Efficacy of Lophira alata Leaf Extract and its Combination with Artesunate in Mice Prior Exposed to Plasmodium berghei

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ABSTRACT
Enhanced antimalarial activity of plant extracts used for treatment of malaria in endemic areas is attributed to partial immunity gained by prior infection. This suggests synergy between immunity and extract activity in treatment. Testing this hypothesis, rodent malaria was used to determine efficacy of Lophira alata leaf extracts in treating malaria in prior infected mice. One round of P. berghei infection and Pyrimethamine drug-cure was used to establish partial immunity in mice. Previously Exposed Mice (PEM) and Previously Unexposed Mice (PUM) mice challenged with P. berghei were used to determine influence of partial antimalarial immunity on efficacy of L. alata leaf extracts, administered alone or in combination with Artesunate (ART) in malaria treatment. There was a significant reduction in parasitemia in PEM when compared to PUM animals (P < 0.001) irrespective of treatment regimen. Administration of L. alata combined with ART significantly reduced parasitemia (P < 0.0032) and prolonged (P = 0.0109) survival than when L. alata was administered alone in infected mice. These findings suggest that the action of L. alata in treating malaria infections in a murine model is enhanced by prior exposure to the malaria parasite. Thus the requirements of using plants in treating malaria in endemic populations may differ for those used in western systems, where trials are carried out with non-immune cohorts. Combining artemisinin derivatives and medicinal plants in malaria exposed populations may provide an alternative control measure in endemic regions and may justify the continued use of these plants by indigenous populations in treating malaria.

Introduction
Malaria control requires concerted efforts to reduce the number of deaths brought about primarily because of drug resistance in Plasmodium falciparum [1]. With the deployment of an effective vaccine still years away and vector resistance to insecticides a growing problem, there is a greater burden on chemotherapy, which has proved to be the most viable option for current eradication efforts [2]. Recent attempts directed at the treatment of resistant infections have been to use Artemisinin and its derivatives administered in combination therapies (ACTs) [3]. However, the high cost of these combinations and cases of increased in vitro and in vivo tolerance of artemisinin and some combinations have been reported in Southeast Asia there is a fear that sub-Saharan Africa may not be immune [4–6]. Thus, the search for newer drugs and combinations are needed to improve treatment options. As a result, further improvement of the methods available for control of malaria in endemic areas may include the use of indigenous medicinal plants as partners for the artemisinins [7–9].

Artemisinin and quinine are two drugs used to treat malaria that were derived from plants [10]. Ethnobotanical surveys have established the folkloric use of medicinal plants in the treatment of febrile illnesses in endemic areas and in recent years, there has been an increase in the number of plant species that have been assessed for in vitro and in vivo antiplasmodial activity [11–14]. Although these studies point to the possibilities of developing novel drugs from medicinal plants, few new antimalarial drugs have actually
been found [9, 15]. Part of the reasons ascribed for the high attri-
tion of most natural compounds from plants is toxicity and lack of
parasitidal activity [16–15]. Nevertheless, in many endemic areas
plant extracts are still popular for medication of parasitic diseases,
particularly in remote areas without access to standard treatment
[9, 17–19].

In areas where malaria is endemic, individuals acquire partial
immunity against malaria only after repeated exposure to the para-
site [20]. In these malaria endemic areas, infected individuals may
recover from infection in spite of harbouring in some cases drug-
resistant P. falciparum. This was also observed in patients with neu-
rospilisis receiving malaria therapy, who were first shown to re-

dress better to treatment upon experiencing several paroxysms of
fever, which then allowed them to mount an immune response
to infection [21]. In addition, the ability to remove chloroquine-re-
sistant parasites in infected individuals has also been attributed to
the acquisition of immunity due to repeated exposure to mosqui-
to infection [22]. P. falciparum parasites bearing drug resistant mu-
tations in genes such as Pfcr and Pfmdr1 have been cleared from
infected individuals in endemic populations after drug treatment
substantiating an important role of prior exposure to parasite in-
fection in the outcomes of drug treatment [23–25]. This ability of
immunity, brought on by prior parasite exposure, to enhance treat-
ment might also explain the efficacy of quinine in regions of high
transmission than in areas of low transmission [26]. Furthermore,
animal model experiments have also pointed to the fact that anti-
malarial drugs clear resistant parasites from partially immune hosts
and that antimalarial treatments during primary Plasmodium
bergehi infection influenced the acquisition of protective immu-
nity against reinfection [27–29]. This phenomenon suggests that a
synergy exists between drug treatment and acquired immunity;
implicating that the natural acquired immunity to malaria possessed
by people living in endemic areas may be responsible for the anti-
plasmodial effect shown by plants used in those regions. The pos-
sibility therefore exists that many medicinal plants used in tradi-
tional medicines may prove effective in people who have been ear-
lier exposed to the disease and possess some level of immunity to
malaria [19].

The plant, L. alata (Ochnaceae), has previously been identified
as being used for the treatment of malaria infection in traditional
medicine through an ethnobotanical survey in Nigeria [30] and its
leaf extract has also been shown to possess in vitro and in vivo an-
tiplasmodial activity in addition to treating febrile conditions,
cough, jaundice, and gastrointestinal disorders [14]. Using the ro-
dent parasite P. berghei, which is a good laboratory model for un-
derstanding the biology of P. falciparum infections, we have stud-
ied the relationship between prior parasite infection and the ca-
pacity of plant extracts to clear malaria parasites in a bid to
determine whether partial immunity enhances the activity of L.
alata in reducing the growth of parasites in partially immune ani-
mals. The ability to limit parasitemia measured by estimating par-
asite growth kinetics has been employed as a surrogate in assess-
ing the levels of host immunity in human hosts and infected mice
[27–29, 31, 32]. The effects of partial immunity estimated via para-
site kinetics and the ability of plant extracts to treat infection have
not been thoroughly examined. Various studies have examined the
contribution of plant extracts in enhancing antimalarial immunity
during or prior to infection [33]. In this work we evaluated the ef-
fect of L. alata leaf extracts administered alone or in combination
with ART on parasitaemia and survival of Previously Exposed Mice
(PEM) and Previously Unexposed Mice (PUM) animals. We envisage
that our results will help give some informed suggestions about al-
ternative therapies utilizing plant products for malaria treatment
in endemic populations.

Materials and Methods

Drug and Extract preparation

The methods for plant collection, authentication and extraction have
been previously described [14]. Briefly, ground fresh leaves of
L. alata (LA) were extracted into redistilled methanol by macer-
atation at room temperature (29–33°C) for 72 h. The resultant mixture
was filtered and concentrated to dryness under reduced pres-
ture using a rotary evaporator (Heidolph Laborata 4001, Ger-
many). ART (Mekophar Chemical Pharmaceutical, Vietnam) and dried
LA extracts were dissolved in 100 % DMSO. The crude extract of LA
was evaluated for its toxicity in non-infected Swiss albino mice aged
2 months weighing 18–20 g. Eighteen mice randomized into six
groups of three mice each were orally administered, 50, 100, 200,
400, 700 or 1000 mg/kg body weight of extract. The mice were ob-
erved for changes in physical appearance and gross behavioural
changes (such as loss of appetite, hair erection, lacrimation, trem-
ors, convulsions, salivation, diarrhea, mortality) for three days.

The concentrations of drug/extracts were adjusted so that the final
dose in mg/kg body weight was administered in a volume 0.2 ml.
All animals were treated with drugs/extracts through oral gavage
once daily starting from Day 3 post-infection.

Mice and parasite

Inbred Swiss albino mice weighing 20 ± 2 g and housed at the ani-
mal facilities of the Department of Zoology, University of Ibadan
were used for all experimental studies. The animals were kept in
cages at room temperature and moisture. They were fed on stand-
ard diet and given drinking water ad libitum. P. berghei ANKA used
for all experiments was obtained from the Malaria Research and
Reference Reagent Resource (MR4) and maintained in mice via se-
rial passage. In vivo animal experiments were approved by the Uni-
versity of Ibadan Ethical Committee on the use of laboratory ani-
imals for research.

Induction of partial immunity

In order to induce partial immunity and primary infection, mice
were inoculated intraperitoneally (IP) with 1 × 10⁶ parasitized red
blood cells (PRBC). Five to six days post-infection (PI), when patent
parasitemia was at about 5 %, mice were treated with pyrimeth-
amine (10 mg/kg orally) (Sigma, St. Louis, MO, USA) administered
over four days a modification of Evans et al., 2006 [34]. Previous
studies have shown that this protocol results in partial-immunity
in infected animals [34]. This infection and drug cure produced the
PEM animals. PEM animals confirmed to have undetectable patent
parasitemia after one week were considered partially immune [34].
Further verification of parasite clearance was made via sub-inocu-
lation of blood from immune animals into naïve recipient mice.
Thin blood films from these mice were analysed after 7 days post-infection, with negative slides confirming total parasite clearance [35]. Parallel control group experiments, were conducted with animals sham infected and administered water. This group served as PUM animals.

**Challenge infection and treatment**

Two weeks after primary infection and drug cure described for PEM and PUM animals, a challenge infection (secondary) was initiated in both PEM and PUM animals. Both groups of animals were inoculated IP with $1 \times 10^6$ PRBC. Seventy-two hours after infection, the curative action of extract, extract/drug combinations in PEM and PUM animals were then treated with extracts (LA) alone or drug plus extracts (ART + LA) to assess curative action of drug regimens according to described methods [36, 37]. Plant extract doses used were based on previous published effective concentrations [14]. Infected untreated (placebo) groups received drug diluents. The six treatment groups for both PEM and PUM animals were as follows: 2 mg/kg ART (Positive Control); 250 mg/kg LA; 500 mg/kg LA; 2 mg/kg ART + 250 mg/kg LA; 2 mg/kg ART + 500 mg/kg LA; Placebo (untreated).

**Monitoring of parasitemia and survival**

For all treatment groups, drugs and extracts were administered for four consecutive days while parasitemia was monitored by daily microscopic examination of Giemsa-stained blood films taken from tail snips of study animals for 60 days. The percentage parasitemia was calculated as parasitemia (%) = \[\frac{\text{number of infected erythrocytes}}{\text{total erythrocytes}}\] \times 100. Mortality and survival was also recorded for animals over the study duration.

**Statistical analysis**

Analyses of all data were performed using GraphPad Prism software version 5.0 (GraphPad Software, Inc, La Jolla, CA, USA). Data are presented as the means ± S.E.M. The statistical significance of the differences was analyzed by one-way ANOVA. Survival data were analysed using the Kaplan-Meier statistical method with Log-Rank significance test. P < 0.05 was considered significant.

**Results**

**Effect of prior infection on course of infection**

Establishment of parasitemia after challenge (secondary) infection took a longer time (day 4 post-infection) to be observed in peripheral blood obtained from tail snips of all PEM animals. Analysis of parasitemia data (▶ Fig. 1a) for the course of infection showed that the pre-patent period for observation of parasitemia was extended by 3 days in PEM placebo group, this group experienced parasitemias which were statistically significantly lower than PUM placebo group for both treated and untreated animals. Furthermore, the level of parasitemia in PEM animals (both treated and untreated) were much lower than corresponding PUM animals ($P < 0.0001$). Artemisinin administered at a concentration of 2 mg/kg significantly reduced parasitemia ($P < 0.01$) in the PEM animals when compared to the PUM animals with parasites appearing in peripheral blood after 10 days PI. It was obvious from comparison of parasitemias between the PEM and PUM mice that partial immunity as a result of prior infection was successful in reducing parasite growth with or without treatment, with treated controls in the PEM, having the most reduced patent parasitemia.

**Effect of prior infection and treatment on course of infection during secondary parasite challenge**

Following the establishment of immunity in the PEM, a challenge (secondary) infection was initiated in the PEM and PUM animals. The results show the parasitemia profiles of PEM (▶ Fig. 1b) and PUM (▶ Fig. 1c) animals treated with LA alone or ART + LA leaf extracts seventy-two hours after the secondary infection. It was observed that the level of parasitemia in PEM group, irrespective of treatment protocol, were significantly lower in all groups when compared with the corresponding PUM groups (▶ Fig. 1b and c). Although LA leaf extracts administered alone reduced parasitemia in both the PEM and PUM animals, the combination of ART + LA reduced parasitemia significantly more in the PEM animals (▶ Fig. 1d) and the combination of 2 mg/kg ART + 500 mg/kg LA was the most effective of all treatment regimes with animals in this group completely resolving patent parasitemias (▶ Fig. 1d).

**Effect of prior infection and treatment on survival**

Survival was significantly prolonged in the PEM animals compared with the PUM animals irrespective of treatment regimen. Although the LA leaf extracts administered alone improved the survival of animals in both the PEM and PUM animals. Survival curves show that after treatment, the combination of ART + LA resulted in a significant increase in survival of the PEM animals, and the combination of 2 mg/kg ART + 500 mg/kg LA was the most effective of all combinations, significantly extending survival in this treatment group after the death of animals in all groups (▶ Fig. 2a and b).

**Discussion**

Numerous studies have described host immunity as an important determinant of antimalarial efficacy [38, 20, 22]. One of the factors upon which the efficacy of antimalarial chemotherapy is deemed to depend on is the host’s immunity [22]. However, in spite of the prevalence of acquired immunity in sub-Saharan Africa, the interaction between plant therapies and immune response has not been fully explored [9]. In this study, we have used parasite kinetics as a surrogate to evaluate the effect of prior infection in enhancing the chemotherapeutic potential of LA in mice infected with P. berghei. The plant LA selected for this study in ethnomedicine is used in treating malaria infections [30], with a recent report demonstrating its in vivo activity in rodent malaria [14]. We sought to assess the in vivo antimalarial activity of LA in monotherapy or in combination with ART in non-immune and partial immune animals. Our intentions were with a view to suggesting alternative therapies for malaria treatment in endemic populations.

Our experiments revealed a significant in vivo antimalarial activity for leaf extracts of LA in PEM animals than in PUM animals. Studies in both humans and animals have shown that immunity initiated by prior infection influences the action of drugs [27–29, 32]. In studies involving patients with malaria, partially immune patients respond better to chemotherapy than non-immune patients.
Several animal studies have implicated immunity via reduced patent parasitemia in immune animals when compared to non-immune animals, as being responsible for enhanced parasite clearance [27–29]. Hence the ability of PEM animals treated with LA to have significantly reduced parasitemias when compared with PUM animals may be attributed to immunity; and we can suggest that LA was able to reduce patent parasitemia significantly better than when immunity was absent as observed in the PUM animals. In vivo response to antimalarial treatment is determined by numerous factors, including parasite load, innate host resistance and naturally acquired immunity [38]. Malaria manifests itself with symptoms including fever and pains and though some plants may lack direct antiplasmodial activity, many have been shown to possess antipyretic, analgesic and immune stimulatory effects that may work in concert with antimalarials [39]. This hypothesis may lend itself to our observations on LA activity in PEM animals where LA was more effective in animals with partial immunity, thereby justifying its use in the traditional treatment of malaria [30]. However, our intentions were to observe if any, improved activity of LA when combined with ART. In the drug combination experiments, there was a greater reduction in parasitaemia when ART was combined with LA in all treatment groups; this parasite decrease was more significant than when ART or LA were administered alone. Parasite reduction was more significant in the PEM than PUM animals. The group of mice treated with the ART + LA combination also had a longer survival time when compared with mice treated with ART or LA alone. Thus, in our study, extract efficacy was further enhanced by the presence of a partner drug ART and partial immunity. ACTs are now accepted as the best treatments for uncomplicated falciparum malaria, replacing other parasite resistant antimalarials [40]. However, the cost, or lack of availability of ACTs precludes their use in the poorest of communities, particularly in remote endemic areas where indigenous medicinal plants are still used for the treatment of febrile infections. Even where they are available, reduced sensitivities of artesinin and its derivatives is a growing problem. Therefore, partnering an artemisinin derivative with an efficacious medicinal plant may improve its efficacy or the therapeutically useful lifetime of the drug before parasite resistance emerges in malaria endemic populations. Consequently, the prospect of combining established antimalarials with bioactive compounds derived from medicinal plants e.g. the combination of chloroquine and febrifugine and isofebrifugine compounds from Hydrangea macrophylla, has been demonstrated [41]. Curcumin from turmeric was found to be effective when combined with artesinin in preventing parasite recrudescence in mice infected with P. berghei [42]. In their study, Nanadkumar and colleagues discovered that in the mouse model, Artemether treatment alone resulted in parasite recrudescence, which was prevented by an Artemether-cur-
Cumin combination treatment. A combination therapy of ART with extracts from Cinchona officinalis in treating P. berghei was shown to be highly efficacious as it completely cleared blood stage infection [43]. Whereas, the aforementioned medicinal plant combination studies demonstrate the improved activity of artemisinin derivatives with medicinal plants, our study highlights the importance of immunity brought about by prior infection in enhancing the effects of the drug/plant combinations.

Identifying new drug combinations is high on the antimalarial control agenda and the discovery of naturally derived compounds may yield new options for drug combinations. The development of an affordable ACT or an alternative cost-effective antimalarial drug is imperative in rural areas where the majority of people are poor. With the problems of increasing levels of drug resistance and difficulties of drug affordability, medicinal plants could be an important and sustainable source of identifying new molecules that can serve as adjuncts to ACTs [44]. Thus, we hope to identify in subsequent studies the particular immune molecules responsible for the enhanced antimalarial activity observed. Our study may lead the way in guiding more extensive animal and human studies. It is also envisaged that bioassay guided fractionation of LA may provide compounds that may be useful for drug combination regimes as noted by Guantai and Chibale 2011 [15]. Although many obstacles still remain before these plant extracts can be approved for use, our data provide a foundation, upon which further exploration into the use of medicinal plants for combination therapy with artemisinin derivatives can be established in sub-Saharan Africa.

**Conclusion**

In conclusion, we sought out to determine whether LA leaf extract and its combination with ART could improve treatment in animals with partial immunity. Mice with prior infection treated with LA significantly reduced parasitemia and prolonged survival, which was marked in animals, treated with a combination of ART and LA. We have shown that an enhanced effect of partial immunity manifested in significantly reduced parasitemia and increased survival is the most likely explanation for the improved antimalarial effect in PEM animals. Malaria control programs at present emphasize the use of ACTs whilst encouraging discovery and identification of new and efficacious drug combinations. The identification of new, active, naturally derived compounds from medicinal plants could provide additional possibilities in the development of ACTs. The potential of combining established antimalarial drugs with other bioactive compounds derived from natural sources, which has been demonstrated experimentally, may provide alternative sources of treatment for malaria in endemic populations. This study also highlights the importance of taking into consideration the existence of partial immune populations of individuals naturally exposed to malaria during drug trials.

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**Conflict of Interest**

The authors declare no conflict of interest.
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