**Original Research Article**

**Effects of the Essential Oil of Dried Fruits of *Piper guineense* (Piperaceae) on Neurological Syndromes Associated with Cerebral Malaria in Mice**

**Abstract**

***Background***: Cerebral Malaria (CM), is associated with neurological syndromes characterized by cognitive and neurobehavioral abnormalities. *Piper guineense* Schum &Thonn is known to possess anti-oxidant and central nervous systemactivities. In this study, we evaluated the effects of essential oilsof *P.guineense*(EOPG) dryfruitson selected behavioral and functional indices in mice with cerebral malaria.

***Method*:**Mice with confirmed CM, following intraperitoneal inoculation with 1 x 107*Plasmodium berghei*ANKA parasitized blood in 0.2 ml of normal saline, were randomly allocated into 14 groups (n=12), namely, parasitized control, quininecontrol, EOPG graded doses (6.25, 12.5, 25, 50, 100 and 150mg/kg), and combination of quinine andEOPG graded doses. Quinine was administered at a dose of 20 mg/kg stat, then 10 mg/kg bid, while EOPG was once daily for 3 days beginning from day 5 post inoculation.Non-parasitized (n = 12)and parasitized controls were treated with the vehicle (5% Tween 80 in distilled water). Parasitemia, weight, survival and behavioral assessment using SHIRPA protocol were taken daily.

***Results*:**EOPG showed anti-plasmodial activity in a dose dependent manner,significantly mitigated mortality rate at higher doses (100 and 150mg/kg), with central nervous systemprotective effects. Also, except for quinine + 6.25 mg/kg EOPG, 100% mortalitywere observed with combination groups, suggesting a potential to precipitate toxicity.

**Conclusion:** The study concluded that EOPGpossesses antimalarial and central nervous system protective effects and may therefore serves to mitigate neurological syndrome in cerebral malaria.

**Keywords:** Cerebral malaria; *Plasmodium falciparum;* SHIRPA; *Piper guineense*; Essential oil

**1. Introduction**

Cerebral malaria (CM) is a complication of severe *Plasmodium falciparum* malaria infection that causes rapidly increasing deadly neurological disorders. It’s responsible for high rate of mortality among infected children in Sub-Saharan Africa each year 1,2, representing roughly 1% of all *P. falciparum* infections3,4. The aftermath effects of CM leaves survivors with acute or long-term physical handicap and neurological dysfunction, even after the infection has been treated 1,5. Neuropsychiatric impairments can appear months or years after CM 6.These manifestations vary between children and adults, and depend on the development of severe symptoms, including coma and status epilepticus6,7.Though its etiology is exceedingly complex, and mechanical or vascular occlusion or sequestration, and inflammatory hypotheses, have been proposed, none could fully explain the pathogenesis of CM1,8.Detailed review on the roles of functional interactions of neurotransmitters and molecular chaperones in the pathology of cerebral malaria has been presented 9.To reduce mortality and increase quality of life, it is important to prevent potential neurological disorders that are often linger beyond antimalarial chemotherapy5,10.To this end, adjuvants have been used in conjunction with very effective antimalarials for emergency situations and to lessen the risk of future occurrence 11–13.

Meanwhile, the use of medicinal plants for a variety of purposes has been unavoidable in all aspects of human survival, even as they continue to bring new therapeutic options 14–17.*Piper guineense*Schum &Thonn (Piperaceae), popularly known as West African Black Pepper, is a perennial West African spice plant with over 700 varieties, grown for its aromatic and strong smell across the world's tropics18,19.With spicy taste,high mineral content, high fibers,as well as trace levels of carbohydrate, protein, and essential vitamins, *P. guineense*possesses high nutritional value, and it fruits and leaves have been used as condiments to flavor foodin both domestic and commercial cuisines 18–21.The many biological and pharmacological activities of its various parts have been demonstrated {reviewed by 18,19}. These include antioxidant 22, antihyperglycemic effects 23, antinociceptive and anti-inflammatory activity 24, anti-plasmodial and analgesic properties25, muscle relaxant properties26,anticonvulsant 27, and hypothermic, sedative, and antipsychotic activity 24,28, as well as displaying synergistic antibacterial and antifungal effects with *P. amarus*29. Specifically, the essential oil of *P.guineense* has been shown to have antioxidant properties, possibly due to the presence of saponins, flavonoids, tannins, alkaloids, and phenols 30,31, as well as antimicrobial32, antinociceptive, anti-inflammatory, and central nervous system effects 24,28.

In this report, we investigated the potential benefits of the essential oil of *P.guineense*on cerebral malaria-induced neurological disorders.This was with a view to determining its potential usefulness as alternative pharmacotherapy for the management of neurological syndromes in CM. Our results provided evidence to support the antimalarial and CNS protective effects of the essential oil of*P. guineense* in a mouse model of cerebral malaria.

**2. Material and Methods**

***2.1. Plant Materials and Preparation of Essential Oil***

Dried fruits of *P.guineense* were purchased from the Central Market, Ondo Town, Ondo State between July and August, 2021. The fruits were identified and authenticated at the herbarium of the Faculty of Pharmacy, Obafemi Awolowo University (OAU), Ile-Ife, Osun State (FPI 2312).Further confirmation was done by checking the plant’s name against http://www.theplantlist.org, an extensive source of medicinal plants.The fruitswere air-dried and mashed into coarse powders using pestle and mortar.The hydro-distillation of essential oils of*P.guineense*(EOPG) was carried out using a Clevenger-type apparatusas earlier described 24,33, yieldingan average of 4.5ml per 500g. The pungent aromatic EOPG was stored in amber glass bottle and kept in a freezer till use. The oil was emulsified with Tween 80 to a final concentration of not more than 5%v/v prior to use.

***2.2. Source and Care of Experimental Animals***

Healthy Swiss albino mice of both sexes (18-22 g) were obtained from the animal house of the Department of Pharmacology, Faculty of Pharmacy, OAU, Ile-Ife, Osun State, and housed in plastic cages with soft wood shavings as bedding. The animals were given free access to normal laboratory feed (Top feed grower, Premier feed mills co. LTD) and water *ad libitum*, and allowed at least 72 hours to acclimatize within the laboratory environment prior to use. All animal studies were carried out in accordance with the standards for the humane use and care of laboratory animals 34,35. The study was approved by the Animal Health Research Ethics Committee, Institute of Public Health, OAU, Ile-Ife, Osun State, Nigeria (IPH/OAU/12/1782).

***2.3. Median Lethal Dose (LD50) and Working Doses Determination***

The median lethal dose**(**LD50) was determined using the Lorke’s method 36with modifications. In the first phase, three increasing doses (10, 100 and 1000 mg/kg of EOPG) was administered intraperitoneally in three groups of nine mice (n=3). Following confirmation of total mortality at 1000 mg/kg, the second phase was conducted using 200, 300, 400, 500, 600 and 800 mg/kg doses with one mouse per dose. During both phases, mice were observed for signs of toxicity and mortality within the 24 hours of treatment.A preliminary assessment to determine safe working doses for this study was conducted using five doses (50, 100, 150, 200 and 250mg/kg) below the LD50. Randomly allocated mice (one per dose) were treated with single daily doses of the EOPG for 72 hours via the intraperitoneal route. Mice were daily monitored for signs of toxicity (hyperactivity, ataxia, muscle rigidity) and mortality.

***2.4. Parasite Inoculation and Cerebral MalariaDevelopment***

The quinine sensitive strain of rodent experimentalparasite, *Plasmodium berghei*ANKA (PbA), was obtained from the Institute for Advanced Medical Research and Training (IMRAT), University College Hospital, Ibadan, Oyo State, Nigeria, into donor mice, which were monitored till parasitized level of about 15 to 20%. Donor mouse was thereafter humanely euthanized by cervical dislocation and blood was obtained by cardiac puncture and diluted with normal saline to concentration of 1 x 107 parasitized red blood cells per 0.2 ml suspension as earlier described 37–39. Each mouse was inoculated intraperitoneally with 0.2 ml of the inoculum suspension on Day 0 and the development of CM and onset of infection weremonitored using Smith-Kline Beecham, Harwell, Imperial College, Royal London Hospital, phenotype assessment (SHIRPA) scales 40,41as modified by Martins *et al*, (2010) 42 andWilson *et al* (2016)43. The onset of infection is determined as the point the CM is considered to have been fully developed using SHIRPA protocol, and beyond which the survival of the animal cannot be guaranteed without therapeutic intervention.

***2.5. Experimental Design***

Mice with confirmed CM were randomly allocated to the following groups (n = 12):parasitized control (5% Tween 80 in distilled water), quinine (20 mg/kg stat, then 10 mg/kg b.i.d), EOPG (6.25, 12.5, 25, 50, 100 and 150 mg/kg), and combination of Quinine andeach of the dose of EOPG.Non-parasitized control (n = 12) was also treated with 5% Tween 80 in distilled water. Treatment was administered for 3 days starting from day 5 post-infection as earlier reported38. Parasitemia was determined daily and average percentage parasitemia was calculatedas earlier described 37.Also, body weight of each mouse was taken daily and relative body weight was determined as percentage of the weight on Day 0.In addition, parasite-induced mortality was recorded and used to evaluate the survival rate per treatment group.

***2.6. Behavioral and Functional Evaluation***

The SHIRPA protocol40,41, as modified by Martins *et al*, (2010) 42 andWilson *et al* (2016)43was used in assessing behavioral and functional analysis. This study employed the SHIRPA behavioral battery of 25 semi-quantitative tests for reflex and sensory functions (visual placing, pinna reflex, corneal reflex, toe pinch, righting reflex), neuropsychiatric functions (spontaneous activity, transfer arousal, touch escape, positional passivity), spinocerebellar functions (grip strength, body tone), muscle and lower motor neuron functions (body position, tremor, pelvic elevation, gait, tail elevation, trunk curl, limb grasping, wire maneuver), and autonomic functions (respiratory rate, palpebral closure, piloerection, skin color, lacrimation, temperature), in all groups beginning from day 3 post infection. In this study, the scoring of the following activities was reversed: tremor, palpebral closure, piloerection, gait, positional passivity, wire maneuver, lacrimation and righting reflex similar to earlier report 42. Details of the functional categories and their associated parameters, as well as the procedures for scoring are as earlier reported40,42.

***2.7. Statistical Analysis***

Functional analysis was performed by quantitatively determining the contribution of each of the SHIRPA activities to their respective functions. Score for each behavioural activity per surviving animal per day was normalized by dividing with the highest score possible for that activity. Average of normalized scores per animal per day for all activities making up a functional category was then computed. This gives the functional score/value per animal per day. The mean of functional value per group of surviving animals per day was then calculated. Quantitative data were expressed as mean ± standard error of mean (mean ± SEM), mean (standard deviation {SD}) or median (lower/upper quarter) and analyzed using the one-way analysis of variance (ANOVA) followed by Turkey’s posthoc test for parametric data or the Kruskal-Wallis test of multiple comparison with false discovery rate (FDR) for nonparametric data. All analysis were compared with unparasitized, parasitized and quinine controls usingPrism version 8/9 (GraphPad, La Jolla, CA) with significant level set to p < 0.05.

3. **Results**

***3.1. Determination of Median Lethal Dose (LD50) and Working Doses***

The median lethal dose (LD50) of EOPG via the intraperitoneal route (i.p) in mice was found to be 273.86 mg/kg, suggesting that the oil is relatively toxic.Therefore, to prevent death arising from the potential toxicity of the test agent following repeated dosing, we conducted a preliminary assessment of the effects of selected doses of EOPG on unparasitized mice, following once daily intraperitoneal administration for three consecutive days. The result showed that doses ≤150 mg/kg body weight can be considered as safe working dose.

***3.2. Effects of EOPG on Weight, Parasitemia and Survival***

*3.2.1. Effects of EOPG on Weights*

The relative body weight changes (Table 1) revealedsignificant (p<0.05) increase in weights across all treatment groups prior to dosage administration when compared to Day 0. These increases dropped sharply on day 5 following the establishment of CM in parasitized mice. Following the dosage administration, the downward trend continued inmost parasitized groups from Days 6 to 8, except at 50, 100 and 150 mg/kg body weight of EOPG which showed significant increases in weights, suggesting that at higher doses the oil may possess potential to arrest or mitigate loss of weight that often rapidly characterize malaria infections. However, except for combination of quinine and 6.25 mg/kg, all animals in other combinations died within 24 hours of first dosage administration (Table 1), suggesting possible potentiation of toxicity.Also, the quinine/6.25 mg/kg combination did not confer any advantage over either used alone.

**Table 1:** Relative weight change following treatment with EOPG

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment Groups** | **Day 0\* (12)** | **Day 3 (12)** | **Day 4 (12)** | **Day 5 (12)** | **Day 6** | **Day 7** | **Day 8** |
| **Unparasitized Control** | 100 ± 0.00 | 108.47 ± 0.73 | 110.76 ± 1.59 | 114.87 ± 1.32 | 113.36 ± 1.05 (12) | 115.40 ± 0.36 (12) | 114.81 ± 1.52 (12) |
| **Parasitized Control** | 100 ± 0.00 | 106.50 ± 1.70 | 113.78 ± 2.59 | 110.50 ± 1.94 | 107.02 ± 1.69a (5) |  |  |
| **Quinine** | 100 ± 0.00 | 107.34 ± 1.61 | 110.45 ± 2.24 | 108.65 ± 1.76 | 106.22 ± 1.04a (8) | 103.17 ± 0.13a (6) | 99.28 ± 1.22a (5) |
| **6.25 mg/kg** | 100 ± 0.00 | 104.16 ± 2.40 | 109.61 ± 1.49 | 106.09 ± 0.62a | 104.68 ± 1.05a (8) | 97.00 ± 0.07a, c (3) | 96.63 ± 0.23a (3) |
| **12.5 mg/kg** | 100 ± 0.00 | 107.99 ± 1.40 | 114.96 ± 3.44 | 106.95 ± 1.65a | 94.95 ± 1.72a, b, c (8) | 89.72 ± 0.32a, c (5) | 86.43 ± 0.25a, c (3) |
| **25 mg/kg** | 100 ± 0.00 | 109.54 ± 1.60 | 111.44 ± 2.43 | 106.81 ± 1.01a | 95.70 ± 1.00 a, b, c (8) | 91.04 ± 0.75a, c (5) | 93.92 ± 1.18a (3) |
| **50 mg/kg** | 100 ± 0.00 | 108.17 ± 1.16 | 114.34 ± 2.88 | 110.66 ± 1.67 | 116.41 ± 2.63c (8) | 115.31 ± 1.13c (5) | 116.34 ± 0.10c (5) |
| **100 mg/kg** | 100 ± 0.00 | 107.73 ± 2.64 | 117.98 ± 2.58 | 114.25 ± 1.13 | 117.79 ± 2.85b, c (8) | 122.64 ± 3.02a, c (8) | 120.58 ± 0.78a, c (6) |
| **150 mg/kg** | 100 ± 0.00 | 105.71 ± 1.40 | 118.96 ± 2.40 | 115.39 ± 2.64 | 118.69 ± 1.77b, c (11) | 121.76 ± 2.22a, c (8) | 119.24 ± 1.01a, c (8) |
| **Quinine + 6.25 mg/kg** | 100 ± 0.00 | 109.04 ± 1.31 | 116.93 ± 2.36 | 113.32 ± 2.42 | 109.63 ± 1.45 (5) | 100.73 ± 0.66a, c (3) | 96.48 ± 1.04a (3) |
| **Quinine + 12.5 mg/kg** | 100 ± 0.00 | 107.43 ± 2.52 | 110.42 ± 1.27 | 98.33 ± 1.41a,b,c |  |  |  |
| **Quinine + 25 mg/kg** | 100 ± 0.00 | 106.22 ± 1.51 | 114.91 ± 1.67 | 93.43 ± 0.96a,b,c |  |  |  |
| **Quinine + 50 mg/kg** | 100 ± 0.00 | 107.07 ± 0.62 | 115.35 ± 2.78 | 92.77 ± 0.80a,b,c |  |  |  |
| **Quinine + 100 mg/kg** | 100 ± 0.00 | 108.86 ± 2.25 | 115.40 ± 1.75 | 93.99 ± 1.57a,b,c |  |  |  |
| **Quinine + 150 mg/kg** | 100 ± 0.00 | 106.39 ± 1.22 | 117.39 ± 3.69 | 98.20 ± 1.26a,b,c |  |  |  |

**\*** Significantly different when compared with Days 3, 4, 5, 6, 7 and 8.

**a**Significantly different when compared with the unparasitized control group

**b**Significantly different when compared with the parasitized untreated control group

**c**Significantly different when compared with standard (Quinine) control group

Results expressed as Mean ± SEM and values with p < 0.05 are considered significant

Number of surviving mice are as indicated in parenthesis

*3.2.2. Effect of EOPG on the Level of Parasitemia*

The onset of CM infection, following intraperitoneal inoculation of 1 x 107 parasitized red blood cells was determined to be Day 5 post-inoculation using SHIRPA protocol. Beyond Day 5, the survival of the animals cannot be guaranteed without therapeutic intervention. Therefore, treatment began on Day 5 and serves as reference point to monitor the disease progression and the effects of therapeutic intervention. All animals across treatment groups had increases in parasitemia level from day 3 to 5 post inoculation(before test agents administration), followed by mostly significant reduction after treatment as compared to the parasitized control (Table 2). Specifically, while there are consistent increases in the level of parasitemia with 6.25 mg/kg EOPG, similar to parasitized control, the administration of 12.5 – 150 mg/kg EOPG showed significant decreases in parasite load in a dose dependent manner, when compared to parasitized control at the onset of infections (Day 5). Also, mostly significant reductions in parasitemia level were observed daily with repeated dosing for each dose level. Moreover, the abilities of 50, 100 and 150 mg/kg EOPG to reduce parasitemia were comparable to the standard control (Quinine). However, the combination of quinine with 6.25 mg/kg EOPG caused a significant reduction in the ability of quinine or EOPG to reduce parasitaemia, suggesting a potential for antagonistic interaction.

*3.2.3. Effects of EOPG on the survival rate of the animals*

The Kaplan-Meier survival plot (Figure 1) revealed that a significant percentage of the animals in most of the treated groups survived the infection longer following the 72-hour treatment after the development of experimental cerebral malaria (ECM) when compared with parasitized control group. The 6.25, 12.5, and 25 mg/kg of EOPG (Figure 1B), and quinine/6.25 mg/kg EOPG combination (Figure 1D) showed comparable ability to increase survival rate in CM mice when compared to parasitized untreated, but at different rate and significantly less than quinine (Figure 1A). However, while 50 mg/kg EOPG showed a comparable survival rate with quinine, 100 and 150 mg/kg EOPG (Figure 1C) showed an improved ability to preserve the animal better, having relatively higher survival rate when compared to the standard.

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**Figure 1: Kaplan-Meier’s survival plot following treatment of CM mice with varying doses**

**of EOPG**. Control groups (A); Varying doses of EOPG (B and C); Quinine/EOPG combinations

(D). QCs in panel D represents the survival plot of all the combinations that died within 24 hours

following the first administration.

**Table 2:** Percentage parasitemia following daily administration of EOPG

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatment Groups** | **% Parasitemia of Surviving Mice Per Day** | | | | | |
| **Day 3 (12)** | **Day 4 (12)** | **Day 5 (12)** | **Day 6\*** | **Day 7\*** | **Day 8\*** |
| **Parasitized Control** | 5.07 ± 0.11 | 6.29 ± 0.18 | 14.37 ± 0.13 | 17.78 ± 0.02 (5) |  |  |
| **Quinine** | 5.11 ± 0.31 | 6.01 ± 0.22 | 13.91 ± 0.19 | 6.88 ± 0.14a (8) | 4.73 ± 0.03 (6) | 2.50 ± 0.09 (5) |
| **6.25 mg/kg** | 5.15 ± 0.11 | 6.51 ± 0.15 | 13.81 ± 0.10 | 16.90 ± 0.15a, b (8) | 28.79 ± 0.11b (3) |  |
| **12.5 mg/kg** | 4.93 ± 0.08 | 6.52 ± 0.13 | 13.92 ± 0.07 | 15.69 ± 0.04a, b (8) | 13.99 ± 0.94b (5) | 8.51 ± 0.30b (3) |
| **25 mg/kg** | 4.86 ± 0.06 | 6.23 ± 0.07 | 14.01 ± 0.10 | 14.30 ± 0.59a, b (8) | 13.42 ± 0.10b (5) | 12.14 ± 0.10b (3) |
| **50 mg/kg** | 4.78 ± 0.25 | 6.17 ± 0.16 | 14.82 ± 0.10 | 11.53 ± 0.10a, b (8) | 3.32 ± 0.05b (5) | 4.35 ± 0.32b (5) |
| **100 mg/kg** | 4.54 ± 0.16 | 6.18 ± 0.25 | 14.27 ± 0.29 | 8.31 ± 0.18a, b (8) | 6.20 ± 0.04b (8) | 5.53 ± 0.11b (6) |
| **150 mg/kg** | 4.78 ± 0.15 | 6.02 ± 0.15 | 13.66 ± 0.05 | 7.20 ± 0.14a (11) | 4.88 ± 0.34 (8) | 3.33 ± 0.41b (8) |
| **Quinine + 6.25 mg/kg** | 5.29 ± 0.16 | 6.10 ± 0.05 | 13.62 ± 0.13 | 8.13 ± 0.04a, b (5) | 9.47 ± 0.09b (3) | 9.84 ± 0.10b (3) |

Data are expressed as Mean ± Standard Error of Mean (SEM) and values are considered significant at p < 0.05

\* All values are significantly different from parasitized control at the onset of infections (Day 5)

aSignificantly different when compared to parasitized control on same day

bSignificantly differentwhen compared to quinine control on same day

D3 to D8 are Days 3 to 8 respectively, and number of surviving mice are as indicated in parenthesis

***3.3. Effects of EOPG on behavioral assessments***

The primary screen of the protocol aids the quantitative assessment of several parameters thereby providing a measure with which phenotypic expressions in mouse are scored to enable comparison of results. Results obtained for Days 5 to 8, from the SHIRPA behavioural battery of the 25 semi-quantitative tests, assessed for motor and lower neuron, spinocerebellar, reflex and sensory, neuropsychiatric and autonomic functions, following daily administration of the test agents, are as shown in Supplementary Tables 1 to 4. On Day 5, the assessed indices largely showed significant reduction in scores when compared to unparasitized control, confirming CM development and onset of infection. As treatment progresses, gradual and dose dependent improvement in activities with repeated dosing of test agents can be observed. Essentially on Days 7 and 8, most activities appeared to be completely reversed at higher doses of 100 and 150 mg/kg, comparable to unparasitized control (Suppl. Tables 3 and 4).Interestingly, Quinine/6.25 mg/kg EOPG showed comparable improvement in SHIRPA activities, suggesting potential for synergistic activity with Quinine at lower dose. Moreover, observed improvements or reduced deterioration rate in the single higher doses of the extract (50, 100, 150mg/kg) as well as the lowest combined dose (Quinine + 6.25 mg/kg), were significantly higher than parasitized control. Meanwhile, lacrimation, trunk curl, limb grasping, and righting reflex were not altered in the presence or absence of the disease, with or without treatment, throughout the study period. Similarly, SHIRPA functional analysis showed comparable trend (Suppl. Figure 5). By Day 8, all functions that were assessed have been restored to normal level by quinine, as well as 100 and 150 mg/kg EOPG, similar to unparasitized control. However, while significantly improving spinocerebellar and autonomic functions, quinine/6.25 mg/kg significantly caused a reduction in muscle and lower motor neuron function, as well as reflex and sensory function, compared to quinine alone, but produced similar effects on neuropsychiatric function (Table 3 and Suppl. Table 5).

**Table 3:** SHIRPA functional analysis following treatment with EOPG

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Muscle & lower motor neuron function** | | **Spinocerebellar function** | | **Reflex/Sensory function** | | **Neuropsychiatric function** | | **Autonomic function** | |
| **Day 5** | **Post-Treatment** | **Day 5** | **Post-Treatment** | **Day 5** | **Post-Treatment** | **Day 5** | **Post-Treatment** | **Day 5** | **Post-Treatment** |
| **Unparasitized** | 0.998 ± 0.017\* | 0.993 ± 0.002 | 1.000 ± 0.000\* | 1.000 ± 0.000 | 1.000 ± 0.000\* | 1.000 ± 0.000\* | 0.987 ± 0.016\* | 0.991 ± 0.001\* | 0.995 ± 0.012\* | 0.995 ± 0.000 |
| **Parasitized Control R** | 0.690 ± 0.018 |  | 0.759 ± 0.016 |  | 0.829 ± 0.023z |  | 0.815 ± 0.015 |  | 0.775 ± 0.019 |  |
| **Quinine** | 0.672 ± 0.021# | 0.949 ± 0.012xy | 0.737 ± 0.025# | 0.931 ± 0.037y | 0.769 ± 0.017#y | 0.981 ± 0.010\* | 0.785 ± 0.037 | 0.824 ± 0.015y | 0.789 ± 0.021 | 0.744 ± 0.032x |
| **6.25 mg/kg** | 0.721 ± 0.071 | 0.851 ± 0.012xyz | 0.775 ± 0.035 | 0.889 ± 0.056 | 0.860 ± 0.067 | 0.694 ± 0.047 | 0.825 ± 0.012# | 0.905 ± 0.020yz | 0.753 ± 0.028# | 0.870 ± 0.019xyz |
| **12.5 mg.kg** | 0.720 ± 0.064 | 0.828 ± 0.021xyz | 0.738 ± 0.029# | 0.917 ± 0.024xy | 0.817 ± 0.059 | 0.784 ± 0.029 | 0.802 ± 0.017# | 0.905 ± 0.011yz | 0.739 ± 0.038 | 0.828 ± 0.020x |
| **25 mg/kg** | 0.676 ± 0.019# | 0.818 ± 0.029xyz | 0.725 ± 0.016# | 0.888 ± 0.015xy | 0.727 ± 0.013#yz | 0.835 ± 0.012 | 0.824 ± 0.050 | 0.913 ± 0.010yz | 0.776 ± 0.030 | 0.877 ± 0.040 |
| **50 mg/kg** | 0.719 ± 0.036# | 0.872 ± 0.018xyz | 0.765 ± 0.012 | 0.826 ± 0.032x | 0.750 ± 0.024# | 0.886 ± 0.007 | 0.788 ± 0.065 | 0.885 ± 0.005yz | 0.808 ± 0.016# | 0.913 ± 0.040yz |
| **100 mg/kg** | 0.641 ± 0.046# | 0.883 ± 0.062y | 0.783 ± 0.029# | 0.921 ± 0.029y | 0.804 ± 0.019# | 0.957 ± 0.001y | 0.812 ± 0.024# | 0.903 ± 0.015yz | 0.797 ± 0.006# | 0.917 ± 0.058yz |
| **150 mg/kg** | 0.713 ± 0.016# | 0.970 ± 0.011y | 0.772 ± 0.017# | 0.959 ± 0.011xy | 0.850 ± 0.017#z | 0.956 ± 0.016y | 0.817 ± 0.026# | 0.928 ± 0.017yz | 0.798 ± 0.006# | 0.977 ± 0.011yz |
| **Quinine + 6.25 mg/kg** | 0.705 ± 0.018 | 0.673 ± 0.076xz | 0.747 ± 0.018# | 0.938 ± 0.062y | 0.822 ± 0.011z | 0.807 ± 0.046 | 0.778 ± 0.064 | 0.888 ± 0.027 | 0.758 ± 0.032 | 0.792 ± 0.007x |

Day 5 is as contained in Suppl. Table 5, and Post-infection is the Mean ± SEM for values on Days 6, 7, and 8 of Suppl. Table 5

\*, #, x, y, zindicates significant difference when compared with other groups, Post-treatment, Unparasitized control, Parasitized control on Day 5, and Quininestandard control respectively. Significant value was set at p < 0.05.

R No Post-treatment values for Parasitized control as none of the animals survived beyond Day 6 post inoculation.

4. **Discussion**

Malaria infection remains catastrophic with increasing cases of resistance to known treatment modalities, and while severe infections and neurological complications from CM seems to be declining globally, the burden is now skewed towards Africa region accounting for about 51% of all global malaria cases 4. With increasing resistance to available and affordable drugs, the need for continuous search for alternative pharmacotherapy is imperative. Essentially, the need to arrest the fatal neurological complications, which often linger to adulthood, is leading the way to more intensive research, with particular focus on natural products, in order to uncover new and effective pharmacotherapeutic agents. In this study, *P. guineense*, a plant with reported anti-plasmodial and CNS activities25,28, was investigated for its potential benefits in mitigating the neurological symptoms associated with CM.

Our results confirmed the anti-plasmodial potential of *P. guineense*, as previously reported 25. However, to our knowledge, this is the first report of the antiplasmodial effects of the essential oil derived from any part of the plant.The anti-plasmodial effects of EOPG were dose-dependent, significantly reducing the level of parasitaemia with increasing doses, and with higher doses (100 and 150 mg/kg) being statistically comparable (p<0.05) to the standard (Quinine) control group. In addition, EOPG showed potential to arrest weight loss often associated with malaria, and increase survival rates in animals.

Meanwhile, the brain's irreplaceable functions, distinctive structure, and incidental aberration can be used to infer functional activities in both normal and diseased states. The SHIRPA protocol main screen provides a reproducible quantitative observational assessment of functional profiles that can help to describe functional anomalies, allowing proper analysis of associated physiologic and pathophysiologic conditions40,41.In this study, the expected onset of neurological problems in all parasitized mice was confirmed by the daily decline in frequency and intensity of functional activities from days 3 to 5. By day 5, all behavioral activities related to neuropsychiatric and motor functions, as well as spinocerebellar and sensory functions, and autonomic functions, that served as indicators of neurological functions, had been clearly established across all groups 42. It should be noted, that in CM-induced mice with impaired muscle and lower motor neuronal function, parasite clearance alone does not imply that further progression of neurological syndromes is slowed as long as the blood brain barrier (BBB) is compromised 44. Also, it has been noted that cognitive impairment may be considered to revolve around the activities of inflammatory cytokines and BBB vascular permeability to induce a deformity in the memory system due to altered memory caused by sequestered inflammatory cells in the brain vasculature 45. While the onset of neurological syndrome in humans may not necessarily imply mortality because there may be recovery after paroxysm 1,8,10, in experimental CM, the probability of losing a significant number of animals hours after CM sets in is high (Martins, et al., 2010). Interestingly, a large number of animals given doses of EOPG alone survived longer, implying that EOPG has the potential to reduce mortality. Also, it's worth noting that EOPG not only demonstrated capacity to reduce the level of parasitaemia and increase survival rate, but also showed capacity to dose-dependently arrest the progression of neurological and functional aberrations, and at higher doses, completely restored functional activities to normal.This effects may be linked to the reported CNS protective and anti-inflammatory activities of EOPG24,28.

Meanwhile, since parasitemia eradication does not prevent the development of NS once CM has set in, the need for adjuvant therapy to prevent or ameliorate cognitive deficits, has been demonstrated (Reis, et al., 2010). However, our attempt at combining EOPG withQunine did not produce desired benefit, due to high rate of mortality. Majority of the animals given a combination of Quinine and graded doses of extract died within 24 hours of their first treatment, save Quinine/6.25mg/kg, raising concerns about the potential toxic effects of indiscriminate use of this plant within the larger population. With low LD50 of EOPG, and the potential toxicity of Quinine, the mortality linked to Quinine/EOPG combination may have resulted from possible potentiation of their individual inherent toxicity, and/or unfavourable pharmacological interaction. Therefore, we submit that the toxicologic potential of this combination need further investigation.

**5. Conclusion**

The findings from the present study suggest that, despite being slightly toxic, the oil has anti-plasmodial and CNS protecting properties in experimental CM. As a result, its potential use alone could help to alleviate NS associated with CM. However, while we seek further investigation into the potential toxicity of combining EOPG and Quinine, caution should be maintained in concurrent administration or indiscriminate use of EOPG with Quinine.

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**Abbreviations**

CM, Cerebral malaria; EOPG, Essential oil of *Piper guineense;*SHIRPA, Smith-Kline Beecham, Harwell, Imperial College, Royal London Hospital, phenotype assessment; OAU, Obafemi Awolowo University; PbA, *Plasmodium berghei*ANKA; IMRAT, Institute for Advanced Medical Research and Training; LD50, Median lethal dose; ECM, experimental cerebral malaria; BBB, Blood brain barrier; NS, Neurological syndrome; ECM, Experimental cerebral malaria.

**References**

1. Bruneel F. Human cerebral malaria: 2019 mini review [Internet]. Vol. 175, Revue Neurologique. Elsevier Masson SAS; 2019. p. 445–50. Available from: https://doi.org/10.1016/j.neurol.2019.07.008

2. Desruisseaux MS, Machado FS, Weiss LM, Tanowitz HB, Golightly LM. Cerebral malaria: A vasculopathy. American Journal of Pathology. 2010;176:1075–8.

3. Shikani HJ, Freeman BD, Lisanti MP, Weiss LM, Tanowitz HB, Desruisseaux MS. Cerebral malaria: We have come a long way. American Journal of Pathology. 2012;181:1484–92.

4. WHO. World malaria report 2021. 2021. 1 – 322 p.

5. Kihara M, Carter JA, Newton CRJC. The effect of Plasmodium falciparum on cognition: A systematic review. Tropical Medicine and International Health. 2006;11:386–97.

6. Monteiro MC, Oliveira FR, Oliveira GB, Romao PRT, Maia CSF. Neurological and behavioral manifestations of cerebral malaria: An update. World Journal of Translational Medicine. 2014;3:9–16.

7. Idro R, Carter JA, Fegan G, Neville BGR, Newton CRJC. Risk factors for persisting neurological and cognitive impairments following cerebral malaria. Archives of Disease in Childhood. 2006;91:142–8.

8. Sierro F, Grau GER. The ins and outs of cerebral malaria pathogenesis: Immunopathology, extracellular vesicles, immunometabolism, and trained immunity. Frontiers in Immunology. 2019;10:1–11.

9. Daniyan MO, Fisusi FA, Adeoye OB. Neurotransmitters and molecular chaperones interactions in cerebral malaria: Is there a missing link? Frontiers in Molecular Biosciences [Internet]. 2022 [cited 2023 Feb 28];9. Available from: https://www.frontiersin.org/articles/10.3389/fmolb.2022.965569

10. Oluwayemi IO. Cerebral Malaria. Malaria Contr Elimination. 2014;03:1–6.

11. Jain K, Sood S, Gowthamarajan K. Modulation of cerebral malaria by curcumin as an adjunctive therapy. Brazilian Journal of Infectious Diseases. 2013;17:579–91.

12. John CC, Kutamba E, Mugarura K, Opoka RO. Adjunctive therapy for cerebral malaria and other severe forms of Plasmodium falciparum malaria. Vol. 8, Expert Review of Anti-Infective Therapy. 2010. p. 997–1008.

13. Serghides L. The Case for the Use of PPARγ Agonists as an Adjunctive Therapy for Cerebral Malaria [Internet]. PPAR Research. 2012 [cited 2019 Sep 25]. Available from: https://www.hindawi.com/journals/ppar/2012/513865/

14. Balunas MJ, Kinghorn AD. Drug discovery from medicinal plants. Life Sciences. 2005;78:431–41.

15. Dzoyem JP, Tshikalange E, Kuete V. Medicinal Plants Market and Industry in Africa. In: Kuete V, editor. Medicinal Plant Research in Africa [Internet]. Oxford: Elsevier; 2013 [cited 2020 Mar 4]. p. 859–90. Available from: http://www.sciencedirect.com/science/article/pii/B9780124059276000242

16. Iwu MM. Handbook of African Medicinal Plants, Second Edition [Internet]. Second. CRC Press; 2014 [cited 2018 Apr 26]. 506 p. Available from: https://www.crcpress.com/Handbook-of-African-Medicinal-Plants-Second-Edition/Iwu/p/book/9781466571976

17. Sareea Al-Rekaby L. Medicinal Plants. Tropical Horticulture. 2017;11:449–632.

18. Besong EE, Balogun ME, Djobissie SFA, Mbamalu OS, Obimma JN. A Review of Piper guineense( African Black Pepper ). International Journal Of Pharmacy & Pharmaceutical Research. 2016;6:369–84.

19. Juliani HR, Koroch AR, Giordano L, Amekuse L, Koffa S, Asante-Dartey J, et al. Piper guineense (Piperaceae): Chemistry, traditional uses, and functional properties of west african black pepper. In: ACS Symposium Series. 2013. p. 33–48.

20. Okonkwo C, Ogu A. Nutritional Evaluation of Some Selected Spices Commonly Used in the South-Eastern Part of Nigeria. Journal of Biology, Agriculture and Healthcare. 2014;4:97–103.

21. Udousoro I, Ekanem Promise. Assessment of proximate compositions of twelve edible vegetables in Nigeria. International Journal of Modern Chemistry. 2013;4:79–89.

22. Uhegbu FO, Imo C, Ugbogu AE. Effect of Aqueous Extract of Piper Guineense Seeds on Some Liver Enzymes, Antioxidant Enzymes and Some Hematological Parameters in Albino Rats [Internet]. Vol. 1, International Journal of Plant Science and Ecology. 2015 p. 167–71. Report No.: 4. Available from: http://www.aiscience.org/journal/ijpsehttp://creativecommons.org/licenses/by-nc/4.0/

23. Wodu CO, Iwuji SC, Macstephen O. Antihyperglycaemic activity of Piper guineense in diabetic female albino wistar rats. International Journal of Pharmaceutical and Phytopharmacological Research. 2017;7:1–4.

24. Oyemitan IA, Kolawole F, Oyedeji AO. Acute toxicity, antinociceptive and anti-inflammatory activity of the essential oil of fresh fruits of Piper guineense Schum Thonn (Piperaceae) in rodents. Journal of Medicinal Plants Research. 2014;8:1191–7.

25. Kabiru AY, Ibikunle GF, Innalegwu DA, Bola BM, Madaki FM. In Vivo Antiplasmodial and Analgesic Effect of Crude Ethanol Extract of Piper guineense Leaf Extract in Albino Mice. Scientifica. 2016;2016:1–6.

26. Udoh FV, Lot TY, Braide VB. Effects of Extracts of Seed and Leaf of Piper guineense on Skeletal Muscle Activity in Rat and Frog. PHYTOTHERAPY RESEARCH. 1999;110:106–10.

27. Abila B, Richens A, Davies JA. Anticonvulsant effects of extracts of the West African black pepper, Piper guineense. Journal of Ethnopharmacology. 1993;39:113–7.

28. Oyemitan IA, Olayera OA, Alabi A, Abass LA, Elusiyan CA, Oyedeji AO, et al. Psychoneuropharmacological activities and chemical composition of essential oil of fresh fruits of Piper guineense (Piperaceae) in mice. Journal of Ethnopharmacology. 2015;166:240–9.

29. Okigbo RN, Igwe DI. Antimicrobial effects of Piper Guineense ‘Uziza’ and Phyllantusamarus ‘Ebe-Benizo’ on Candida albicans and Streptococcus faecalis. Acta Microbiologica et ImmunologicaHungarica. 2007;54:353–66.

30. Etim OE, Egbuna CF, Odo CE, Udo NM, Awah FM. In vitro Antioxidant and Nitric Oxide Scavenging Piper guineense Seeds. Global Journal of Research on Plants and Indigenous Medicine. 2013;2:475–84.

31. Oboh G, Ademosun AO, Odubanjo OV, Akinbola IA. Antioxidative properties and inhibition of key enzymes relevant to type-2 diabetes and hypertension by essential oils from black pepper. Advances in Pharmacological Sciences. 2013;2013:1–7.

32. Oyedeji OA, Adeniyi BA, Ajayi O, König WA. Essential Oil Composition of Piper guineense and its Antimicrobial Activity . Another Chemotype from Nigeria. PHYTOTHERAPY RESEARCH. 2005;364:362–4.

33. Oyemitan IA, Elusiyan CA, Akinkunmi EO, Obuotor EM, Akanmu MA, Olugbade TA. Memory enhancing, anticholinesterase and antimicrobial activities of β-phenylnitroethane and essential oil of Dennettiatripetala Baker f. Journal of Ethnopharmacology. 2019;229:256–61.

34. Franco NH, Correia-neves M, Olsson IAS. How ‘‘ Humane ” Is Your Endpoint ?— Refining the Science-Driven Approach for Termination of Animal Studies of Chronic Infection. PLoS pathogens. 2012;8:e1002399 (1-4).

35. National Research Council USA. Guide for the Care and Use of Laboratory Animals [Internet]. 8th ed. Washington (DC): National Academies Press (US); 2011 [cited 2017 Feb 24]. (The National Academies Collection: Reports funded by National Institutes of Health). Available from: http://www.ncbi.nlm.nih.gov/books/NBK54050/

36. Lorke D. A new approach to practical acute toxicity testing. Arch Toxicol. 1983;54:275–87.

37. Adepiti AO, Elujoba AA, Bolaji OO. In vivo antimalarial evaluation of MAMA decoction on Plasmodium berghei in mice. Parasitology Research. 2014;113:505–11.

38. Adeyemi O, Ige O, \ldots MAAJ of C, 2020 U. In vivo anti-malarial activity of propranolol against experimental Plasmodium berghei ANKA infection in mice. african journal of clinical and experimental biology. 2020;21:333–9.

39. Basir R, Rahiman SSF, Hasballah K, Chong WC, Talib H, Yam MF, et al. Plasmodium berghei ANKA infection in ICR mice as a model of cerebral malaria. Iranian Journal of Parasitology. 2012;7:62–74.

40. Lalonde R, Filali M, Strazielle C. SHIRPA as a Neurological Screening Battery in Mice. Vol. 1, Current Protocols. 2021.

41. Rogers DC, Fisher EMC, Brown SDM, Peters J, Hunter AJ, Martin JE. Behavioral and functional analysis of mouse phenotype: SHIRPA, a proposed protocol for comprehensive phenotype assessment. Mammalian Genome. 1997;8:711–3.

42. Martins YC, Werneck GL, Carvalho LJ, Silva BPT, Andrade BG, Souza TM, et al. Algorithms to predict cerebral malaria in murine models using the SHIRPA protocol. Malaria Journal. 2010;9:1–13.

43. Wilson KD, Stutz SJ, Ochoa LF, Valbuena GA, Cravens PD, Dineley KT, et al. Behavioural and neurological symptoms accompanied by cellular neuroinflammation in IL-10-deficient mice infected with Plasmodium chabaudi. Malaria Journal. 2016;15:1–12.

44. Reis PA, Comim CM, Hermani F, Silva B, Barichello T, Portella AC, et al. Cognitive dysfunction is sustained after rescue therapy in experimental cerebral malaria, and is reduced by additive antioxidant therapy. PLoS Pathogens. 2010;6:1–16.

45. Desruisseaux MS, Gulinello M, Smith DN, Lee SHC, Tsuji M, Weiss LM, et al. Cognitive dysfunction in mice infected with Plasmodium berghei strain ANKA. Journal of Infectious Diseases. 2008;197:1621–7.

**FIGURE LEGENDS**

**Figure 1: Kaplan-Meier’s survival plot following treatment of CM mice with varying doses**

**of EOPG**. Control groups (A); Varying doses of EOPG (B and C); Quinine/EOPG combinations

(D). QCs in panel D represents the survival plot of all the combinations that died within 24 hours

following the first administration.

**SUPPLEMENTARY TABLES**

**Table S1:**SHIRPA Behavioral Assessment on Day 5

**Table S2:**SHIRPA Behavioral Assessment on Day 6

**Table S3:**SHIRPA Behavioral Assessment on Day 7

**Table S4:**SHIRPA Behavioral Assessment on Day 8

**Table S5:**SHIRPA Functional Analysis