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Biochemical and Hematological Derangement in *Plasmodium falciparum* Infected Patients Attending Health Facilities in Northern Taraba State, Nigeria

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ABSTRACT

Plasmodium falciparum predominates as the leading cause of malaria-related mortality, particularly in sub-Saharan Africa, posing a significant global health threat. This study aims to assess the hematological and biochemical alterations attributed to *P. falciparum* infection among patients seeking care in health facilities across Northern Local Government Areas of Taraba State, encompassing Jalingo, Lau, and Zing. A prospective cross-sectional study method was adopted and enrolled 1,500 participants who underwent testing for P. falciparum using Giemsa-stained blood film examination, Rapid Diagnostic Test (RDT), and Polymerase Chain Reaction (PCR). Hematological parameters, including Packed Cell Volume (PCV), white blood cell counts, and erythrocyte sedimentation rate (ESR), as well as biochemical markers such as albumin, bilirubin, and electrolyte levels, were assessed. Results shows that, out of 1,500 individuals, 304 were infected with P. falciparum, representing a prevalence of 20.3%. Significant differences were observed in hematological and biochemical parameters between infected and non-infected participants, including lower PCV and platelet counts, elevated neutrophil counts, and altered liver enzyme levels among parasitized individuals. The study also compared the diagnostic performance of RDT and microscopy, revealing variations in sensitivity and specificity. This study underscores the clinical utility of hematological and biochemical parameters in malaria management, particularly in resource-limited settings like Nigeria. The findings highlight the importance of comprehensive diagnostic approaches and suggest integrating these adjunct tools into malaria treatment protocols to enhance patient care and outcomes.

Keywords: Malaria, Derangement, Haematological, Biochemical, Plasmodium falciparum

INTRODUCTION

Malaria remains a significant parasitic disease in the tropics, leading to increased morbidity and mortality. *Plasmodium falciparum* is predominant in sub-Saharan Africa, while

Plasmodium vivax prevails outside of Africa, particularly in the WHO South-East Asia region. Mortality rates are high in severe malaria cases, often associated with altered haematological and biochemical parameters, contributing to common complications (Khuraiya *et al*., 2016). *P. falciparum* accounts for over 90% of global malaria mortality, with an estimated 781,000 deaths and 225 million cases annually (Snow, 2005; WHO, 2018). Clinical diagnosis of malaria, primarily based on fever symptoms, lacks specificity and often results in overuse of antimalarial drugs, reducing healthcare quality (Erhart *et al*., 2007). While microscopic diagnosis remains the gold standard, its sensitivity and specificity, particularly in endemic African areas, are limited due to the need for technical expertise, time consumption, and healthcare deficiencies (WHO, 2009; Maina *et al*., 2010). Haematological derangements are common complications in malaria, influenced by various factors including malaria species, age, gender, and endemicity level. Severe anaemia, particularly attributed to *P. falciparum*, peaks in children under two years of age and significantly affects disease outcome (Waitumbi *et al*., 2000; Miana *et al*., 2010). Haematological changes in malaria encompass anaemia, thrombocytopenia, leucocytosis, leukopenia, lymphopenia, monocytosis, eosinophilia, and neutrophilia, with inflammatory biomarkers often associated with eosinophilia during acute illness (Tobo´n-Castan˜o *et al*., 2015; D'souza *et al*., 2017). Thrombocytopenia is a common finding in both *vivax* and *falciparum* malaria, with platelet survival reduction indicating disease severity (D'souza *et al*., 2017). *P. falciparum* invasion of red blood cells and subsequent haemoglobin consumption lead to anaemia, exacerbating the disease's severity (Tilley *et al*., 2011; Sakzabre *et al*., 2020). Moreover, malaria infections disrupt haematopoietic physiology, altering haematological parameters associated with parasitemia, hemoglobinopathy, nutritional status, demographic factors, and immunity (Price *et al*., 2001; Khan *et al*., 2012; Awoke & Arota, 2019). Global hematological abnormalities during malaria infections have been recorded, with significant decreases in haemoglobin, platelets, white blood cells, and lymphocytes observed in malaria patients (Awoke & Arota, 2019). The impact of malaria primarily affects tropical regions due to conducive breeding conditions for mosquitoes, such as high humidity and rainfall levels (Eze *et al*., 2012).

Blood's physicochemical properties remain constant under normal conditions but undergo variations in pathological states like malignancy, genetic defects, malnutrition, and parasitic infections. Haematological and biochemical alterations occur in malaria-infected blood, contributing to common complications associated with the disease. These alterations vary based on malaria endemicity, haemoglobinopathies, nutritional status, demographic factors, and immunity levels (Price *et al*., 2001; Erhart *et al*., 2007). Understanding these alterations aids clinicians in establishing accurate diagnoses and therapeutic interventions.

Biochemical abnormalities observed in malaria-infected patients include elevated bilirubin, liver enzymes, and creatinine levels, complicating the disease. Acute malaria infection often leads to increased serum activity of liver enzymes and bilirubin levels, indicating acute liver injury (Al-Salahy *et al*., 2016). Renal abnormalities, such as elevated blood urea and decreased creatinine clearance, are directly associated with heavy parasitaemia levels in malaria cases (Sharma *et al*., 2012). These abnormal blood and biochemical profiles play a crucial role in causing fatal complications, contributing to high morbidity and mortality rates. This study aims to assess haematological and biochemical abnormalities caused by *Plasmodium falciparum* infection in patients visiting healthcare facilities in Northern Taraba State, with objectives

including determining P. *falciparum* prevalence and evaluating haematological and biochemical indices in infected patients in the region.

MATERIALS AND METHODS

Study Area

Taraba State, the second largest in Nigeria by landmass, is situated in the southern part of northeastern Nigeria along the eastern border with Cameroon. Spanning between latitude 6° 25'N and 9° 30'N and longitude 9°30'E and 11° 45'E, it shares borders with Nasarawa, Plateau, Bauchi, Gombe, and Adamawa States, as well as Benue State to the southwest and the Republic of Cameroon to the south and southeast. Comprising 16 Local Government Areas (LGAs) and three Senatorial districts, Northern Taraba, where this study focuses, consists of six LGAs: Ardo Kola, KarimLamido, Lau, Jalingo, Yorro, and Zing.

Study Sites

The study was conducted in three centers across three randomly selected LGAs in Taraba State: Federal Medical Centre in Jalingo, General Hospital in Lau, and General Hospital in Zing.

Study Population and Selection of Subjects

Participants aged 1 year and above were considered for this study after providing written consent. A total of 1,500 patients diagnosed with Plasmodium species using routine laboratory methods, including Giemsa stained blood film examination and Immunochromatography following the WHO protocol (WHO, 2010), were included. A random selection of 500 participants from each center across the three chosen LGAs was conducted.

Inclusion and Exclusion Criteria

Inclusion Criteria: Only consenting subjects were included, and only individuals with P. *falciparum* infection were considered.

Exclusion Criteria: Subjects who refused consent and those with co-infections with other Plasmodium species or underlying medical conditions affecting biochemical or hematological indices, including liver and kidney problems, were excluded. Children under 1 year old were also excluded.

Research Design

This prospective cross-sectional study involves subjects with P. *falciparum* malaria infection as test subjects and P. falciparum-negative subjects as controls.

Data Collection

Samples were collected anonymously, with each given a coded number, and data including demographics, such as age, gender, marital status, and educational status, were recorded over a 12-month period, with each study center allocated four months.

Sample Handling and Disposal

Samples were handled by professional laboratory technicians or scientists, tested for infection status, and then incinerated. Data collected were kept confidential and used only for research purposes, with individual test results provided upon request.

Sample Size Estimation

The sample size was determined using the standard formula for sample size calculation:

$$\text{Sample size } n = \frac{(Z_{1-a})^2 \times P(1-P)}{d^2}$$

Where n = minimum sample size,

Z_{1-a} value of standard normal deviation which is at 95% confidence level has been found to be 1.96.

P=best estimate of the population prevalence obtained from the literature review.

d=proportion of sample error in a given population.

At prevalence rate of plasmodium malaria of 19.2% (Yakubu *et al*., 2019), using 5% precision at 95% confidence level, the minimum sample size n for this study is calculated as follows:

$$\text{Sample size } n = \frac{(Z_{1-a})^2 \times P(1-P)}{d^2}$$

Where Z=1.96,

P=19.2%, 0.192 d= 5%, 0.05

Therefore, $n = \frac{(1.96) \times 0.192 \times (1-0.192)}{0.05^2}$

n=238

The minimum sample size is 238 per LGA

Added attrition was = 110% of 238

Total sample size=500 x 3 =1500

Research Instrument

Questionnaire: A structured questionnaire was administered to all consenting participants to capture demographic characteristics such as sex, age, marital status, educational level, and any existing medical conditions.

Informed Consent: Written informed consent was obtained from all patients in accordance with standards for human experimentation and the Helsinki Declaration.

Ethical Approval

Ethical approval was obtained from the Taraba State Ministry of Health Ethical Committee and presented to the health facilities where blood samples were collected, following the Declaration on the Rights of the Patient. For participants under 18 years old, consent was provided by their guardians or parents.

Collection and Preparation of Blood Specimen

Blood samples, collected by trained personnel, were processed and divided into plain bottles for coagulation and EDTA bottles for malaria parasite tests and hematological studies. Coagulated samples were centrifuged, and serum was stored frozen until required for biochemical analyses. Safety protocols were followed during sample collection, and participants with adverse reactions were referred to a physician at the facility.

Preparation of Blood Films

Thick and thin blood films were prepared on the same slide for each subject and stained using 10% Giemsa stain according to standard procedures (Cheesebrough, 2006). A clean, grease-free microscope slide received a small drop of blood at its center and a larger drop (about 15mm) at one end. Using a smooth edge slide spreader, the thin blood film was immediately spread, while the larger drop was spread to create a thick film covering an area of approximately 15 x 15mm. The slide was left to air dry. The thin film was fixed with absolute methanol for two minutes without touching the thick films.

Giemsa Staining Technique

Giemsa stain was diluted to a 10% solution (90ml buffered distilled water pH 7.0 to 10ml Giemsa stain) in a measuring cylinder and mixed. Slides were placed on a staining rack and flooded with the diluted stain, allowing it to stain for 45-60 minutes. After staining, slides were washed with buffered distilled water pH 7.0, wiped with cotton wool, and then air-dried. A drop of oil immersion was applied to a well-stained and appropriately thin area of the film, which was examined for malaria parasites and pigments, confirmed by examining the thin blood films.

Parasite Density Test

Measurement of parasite density of peripheral blood smear was conducted using Giemsa stained techniques. Films were examined microscopically at x100 magnification under oil immersion as per Cheesbrough (1998) and Sumbele *et al*. (2014). Parasitaemia level was graded in microliters (µl) of blood thick film preparation according to WHO (2005), categorized as low+ (1 to 999/µl), moderate++ (1000 to 9999/µl), and severe+++ (> 10,000/µl).

The parasite density was counted according to the WHO standard formula (WHO, 2015).

$$\text{Parasite}/\mu l = \frac{\text{number of parasites counted x8000 white cells}/\mu l}{\text{Number of white cells counted}}$$

Where 8000 = putative means of leucocytes.

Haematological Studies

Haematological parameters, including Packed Cell Volume (PCV), neutrophils,

lymphocytes, monocytes, eosinophils, basophils, total white blood cell (TWBC) count, total platelet count, and erythrocyte sedimentation rate (ESR), were analyzed using the hematology auto-analyzer (Sysmex XTI 2000).

Biochemical Studies

Biochemical parameters, such as aspartate transaminase (ASAT), alanine transaminase (ALAT), blood urea, creatinine, albumin concentration, total protein, total bilirubin, direct bilirubin, sodium (Na+), potassium (K+), chloride (Cl-), and bicarbonate (CO3), were estimated using standard assay kits (Hoffmann-La Roche Ltd, US). All tests, except for serum iron, were run on the Cobas C 311 analyzer (Hoffmann-La Roche Ltd, US). All samples and reagents were brought to room temperature before analysis, and tests were performed according to the manufacturer's instructions.

STATISTICAL ANALYSIS

Data were analyzed using SPSS V28. Chi-square was utilized to compare the prevalence of malaria infection across age, sex, occupation, and educational status. The Odd Ratio (OR) was determined through logistic regression to assess the relationship between malaria infection and haematological parameters. The general linear model was employed to differentiate haematological and biochemical parameters of patients. T-test was used to determine the relationship between haematological and biochemical parameters of malaria parasitized and non-parasitized subjects, with statistical significance set at 0.05.

RESULTS

Overall pattern of Distribution of *falciparum* Malaria in the Study Area

Table 1 presents the distribution of malaria across three different study areas: Jalingo, Lau, and Zing. Each study area underwent examination of 500 individuals for malaria. In Jalingo, 127 out of 500 individuals were infected, accounting for a prevalence of 25.4%. In Lau, 94 out of 500 individuals were infected, resulting in an infection rate of 18.8%. In Zing, 83 out of 500 individuals were infected, resulting in a prevalence of 16.6%. Across all study areas, a total of 304 out of 1500 individuals were infected, making up a prevalence of 20.3%. The Chi-square distribution indicates a significant difference in malaria distribution among the study areas (χ =12.979; P<0.05).

Table 1: Overall pattern of Distribution of Malaria in the Study Area

Study Area	No. Examine	No. Infected (%)
Jalingo	500	127 (25.4)
Lau	500	94 (18.8)
Zing	500	83 (16.6)
Total	1500	304 (20.3)
χ =12.979; P<0.05		

Gender prevalence of Malaria in the Study Area

Table 2 presents the prevalence of malaria based on gender across the study areas. In Jalingo, among males, 64 out of 241 individuals were infected with malaria, resulting in a prevalence of 26.6%. Among females, 63 out of 259 individuals were infected, with a prevalence of 24.3%. In Lau, among males, 50 out of 203 individuals were infected, resulting in a prevalence of 19.8%, while among females, 44 out of 203 individuals were infected, with a prevalence of 17.8%. In Zing, among males, 39 out of 237 individuals were infected, resulting in a prevalence of 16.5%, whereas among females, 44 out of 263 individuals were infected, with a prevalence of 16.7%. Overall, male respondents had a slightly higher prevalence of 20.9% (153/731) compared to females, who had a prevalence of 19.6% (151/769).

Table 2: Gender prevalence of Malaria in the Study Area

Study Area	Sex	No. Examine	No. Infected (%)
Jalingo	Male	241	64 (26.6)
	Female	259	63 (24.3)
Lau	Male	203	50 (19.8)
	Female	203	44 (17.8)
Zing	Male	237	39 (16.5)
	Female	263	44 (16.7)
Total	Male	731	153 (20.9)
	Female	769	151 (19.6)
Overall Total	Male + Female	1500	304 (20.3)

Age related Distribution of Malaria in the Study Area

Table 3 provides the distribution of malaria cases based on age groups and gender within the study area. For the age group 1-5 years, among males, 14 out of 15 individuals were infected (93.3%), while among females, 17 out of 37 individuals were infected (45.9%). For the age group 6-10 years, among males, 3 out of 4 individuals were infected (75.0%), whereas among females, 5 out of 11 individuals were infected (45.4%). This pattern continues across different age groups, indicating varying infection rates among different age and gender groups.

Table 3: Age related Distribution of Malaria in the Study Area

Age (Years)	No. Examined	No. Infected (%)
1-5	52	31 (59.6)
6-10	15	8 (53.3)
11-17	276	46 (16.6)
18-30	692	148 (21.4)
31-40	245	35 (14.2)
41-50	141	21 (14.8)
>50	79	15 (18.9)
Total	1500	304 (20.3)

Occupation related Prevalence of *P. falciparum* infection in the study area

Table 4 provides the overall occupation-related prevalence of *P. falciparum* infection in the study areas. Farmers had the highest prevalence of 7.5% (112/1500) followed by traders with a prevalence of 6.8% (103/1500), civil servant 4.1% (62/1500) and the least been students 1.5% (23/1500). The Chi-square distribution (χ =12.348; P<0.05) showed a significant association.

Prevalence of Malaria according to Educational Level in the study area

Table 4 presents the overall prevalence of malaria according to educational level within the study areas. The table showed that participants with secondary education had the highest prevalence of 10.1% (150/1500) followed by those with no formal education with a prevalence of 4.2% (63/1500), tertiary 3.8% (57/1500) and the least been 2.3% (34/1500). Overall, out of 1500 individuals examined across all occupations in the study area 304 (20.3%) were infected with *P. falciparum* malaria. The Chi-square distribution (χ = 229.342; P<0.05) indicates a significant association between educational level and *P. falciparum* infection in the study areas.

Prevalence of Malaria according to Marital Status in the study area

Table 4 presents the prevalence of *P. falciparum* infection based on marital status in the Study Areas. The table showed that participants who are single had the highest prevalence of 13.8% (207/1500) followed by married participants with a prevalence of 5.7% (86/1500), divorced/separated 0.7% (10/1500) and the least been those who are widowed 0.1% (1/1500). The Chi-square distribution (χ = 98.488; P<0.05) indicates a significant association between marital status and malaria prevalence within the study area.

Table 4: Overall Prevalence of Malaria according to Educational Level in the study area

	Jalingo		**Lau**		**Zing**		**Total**		**χ**	**P**
	No. Examined	**Infected (%)**	**No. Examined**	**Infected (%)**	**No. Examined**	**Infected (%)**	**No. Examined**	**Infected (%)**		
Age (Years)										
1-5	7	7 (1.4)	19	12 (2.4)	26	12 (2.4)	52	31 (59.6)		
6-10	2	2 (0.4)	4	1 (0.2)	9	5 (1.0)	15	8 (53.3)		
11-17	117	35 (7.0)	78	6 (1.2)	81	5 (1.0)	276	46 (16.6)		
18-30	207	42 (8.4)	242	51 (10.2)	243	55 (11.0)	692	148 (21.4)		
31-40	80	18 (3.6)	83	13 (2.6)	82	4 (0.8)	245	35 (14.2)		
41-50	52	11 (2.2)	54	10 (2.0)	35	0 (0.0)	141	21 (14.8)		
>50	35	12 (2.4)	20	1 (0.2)	24	2 (0.4)	79	15 (18.9)		
Total	500	127 (25.4)	500	94 (18.8)	500	83 (16.6)	1500	304 (20.3)		
Occupation									**12.348**	**<0.05**
Civil Servant	130	25 (5.0)	101	18 (3.6)	137	23 (4.6)	368	62 (4.1)		
Farmer	193	41 (8.2)	205	33 (6.6)	205	38 (7.6)	603	112 (7.5)		
Student	41	7 (1.4)	69	16 (3.2)	28	0 (0.0)	138	23 (1.5)		
Trader	136	54 (10.8)	125	27 (5.4)	130	22 (4.5)	391	103 (6.8)		
Total	500	127 (25.4)	500	94 (18.8)	500	83 (16.6)	1500	304 (20.3)		
Educational Level									**229.342**	**<0.05**
No Formal Education	108	12 (2.4)	126	15 (3.0)	193	36 (7.2)	433	63 (4.2)		
Primary	36	19 (3.8)	23	7 (1.4)	34	8 (1.6)	93	34 (2.3)		
Secondary	318	61 (12.2)	335	56 (11.2)	259	33 (6.6)	912	150 (10.1)		
Tertiary	38	35 (7.0)	16	16 (3.2)	8	6 (1.2)	62	57 (3.8)		
Total	500	127 (25.4)	500	94 (18.8)	500	83 (16.6)	1500	304 (20.3)		
Marital status									**98.488**	**<0.05**
Single	254	81 (16.2)	265	66 (13.2)	241	60 (12.0)	760	207 (13.8)		
Married	237	37 (7.4)	233	26 (5.2)	259	23 (4.6)	729	86 (5.7)		
Divorced/Separated	8	8 (1.6)	2	2 (0.4)	0	0 (0.0)	10	10 (0.7)		
Widowed	1	1 (0.2)	0	0 (0.0)	0	0 (0.0)	1	1 (0.1)		
Total	500	127 (25.4)	500	94 (18.8)	500	83 (16.6)	1500	304 (20.3)		

Malaria Parasitaemia per-highfield in the Study Area

Table 5 presents the distribution of malaria parasitemia per highfield in the study areas. The highest mild infection (+) was recorded in Jalingo 15.0% (75/500) while the lowest was in Zing 74.6% (373/500). The table also shows that the highest moderate infection (++) was recorded in Lau 7.2% (36/500) while the lowest was in Zing 6.0% (30/500). The highest severe infection (+++) was recorded in Jalingo 4.2% (21/500) while the lowest was in Zing 3.0% (15/500).

Table 5: Malaria Parasitaemia per-highfield in the Study Area

Study Area	Negative (%)	+ (%)	++ (%)	+++ (%)	Total
Jalingo	373 (74.6)	75 (15.0)	31 (6.2%)	21 (4.2%)	500 (100.0)
Lau	406 (81.2)	39 (7.8)	36 (7.2)	19 (3.8)	500 (100.0)
Zing	417 (83.4)	38 (7.6)	30 (6.0)	15 (3.0)	500 (100.0)
Total	1196 (79.7)	152 (10.1)	97 (6.5)	55 (3.7)	1500 (100.0)

The prevalence of *P. falciparum* infection according to Risk factors among patients attending health facilities in Northern Taraba State.

Participants who did not sleep under insecticide-treated nets exhibited a significantly higher prevalence of 91.0% compared to those who did (P<0.05), as shown in Table 6. There was no statistically significant difference between respondents with bushes around their houses and those without (P >0.05). Participants that reported presence of stagnant water around the house had 94.44% infection prevalence and those without window nets around the house had 21.85% prevalence which was statistically significant (P<0.05), while higher prevalence was observed among those who opened doors and windows at night (23.77%) compared to those who did not (21.99%). Participants who did not spray their rooms with insecticides had a higher prevalence of 20.87%, although this difference was not statistically significant (P>0.05). Additionally, the prevalence according to area of residence indicated that individuals in rural areas had a significantly higher susceptibility to P. *falciparum* prevalence (23.49%) compared to those in semi-urban (18.45%) and urban areas (19.04%) (P<0.05).

Table 6: Risk factors associated with *P. falciparum* infection in the Study Area

Risk Factors	N	Infection Prevalence	Chi-square	P-value
Sleep under Insecticide Treated Nets				
Yes	1321	141 (10.6)	630.408	0.000
No	179	163 (91.0)		
Total	1500	304 (20.3)		
Bush around house				
Yes	419	75 (17.9)	2.016	0.156
No	1081	229 (21.1)		
Total	1500	283 (20.3)		
Stagnant water around house				
Yes	54	51 (94.4)	190.740	0.000
No	1446	253 (17.5)		
Total	1500	304 (20.3)		
Window net around house				
Yes	493	84 (17.0)	4.736	0.030
No	1007	220 (21.8)		
Total	1500	304 (20.3)		

Open door at night				
Yes	610	145 (23.7)	7.811	0.005
No	890	159 (17.8)		
Total	1500	304 (20.3)		
Open window at night				
Yes	322	45 (13.9)	10.044	0.002
No	1178	259 (21.9)		
Total	1500	304 (20.3)		
Spray room with insecticide				
Yes	785	155 (19.7)	0.277	0.599
No	715	149 (20.8)		
Total	1500	304 (20.3)		
Area of Residence				
Rural	224	69 (30.9)	18.092	0.000
Semi-urban	442	81 (18.3)		
Urban	834	154 (18.5)		
Total	1500	276 (20.3)		

Hematological Parameters of Malaria Infected patients and uninfected participants

Table 7 describes the statistical comparisons of the derangement of malaria parasite infection on various haematological parameters. The parameters investigated include Packed Cell Volume (PCV), neutrophils, lymphocyte count, monocytes, eosinophil count, basophil count, total white blood cell count, platelet and erythrocyte sedimentation rate. Results showed that malaria-infected patients had a significantly lower mean packed cell volume (PCV < 33) compared to those without parasitemia. The mean packed cell volume (PCV) values were 32.88 ± 7.582 SD (standard deviation) for the infected group, whereas the non-infected group had 38.81 ± 1.323 SD ($P<0.05$). The patients who were infected had a higher neutrophil count of 56.41 ± 9.846 compared to non-parasitized patients, whose neutrophil count was 48.27 ± 3.620 ($P<0.05$). The result also shows that malaria-infected patients had a significantly decreased lymphocyte count, 29.28 ± 9.402. In contrast, uninfected patients had a lymphocyte count with a mean value and standard deviation of 37.24 ± 4.690 ($P<0.05$). The monocyte counts in infected patients, with a value of 8.11 ± 1.962 was slightly lower compared to uninfected patients, with a value of 8.12 ± 2.115. However, the observed difference did not show statistically significant difference ($P>0.05$). A statistically significant difference was observed between the eosinophil counts of malaria-infected patients and uninfected participants, with eosinophil levels being lower in uninfected participants (5.08 ± 1.007) compared to infected patients (5.34 ± 1.569) ($P<0.05$) which indicates a notable difference in average eosinophil values. The basophil counts in infected patients with *P. falciparum* were non-significantly lower than those without parasitemia, with values of 0.46 ± 0.669 and 0.54 ± 1.196, respectively ($P>0.05$). The total white blood cell counts in infected patients with a value of 5.734 ± 3.7846 was significantly lower than that of the uninfected participants which was 7.378 ± 1.7049 ($P<0.05$). The platelet counts in uninfected patients, with a value of 303.00 ± 62.700 was significantly higher compared to infected patients, with a value of 201.88 ± 90.342($P<0.05$). The patients who were infected had a significantly higher erythrocyte sedimentation rate of 13.38 ± 9.689 compared to uninfected participants 4.27 ± 1.523 ($P<0.05$).

Table 7: Hematological Parameters of Malaria Infected patients and uninfected participants

Haematological Parameters	Non-Parasitized (N=1195)	Parasitized (N=304)	t-test	p-value
Packed Cell Volume %	38.81 ± 1.323	32.88 ± 7.582	25.563	0.000
Neutrophils %	48.27 ± 3.620	56.41 ± 9.846	23.103	0.000
Lymphocytes %	37.24 ± 4.690	29.28 ± 9.402	20.835	0.000
Monocytes %	8.12 ± 2.115	8.11 ± 1.962	0.126	0.900
Eosinophils %	5.08 ± 1.007	5.34 ± 1.569	3.498	0.000
Basophils %	0.54 ± 1.196	0.46 ± 0.669	1.083	0.279
TWBC /L	7.378 ± 1.7049	5.734 ± 3.7846	11.192	0.000
Platelet (μ/L)	303.0 ± 62.700	201.88 ± 90.34	22.729	0.000
ESR (mm/hr)	4.27 ± 1.523	13.38 ± 9.689	31.050	0.000

ESR-Erythrocyte Sedimentation Rate, TWBC-Total White Blood Cell Count

Haematological Parameters in Malaria Parasitized in Relation to Age Group Compared with WHO Standard in the Study Area

Table 8 presents hematological parameters in malaria-infected individuals across various age groups compared with WHO standards in the study area.

PCV % (Packed Cell Volume): The PCV % values were highest in the age group 41-50 years (63.75±5.80) and lowest in the age group 6-10 years (28.00±6.54), falling below the WHO standard range of 40-50%.

Neutrophils %: Neutrophils % values were highest in the age group 6-10 years (35.38±7.66) and lowest in the age group >50 years (52.80±8.71), generally within the WHO standard range of 45-75%.

Lymphocytes %: Lymphocytes % values were highest in the age group >50 years (33.20±8.85) and lowest in the age group 6-10 years (22.25±6.67), generally within the WHO standard range of 25-45%.

Monocytes %: Monocytes % values were highest in the age group 18-30 years (8.53±1.71) and lowest in the age group 41-50 years (7.10±1.89), falling within the WHO standard range of 2-10%.

Eosinophils %: Eosinophils % values were highest in the age group 11-17 years (5.70±1.59) and lowest in the age group 41-50 years (4.81±1.83), within the WHO standard range of 1-6%.

Basophils %: Basophils % values were highest in the age group 31-40 years (0.69±0.47) and lowest in the age group 41-50 years (0.24±0.43), generally within the WHO standard range of 0-2%.

Total White Blood Cell Count (TWBC): TWBC values were highest in the age group >50 years (6.62±2.98) and lowest in the age group 6-10 years (3.66±1.18). The highest mean values exceeded the WHO standard range of 4-11x10^9/L.

Platelet Count: Platelet Count values were highest in the age group 41-50 years (224.67±92.03) and lowest in the age group 6-10 years (137.88±28.30), with the lowest mean value falling below the WHO standard range of 150,000-450,000.

Erythrocyte Sedimentation Rate (ESR): ESR values were highest in the age group 1-5 years (18.61±12.97) and lowest in the age group >50 years (11.33±6.90), generally exceeding the WHO standard range of 3-7mm/hr across different age groups.

Table 8: Haematological Parameters in Malaria Parasitized in Relation to Age Group Compared with WHO Standard in the Study Area

Age (Years)	PCV %	Neutrophils %	Lymphocytes %	Monocytes %	Eosinophils %	Basophils %	TWBC	Platelet µ/L	ESR mm/hr
1-5	30.68±9.06	60.87±11.90	24.65±9.42	7.58±1.64	5.03±1.85	0.42±0.50	5.38±5.25	158.13±80.89	18.61±12.97
6-10	28.00±6.54	63.75±5.80	22.25±6.67	8.25±2.18	5.25±0.88	0.38±0.51	3.66±1.18	137.88±28.30	15.63±9.45
11-17	33.61±8.43	54.37±8.12	31.09±8.82	8.07±2.09	5.70±1.59	0.46±0.50	5.68±3.06	215.89±101.45	12.63±9.13
18-30	33.18±7.22	56.53±9.70	29.07±9.41	8.53±1.71	5.39±1.46	0.45±0.81	5.56±3.52	203.05±89.07	12.84±9.09
31-40	32.17±6.75	55.31±11.30	29.71±9.70	7.34±2.40	5.34±1.55	0.69±0.47	6.59±4.45	210.74±90.08	13.26±8.43
41-50	35.38±7.66	55.00±8.06	32.76±7.79	7.10±1.89	4.81±1.83	0.24±0.43	6.29±4.28	224.67±92.03	11.86±11.62
>50	33.13±6.05	52.80±8.71	33.20±8.85	8.20±2.33	5.13±1.72	0.60±0.50	6.62±2.98	219.33±73.99	11.33±6.90
WHO Standard	40-50	45-75	25-45	2-10	1-6	0-2	4-11x10^9/L	150k-450k	3-7

PCV-Packed Cell Volume; TWBC-Total White Blood Cell

Biochemical Parameters of Malaria-infected participants and uninfected participants

Table 9 illustrates the statistical comparisons of biochemical parameters between malaria-infected and uninfected participants. Malaria-infected patients exhibited significantly higher levels of albumin (51.960 ± 15.190) compared to uninfected participants (44.609 ± 31.0650) (P<0.05). Additionally, ASAT levels were elevated in infected patients (14.19 ± 7.468) compared to uninfected participants (7.58 ± 2.216) (P<0.05), while ALAT levels were also significantly higher in infected patients (13.244 ± 6.9411) compared to uninfected participants (6.279 ± 2.0270) (P<0.05). Total protein counts were higher in infected patients (87.021 ± 51.1779) compared to uninfected participants (69.463 ± 7.7445) (P>0.05). Total bilirubin and direct bilirubin levels were significantly higher in infected patients (18.670 ± 11.1723 and 5.606 ± 3.1772, respectively) compared to uninfected participants (9.654 ± 3.9785 and 0.649 ± 0.6775, respectively) (P<0.05). Infected patients exhibited lower sodium (132.094 ± 15.0416) and potassium (3.7277 ± 1.96240) levels compared to uninfected participants (139.711 ± 5.9261 and 4.0427 ± 0.40986, respectively) (P<0.05), as well as lower chloride levels (96.365 ± 23.2144) compared to uninfected participants (101.474 ± 4.3655) (P<0.05). Urea levels were higher in infected patients (10.766 ± 7.3256) compared to uninfected participants (6.658 ± 2.0896) (P<0.05), while bicarbonate levels were significantly higher in infected patients (33.984 ± 32.4976) compared to uninfected participants (25.997 ± 5.9328) (P<0.05). Furthermore, creatinine levels were elevated in infected patients (114.704 ± 33.3590) compared to uninfected participants (77.106 ± 22.2956) (P<0.05).

Table 9: Biochemical Parameters of Malaria Parasitized participants and non-parasitized participants

Biochemical Parameters	Non-Parasitized (N=1195)	Parasitized (N=304)	t-test	p-value
Albumin (ALB) g/L	44.609 ± 31.065	51.960 ± 15.190	3.977	0.000
Aspartate Transaminase (ASAT) g/L	7.58 ± 2.216	14.19 ± 7.468	26.337	0.000
Alanine Transaminase (ALAT) g/L	6.279 ± 2.0270	13.244 ± 6.9411	29.992	0.000
Total Protein (TP) g/L	69.463 ± 7.7445	87.021 ± 51.1779	11.259	0.000
Total Bilirubin (TB) µ/L	9.654 ± 3.9785	18.670 ± 11.1723	22.817	0.000
Direct Bilirubin (DB) µ/L	3.649 ± .6775	5.606 ± 3.17720	19.541	0.000
Sodium (Na^+) mmol/L	139.711 ± 5.926	132.094 ± 15.041	13.768	0.000
Potassium (K^+) mmol/L	4.0427 ± .40986	3.7277 ± 1.96240	5.131	0.006
Chloride (Cl^-) mmol/L	101.474 ± 4.365	96.365 ± 23.2144	7.135	0.000
Bicarbonate (CO_3) mmol/L	25.997 ± 5.9328	33.984 ± 32.4976	7.990	0.000
Urea (U) mmol/L	6.658 ± 2.0896	10.766 ± 7.3256	16.869	0.000
Creatinine (Cr) mmol/L	77.106 ± 22.295	114.704 ± 33.359	23.366	0.000

Biochemical Parameters in Malaria-Infected Respondents Across Age Groups Compared with WHO Standards in the Study Area

Table 10 presents the biochemical parameters in malaria-infected respondents across different age groups compared with WHO standards in the study area.

Albumin (ALB): The ALB values among malaria-infected individuals in the study area were highest in the age group 6-10 years (60.48±13.05) and lowest in the age group >50 years (47.52±10.07). ALB values across different age groups among malaria-infected respondents in the study area generally fall within the WHO standard range of 35-50 g/L.

Aspartate Transaminase (ASAT): ASAT values among malaria-infected individuals in the study area were highest in the age group 6-10 years (19.00±8.19) and lowest in the age group >50 years (9.73±5.27). Mean values across different age groups are generally higher than the WHO standard range of up to 12 u/L.

Alanine Transaminase (ALAT): ALAT values among malaria-infected individuals in the study area were highest in the age group 6-10 years (18.62±8.48) and lowest in the age group >50 years (9.60±4.54). Mean values across different age groups are generally higher than the WHO standard range of up to 12 u/L.

Total Protein (TP): TP values among malaria-infected individuals in the study area were highest in the age group 6-10 years (95.43±20.59) and lowest in the age group 41-50 years (76.01±17.95). The mean TP values across different age groups among malaria-infected respondents are generally higher than the WHO standard range of 58-80 g/L.

Total Bilirubin (TB): TB values among malaria-infected individuals in the study area were highest in the age group 6-10 years (23.55±7.46) and lowest in the age group >50 years (14.11±4.75). Mean values across different age groups are generally higher than the WHO standard range of up to 17 u/L.

Direct Bilirubin (DB): DB values among malaria-infected individuals in the study area were highest in the age group 6-10 years (7.16±2.50) and lowest in the age group >50 years (3.99±1.35). Mean values across different age groups are generally higher than the WHO standard range of up to 4.3 u/L, except in the age group >50 years.

Sodium (Na+): Na+ values among malaria-infected individuals in the study area were highest in the age group 31-40 years (136.01±11.45) and lowest in the age group 41-50 years (123.45±37.41). Mean values across different age groups are generally lower than the WHO standard range of 135-145 mmol/L but fall within the WHO standard in the age groups 31-40 years and >50 years.

Potassium (K+): K+ values among malaria-infected individuals in the study area were highest in the age group 31-40 years (4.48±2.83) and lowest in the age group 6-10 years (2.46±0.80). Mean values across different age groups are generally within the WHO standard range of up to 3-5 mmol/L, except in the age group 6-10 years.

Chloride (Cl-): Cl- values among malaria-infected individuals in the study area were highest in the age group >50 years (104.83±9.24) and lowest in the age group 6-10 years (82.13±8.89). Mean values across different age groups are generally within the WHO standard range of up to 95-110 mmol/L, except in the age groups 6-10 years, 11-17 years, and 41-50 years.

Bicarbonate (CO3): CO3 values among malaria-infected individuals in the study area were highest in the age group 1-5 years (53.64±66.44) and lowest in the age group 11-17 years (24.14±5.46). Mean values across different age groups are generally higher than the WHO standard range of up to 21-31 mmol/L, except in the age groups 11-17 years, 41-50 years, and >50 years.

Urea (U): Urea values among malaria-infected individuals in the study area were highest in the age group 6-10 years (12.25±6.24) and lowest in the age group 41-50 years (7.80±5.02). Mean values across different age groups are generally higher than the WHO standard range of up to 1.7-9.1 mmol/L, except in the age groups 41-50 years and >50 years.

Creatinine (Cr): Cr values among malaria-infected individuals in the study area were highest in the age group 1-5 years (130.04±22.85) and lowest in the age group 41-50 years (103.16±35.05). Mean values across different age groups are generally within the WHO standard range of up to 44-132 mmol/L.

Table 10: Biochemical Parameters in Malaria Parasitized Respondents in Relation to Age Group Compared with WHO Standard in the Study Area

Age	ALB	ASAT	ALAT	TP	TB	DB	Na^+	K^+	Cl^-	CO_3	U	Cr
1-5	60.28± 14.67	18.61± 8.58	16.54± 7.62	93.33± 20.87	22.11± 7.28	6.98± 3.85	131.36± 14.22	4.08± 3.31	96.21± 18.92	53.64± 66.44	12.17± 6.62	130.04± 22.85
6-10	60.48± 13.05	19.00± 8.19	18.62± 8.48	95.43± 20.59	23.55± 7.46	7.16± 2.50	123.70± 15.12	2.46± 0.80	82.13± 8.89	44.06± 19.74	12.25± 6.24	128.17± 33.88
11-17	51.02± 15.05	13.41± 6.79	11.71± 6.24	85.95± 20.21	17.38± 7.21	5.96± 3.64	132.92± 10.97	3.68± 1.46	93.93± 22.00	24.14± 5.46	11.59± 12.25	113.92± 32.09
18-30	51.00± 15.05	14.07± 7.02	13.35± 6.80	88.15± 70.64	18.90± 14.03	5.41± 2.94	132.45± 11.33	3.62± 1.61	96.81± 27.98	31.03± 8.03	10.97± 6.12	111.14± 36.61
31-40	52.01± 13.91	13.97± 8.00	13.17± 7.06	85.71± 18.01	19.10± 7.85	5.55± 3.13	136.01±	4.48± 2.83	98.97± 16.80	44.54± 65.98	10.00± 5.87	120.89± 26.96
41-50	47.56± 12.29	11.71± 7.19	11.33± 6.42	76.01± 17.95	15.29± 6.26	4.62± 3.03	123.45± 37.41	3.36± 0.91	93.78± 7.57	28.99± 7.80	7.80± 5.02	103.16± 35.05
>50	47.52± 10.07	9.73± 5.27	9.60± 4.54	76.44± 12.04	14.11± 4.75	3.99± 1.35	135.50± 7.50	3.58± 1.06	104.83± 9.24	29.17± 5.27	8.16± 4.21	111.92± 22.40
WHO Standard	35-50	Up to 12	Up to 12	58-80	Up to 17	Up to 4.3	135-145	3-5	95-110	21-31	1.7-9.1	44-132

ALB-Albumin; ASAT-Aspartate Transaminase; ALAT-Alanine Transaminase; TP-Total Protein; TB-Total Bilirubin; DB-Direct Bilirubin; Na^+-Sodium; K^+-Potassium; Cl^- Chloride; CO_3 Bicarbonate; U-Urea; Cr-Creatinine

DISCUSSION

Prevalence of *Falciparum* Malaria among Demographic Indices

Despite significant progress since 2000, morbidity and mortality due to malaria have not significantly decreased yet (Choi *et al*., 2019). Malaria remains a major health problem, especially in underdeveloped nations like Nigeria. According to this study, the prevalence of malaria through microscopy was 20.27%. The findings reveal that malaria is still prevalent in many urban and rural communities of Jalingo, Zing, and Lau Local Government Areas of Taraba State, Nigeria. This prevalence rate reflects Taraba as a high-risk area for malaria transmission, aligning with Nigerian malaria risk map estimates ranging from less than 20% to over 70% in certain zones (Onyiri, 2015). This study's findings are consistent with others reported from Ibadan, Akure, Taraba, and other Nigerian states (Okonko *et al*., 2010, 2012; Bello and Ayede, 2019; Houmsou *et al*., 2010; Elkanah *et al*., 2020; Adefioye *et al*., 2007; Oladeinde *et al*., 2012; Amuta *et al*., 2014; Singh *et al*., 2014; Dawaki *et al*., 2016). The high prevalence of malaria can be attributed to various factors such as favorable environmental conditions, stagnant water for mosquito breeding, poverty hindering access to recommended treatment, and occupational activities exposing people to mosquito bites (Awosolu *et al*., 2020).

Regarding gender, malaria prevalence was higher in males (20.85%) compared to females (19.71%), consistent with previous studies (Al-Mekhlafi *et al*., 2011; Winskill *et al*., 2011; Loha and Lindtjørn, 2012; Hailemariam and Gebre, 2015; Alemu *et al*., 2012; Gebretsadik *et al*., 2018; Awosolu *et al*., 2019), possibly due to males' engagement in outdoor activities. However, some reports indicated higher malaria infection among females (Ibekwe *et al*., 2009; Elkanah *et al*., 2020). Control interventions, especially targeting treatment and prevention through bed nets, often prioritize females and children.

The prevalence of 23.49% in rural areas of Taraba State is significantly higher compared to urban and semi-urban communities, consistent with reports from other regions (Wang *et al*., 2005; Baragatti *et al*., 2009; Awosolu *et al*., 2019; Woldearegai *et al*., 2019; Anumudu *et al*., 2006; Pond, 2013). Lower malaria prevalence in urban areas may result from better access to healthcare facilities, well-designed houses protecting against mosquito vectors, improved amenities, and reduced mosquito breeding sites.

Regarding age-specific prevalence, the highest malaria infection was observed in the 1-10 years age group, consistent with previous studies (Hailemariam *et al*., 2013; Zgambo *et al*., 2017). Children under five years are particularly vulnerable to malaria, attributed to gradual loss of maternal immunity and low acquired immunity compared to adults (WHO, 2018). Prevention efforts should focus on this age group, emphasizing mosquito net provision. Additionally, males exhibited higher malaria prevalence and mean parasite density than females, consistent with reports from other endemic areas (Escobar *et al*., 2020).

Malaria prevalence based on education was significantly higher (10.17%) among those who completed secondary education, consistent with studies showing that knowledge of malaria transmission, prevention, and control can be independent of educational status (Muchena *et al*., 2017; Dube *et al*., 2019). However, other reports suggest that education significantly influences people's knowledge, attitudes, and practices, leading to reduced malaria infection (Adedotun *et al*., 2010; Eteng *et al*., 2014; Dawaki *et al*., 2016).

Regarding occupation, traders had significantly higher prevalence (18.70%) compared to civil servants, students, and farmers, possibly due to outdoor activities

increasing the risk of infection ($\chi 2 = 22.058$; $P< 0.05$).

Prevalence of *Falciparum* Malaria across Northern Zones of Taraba State

Jalingo exhibited the highest prevalence of 25.4%, surpassing a previous report of 14.02% by Agere *et al*. (2019). Lau recorded a prevalence of 18.8%, contrasting with a previous 45% prevalence within the same locality (Adiel *et al*., 2021). Zing presented the lowest prevalence of 16.6%, marking the first reported malaria study in Zing Local Government Area, warranting further investigation in the region. Despite Jalingo's urban setting, it displayed the highest malaria prevalence, mirroring observations in other urban centers like Libreville and Ouagadougou (Wang *et al*., 2005; Mourou *et al*., 2012). Urban factors such as socio-environmental lifestyle, rural-urban migration, and artificial vector breeding sites contribute to increased malaria prevalence in urban areas (De Silva and Marshall, 2012).

Prevalence of *Falciparum* Malaria and Associated Risk Factors

The findings of our study revealed that not sleeping under insecticide-treated mosquito nets, the presence of stagnant water around the house, absence of window nets, and leaving doors and windows open at night were significant risk factors associated with the spread of *falciparum* malaria in the study area ($P<0.05$). These results align with previous studies conducted in Nigeria and other malaria-endemic regions by Siri *et al*. (2010), Alemu *et al*. (2011), Ceesay *et al*. (2012), Zhou *et al*. (2012), Zgambo *et al*. (2017), Baragatti *et al*. (2019), and Awosolu *et al*. (2020). The majority of communities in Taraba are still underdeveloped, providing conducive settings for mosquito breeding sites. Malaria is most prevalent in tropical and subtropical regions where the female Anopheles mosquito, which transmits the malaria parasite, thrives. Regions like Jalingo, Lau, and Zing with high temperatures and humidity provide ideal breeding grounds for mosquitoes. Factors such as stagnant water, deforestation, urbanization, and irrigation systems can influence mosquito breeding habitats and increase the risk of malaria transmission. Additionally, poverty, lack of access to healthcare, inadequate housing, and poor sanitation contribute to higher malaria prevalence rates. Limited resources may hinder effective prevention measures such as insecticide-treated bed nets and indoor residual spraying. Our study also found that participants living in rural areas had a higher malaria prevalence than those in semi-urban and urban communities, which was statistically significant ($P<0.05$). This finding is supported by studies conducted in malaria-endemic zones (Wang *et al*., 2005; Siri *et al*., 2010). Generally, people are at greater risk when traveling from urban areas to rural areas due to the high presence of mosquito vectors in rural areas. This risk is further exacerbated by the lower immunity of urban dwellers (Carme, 1994). Chemoprophylactic drugs are recommended for use before and during such visits to rural areas to prevent malaria infection.

Haematological Derangements due to *P. falciparum*

This study revealed a significant decrease in PCV, platelet count, TWBC, lymphocytes, monocytes, eosinophils, and basophils, alongside an increase in neutrophils, eosinophils, and ESR among participants infected with P. *falciparum* compared to negative participants. These deviations from normal values indicate anaemia, as supported by Francis *et al*. (2014), Bawah *et al*. (2018), Awoke and Arota (2019), and Elkanah *et al*. (2020). Malaria is known to cause severe anaemia and complications, including death, as documented by various studies (White, 2018). A study by Kotepui *et al*. (2014) in Thailand observed similar haematological alterations in

malaria cases compared to controls, including reductions in RBCs, hemoglobin, and platelets, alongside increases in MCV, monocytes, lymphocytes, and MCHC. They suggested these parameters as potential predictors of malaria infection, aiding in diagnosis and management. White blood cells play a crucial role in the body's defence against malaria, evidenced by an overall increase in total WBC count among infected children, although not statistically significant, consistent with Bawah *et al*. (2018) in Ghana. Changes in WBCs during malaria depend on factors like parasitaemia and host immune status (Abdalla and Pasvol, 2004; Faga *et al*., 2020; Xin-zhuan *et al*., 2020).

This study showed a significant difference in lymphocyte count in malaria infected participants compared to those who are negative, which disagrees with the report of Abdalla *et al*. (1988) and Adedotun *et al*. (2013) which found lymphocyte count remaining unchanged during an acute malaria infection. This study showed significant change in monocyte count in malaria infected participants compared to the non-infected patients. This is in agreement to a previous study which found monocytosis as one of the most significant observations of hematological changes among children infected with malaria as reported by Bawah *et al*., (2018) and Elkanah *et al*. (2020). Neutrophil count differences between infected and uninfected participants were significant, contradicting findings from Ghana, India, and Singapore (Wickramasinghe *et al*., 2000; Akhtar *et al*., 2012; Bawah *et al*., 2018), where no significant increase was reported. Pathophysiological mechanisms involving neutropenia in malaria include augmented margination and sequestration of neutrophils due to increased expression of adhesion molecules (ICAM-1 and VCAM-1) (Clark *et al*., 2006).

Eosinophil count significantly increased in malaria-infected participants, corroborating studies linking eosinophil levels to malarial infection (Ayyadevara, 2022; Anjorin *et al*., 2023). Although eosinophilia was prevalent in children, it did not affect malaria susceptibility, as reported by Bejon *et al*. (2008). Basophil count was also significantly higher in infected participants, with research suggesting multifaceted roles of basophils in malaria, including protection against intestinal permeability (Kotepui *et al*., 2014).

This study found a strong association between platelet count and P. *falciparum* infection, consistent with previous reports (Bawah *et al*., 2018; Awosolu *et al*., 2021). Platelet count was also significantly lower in infected participants compared to the non-infected. Thrombocytopenia, characterized by low platelet count, is a common haematological abnormality in malaria patients, attributed to spleen-mediated platelet destruction and disseminated intravascular coagulopathy.

Biochemical Derangements Due to P. *falciparum* Infection

This study revealed a significant decrease in Sodium (Na+), Potassium (K+), and Chloride (Cl-) levels, alongside a notable increase in Albumin, Aspartate Transaminase, Alanine Transaminase, Total Protein, Total Bilirubin, Direct Bilirubin, Bicarbonate, Urea, and Creatinine levels in P. falciparum-infected participants compared to non-infected participants ($P<0.05$) (Sharma *et al*., 2012; Chidoka and Toochukwu, 2012). Das *et al*. (2019) conducted a case-control study reporting significant increases in Aspartate Transaminase, Alanine Transaminase, Total Protein, Total Bilirubin, Urea, and Creatinine levels among malaria cases, corroborating our findings. They also noted a significant increase in Direct Bilirubin, consistent with our study. Ayyadevara (2022) suggested that these parameters indicate disease prognosis and emphasized their importance in preventing malaria complications through early detection and management.

Singh *et al*. (2015) conducted a retrospective study comparing liver and renal parameters in *vivax* and *falciparum* malaria cases. They found *falciparum* malaria to have a more pronounced effect on these parameters. Our study also observed significant decreases in Sodium (Na+), Potassium (K+), and Chloride levels in *falciparum* malaria cases compared to non-parasitized participants, consistent with findings from India by Ayyadevara (2022).

Elbadawi *et al*. (2013) conducted a case-control study in Sudan among pregnant women, observing significant reductions in urea, creatinine, potassium, and sodium levels in malaria cases compared to controls. While our study aligns with their findings regarding potassium and sodium, there is a discrepancy concerning urea and creatinine levels. This inconsistency may stem from variations in study populations, disease severity, or other factors warranting further investigation.

CONCLUSION

In this study, both hematological and biochemical parameters significantly differed between malaria-infected and non-infected individuals. Parameters such as Packed Cell Volume, lymphocytes, monocytes, basophils, total white blood cell count, and platelet count were lower in infected subjects, while Erythrocyte Sedimentation Rate, neutrophils, and eosinophils were higher. Similarly, biochemical parameters including Albumin, Alanine Transaminase, Aspartate Transaminase, Total Protein, Direct Bilirubin, Total Bilirubin, Bicarbonate, Urea, and Creatinine were significantly higher in infected subjects, while Sodium, Potassium, and Chloride were lower. These alterations indicate a strong statistical association between abnormal hematological and biochemical parameters and malaria complications. Future treatment strategies should be tailored to the specific needs of malaria-endemic populations in resource-limited settings similar to Taraba and Nigeria.

Recommendations include utilizing hematological and biochemical tools as adjuncts in malaria management, expanding training for laboratory technicians in microscopy for enhanced detection, intensifying distribution of insecticide-treated mosquito nets by government and NGOs to reduce parasitemia, strengthening malaria eradication efforts and conducting detailed analysis and periodic monitoring of hematological and biochemical parameters to predict and manage serious complications effectively.

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