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Phytochemical, Nutritional, Metal Composition, Haematological and Antimalarial Evaluation of the Leaf Extract of *Morinda Citrifolia* L. (Noni)

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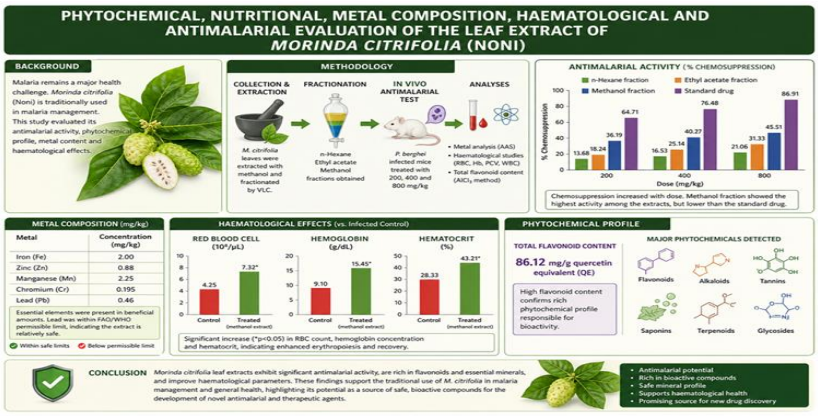
ABSTRACT

Malaria remains one of the most devastating tropical diseases, responsible for significant morbidity and mortality, particularly in developing countries. This study aimed to evaluate the antimalarial activity, phytochemical composition, metal content, and haematological effects of *Morinda citrifolia* leaf extracts in order to establish their therapeutic potential and safety profile. Leaf extracts were fractionated using vacuum liquid chromatography, and n-hexane, ethyl acetate, and methanol fractions were assessed for in vivo antiplasmodial activity against *Plasmodium berghei* in infected mice at doses of 200, 400, and 800 mg/kg. Additionally, metal analysis, haematological studies on red and white blood cells, and total flavonoid content determination were carried out using standard analytical methods The antimalarial evaluation revealed dose-dependent chemosuppression, with values increasing from 13.68–36.19% at 200 mg/kg to 21.06–45.51% at 800 mg/kg across the extracts, indicating significant antiplasmodial activity, although lower than that of the standard drug. Metal analysis showed the presence of essential elements such as iron (2.00 mg/kg), zinc (0.88 mg/kg), manganese (2.25 mg/kg), and chromium (0.195 mg/kg), with lead (0.46 mg/kg) remaining within FAO/WHO permissible limits, suggesting the extract is relatively safe. Haematological studies demonstrated significant increases in red blood cell count, hemoglobin concentration, and hematocrit levels in treated rats, indicating positive effect on erythropoiesis. The methanol leaf extract exhibited high total flavonoid content of 86.12 mg/g quercetin equivalent, confirming the plant's rich phytochemical profile. In conclusion, *Morinda citrifolia* leaf extracts possess notable antimalarial activity, are rich in flavonoids and essential minerals, and exhibit beneficial haematological effects, supporting their traditional use in malaria management and general health. These findings suggest that *M. citrifolia* leaves may serve as a promising source of safe, bioactive compounds for the development of novel antimalarial and therapeutic agents.

Keywords: *Morinda Citrifolia*; Antimalarial Activity; Mineral Composition; Phytochemicals; Haematological Parameters

INTRODUCTION



Malaria remains a major global public health challenge, particularly in tropical and subtropical regions, where it continues to cause substantial morbidity and mortality. The disease is caused by *Plasmodium* parasites and transmitted to humans through the bite of infected female *Anopheles* mosquitoes. Recent estimates indicate that malaria accounts for hundreds of millions of clinical cases and hundreds of thousands of deaths annually, with children under five years of age being the most vulnerable population group (World Health Organization [WHO], 2023). Among the *Plasmodium*

species that infect humans, *Plasmodium falciparum* is responsible for the majority of malaria-related deaths, especially in sub-Saharan Africa, and is commonly associated with severe complications such as anaemia resulting from extensive destruction of red blood cells (White *et al*., 2014; Talakpo *et al*., 2019).

The malaria parasite undergoes a complex life cycle involving both human and mosquito hosts. Following transmission, sporozoites migrate to the liver, where they invade hepatocytes and multiply asexually before entering the bloodstream. In the erythrocytic phase, parasites progress through the ring, trophozoite, and schizont stages within red blood cells, leading to cell rupture, anaemia, and the characteristic clinical manifestations of malaria (Cowman *et al*., 2016). Despite sustained malaria control efforts, including vector control strategies and antimalarial chemotherapy, the disease remains a significant global health burden (Amato *et al*., 2018). The rapid emergence and spread of drug-resistant *Plasmodium* strains have further compromised the effectiveness of existing antimalarial drugs, highlighting the urgent need for new, safe, and effective therapeutic agents.

Medicinal plants have historically served as an essential source of healthcare across many cultures and civilizations. Beyond their nutritional value, plants are rich in secondary metabolites that exhibit diverse biological activities. Ethnomedicine has played a pivotal role in modern drug discovery, with several widely used antimalarial drugs originating from plant sources (Olugbue *et al*., 2026). Consequently, medicinal plants remain an invaluable reservoir for the identification and development of novel antimalarial compounds, particularly in regions where access to conventional medicines may be limited.

One such plant is *Morinda citrifolia* L. (Rubiaceae), commonly known as Noni, a tropical evergreen species traditionally used in Southeast Asia, the Pacific Islands, and parts of Africa for the treatment of fever, infections, inflammation, and parasitic diseases (Potterat & Hamburger, 2007). Scientific investigations have demonstrated that *M. citrifolia* possesses a wide range of pharmacological properties, including antimicrobial, antioxidant, immunomodulatory, and anti-inflammatory activities (Fagbohun *et al.*, 2012; Hirazumi & Furusawa, 1999**;** Ebrahimzadeh *et al*., 2008). The plant is rich in phenolic compounds, flavonoids, tannins, and essential minerals, all of which may contribute to its therapeutic effects. These properties are particularly relevant in malaria, a disease characterized by oxidative stress, inflammation, and haematological disturbances such as anaemia.

In recent years, *Morinda citrifolia* has gained increasing scientific and commercial attention due to its widespread use as a dietary supplement and traditional medicine across the Pacific, Asia, and Africa (Wang *et al*., 2019; Elkins, 2018). It ranks among the most commonly utilized medicinal plants for the management of various ailments and the promotion of general health (Krauss, 2019). Clinical studies have reported beneficial effects of noni consumption in conditions such as diabetes and rheumatoid arthritis (Nerurkar *et al*., 2015). In addition to its medicinal applications, noni also possesses significant industrial value, with its roots used for red dye production and its leaves bark, and fruits processed into food, cosmetic, and pharmaceutical products (Dixon & Siva, 2019, Jahurul *et al*., 2021). The growing global popularity of noni reflects increasing interest in its therapeutic and economic potential (Mandukhail *et al*., 2010).

Despite its extensive traditional use and promising bioactive profile, the antimalarial efficacy, safety, and haematological effects of *M. citrifolia* leaves, remain inadequately characterized through systematic scientific studies (Fagbohun *et al.*, 2012; Hirazumi & Furusawa, 1999). Comprehensive evaluation of its phytochemical constituents, metal composition, biological activity, and physiological effects is therefore essential to validate its ethno medicinal claims and assess its suitability as a source of novel antimalarial agents.

The present study was undertaken to evaluate the antimalarial potential, phytochemical composition, metal content, and haematological effects of *Morinda citrifolia* leaf extracts. Specifically, the study aimed to assess the antiplasmodial activity of the extracts against *Plasmodium berghei*, determine their metal composition and total flavonoid content, and investigate their effects on red and white blood cell parameters using experimental animal models.

MATERIALS AND METHODS

Sample Collection, Preparation and Extraction

Fresh leaves of *Morinda citrifolia* L. were collected in August 2023 from a local market in Benin City, Edo State, Nigeria. The plant material was authenticated by a botanist in the Department of Plant Biology and Biotechnology, Faculty of Life Sciences, University of Benin, Benin City, Nigeria, and a voucher specimen was deposited in the departmental herbarium under the reference number UBH-M427. The leaves were air-dried at ambient temperature, mechanically ground into a fine powder, and stored in airtight containers until further analysis**.** 300g of the powdered sample was macerated in 750 mL of ethanol for 72 h with continuous agitation. The mixture was filtered using Whatman No. 1 filter paper, and the filtrate was concentrated under reduced pressure at 50 °C using a rotary evaporator. The dried extract was weighed and stored in a refrigerator until use (Ogbeide *et al*., 2022).

Elemental Analysis

Sodium (Na) and potassium (K) contents of the leaf extract were determined using a flame photometer, while calcium (Ca), magnesium (Mg), iron (Fe), copper (Cu), and zinc (Zn) were quantified using an atomic absorption spectrophotometer (AAS) following standard analytical procedures.

Proximate Analysis

Ash and Moisture Content

Two grams (2g) of the dried sample was placed into a pre-weighed porcelain crucible and transferred into a preheated muffle furnace set at 900 °C. The furnace was maintained for 1 h, after which the crucible and its contents were removed and placed in a desiccator to cool. After cooling, the crucible and its contents were reweighed, and the weight was recorded. The percentage ash content was then calculated using the appropriate formula (18).

$\text{Ash} = \frac{\text{Wash}}{wo}\text{X100 \%}$

W_{ash} = content weight after final drying.

W_o = the dried weight of the sample.

The ratio of the change in weight to the original weight expressed in percentage gives the moisture content given by:

$\frac{\text{WO}-Wdry}{wo}$ (%)

Crude Fibre Determination

Crude fibre was determined using the AOAC (AOAC, 2019) method. Four grams (4g) of dried sample was boiled for 30 min in 4% H_2SO_4, filtered, and washed until acid-free. The residue was subsequently boiled for another 30 min in 5% NaOH, filtered, and washed until alkali-free. The final residue

was washed with 95% ethanol, dried at 110 °C, weighed, and then ashed at 550 °C for 8 h. After cooling, the crucible was reweighed. All determinations were carried out in triplicate.

% Crude Fibre $=\frac{100\ (y-\ a)}{x}$

x = Weight of sample (g), y = Weight of insoluble matter (g), a = Weight of Ash (g)

Crude Fat Determination

Crude fat was determined using the Soxhlet extraction method described by Pearson (Nielsen, 2017). Three grams (3g) of moisture-free sample was placed in fat-free thimbles and extracted with petroleum ether (60–80 °C) for 8 h. After extraction, the thimbles were dried at 70 °C to constant weight. Fat content was calculated from the difference in sample weight before and after extraction. % Fat $=\frac{X-Y}{Z}$, where,

x = Weight sample and thimble and oil, Y = Weight of empty thimble and Z = Weight of sample.

Crude Protein Determination:

Three grams (3g) of defatted sample was digested with concentrated H_2SO_4 in the presence of a $CuSO_4$–Na_2SO_4–SeO_2 catalyst mixture. Digestion was carried out under controlled heating until a clear solution was obtained. The digest was cooled, transferred to a 100 mL volumetric flask, and diluted to volume with distilled water prior to further analysis.

Crude Nitrogen Determination*:*

An aliquot of 5 mL of the digested filtrate was transferred into a 25 mL standard flask using a 10 mL pipette. To this, 2.5 mL of alkaline phenate reagent was added and the mixture was shaken thoroughly. Subsequently, 1.0 mL of sodium potassium tartrate solution was added and mixed, followed by the addition of 2.5 mL of sodium hypochlorite. The solution was then diluted to volume with distilled water and mixed thoroughly. The absorbance of the resulting coloured solution was measured at 630 nm using a UV–visible spectrophotometer. Nitrogen standard solutions were prepared and treated in the same manner as the samples.

$$\%N = \frac{\text{Reading.X Slope Reciprocal X Color Vol.X Digest Vol.}}{\text{Weight of Sample X Aliquot Taken X 10000}}$$

% Crude Protein = %Nitrogen×6.25 (Skoog *et al.*, 2014)

Estimation of Total Carbohydrate

Total carbohydrate content of the diet samples was estimated by difference. This was calculated by subtracting the combined percentages of crude protein, crude fat, moisture, crude fibre, and ash from 100%.

Wet Ashing of Sample

Samples were digested using a modified method of Victor Dmitrievich (Skoog *et al*., 2021). Three grams (3g) of sample was treated with a nitric acid–perchloric acid mixture (3:1) and heated sequentially at 40 °C and 100 °C. After cooling, the digest was diluted with distilled water, filtered, and made up to 100 mL in a volumetric flask.

Total Phenol

Total phenolic content was determined using the Folin–Ciocalteu assay (Singleton *et al*., 199). Extract (0.5 mL, 1,000 µg/mL) was reacted with diluted Folin–Ciocalteu reagent and sodium carbonate, followed by incubation at room temperature for 90 min. Absorbance was measured at 750 nm. Results were expressed as mg gallic acid equivalents per gram of extract using a gallic acid standard curve (12.5–150 mg/L).

Total Flavonoid

Total flavonoid content was determined using the aluminium chloride colorimetric method (10). Extract (0.5 mL, 1 mg/mL) was reacted with methanol, aluminium chloride, potassium acetate, and, distilled water, followed by incubation at room temperature for 30 min. Absorbance was measured at 415 nm, and result was expressed as mg quercetin equivalents per gram of extract using a quercetin standard curve (12.5–150 mg/L)

Haematological Studies

Twelve (12) Swiss albino rats of both sexes, weighing between 84 and 151 g, were used. The animals were randomly assigned into four groups (n = 3 per group). They were acclimatized to laboratory conditions for fourteen (14) days prior to the commencement of the experiment and were allowed free access to standard grower pellet diet and water *ad libitum*. The animals were fasted overnight before each experimental procedure, with free access to water.

All experimental procedures involving animals were conducted in accordance with institutional guidelines for the care and use of laboratory animals, with ethical approval obtained from the appropriate committee (Ethical Clearance No: LSC23106). The test extract was administered orally to the rats at graded doses calculated based on body weight. The stock solution was prepared using the formula:

$$\text{Stock solution (mg/mL)} = \frac{\text{Dose (mg/kg)} \times \text{Body weight (g)}}{1000}$$

For example, at a dose of 800 mg/kg for a rat weighing 159 g, the calculated stock concentration was 127.2 mg/mL. The administered volume for each animal was subsequently determined based on the prepared stock solution.

At the end of the treatment period, blood samples were collected for haematological analysis, including red and white blood cell parameters, using standard laboratory methods.

Statistical analysis was performed using GraphPad Prism version 6. Results were expressed as mean ± standard error of the mean (SEM). Statistical significance was determined using one-way analysis of variance (ANOVA), followed by Dunnett's post hoc test, with values of $p < 0.05$ considered statistically significant.

Parasite Inoculation:

Plasmodium berghei obtained from NIMR, Lagos, was used for infection. Blood from donor mice was collected using trisodium citrate as anticoagulant and diluted with normal saline to obtain 5×10^7 parasitized erythrocytes per mL. Each experimental mouse was infected intraperitoneally with 0.1 mL of the suspension (18).

Preparation of Giemsa Solution:

Giemsa powder (3.5 g) was dissolved in a mixture of 250 mL glycerol and 250 mL methanol in a dark room. The solution was stored in a dark reagent bottle for a week (18).

Preparation of Phosphate Buffer Saline (PBS):

Sodium dihydrogen phosphate (10.9 g) and 3.2 g of disodium hydrogen phosphate were dissolved in distilled water, and the solution was adjusted to a pH of 7.2 using a dilute solution of NaOH (18).

Evaluation of Suppressive Activity on Early Infection (4-day test):

The 4-day suppressive test was used to evaluate antiplasmodial activity against early *P. berghei* infection. Twenty-five Swiss albino mice were infected intraperitoneally with 1×10^7 parasitized erythrocytes and

divided into five groups (n = 5). Groups A–C received the extract orally at 200, 400, and 800 mg/kg, respectively, Group D was untreated, and Group E received chloroquine (5 mg/kg). Treatments were administered daily from D1 to D4.

Evaluation of Parasitaemia

Blood smears were prepared from tail blood of mice on day five. Thin films were methanol-fixed, and all smears were Giemsa-stained. Parasitaemia was assessed microscopically under oil immersion by counting parasitized red blood cells in ten fields. Percentage parasitaemia and percentage suppression were calculated relative to the negative control.

RESULTS AND DISCUSSION

The results of the elemental composition, percentage extraction yield, proximate composition, total phenolic content, haematological parameters, in vivo antimalarial activity, chemo-suppression, mean survival time, and flavonoid content of *Morinda citrifolia L.* leaf extract are presented in Tables 1–7.

Percentage Extraction Yield

The percentage yield of the *Morinda citrifolia* L. leaf extract was 18.83%, calculated as:

% Yield = (Weight of dried extract/Weight of sample used for extraction) × 100

Table 1: Elemental Composition of *Morinda Citrifolia L.* Leaf Extract

Elements	Concentration mg/kg
Pb	0.460
Cd	Nil
Zn	0.880
Cr	0.195
Mn	2.250
Fe	2.000
Ni	Nil

Nil= Not detected.

Table 2: Proximate Composition of *Morinda Citrifolia L.* Leaves (g/100 g Sample)

Nutrient	Composition
Crude protein	2.18 ±0.65
Ash content	0.63 ± 0.15
Carbohydrate	40.04 ± 0.67
Moisture content	4.59 ± 0.035
Crude fiber	4.60 ± 1.82
Crude fat	3.65 ± 0.96

Total phenolic content of *Morinda citrofolia L.* =29.13 ± 0.23

Table 3: Effects of *Morinda Citrifolia L.* Leaf Extract on White Blood Cell Indices in Rats

Parameters	Control	200 mg/kg PALE	400 mg/kg PALE	800 mg/kg PALE
WBC x 103 / ul	9.60±0.40^{a}	8.80±0.30^{a}	8.70±0.40^{a}	6.35±0.75^{a}
LYM x 103 / ul	8.90±0.40^{a}	7.90±0.10^{a}	7.80±0.30^{a}	5.85±0.65^{a}
MID x 103 / ul	0.55±0.05^{a}	0.75±0.15^{b}	0.70±0.10^{b}	0.40±0.01^{a}
GR x 103 / ul	0.15±0.05^{a}	0.20±0.00^{a}	0.20±0.00^{a}	0.10±0.00^{a}
LYM %	92.65±0.25^{a}	91.80±0.50^{a}	90.05±0.35^{a}	91.80±1.00^{a}
MID %	5.75 ±0.15^{a}	8.20 ±1.50^{b}	8.10±0.50^{b}	6.05±1.05^{a}
GR %	1.60±0.10^{a}	2.15±0.15^{a}	2.70±0.30^{b}	2.15±0.05^{a}

Values are Mean ± SD. Different superscripts (^{a},^{b}) indicate significant difference ($p < 0.05$). WBC = White blood cells, LYM = Lymphocytes, MID = Monocytes, GR = Granulocytes.PALE = Polyherbal aqueous leaf extract.

Table 4: Effects of *Morinda citrifolia L.* Leaf Extract on Red Blood Cell Indices in Rats

Parameter	Control	200 mg/kg PALE	400 mg/kg PALE	800 mg/kg PALE
RBC x 106/ul	7.03±0.34^{a}	7.40±0.15^{a}	7.54±0.06^{a}	7.60±0.06^{b}
Hgb.g/d l	14.85±0.55^{a}	15.90±1.00^{a}	16.60±0.10^{b}	16.30±0.15^{b}
HCT%	38.60±0.10^{a}	40.25±2.05^{a}	39.75±0.85^{a}	41.60±1.80^{b}
MCV.f l	55.10±2.50^{a}	54.45±1.65^{a}	54.35±0.05^{a}	54.80±2.80^{a}
MCH.pg	21.05±0.25^{a}	21.40±0.90^{a}	22.00 ±0.30^{a}	21.40±0.20^{a}
MCHC.g/d l	38.40±1.30^{a}	40.15±0.25^{a}	41.75±0.65^{b}	36.20±3.16^{a}
RDW-SD fL	29.90±2.10^{a}	29.90±0.00^{a}	27.80±0.00^{a}	31.00±3.20^{a}
RDW-CV %	14.75±0.55^{a}	14.90±0.30^{a}	13.80±0.00^{a}	15.30±1.00^{a}

Red blood cells (RBC), haemoglobin (HGB), haematocrit (HCT), mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), mean cell haemoglobin concentration (MCHC), red cell distribution width (RDW). PALE (polyherbal aqueous leaf extract). Values are Mean ± SD, Different superscripts indicate significant difference ($p < 0.05$).

Table 5: Effect of the Extracts and Standard Drug (Chloroquine) on *P. berghei*

Treatment	Dosage (mg/kg)	D5 (%±SEM)	D6 (%±SEM)	D7 (%±SEM)	D8 (%±SEM)
Untreated	_	5.36±0.02	7.02±0.18	8.77±0.14	10.16±0.24
Extract	200	3.42±0.11	5.03±0.21	6.86±0.34	8.77±0.21
Extract	400	3.23±0.18	4.87±0.12	6.51±0.16	8.21±0.18
Extract	800	2.92±0.23	4.51±0.03	6.28±0.02	8.02±0.14
Chloroquine	5	0.12±0.03	0.42±0.06	0.68±0.05	1.18±0.07

Untreated = Negative control, Chloroquine = Positive control

Table 6: Mean survival time and %Chemo-suppression of *P. berghei* by the Leave of *Morinda citrifolia L.* and Standard drug (chloroquine)

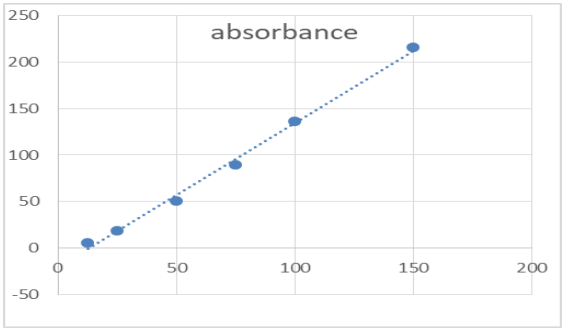
		Average % Chemo-suppression				
Treatment	**Dosage (mg/kg)**	**D5 (%)**	**D6(%)**	**D7(%)**	**D8(%)**	**Mean Survival time (Mt ± SD)**
Untreated	_	_	_	_	_	14 ± 3.22
Extract	200	36.19	28.35	21.78	13.68	17 ± 3.10
Extract	400	39.74	30.63	25.77	19.19	20 ± 2.41
Extract	800	45.52	35.75	28.39	21.06	26 ± 1.41
Chloroquine	5	97.76	94.02	92.25	88.39	28 ± 0.45

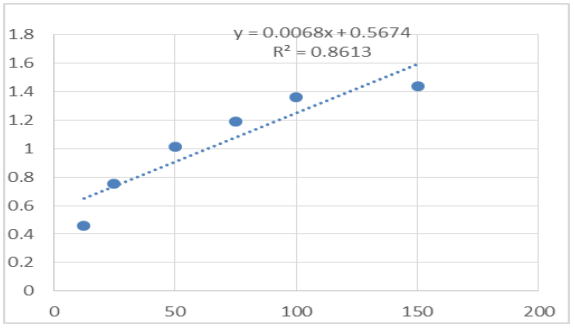
Untreated = Negative control, Chloroquine = Positive control

Table 7: Analytical Data for Flavonoid Content of the Aqueous Extract of *Morinda citrifolia L.*

Concentration	Absorbance
12.5	0.459
25	0.759
50	1.016
75	1.190
100	1.304
150	1.438

Concentration	Absorbance
12.52	5.738
25	18.83
50	50.8
100	89.25
125	136.4
150	215.7





DISCUSSION

Elemental and Proximate Composition

Elemental and proximate analyses of *Morinda citrifolia L.* (noni) leaves revealed a nutritionally and chemically rich profile. Elemental analysis showed the presence of essential and trace metals, including manganese (Mn), iron (Fe), chromium (Cr), zinc (Zn), and lead (Pb). Manganese recorded the highest concentration (2.25), followed by iron (2.00) and chromium (0.195), while cadmium (Cd) and nickel (Ni) were not detected. Proximate composition (g/100 g) indicated appreciable levels of carbohydrates (40.04), moisture (4.59), crude fibre (4.60), crude fat (3.65), crude protein (2.18), and ash (0.63). The high carbohydrate content highlights the plant's energy potential, while fibre supports digestive health and protein contributes to tissue growth and maintenance. Ash content reflects total mineral composition, and the high moisture level may influence freshness and shelf life. Overall, these results demonstrate the nutritional value and mineral richness of *Morinda citrifolia L.* leaves.

Total Phenolic Content

In this study, the total phenolic content (TPC) of the methanolic leaf extract of *Morinda citrifolia L.* (noni) was quantified using the Folin–Ciocalteu (F–C) assay, with gallic acid employed as the reference standard. A calibration curve was generated from the absorbance values of known concentrations of gallic acid, and the TPC of the extract was calculated using the regression equation obtained from the

standard curve (Absorbance = 0.0216x − 0.6186). Results were expressed as milligrams of gallic acid equivalents per gram of dry extract (mg GAE/g).

The methanolic leaf extract exhibited a TPC value of 29.13 ± 0.23 mg GAE/g, indicating a substantial presence of phenolic compounds. This finding supports existing knowledge regarding the importance of phenolics as bioactive constituents in plant extracts. Phenolic compounds are well recognized for their strong antioxidant properties and their association with various health-promoting effects. The appreciable phenolic content observed in *Morinda citrifolia L.* leaves suggests that the plant may serve as a valuable natural source of antioxidants, which likely underpins its widespread use in traditional herbal medicine and justifies continued scientific Investigation.

Antimalarial Studies

The antimalarial activity of *Morinda citrifolia L.* (Noni) extract was evaluated by monitoring parasitaemia levels in *Plasmodium berghei*–infected mice. In the untreated (negative control) group, parasitaemia increased progressively from day five today eight, reflecting the normal course of infection in the absence of intervention. In contrast, treatment with the Noni extract at doses of 200, 400, and 800 mg/kg resulted in a marked reduction in parasitaemia relative to the negative control. This reduction occurred in a dose-dependent manner, indicating that higher extract concentrations were more effective in suppressing parasite proliferation.

When compared with chloroquine, the standard antimalarial drug, the Noni extract exhibited lower efficacy. Chloroquine administered at 5 mg/kg produced a pronounced and sustained decrease in parasitaemia throughout the observation period, confirming its superior antimalarial potency. Nonetheless, the observed suppressive effect of the Noni extract, particularly at higher doses, suggests the presence of bioactive compounds with antiplasmodial potential. These findings support the possible use of *Morinda. Citrifolia L.* as a complementary antimalarial agent and justify further investigations into its active constituents, mechanism of action, and safety profile.

Hematological Studies

The hematological data indicate that the PALE extract markedly influenced white blood cell parameters. Treatment with PALE resulted in an overall increase in total white blood cell (WBC) counts, accompanied by reductions in lymphocyte (LYM), monocyte (MID), and granulocyte (GRX) counts. However, differential analysis showed a decrease in lymphocyte percentage alongside increases in MID and GRX percentages. These alterations suggest that the PALE extract modulates immune function by influencing both the production and distribution of leukocyte subtypes. The elevated WBC count may reflect enhanced leukopoiesis or reduced leukocyte apoptosis, while the reduced lymphocyte levels may be associated with suppressed lymphocyte production or increased apoptosis. Conversely, increased MID and GRX values may indicate stimulated monocyte and granulocyte production or decreased cell clearance. Collectively, these shifts in leukocyte profiles suggest that PALE extract possesses immunomodulatory potential and may influence immune responses to infection and inflammation. PALE treatment significantly improved red blood cell (RBC) parameters in rats. Compared with the control group, PALE-treated rats showed increased hematocrit (HCT), haemoglobin (Hgb), and RBC counts, indicating enhanced erythropoiesis and improved oxygen-carrying capacity of the blood. Evaluation of erythrocyte indices revealed no significant changes in mean corpuscular volume (MCV) or mean corpuscular haemoglobin (MCH), while mean corpuscular haemoglobin concentration (MCHC) increased, suggesting a higher haemoglobin concentration within red blood cells. Red cell distribution width (RDW), an indicator of erythrocyte size variability, was not significantly affected by PALE. Overall, these findings suggest that PALE positively modulates erythropoietic function without altering red blood cell morphology, highlighting its potential usefulness in the management of anaemia and related hematological disorders.

Total Flavonoid Content

The results indicate that total flavonoid content (TFC) increased with extract concentration, reaching its highest value at 150 mg/L and the lowest at 12.5 mg/L. This demonstrates a concentration-dependent increase in flavonoid content in the extracts as indicated from table 7 above.

CONCLUSION

This study demonstrates that *Morinda citrifolia L.* possesses significant nutritional, antioxidant, haematological, and antimalarial properties. Proximate and elemental analyses revealed essential nutrients and minerals, while appreciable phenolic and flavonoid contents indicated strong antioxidant potential. The extract positively modulated red and white blood cell parameters and showed dose-dependent antiplasmodial activity against Plasmodium berghei, although less effective than chloroquine. These findings support the medicinal relevance of *Morindsa citrifolia L.* and justify further studies on its bioactive compounds, safety, and therapeutic applications.

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