords
Malaria
Epidemiology
Prevalence
Abortion
Morbidity
Mortality

Abstract

Malaria is a serious infectious disease caused by the *Plasmodium* parasite, transmitted primarily through the bites of infected female *Anopheles* mosquitoes. In tropical and subtropical regions, malaria remains a significant public health concern, contributing to high morbidity and mortality rates globally. In this review, we emphasize epidemiological studies conducted in various countries, with a particular focus on different regions of India. The selection of India for these studies is driven by its vast geographical diversity, varying topographies, and distinct weather patterns. Additionally, India faces challenges such as high genetic diversity of the malaria parasite, insecticide resistance, and the rapid evolution of drug resistance. Due to its complex epidemiological landscape and history, India has emerged as a key region for malaria research. Malaria prevalence is notably higher among pregnant women, leading to adverse outcomes such as premature delivery, abortion, and intrauterine foetal death. To effectively combat malaria, it is essential to consider economic factors alongside preventive measures that have been implemented, while identifying areas that require further improvement.

1. Introduction

The term “malaria” means ‘bad air’. Human malaria is a parasitic disease caused by protozoan which belongs to the Family-Plasmodiidae, and Genus-Plasmodium. *Plasmodium* species are parasitic with no locomotory organelle. There are four species of *Plasmodium, i.e., P. malariae, P. falciparum, P. vivax,* and *P. ovale* among which *P. falciparum* is the most virulent. People get exposed to disease by bites of infected female *Anopheles* mosquitoes that breed in stagnant water. Salivary glands of mosquitoes carry sporozoites which transfer to the human bloodstream during blood meal and then they transfer to the liver where maturation and reproduction take place (Garrido *et al.,* 2019). *P. falciparum* infections are more common in school-aged children than younger adults. This infection leads to poor health, anaemia, and low cognitive function (Cohee *et al.,* 2020). Symptoms that usually appear within two weeks are headache and fever, joint pain, dark urine, jaundice, tiredness, difficulty in breathing and severe cases of death (WHO, 2024). It is a widespread disease that includes tropical and subtropical regions. Most commonly occur in Sub-Saharan Africa, America, and Asia (Garrido *et al.,* 2019).

Apart from bites of an infected mosquito, malaria is caused through blood transfusion of malaria-infected persons, by sharing unsterile malarial needles which are used to inject drugs through a parenteral route causing human-human transmission.. Transmission through vectors including *Culex, Aedes,* and *Anopheles*, the infected mother may also pass malaria to her baby during birth called congenital malaria. In humans, 4 species are identified which is discussed in Table 1. A rare type is *P. knowlesi,* which is often mistaken for quartan malaria and primarily occurs in endemic areas are Malaysia, Thailand, and Cambodia. It can cause death, if not treated quickly and effectively (Garrido *et al.,* 2019).

1.1 *Plasmodium* life cycle

When a female *Anopheles* mosquito bites a healthy individual, it injects *Plasmodium* sporozoites into the bloodstream *via* its saliva. The incubation period of malaria varies between 7 to 30 days, depending on the species of the malarial parasite. Once inside the human body, the sporozoites travel to the liver, where they undergo further replication and maturation, transitioning into merozoites. These merozoites then infect red blood cells (RBCs), where they develop into trophozoites. The trophozoites multiply further, forming schizonts through repeated cycles of replication. As schizonts mature, they rupture the RBC membranes, releasing more merozoites into the bloodstream and initiating phagocytosis by the spleen. The spleen helps clear the infected RBCs, but this process also contributes to severe anaemia and the folic acid deficiency (Garrido *et al.,* 2019).

1.2 Diagnosis

- **Microscopy:** Thick and thin smears; peripheral blood smear which is a gold standard.
- **Rapid diagnostic test:** Dipstick test, immunochromatographic test, and detection of antigens-HRP2, aldolase.
- **Other tests:** serological tests, polymerase chain reaction and radioimmunoassay (Garrido *et al.,* 2019).

Corresponding author: Ms. Fatima Umaira Saeed
Assistant Professor, Department of Pharmacology, RBVRR Women's College of Pharmacy, Affiliated to Osmania University, Hyderabad-500027, Telangana State, India
E-mail: fatimaumairasaeed@gmail.com
Tel.: +91-9392301704

Table 1: Types of *Plasmodium* species and their severity

Types of *Plasmodium*	Endemic area	Febrile seizures period	Relapses	Time of cycle	Involvement and severity
P. falciparum	In all endemic areas	Irregular crisis	No long term relapses	36-48 h	Very serious and it can cause death if not treated properly
P. vivax	South America and Asia	Every two days	Yes	44-48 h	Very serious that death can happen, but with delayed onset
P. malariae	South America and Asia	Every two days	No, but long term recognised	72 h	Moderate, less frequently
P. ovale	Africa	Every two days	Possible but spontaneous recovery	48 h	Moderate, less frequently

2. Treatment

i. **Uncomplicated malaria by *P. falciparum*:** In the case of chloroquine sensitivity drug:

- 1500 mg base chloroquin ephosphate for adults.
- 25 mg of base chloroquin ephosphate for children.
- In the case of chloroquine resistance – Quinine sulphate + antibiotics like TTC's. So, the adult dose is 542 mg base orally.

ii. **By *P. malariae*:** Chloroquine phosphate is recommended.

iii. **By *P. vivax*:** Chloroquine phosphate + primaquine phosphate 30 mg base orally for 14 days.

iv. **Severe malaria:** The drugs for adults and children will be given by intravenous route and the drugs are quinidine gluconate + doxycycline or TTC or clindamycin.

v. **Artemisinin:** The first line treatment was used against the asexual erythrocytic stage of *P. falciparum*.

vi. **Primaquine:** It is very active against pre-erythrocytics porozoites and gametocytes which means it is active at all stages. It is contraindicated in pregnancy or in lactating mothers (Garrido *et al.,* 2019).

3. Plant sources which are used in the prevention of malaria

Utilizing plant-based sources for the prevention and treatment of malaria has gained attention due to their rich chemical diversity, cost-effectiveness, and accessibility, especially in malaria-endemic regions (Newman *et al.,* 2016). Below are key reasons for the use of plant-based approaches:

3.1 Natural antimalarial compounds

Plants have long been a source of bioactive compounds, including artemisinin and quinine. Artemisinin is derived from *Artemisia annua* and forms the basis for artemisinin-based combination therapies (ACTs), which are highly effective in treating malaria (Mishra *et al.,* 2020). Quinine is extracted from the bark of the *Cinchona* tree and was one of the earliest and most effective treatments for malaria.

3.2 Lower risk of resistance

Plant-based treatments, with their complex chemical profiles, may reduce the likelihood of resistance compared to synthetic drugs. This is particularly valuable in regions where synthetic antimalarials are limited and resistance is a growing concern.

3.3 Accessibility in endemic areas

Many malaria-endemic regions are in developing countries where access to pharmaceutical drugs may be limited. Locally available plants offer an affordable and accessible alternative for malaria prevention and treatment.

3.4 Sustainability and renewability

Cultivating medicinal plants like *Artemisia annua* provides a renewable source of antimalarial compounds, reducing dependence on synthetic production and promoting sustainability (Krishna *et al.,* 2008).

3.5 Source of new drug development

Research into plants traditionally used in medicine can lead to the discovery of new antimalarial drugs. Ethnobotanical studies often uncover plants with bioactive compounds that can be further explored and optimized (Cowman *et al.,* 2016).

3.6 Potential for combination therapies

Plant-derived compounds can be used in combination with other drugs to enhance efficacy and reduce resistance development. For example, artemisinin is often combined with other antimalarial agents like lumefantrine (Efferth and Koch, 2011).

3.7 Local knowledge and practices

Traditional medicine systems often incorporate plant-based remedies for febrile illnesses like malaria, providing a foundation for scientific validation and integration into modern medicine. However, challenges such as quality control, standardization, and sustainable harvesting need to be addressed to fully incorporate plant-based treatments.

4. Global study of malaria

As we know the major parasitic disease in the overall world is malaria. Two forms of malaria are seen in Africa. The first is severe malaria anaemia which is mostly seen in higher transmission places where kids are mostly affected and cerebral malaria is mostly seen in moderate transmission areas and older children (Greenwood, 1997).

Table 2: Different plant sources which are used for prevention of malaria

Plant name	Chemical constituent	Structure	Active compound	Antimalarial role	Reference
Artemisia annua	Artemisinin, flavonoids	Lactone structure	Artemisinin	Effective against *P. falciparum,* widely used in combination-therapies formalaria.	National Institute of Allergy and Infectious Diseases, 2024
Azadiractha indica	Azadirachtin, lilimonoids	Complex triterpe-noid structure	Azadirachtin	Exhibit inhibitory effects on mosquito vectors and parasites in malaria.	National Institute of Allergy and Infectious Diseases, 2024
Cinchona officinalis	Quinine, alkaloids	Quinoline structure	Quinine	Historically significant, used in treating malaria and chloroquin resistant strain.	National Institute of Allergy and Infectious Diseases, 2024
Swertia chiratia	Mangiferin, amarogentin	C-glycoside, fla-vonoid structure	Amarogentin	Potent antimalarial activity against *P. vivax* and *P. falciparum.*	National Institute of Allergy and Infectious Diseases, 2024
Tinospora cordifolia	Alkaloids, glycosides	Berberine-like alkaloid structure	Berberine	Enhances immunity and directly impacts parasitic growth.	Kumar *et al.,* 2023
Andrographis paniculata	Andrographolide, diterpinoids	Diterpene lactone structure	Andrographolide	Suppresses parasite replication and boost immune responses.	Kumar *et al.,* 2023
Curcuma longa	Curcumin, tumerones	Polyphenolic structure	Curcumin	Inhibits parasitic in-vasion and reduce infla-mmation caused by malaria.	Kumar *et al.,* 2023
Moringa oleifera	Flavonoids, phenolic acids	Flavonoid glycoside structure	Kaempferol	Supports reduction of oxidative stress and parasite burden.	Kumar *et al.,* 2023

4.1 Epidemiology study of malaria in Nigeria

Omolade and Okwa (2010) performed a study on the students of the Lagos State University in the rainy season. They randomly selected 100 of students and faculty from each department. Out of 330 males, 250 males were infected and out of 270 females, 250 were infected. They reported that women are more infected than men and the prominent species found were *P. falciparum* and *P. malariae*. Men with HbAA were more infected than women (Bruce *et al.,* 1952). In rural areas, malaria is holoendemic and in urban areas, it is hyperendemic. Morbidity and mortality are seen due to growing drugs, insecticide resistance, and weather changes and also due to deterioration in health conditions. During the start of the study, even though, the malarial parasite was present in the participant's blood they were asymptomatic. Similarly, Bruce Chwatt (1970) reported the same that in starting day's patients may be asymptomatic when he performed a longitudinal study on the African students. In sub-Saharan Africa, Brabin and Brabin (2005) reported that malaria and HIV were responsible for the burden of disease and also caused anaemia. The role of socio-demographics is also important. In a study, the students who used to roam out at night were more infected than the students who used to stay indoors as this mosquito bites more during the night time and the students who covered their whole bodies with long-sleeved dresses and pants were less affected than others (Omolade and Okwa, 2010).

4.2 Epidemiology study of malaria incidence in vhembe District, South Africa

The study involves three malarial seasons because it was performed from the year 2015 July to 2018 June. So, daily malaria cases were collected and reported in their system. Statistical analysis was conducted two times a week.

Primarily is to know the incidence time series from each locality and secondly to know the patterns and hierarchical clustering. This was done by using ward's method or algorithm and the number of patterns were identified by PCA, *i.e.,* principal components analysis on validity indices. So, all of these simultaneously gave better Dunn index, width Silhouette, Connectivity index, and % of inertia of PCA results. So, a total of four malaria incidence patterns were identified which are discussed in the Table 3. Malaria transmission is seasonal in South Africa. Generally, it starts to increase in October, peaks in Jan-Feb, and decreases in May. During rainfall, mosquitoes bite more as they produce more eggs and therefore transmit malaria more than in a usual manner. By newly developed diagnostics, treatments, and vector control South Africa has reached the pre-elimination stage (Dieng *et al.,* 2023).

Table 3: The different malarians patterns

Factors	Very low	Low	Intermediate	High
Area	Include 391 localities mostly from between Makhado and Thulamela	Include 54 localities mostly from Thulamela Masina	Include 20 localities mostly from Musina	Include 9 localities from north masina close to the river
Incidence	Lowest	Lowest	2nd highest	Highest
Cumulative incidence	2.4 cases/1000 person-year	16.2 cases/1000 person-year	54.1 cases/1000 person-year	181.2 cases/1000 person-year
Median incidence	3 cases/1000 person-years	21.7 cases /1000 person-years	57.3 cases /1000 person -years	211.3 cases/1000 person-years
Seasonal peak	Important during the end of 2nd malarial season	Important during the end of 2nd malarial season	Important during the end of 3rd malarial season	Important during the beginning of 3rd malarial season

4.3 Southeast Asia

The major cause of zoonotic malaria in Southeast Asia is *P. knowlesi*. In *Plasmodium* infected patients, it has been found that the product of heme metabolism is hemozoin and this hemozoin can be detected by Gazelle-Hemex Health, USA. Zoonotic malaria is a burden in Malaysia with many cases present and death reports. There was an increased incidence of *P. knowlesi* in Malaysia. The reported sensitivity of Gazelle was 95% threshold as an alternative to microscopy. Studies for malarial diagnosis of *P. falciparum, P. ovale, P. vivax,* and *P. malariae* reported 82% performance of Gazelle compared to PCR (Tan *et al.,* 2023).

4.4 Turkey

Mert *et al.* (2003) conducted a retrospective study on 29 males and 4 females. The Health Ministry has given data on malaria cases in that country. By collecting blood samples, the diagnosis was done by a thin smear of blood preparation in the febrile period of all cases. So, the most reported was *P. vivax*, followed by *P. falciparum*. The majority of the patients had symptoms like a fever (100%); anaemia (70%); splenomegaly (91%) and a rise in sedimentation rate. The health ministry said the most common species found is *P. vivax* (100%) (Mert *et al.,* 2003).

4.5 Palawan

Before world War 2, the Philippines reported two million cases of malaria in a year and four million cases of malaria during and after the War. There are still many infected patients and many cases are unreported because of acute conditions. Researchers conducted a longitudinal study on the West Coast of the Island of Palawan. The reason why a longitudinal study was selected is because it gives the seasonal variations in vector and disease and also shows or identifies the incidence of disease. The reason to select this site or location was according to Malaria Eradication Service-Personnel Communication Palawan is the most malarious area in the Philippines and geography or population characteristics and rainfall vary very little throughout the island. The study was performed by them in the years 1986-March, June, and September and in the years 1987-January, April, and July. 18-31.6% was the prevalence of malaria. Mostly, the bites of mosquitoes or malaria incidence were found during rainfall because of increased *Plasmodium* species. During the dry season, it was 7.4/man/night, and during the rainy season, it was 59.4/man/night. They also reported the prevalence of Giemsa smear positive (Richard *et al.,* 1988).

4.6 Iran

The study was done from 2011-2014. The incidence decreased in the four years of the research = 4.7, 2.1, 1.8, 1.59 per 100000 people. Most infected cases were men from rural areas and the age category was 16 to 25 years. The majority were detected at the trophozoite stage. It has been reported that the most prevalent species was *P. vivax* (Faezeh *et al.*, 2016).

4.7 Seasonal effect on malaria in Papua New Guinea

Near the mountainside and on steep slopes there was less formation of standing pools of water because rainfall water used to flow off in lower small streams. During the dry season when the water level is low, it leads to the formation of breeding habitats (Cleary *et al.,* 2022).

4.8 Epidemiological study in India

Research done by Prakash Kengnal *et al.* (2016) and they reported that the morbidity and burden of public health in India is Malaria. The study period is of 13 years, *i.e.*, from 2001 to 2013. A total of 20,728,060, malaria cases were reported and confirmed from which 12,760 people died and it has been reported that there is a decreased incidence of malaria during the study when compared to data from previous studies. In India, predominantly *P. falciparum* species are found then after that *P. vivax*. A higher prevalence rate in India was found in Arunachal Pradesh, Orissa, Meghalaya, Dadar, and Nagar Haveli, Mizoram. They used one-way ANOVA to check the unequal distribution between the states. ANOVA results were F=19.075 and p=0.000. The Chi-square test was used for testing the confidence interval. Rare prevalence rates were found in Kerala, Jammu and Kashmir, Himachal Pradesh, Delhi, Bihar, Sikkim, Punjab, Uttarakhand and Pondicherry. There was a difference in the transmissibility of malaria cases in different areas (Kengnal *et al.,* 2016).

4.9 Malaria in Mizoram along India-Bangladesh borders

Mizoram in northeast India is a place where transmission of malaria is continuously high. There was a decrease in death cases, *i.e.,* in 2010, it was 1018 and in 2020, it was 93. In nine different districts of Mizoram, the study was performed between 2015 and 2021 and the malarial cases reported were 55,778. A total of 84.78% were cases of *P. falciparum* and 15.2% of *P. vivax*. In Lawngtlai district, the prevalence of *P. falciparum* and *P. vivax* was highest. Annual parasite index (API) in the year 2015 reported a prevalence of 27.4, then decreased to 4.3 in 2018. But again in 2019, there was a rise in the malarial cases with a total of 4870 cases, and in 2020 total of 6951 cases, and in 2021 total of 5166 cases were reported. Though, Mizoram is malaria endemic, in most regions of the country the malaria incidence and prevalence are decreasing (Lalmalsawma *et al.,* 2023).

5. How is malaria different in India when compared to other countries

Malaria is a complex and evolving infectious disease in India. The first reason is because of high malarial resistance. The second reason is because of the eco-temporal situation where there is diversity in vector species. The third reason is unique climatic and topographic changes. The fourth reason is genetic diversity in the immune system of parasites. India has had a lot of burden of malaria since the 19^{th} century. Other reasons are socio-economic growth, developing countries, and population growth with developmental activities. Therefore, India stands at a high level for malaria incidence apart from Africa. *P. falciparum* and *P. vivax* are responsible for morbidity and mortality (Singh *et al.,* 2009).

5.1 Epidemiological study of malaria in Central India where there is lower transmission

An epidemiological study of malaria in Madhya Pradesh, it has a vast forest and tribal settlement. Here, the study was performed in different districts like Panana district and Mandla district. The longitudinal study research period starts from 2003 to 2005. Based on the study, they found that *P. falciparum* is most prevalent and then the higher risk was of *P. vivax*. They reported that the risk of *P. falciparum* was 31.6% and the confidence interval was 95%. *P. vivax* was 7.8% and confidence interval=95%. The prevalence of malaria in Central India is listed in Table 4.

Table 4: Prevalence of malaria in Central India

Year	Prevalence	Odds ratio	Confidence interval
2003	30.2%	1.6	95%
2004	46.6%	2.0	95%
2005	58.6%	1.6	1.2-2.1

Based on the statistical results (Chi-Square =12.05, degrees of freedom = 2, $p<0.0001$), an increasing trend in malaria prevalence can be observed. Another vector species, *Anopheles culicifacies*, was present in all villages across all seasons. In India, this species is responsible for approximately 60% of malaria transmission. Young children and individuals with low immunity are at a higher risk of contracting malaria (Singh *et al.,* 2003).

5.2 Epidemiological study in Jharkhand

Manoj Das *et al.* (2017) conducted a study on 945 individuals from Dumargarhi, a tribal village from May 2014 to September 2016. Malarial cases were confirmed by microscopy. To determine the point prevalence they used four cross-sectional surveys (CSS). High transmission was observed from October to December and low transmission was observed from June to August. Therefore, it is a hyperendemic region for the following reasons:

- Children showed a high malaria attack rate.
- Results of children were high incidence and prevalence rate.

In this study, population group, there was a decrease in prevalence by increasing the age. In the 6-10 years age group, the level was 23,601 parasites decreased in the adult group (Das *et al.,* 2017).

5.3 Epidemiological study in West Bengal

Purulia which is a district in West Bengal, India is a malarial-prone district. Reports showed that the study period started on January 1, 2016, to December 31, 2020. Above 15 years age groups were majorly affected, *i.e.,*72.6%. Males (60%) individuals were more prone than females. Purulia district has an annual rainfall of 1268 mm and temperature in winter ranges from 6 and in summer 46^0 C. Out of 20 blocks from this district according to API 2016, half of which are malaria-endemic. Participants who were engaged in outdoor activities were more infected by malaria. To check the malarial cases in scheduled caste (SC) and scheduled tribe (ST) people in this region over the past 5 years another analysis was done. SC=2833 cases (48%) and ST=2509 cases (42%). So, ST people were highly affected χ^2=42.79 and $p<0.05$ (Pradhan *et al.,* 2022).

5.4 Epidemiological study of effects of malaria on pregnant women in Central India

A study was performed in Jabalpur to check the relationship between malaria and pregnant ladies (Singh *et al.,* 2023). This Jabalpur area is selected because most people are exposed to *P. falciparum* and *P. vivax*. They conducted the study from the year 1992-95 on pregnant women who used to visit hospitals during the fourth and fifth month of gestation and more than 3-4 visits before delivery. A total of 2127 pregnant women, among which 121 were infected with *P. vivax* (33%) and *P. falciparum* (67%) from which there were 17 cases of cerebral malaria. Two control groups were selected by them, the first one for checking the prevalence of vivax/falciparum and density of parasites in non-pregnant women infected by malaria. The second group was to check and compare anaemia and low birth weight in uninfected pregnant women who had fever. Among all, the pregnant ladies with malarial infection, individuals affected with *P. falciparum* were more anaemic. When compared to infected non-pregnant women and pregnant women, the *falciparum* resulted in more anaemia in infected pregnant women. The mean birth weight of the baby was lower in the infected group than in the non-infected group. When compared with the species the *falciparum* infection gave a lower birth weight than *vivax* infection. In the infected group, 89% of babies weighed <2.5 kg and from the control group 38% weighed less than 2.5 kg, so statistically the result is highly significant. During the first trimester, three abortions were recorded from women infected with *falciparum* infection, and two stillbirths were recorded. Only one abortion and one stillbirth were reported from *vivax*. Only one abortion was reported from non-infected women. The major complication found during pregnancy was cerebral malaria. The other effects were seen intrauterine death of the foetus, premature birth, abortion, and maternal death. (Bruce *et al.,* 1952).

6. Epidemiology and control of malaria during COVID-19

In 2000 worldwide, the cases of malaria were 238 million. In 2019, it was reduced to 229 million from 87 malaria endemic countries. The WHO-African region contributed 97% from Southeast Asia. According to the national vector borne disease control program (NVBDCP) in India, there were 181,831 malaria cases during 2020. Fear of COVID-19 increased during that period, and thus people hide their fever from health workers during surveys and did not go to the hospital for check-ups or treatment. So, to overcome this, the following things were done that is IRS spraying followed SOP; health workers were encouraged to check their malarial status during medical camps by following COVID-19 protocols. Medical workers and health workers were sensitized with regular training in RDT kits and malarial treatment protocols (Pradhan *et al.,* 2022).

7. Control and prevention of malaria

A major precaution against mosquito bites was the use of bed nets. Education on health, proper use of malaria drugs, avoiding bites of mosquitoes, and seeking a doctor in early symptoms of malaria and stagnant water pools must be cleaned around the campus (Okwa *et al.,* 2010). The incidence of malaria is decreasing in the infected population as well as in travellers also by the use of permethrin-impregnated clothing. They will be killing the mosquitoes, ticks, and flies on contact (Garcia and Lynne, 2010). So, to control the disease following precautions are done:

- **Mosquito eradication:** Vector control, *i.e.,* by applying oil to places where there is stagnant water (Yeka *et al.,* 2012).
- Prevention of mosquito bites.
- **Prophylactic drugs:** Firstly during the seventeenth century, quinine was used. Then from the twentieth century, alternatives like chloroquine and primaquine were used. Current drugs that are used to prevent malaria are mefloquine (Lariam), doxycycline, and combinations like atovaquone and proguanil hydrochloride.
- **Integrated vector management (IVM):** The main aim is to reduce the bites by controlling anophelines mosquitoes. This can be achieved by keeping water clean and using chemical larvicides for the prevention and control of malaria.
- **Indoor residual spraying (IRS):** Spraying of insecticides in the malaria-infected areas at interior walls of the home. The very first and most popularly used insecticide is DDT. In no time, this was also used in agriculture as pest control, but due to over-spraying of DDT, it has led to DDT resistance.
- **Education:** Recognising the symptoms of malaria at an early stage helped in reducing the number of cases of malaria and also educating the people on the usage of clean water. Prevention of disease can be done by using environmental protection like insect repellent; dressing in long sleeves and pants; applying permethrin on clothes; while sleeping and using a mosquito net; stagnant water should be cleaned (Garrido *et al.,* 2019).
- **Immunization and chemoprophylaxis:** Due to lack of knowledge, complex life cycle, and genetic variability, the effective vaccine is not yet developed but it will rely on the genomics. Vaccines are still in development and chemoprophylaxis is desirable for pregnant women also, but by considering the risk-benefit ratio.
- **Environmental management** will reduce the breeding sites of mosquitoes, so the National and International bodies must support the control programs and be aware of careful environmental planning (World Health Organization, 1993). Sociologists, entomologists, and epidemiologists should check for population migration to control malaria (Dash *et al.*, 2008; Sharma *et al.,* 1996).

India has aimed for the complete elimination of malaria by 2030 with the following targets:

- Eliminate malaria from low to moderate transmission areas.
- To bring the incidence of malaria to <1 per 1000 population in all places.
- Eliminate transmission from the overall country by 2027.
- Recurrence prevention and malaria-free environment by 2030 and further (Manguin *et al.,* 2018).

8. Knowledge, attitude, and practice (KAP) in control and prevention of malaria

According to the study done by Nzooma *et al.* (2017) in four zones of Zambia, they have used the cross-sectional survey on KAP and performed data analysis by using both inferential statistics and descriptive statistics. Knowledge about malaria regarding a mosquito and the capacity to kill a person and knowledge about fever being a sign of malaria was known to almost the population from all four places. The main sources of information were health facilities and community health workers (CHWs). However, more knowledge regarding control and prevention is needed which can be done by enhancing availability channels to the common public (Nzooma *et al.,* 2017). Progress for control and prevention of malaria has increased in the last decades, but it did not bring about the complete eradication of malaria. The methods that are currently in development are twenty-five projects for vaccines, forty-seven medicines, and thirteen vector control products, and all of these aim for new tools to detect at an early stage, treat, and prevent malaria (Hemingway *et al.,* 2016). However, ITNs and IRS are the key to malaria prevention and control because of their proven impact on reducing the cases of malaria (Tizifa *et al.,* 2018).

9. Control of malaria during pregnancy

According to epidemiological studies, pregnant ladies are more susceptible to malaria and there is a risk of anaemia and birth complications. Indian government must take measures and specific recommendations to address malaria in pregnancy (MiP) in India which include:

- Use of insecticide treated nets (ITNs) for both pregnant women and the general public.
- Use of antimalarial chemoprophylaxis in antenatal clinics, conducting awareness programs, educating about the risks and benefits of therapy, and educating the women about MiP.
- Use of developed drugs such as intermittent preventive therapy (IPTp) and look for safety and pharmacokinetic profiles.

If, all of these are followed then there will be a reduced burden of MiP in India (Brooks *et al.,* 2008).

10. Control of malaria vectors in the rice fields

In the entire world rice is the major food grain and its demand is increasing. So, to keep up with demand, there is more and more production of rice. So, more and more harvesting is resulting in inappropriate security and irrigated and rain fed lowland rice production giving rise to large numbers of mosquitoes. According to the study, rice cultivation areas (like Sub-Saharan Africa, Indonesia, Peru, and Central Asia) have more abundant malarial transmission than those areas where there is no cultivation. According to the study, anopheline larval numbers were decreased by up to 90% because of the use of synthetic organic chemicals, examples include pyrethroids (deltamethrin) and organophosphates (temephos) in Asian and African rice fields. So, it was reported that during all the development stages, the malarial vector was in control due to the usage of fish, chemical and biological larvicides (Chan *et al.,* 2022). Hence, agricultural developments may eliminate malaria by use of chemicals, bolstering mosquito populations. Among the overall world, 93% of cases of malaria are from Africa, and the child age group of less than five years is affected the most (Shah *et al.,* 2022). Larval source management includes:

- Habitat modification which includes permanent change of water and land.
- Habitat manipulation includes drain clearance and manipulation of water level.
- Larviciding which includes the use of insecticides in water for the control of mosquitoes.
- Biological control includes the use of predatory fish or parasites which are enemies to aquatic habitat (Tizifa *et al.,* 2018).

Malaria which is a vector-borne disease is not vaccine-preventable but “individual preventive behaviour” and adherence towards it will effectively reduce the chance of malaria (Lopes *et al.,* 2023).

- The use of long lasting insecticidal nets (LLINs) and insecticidal residual spraying (IRS) will not be enough to eliminate malaria (Cissoko *et al.,* 2022). To control malaria, interventions should look for vector resistance (Fillinger *et al.,* 2023).
- Elimination of malaria requires the use of evidence-based, goal-oriented, approaches at local, state, and national levels (Christofferson *et al.,* 2019).
- To reduce the transmission of malaria, the usage of current spraying methods is effective in the malarial treatment. Future control for malaria in India will follow the global malaria control strategies, World Health Organization to which India is a signatory.
- The four basic elements of this strategy are: to provide early diagnosis, plan and implement vector control measures, detect at an early stage, and strengthen the applied research to promote assessment of the country’s malarial situation.

11. Future aspects to consider for malarial epidemiological studies

1. **Genetic insights:** It will give valuable insights into drug resistance, transmission patterns, and development of more effective vaccines.
2. **Climate change impact:** Future studies should focus on assessing the impact of changing climatic conditions on malaria prevalence, allowing for proactive planning and targeted interventions.
3. **Technological innovations:** The use of advanced technologies such as remote sensing, geographic information systems (GIS), and big data analysis can revolutionize malaria epidemiological studies. These tools can help identify high-risk areas, track the movement of infected individuals, and optimize resource allocation for prevention and control efforts.
4. **Integrated approaches:** Emphasizing interdisciplinary collaboration between epidemiologists, entomologists, immunologists, social scientists, and policymakers can lead to comprehensive approaches to malaria control.
5. **Community engagement:** Involving local communities in epidemiological studies is essential for effective malaria control.

By delving into these future aspects, malaria epidemiological studies can continue to evolve and contribute to the global effort to eradicate malaria. Together, we can pave the way for a malaria-free future.

12. Conclusion

Malaria remains a significant global health challenge, particularly in tropical and subtropical regions. Understanding the epidemiology of malaria, including its transmission dynamics, environmental factors, and socio-economic impacts, is crucial for devising effective control strategies. Plant-based interventions have emerged as a promising addition to conventional malaria control measures. Bioactive compounds derived from plants offer potential for novel antimalarial drugs, mosquito repellents, and larvicides, providing sustainable, cost-effective, and eco-friendly alternatives to synthetic chemicals. However, the widespread application of plant-based strategies requires further research into their efficacy, safety, and scalability. Integrating traditional knowledge with modern scientific advancements can enhance the development of these interventions. Collaborative efforts involving communities, researchers, and policymakers are essential to harness the full potential of plant-based approaches. By combining these strategies with existing control measures, we can move closer to reducing the global burden of malaria and achieving long-term eradication goals.

Acknowledgements

The authors would like to acknowledge and thank RBVRR Women’s College of Pharmacy, Barkatpura, Hyderabad, Telangana, India, for their continued support throughout this review.

Conflict of interest

The authors declare no conflicts of interest relevant to this article

References

Brooks, M. I.; Singh, N. and Hamer, D. H. (2008). Control measures for malaria in pregnancy in India. Indian J. Med. Res., **128**(3):246-253.

Bruce-Chwatt, L. J. (1952). Malaria in African infants and children in Southern Nigeria. Ann. Trop. Med. Parasitol., **46**(2):173-200. https://doi.org/10.1080/00034983.1952.11685522.

Cowman, A. F.; Healer, J.; Marapana, D. and Marsh, K. (2016). Malaria: Biology and disease. Cell, **167**(3):610-624. https://doi.org/10.1016/j.cell.2016.07.055.

Chan, K.; Bottomley, C. and Saito, K. (2022). The control of malaria vectors in rice fields: A systematic review and meta-analysis. Sci. Rep., **12**:19694.

Christofferson, R. C.; Parker, D. M.; Overgaard, H. J.; Hii, J.; Devine, G.; Wilcox, B. A. (2020). Current vector research challenges in the Greater Mekong Subregion for dengue, malaria, and other vector-borne diseases: A report from a multisectoral workshop March 2019. PLoSNegl. Trop. Dis., **14**(7):e0008302.

Cissoko, M.; Magassa, M. and Sanogo, V. (2022). Stratification at the health district level for targeting malaria control interventions in Mali. Sci. Rep., **12**:8271.

Cleary, E.; Hetzel, M. W. and Clements, A. C. A. (2022). A review of malaria epidemiology and control in Papua New Guinea 1900 to 2021: Progress made and future directions. Front. Epidemiol., **2**:980795.

Cohee, L. M.; Opondo, C.; Clarke, S. E.; Halliday, K. E.; Cano, J.; Shipper, A. G. and Chico, R. M. (2020). Preventive malaria treatment among school-aged children in sub-Saharan Africa: A systematic review and meta-analyses. Lancet Glob. Health, **8**(12):e1499-e1511.

Dash, A. P.; Valecha, N.; Anvikar, A. R. and Kumar, A. (2008). Malaria in India: Challenges and opportunities. J. Biosci., **33**(4):583-592.

Das, M. K.; Prajapati, B. K. and Tiendrebeogo, R. W. (2017). Malaria epidemiology in an area of stable transmission in the tribal population of Jharkhand, India. Malar. J., **16**:181.

Dieng, S.; Adebayo-Ojo, T. C. and Kruger, T. (2023). Geo-epidemiology of malaria incidence in the Vhembe District to guide targeted elimination strategies, South Africa, 2015-2018: A local resurgence. Sci. Rep., **13**:11049.

Efferth, T. and Koch, E. (2011). Complex interactions between phytochemicals. The multi-target therapeutic concept of phytotherapy. Curr. Drug Targets, **12**(1):122-132. https://doi.org/10.2174/138945011793591626.

Faezeh, N.; Fatemeh, G.; Ahmad, R. and Abbas, N. (2016). Epidemiological status of malaria in Iran, 2011-2014. Asian Pac. J. Trop. Med., **9**(11):1055-1061.

Fillinger, U.; Denz, A. and Njoroge, M. M. (2023). A randomized, double-blind placebo-control study assessing the protective efficacy of an odour-based 'push-pull' malaria vector control strategy in reducing human-vector contact. Sci. Rep., **13**:11197.

Garcia, L. S. (2010). Malaria. Clin. Lab. Med., **30**(1):93-129.

Garrido-Cardenas, J. A.; González-Cerón, L.; Manzano-Agugliaro, F. and Mesa-Valle, C. (2019). *Plasmodium genomics*: An approach for learning about and ending human malaria. Parasitol. Res., **118**(1):1-27.

Hemingway, J.; Shretta, R.; Wells, T. N. C.; Bell, D.; Djimdé, A. A. and Achee, N. (2016). Tools and strategies for malaria control and elimination: What do we need to achieve a grand convergence in malaria?

Kengnal, P. and Holyachi, S. (2016). Epidemiology of malaria cases in India: A statistical analysis. Int. J. Trop. Dis. Health, **18**(3):1-8.

Krishna, S.; Bustamante, L. Y.; Haynes, R. K. and Staines, H. M. (2008). Artemisinins: Their growing importance in medicine. Trends Pharmacol. Sci., **29**(10):520-527. https://doi.org/10.1016/j. tips. 2008.07.004.

Kumar, S.; Bhardwaj, A. and Srivastava, K. (2024). Medicinal plants with potential antimalarial activity. Science Direct. Retrieved from https://www.sciencedirect.com.

Lalmalsawma, P.; Balasubramani, K. and James, M. M. (2023). Malaria hotspots and climate change trends in the hyper-endemic malaria settings of Mizoram along India-Bangladesh borders. Sci. Rep., **13**:4538.

Manguin, S. and Dev, V. (2018). Declining transmission of malaria in India: Accelerating towards elimination. In towards malaria elimination - A leap forward, 10.5772/intechopen.69750.

Mert, A.; Ozaras, R.; Tabak, F.; Bilir, M.; Ozturk, R. and Aktuglu, Y. (2003). Malaria in Turkey: A review of 33 cases. Trop. Doct., **18**(6):579-582.

Mishra, N.; Singh, N.; Srivastava, S.; Mallick, R. K. and Chaturvedi, D. (2020). Antimalarial natural products: The lead scaffolds. Pharmacol. Res., **161**:105250. https://doi.org/10.1016/j.phrs.2020.105250.

National institute of allergy and infectious diseases (NIAID).(2024). Malaria prevention, treatment, and control strategies. Retrieved from https://www.niaid.nih.gov

Newman, D. J. and Cragg, G. M. (2016). Natural products as sources of new drugs from 1981 to 2014. J. Nat. Prod., **79**(3):629-661. https://doi.org/10.1021/acs.jnatprod.5b01055.

Nzooma, M. S.; Tembo-Mwase, E.; Gebreslasie, M. and Mukaratirwa, S. (2017). Knowledge, attitudes, and practices in the control and prevention of malaria in four endemic provinces of Zambia. S. Afr. J. Infect. Dis., **32**(1):29-39.

Okwa, O. and Ibidapo, C. (2010). The malaria situation, perception of cause and treatment in a Nigerian University. J. Med. Med. Sci., **1**:213-222.

Pace Hospitals (2023). Malaria symptoms, causes, types, complications and prevention. Retrieved from https://www.pacehospitals.in

Pradhan, S.; Dolai, T. K. and Mandal, A. K. (2022). Malaria epidemiology and its control during the COVID-19 pandemic situation in India. Curr. Sci., **123**:1299.

Pradhan, S.; Hore, S. and Maji, S. K. (2022). Study of epidemiological behaviour of malaria and its control in the Purulia district of West Bengal, India (2016-2020). Sci. Rep., **12**(1):630.

Richard, B. (1988). Epidemiology study of malaria in Palawan. Philipp. J. Microbiol. Infect. Dis., **17**(2):41-48.

Shah, H. A.; Carrasco, L. R. and Hamlet, A. (2022). Exploring agricultural land-use and childhood malaria associations in sub-Saharan Africa. Sci. Rep., **12**:4124.

Sharma, V. P. (1996). Malaria: Cost to India and future trends. Southeast Asian J. Trop. Med. Public Health, **27**(1):4-14.

Singh, N.; Chand, S. and Mishra, A. (2006). Epidemiology of malaria in an area of low transmission in Central India. Am. J. Trop. Med. Hyg., **75**:812-816.

Singh, N.; Shukla, M. and Sharma, V. (2024). Epidemiology of malaria in pregnancy in Central India. Reveiws, pp: 196-220.

Singh, V.; Mishra, N.; Awasthi, G.; Dash, A. and Das, A. (2009). Why is it important to study malaria epidemiology in India? Trends Parasitol., **25**(10):452-457.

Tan, A. F.; Thota, P. and Sakam, S. S. B. (2023). Evaluation of a point-of-care hemozoin assay (Gazelle device) for rapid detection of *Plasmodium knowlesi* malaria. Sci. Rep., **13**:4760.

Tizifa, T. A.; Kabaghe, A. N. and McCann, R. S. (2018). Prevention efforts for malaria.Curr. Trop. Med. Rep., 5(1):41-50.

World Health Organization.(1993). A global strategy for malaria control. Available at: https://apps.who.int/iris/handle/10665/41785

Yeka, A.; Gasasira, A. and Mpimbaza, A. (2012). Malaria in Uganda: Challenges to control on the long road to elimination: I. Epidemiology and current control efforts. Acta Trop., **121**(3):184-195.

Citation **Shruti Vyas and Fatima Umaira Saeed (2024). Understanding the epidemiology of Malaria: Insights into plant-based prevention and control strategies. J. Phytonanotech. Pharmaceut. Sci., 4(4):39-46. http://dx.doi.org/10.54085/jpps.2024.4.4.6**