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Clinico-haematological and Serum Biochemical Changes Associated with Foot and Mouth Disease in some Breeds of Cattle in Oyo State, Nigeria

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ABSTRACT

Foot and mouth disease (FMD) is considered one of the major hindrances to the growth of animal husbandry in Nigeria, with a projected annual loss of about 7 billion naira. We sought to establish the haematological and biochemical features in Nigerian indigenous cattle naturally infected with Food and Mouth Disease Virus (FMDV) by comparing the haematological and biochemical features between breeds, sex, and age. Forty cattle showing clinical manifestations and confirmed positive for FMD with the FMD rapid diagnostic kit were sampled for this study. Standard hematological and serum biochemical techniques were adopted for the analysis. There were more clinical FMD cases in the White Fulani breed (50%) compared with Red Bororo (10%), females (60%) compared to males (40%), and adults (60%) compared to young (40%) cattle, respectively. There were no significant differences between males and females in all the biochemical and haematological parameters, except neutrophils and absolute neutrophils which had p-values of 0.022 and 0.003, respectively. There were more cases of FMD in white Fulani, females, and adults than in other breeds, males and young cattle, respectively. Red Bororo breed, female and adult FMD-infected cattle had higher hematological and biochemical parameters compared to other breeds, male and young FMD infected cattle respectively. Generalized neutrophilia, lymphopenia, hypoproteinemia, increased ALT, and decreased AST enzymes were observed when compared with reference values.

Keywords: Foot and mouth disease virus; Biochemical parameters; Haematological parameters; Cattle; Nigeria.

INTRODUCTION

Agriculture contributes nearly forty percent to the Nigerian Gross Domestic Product (GDP), and about seventy percent of the working population makes their livelihoods through agriculture in Nigeria (Odetola and Etumnu, 2013). The livestock sector is responsible for much of the agricultural contribution to GDP in Nigeria. However, the sector is being confronted with so many challenges, with diseases being a major threat to livestock production in Nigeria (Erdaw, 2023). One of these major clinical diseases is foot-and-mouth disease (FMD).

FMD remains one of the most globally important and highly infectious diseases of animals, with serious livestock morbidity and mortality, huge costs of control, trade restriction impacts, and highly disruptive widespread epidemics (Knight-Jones *et al*., 2016). It is a disease that affects all cloven-hoofed wild and domesticated animals and is highly contagious and transboundary (Chase-Topping *et al*., 2013). There are seven different serotypes of FMD, each with different genetic lineages, diverse topotypes, and strains. These serotypes are: O, A, C, and South African Territories

(SAT) 1, SAT 2, SAT 3, and Asia (Klein and Flanagan, 2016; Jemberu *et al*., 2016). SAT 1, SAT 2, and SAT 3 serotypes are normally restricted to the Africa continent, Asia 1 to Asia continent, whereas the O and A serotypes distribution is worldwide.

FMD is responsible for a severe decline in productivity in infected herds, as it results in a drastic reduction in milk and weight gain in affected cattle. Direct losses associated with FMD can occur in different ways. These include reduction of milk yield, development of mastitis due to secondary bacterial infection, lameness of cattle that are used for draught, abortion and reduced conception in dams, mortality in calves due to myocarditis, and the unwillingness of dams to permit suckling of the calves, which may eventually lead to the death of the calf. The indirect losses are those incurred due to the extra costs used in diagnosing and treating infected cattle, vaccination programs, disease surveillance, and animal movement control strategies (Alhaji *et al*., 2020).

The endemic nature of the disease and the inability to successfully establish a vaccination program due to the specificity of the various serotypes have made the disease one of the major and persistent limiting factors responsible for the creeping growth of the cattle production industry in Nigeria.

In Nigeria, two cycles perpetuate the epidemiology of FMD, namely the sylvatic cycle and the domestic cycle. Foot-and-mouth disease can be argued to be the most economically important disease of livestock production in Nigeria (Alhaji *et al*., 2020). The endemicity of this viral condition has been linked extensively to the presence of serotypes A and SAT 2 in Nigeria (Ularamu *et al*., 2020). There have been previous reports of an exhibition of unique adaptive traits that enable tolerance and possible variations in disease susceptibility among the indigenous cattle population (Mwai *et al*., 2015)**.** This has yet to be established for FMD among indigenous cattle in Nigeria. Also, the roles and extent of hematological and biochemical parameter deviations as diagnostic and prognostic tools in disease management cannot be underestimated; serum metabolite concentration deviations may be indicators of different disease conditions in animals.

Considering the economic importance of FMD in Nigeria, few or very minimal data are available on the extent of deviation in hematological and biochemical parameters in FMD-infected Nigerian breeds of cattle. Furthermore, the roles of some intrinsic factors such as breed, sex, and age regarding susceptibility or tolerance to FMDV infection have not been elucidated among Nigerian indigenous cattle. There have been arguments about possible variations in susceptibility to FMD among different breeds, sexes, and ages of cattle, with no previous study to confirm or establish this assumption. Adequate knowledge of the occurrence of FMD among Nigerian indigenous cattle and their hematological and biochemical features will assist in the development of a therapeutic model that will help minimize the stress and negative socioeconomic consequences of the disease in Nigeria.

The present study was designed to establish the frequency of FMD in Nigerian indigenous cattle of different breeds, sexes and ages and note the haematological and biochemical parameters associated with natural infection of the disease.

MATERIALS AND METHODS

Ethical Statement

Research international standards according to the guidelines for the ethical use of animals in research and the guidelines according to the University of Ibadan were duly adhered to while sampling and laboratory analyses (Sherwin *et al*., 2003). The procedure involved in this sampling was less invasive and caused minimal discomfort to the animals. Therefore, no ethical approval was sought.

Study location

Sampling was done at the Akufo farm settlement in Ido local government area, Oyo state, where there was a reported outbreak of FMD in July 2022. The location covers an area of 986 km2, with about 57% of the total land being used for agricultural purposes and has a population of 103,261 based on the 2006 national census. The local government is in the rainforest zone of Nigeria between latitudes 6° 45’ N and 9° 41’ N and longitudes 2° 30’ E and 5° 15’ E. The area has alternating dry and wet seasons, which is typical of the tropics. Its annual rainfall and temperature average 1200–1500 mm and 28 °C, respectively (Adebayo *et al*., 2020).

Animal sampling

A herd of 66 cattle with a reported outbreak of FMD in July 2022 was analyzed for this study. Field records for breed, sex, and age were assessed and documented appropriately. Breeds were morphologically identified based on their body coat color, body conformation, dewlap length, size of hump, height, and other features. Sex was determined by examining the anatomical nature of the reproductive genitalia and the presence or absence of mammary glands, and age was determined by using the rostral dentition method as previously described by Olaogun and Lasisi (2015) and Charles and Adedayo (2018).

Forty cattle showing clinical manifestations of FMD, including blisters on the lips, tongue and coronary bands, salivation, and lameness were selected. They were further examined and confirmed positive for FMD with the FMD rapid diagnostic kit. 5mls of blood was aseptically collected via venipuncture of the jugular, using vacutainer set into BD vacutainer with EDTA (Purple-top tube) and BD vacutainer blood activator tube (Red-top tube) for the whole blood and serum respectively (Greiner Bio-One GmbH, Kremsmünster, Austria). These were appropriately labeled, and immediately stored in a thermos flask with an ice pack. These packed samples were transported under standard conditions to the general laboratory of the Department of Veterinary Medicine, University of Ibadan, where they were immediately processed and analyzed.

Rapid diagnostic kit procedure

The Herdscreen ®FMD NSP Antibody Rapid test kit was used for the confirmatory diagnosis of foot-and-mouth disease in the sampled animals. The following highlights the procedure for the test: the test cassette was removed from the foil pouch and placed on a horizontal surface, and 10µl of whole blood was collected via venipuncture and added to a well labeled ‘S’ using a dropper provided in the kit. Afterwards, time was given for the absorption of the whole blood into the well, two drops of the diluent were added, and the entire set-up was observed for ten minutes, after which the result was read.

The result was interpreted by the appearance or absence of a colored line on the ‘C’ or ‘T’ band of the test cassette. A color line on the ‘C’ band only indicates the absence of foot-and-mouth disease antibodies in the blood sample. Color lines on the ‘C’ and ‘T’ bands of the test cassette read positive for the presence of antibodies to FMD, and a single-colored line on the ‘T’ band gives an invalid test result (Wong *et al*., 2020).

Haematological and biochemical analyses

The haematological analysis was done according to the standard procedures described by Fernandez *et al*. (2000). The following hematological parameters were analyzed: haemoglobin concentration using the cyanometheamoglobin method; haematocrit (PCV) using the microhaematocrit centrifuge method; erythrocyte and leucocyte count using the Neubeur haemocytometer; mean corpuscular haemoglobin (MCH), mean corpuscular volume (MCV), and mean corpuscular hemoglobin concentration (MCHC) were all estimated using the haematocrit, erythrocyte count, and hemoglobin concentration as previously described (Knight-Jones *et al*., 2016; Olaogun and Oyetoyinbo, 2020; Olaogun and Onwuzuruike, 2018; Olaogun and Jeremiah, 2018; Adedokun *et al*., 2023).

Serum was harvested after centrifugation at 1,400 g for 5 min. The serum samples were then stored at -20 °C until analyzed. The sera were analyzed for some biochemical parameters such as total protein, albumin, globulin, blood urea nitrogen, cholesterol, glucose, triglycerides, aspartate aminotransferase (AST), alanine aminotransferase (ALT), alkaline phosphatase (ALP), sodium ion (Na^+), and potassium ion (K-) using commercial test kits supplied by Fortress Diagnostics Limited (U.K.) (Charles and Adedayo, 2018; Orihuela and Galina, 2019; Adedokun *et al*., 2023).

Statistical analysis

Microsoft Excel 2013 was used to organize and classify all the collected field and laboratory data. The collected data were summarized using descriptive statistics to establish frequencies and percentages and presented in tables. The mean ±SD of hematological and serum biochemical parameters were analyzed using one-way analysis of variance (ANOVA) for the breeds of all the sampled cattle. A student's t-test was employed to compare the mean ±SD between the sexes and ages of cattle. P >0.05 was used to establish the level of statistical significance. All statistical tests were conducted using SPSS version 26 (SPSS Inc., Chicago).

RESULTS

The frequency and percentage reveals as follow: 8 Sokoto Gudali (20%), 4 Red Bororo (10%), 20 White Fulani (50%), and 8 Crosses (20%). Females were (24, 60%) compared to males (16, 40%). Adults were 24 (60%) compared to young cattle that were16 (40%) (Table 1).

Table 1: Frequency of occurrence of FMD infection among different cattle breeds, sexes and ages sampled at the study locations

Breed	Frequency (n=40)	Percentage (%)
Sokoto gudali	8	20
Red Bororo	4	10
White Fulani	20	50
Cross breeds	8	20
Sex	Frequency (n=40)	Percentage (%)
Female	24	60
Male	16	40
Age	Frequency (n=40)	Percentage (%)
Young	16	40
Adult	24	60

N= number

All the hematological parameters of FMDV-infected cattle of all the breeds were within the normal reference range, except MCV, MCH, platelets, and lymphocytes which were lower and neutrophil which was significantly higher than the reference values. Of all the cattle breeds infected with FMDV, the White Fulani breed had the lowest hematological parameters, whereas the Red Bororo breed seemed to have the highest (Table 2).

Table 2: Breeds of cattle and their Haematological parameters (Mean ± SD)

Haematological Parameters	Red Bororo	White Fulani	Sokoto Gudali	Cross	P-value	**Ref Value
PCV (%)	29.00 ± 0.26	23.40 ± 1.52	26.00 ± 4.24	23.50 ± 6.36	0.467	24–46
Hb count (g/dl)	9.50 ± 0.46	7.64 ± 0.50	8.50 ± 1.41	7.70 ± 2.12	0.472	8–15
RBC count($x10^6$/µl)	9.85 ± 1.35	9.16 ± 1.29	9.54 ± 1.29	9.13 ± 2.13	0.963	5–10
MCV (fl)	29.44 ±0.77	25.95 ±3.88	27.22 ± 0.76	27.31 ± 13.35	0.960	40–60
MCH (pg)	9.64 ± 0.77	6.55 ± 3.09	8.90 ± 0.28	8.94 ± 4.43	0.663	11–17
MCHC (g/dl)	32.76 ± 0.03	32.65 ± 0.05	32.69 ± 0.11	32.75 ±0.16	0.536	30–36
Platelet count ($x10^3$/ mcL)	8.00 ± 0.00	8.00 ± 0.00	8.00 ± 0.00	8.00 ± 0.00	1.000	100–800
WBC count ($x10^3$/ mcL)	6.00 ± 0.57	6.16 ± 0.36	6.20 ± 0.28	6.20 ± 0.85	0.984	4-12
Lymphocyte (%)	32.00 ± 6.34	36.40 ± 5.13	36.00 ± 5.66	32.00 ± 2.83	0.675	45-75
Neutrophil (%)	67.00 ± 5.34	62.80 ± 4.97	62.50 ± 6.36	66.50 ± 2.12	0.720	15–33
Monocyte (%)	1.0±0.34	1.40 ± 0.55	1.50 ± 0.71	1.50 ± 0.71	0.905	0-8

Significant difference was taken at p values P <0.05. NA = not available. PCV= Packed cell volume; Hb = Hemoglobin concentration; RBC= Red blood cell; MCV= Mean corpuscular volume; MCH=Mean corpuscular haemoglobin; MCHC= Mean corpuscular hemoglobin concentration; WBC= White blood cell. **(Latimer, 2011; Weiss, 2010)

When compared to the normal reference values, breeds and the Mean±S.D. of biochemical indices show elevated ALT and K+, decreased AST and Na-, and generalized decreased in total protein and albumin. Overall research results show that among native Nigerian cattle breeds, the Red Bororo breed has the highest biochemical parameters, whereas the White Fulani breed appears to have the lowest biochemical indices during the FMDV infectivity phase (Table 3).

Table 3: Breeds of cattle and their biochemical parameters (Mean ± SD)

Biochemical Parameters	Red Bororo	White Fulani	Sokoto Gudali	Cross	P-value	**Ref Value
Total serum protein (g/dl)	3.21 ± 0.44	2.55 ± 0.31	2.82 ± 0.54	2.64 ± 0.74	0.602	6.7–7.5
Albumin(g/dl)	1.10 ± 0.04	1.01 ± 0.01	1.07 ± 0.05	1.03 ± 0.04	0.055	2.5–3.8
Globulin(g/dl)	2.11 ± 0.53	1.54 ± 0.31	1.76 ± 0.49	1.62 ± 0.70	0.682	3.0–3.5
Glucose (mg/dl)	56.00 ± 4.33	46.20 ± 4.09	52.50 ± 7.78	49.00 ± 7.07	0.366	40–100
Cholesterol (mg/dl)	30.00 ± 2.53	25.80 ± 1.48	29.50 ± 3.54	25.00 ± 7.07	0.448	NA
Triglycerides (mg/dl)	42.00 ± 6.33	34.20 ± 5.07	39.00 ± 4.24	34.00 ± 8.49	0.533	NA
Creatinine (mg/dl)	1.42 ± 0.22	1.14 ± 0.16	1.25 ± 0.16	1.27 ± 0.38	0.651	0.5–2.2
AST (mol/l)	35.00 ± 2.22	25.80 ± 3.63	31.00 ± 7.07	27.50 ±7.78	0.412	60–125
ALT (mol/l)	26.00 ± 4.22	16.40 ± 4.77	24.00 ± 5.66	17.50 ± 10.61	0.398	4–11
ALP (mol/l)	33.00 ± 2.21	22.60 ± 5.37	25.00 ± 1.41	25.00 ± 7.07	0.422	10–77
Na^+(mEq/l)	45.00 ± 3.21	35.40 ± 4.39	41.50 ± 7.78	37.00 ± 9.90	0.483	136–144
K^+(mEq/l)	42.00 ± 4.21	26.20 ± 6.02	34.50 ± 13.44	30.00 ± 14.14	0.464	3.6–4.9

None have values that were statistically significant. Significant difference was taken at p values P <0.05. NA = not available. AST= Aspartate aminotransferase; ALT= Alanine aminotransferase; ALP = Alkaline phosphatase; Na^+= sodium ion; K^-= Potassium ion. **(Latimer, 2011; Weiss, 2010)

Most of the haematological parameters show no statistically significant changes ($p<0.05$) when comparing the Mean±S.D. with the sex of the cattle, except for neutrophil values, where P-values are 0.022. A discernible decline was seen when comparing the Mean±S.D. values of MCV, MCH, platelets, and lymphocytes in both sexes to the normal reference values. Neutrophils in infected cows and bulls had values of 66.33±1.21 and 60.25±5.19, respectively, which were significantly higher than the reference values. In general, during the FMD infection phase, the haematological parameters of cows appeared better than those of bulls (Table 4).

Table 4: Haematological parameters (Mean ± SD) of FMD infected male and female cattle

Erythrocytic Parameter	Female	Male	P-value	**Ref Value
PCV (%)	24.67 ± 4.03	24.25 ± 2.50	0.860	24–46
Hb count (g/dl)	8.07 ± 1.33	7.93 ± 0.85	0.856	8–15
RBC count($x10^6$/µl)	9.50 ± 1.36	8.99 ± 1.09	0.545	5–10
MCV (fl)	26.35 ± 5.02	27.54 ± 6.35	0.749	40–60
MCH (pg)	7.01 ± 3.20	9.00 ± 2.11	0.310	11–17
MCHC (g/dl)	32.70 ± 0.06	32.67 ± 0.13	0.714	30–36
Platelet count ($x10^3$/ mcL)	8.00 ± 0.00	8.00 ± 0.00	1.000	100–800
WBC count ($x10^3$/ mcL)	6.27 ± 0.41	6.00 ± 0.33	0.312	4-12
Lymphocyte (%)	32.83 ± 2.04	38.25 ± 5.56	0.057	45-75
Neutrophil (%)	66.33 ± 1.21	60.25 ± 5.19	0.022*	15–33
Monocyte (%)	1.33 ± 0.52	1.50 ± 0.58	0.645	0-8

* Indicates statistically significance. Significant difference was taken at p values P <0.05. NA = not available. PCV= Packed cell volume; Hb = Hemoglobin concentration; RBC= Red blood cell; MCV= Mean corpuscular volume; MCH=Mean corpuscular haemoglobin; MCHC= Mean corpuscular hemoglobin concentration; WBC= White blood cell. **(Latimer, 2011; Weiss, 2010).

When the Mean±S.D. of the biochemical parameters of naturally FMD-infected animals from cows and bulls were compared, none of the indices exhibited a statistically significant difference ($p<0.05$). Even though the study's observations revealed that only a small percentage of the parameters were within the normal reference range, most parameters had significant decreased effects when compared to the normal reference values. In naturally FMD-infected cows and bulls, there were elevated ALT and K-, decreased AST and Na+, globulin, and protein relative to normal reference values. However, in general, the parameters seemed to be greater in naturally FMDV-positive cows than in naturally FMDV-positive bulls (Table 5).

There were no statistically significant differences seen between young and adult naturally FMD-infected cattle based on the values of their Mean±S.D. of haematological parameters. Apart from neutrophil counts, which were abnormally high in both young and adult FMD-infected calves when compared to normal reference values, the hematological indices were generally low. Adult FMDV infected animals generally seemed to possess higher haematological parameters compared to young FMDV-infected cattle (Table 6)

Table 5: Biochemical parameters (Mean ± SD) of FMD infected male and female cattle

Biochemical Parameters	Female	Male	P-value	**Ref values
Total serum protein (g/dl)	2.75 ± 0.48	2.61 ± 0.37	0.632	6.7–7.5
Albumin(g/dl)	1.04 ± 0.05	1.02 ± 0.02	0.515	2.5–3.8
Globulin(g/dl)	1.71 ± 0.45	1.58 ± 0.35	0.654	3.0–3.5
Glucose (mg/dl)	50.33 ± 6.09	47.00 ± 5.10	0.394	40–100
Cholesterol (mg/dl)	26.83 ± 4.22	26.75 ± 2.50	0.973	NA
Triglycerides (mg/dl)	37.00 ± 5.44	34.25 ± 5.91	0.470	NA
Creatinine (mg/dl)	1.24 ± 0.17	1.18 ± 0.25	0.621	0.5–2.2
AST (mol/l)	29.17 ± 5.95	26.50 ± 4.51	0.470	60–125
ALT (mol/l)	20.00 ± 7.16	17.75 ± 5.91	0.618	4–11
ALP (mol/l)	25.83 ± 4.92	22.75 ± 6.18	0.404	10–77
Na^+(mEq/l)	39.00 ± 6.90	36.25 ± 5.44	0.524	136–144
K^+(mEq/l)	32.17 ± 10.01	27.25 ± 8.62	0.446	3.6–4.9

None have values that are statistically significant. Significant difference was taken at p values P <0.05. NA = not available. AST= Aspartate aminotransferase; ALT= Alanine aminotransferase; ALP = Alkaline phosphatase; Na^+= sodium ion; K^-= Potassium ion. **(Latimer, 2011; Weiss, 2010).

Table 6: Haematological parameters (Mean ± SD) of FMD infected cattle in different age groups

Hematological Parameters	Young	Adult	P-value	**Ref Value
PCV (%)	24.75 ± 4.65	25.33 ± 3.14	0.817	24–46
Hb count (g/dl)	8.10 ± 1.54	8.28 ± 1.04	0.826	8–15
RBC count($x10^6$/µl)	9.69 ± 1.40	9.17 ± 1.27	0.560	5–10
MCV (fl)	26.32 ± 8.04	27.82 ± 2.88	0.680	40–60
MCH (pg)	8.60 ± 2.67	7.50 ± 3.20	0.586	11–17
MCHC (g/dl)	32.72 ± 0.12	32.70 ± 0.07	0.698	30–36
Platelet count ($x10^3$/ mcL)	8.00 ± 0.00	8.00 ± 0.00	1.000	100–800
WBC count ($x10^3$/ mcL)	6.20 ± 0.52	6.13 ± 0.33	0.807	4-12
Lymphocyte (%)	34.50 ± 5.26	39.17 ± 13.15	0.525	45-75
Neutrophil (%)	64.25 ± 4.99	65.17 ± 3.66	0.744	15–33
Monocyte (%)	1.25 ± 0.50	1.50 ± 0.55	0.486	0-8

None have values that are statistically significant. Significant difference was taken at p values P <0.05. NA = not available. PCV= Packed cell volume; Hb = Hemoglobin concentration; RBC= Red blood cell; MCV= Mean corpuscular volume; MCH=Mean corpuscular haemoglobin; MCHC= Mean corpuscular hemoglobin concentration; WBC= White blood cell. **(Latimer, 2011; Weiss, 2010).

Comparison of mean±S.D. of biochemical indices of naturally FMD-infected cattle between young and adult cattle showed no statistically significant differences ($p<0.05$). There were generalized decreased in the values of Total protein, albumin, globulin, AST and Na-ions, and increased ALT and K-ions. According to this present study, the total biochemical parameters related to age show comparatively higher values in adults compared to young FMD-infected cattle (Table 7).

Table 7: Biochemical parameters (Mean ± SD) of FMD infected cattle in different age groups

Biochemical Parameters	Young	Adult	P-value	**Ref values
Total serum protein (g/dl)	2.73 ± 0.54	2.80 ± 0.41	0.808	6.7–7.5
Albumin(g/dl)	1.04 ± 0.05	1.05 ± 0.05	0.660	2.5–3.8
Globulin(g/dl)	1.69 ± 0.50	1.76 ± 0.38	0.807	3.0–3.5
Glucose (mg/dl)	50.25 ± 6.85	50.83 ± 5.56	0.885	40–100
Cholesterol (mg/dl)	27.00 ± 5.29	28.00 ± 2.61	0.697	NA
Triglycerides (mg/dl)	36.25 ± 6.24	38.33 ± 3.39	0.509	NA
Creatinine (mg/dl)	1.23 ± 0.26	1.27 ± 0.14	0.780	0.5–2.2
AST (mol/l)	28.75 ± 6.80	29.83 ± 5.15	0.781	60–125
ALT (mol/l)	19.25 ± 8.62	21.67 ± 5.28	0.593	4–11
ALP (mol/l)	24.50 ± 4.43	26.50 ± 4.18	0.490	10–77
Na^+(mEq/l)	38.50 ± 8.27	40.00 ± 5.66	0.740	136–144
K^+(mEq/l)	31.50 ± 12.26	33.00 ± 8.94	0.827	3.6–4.9

None have values that are statistically significant. Significant difference was taken at p values P <0.05. NA = not available. AST= Aspartate aminotransferase; ALT= Alanine aminotransferase; ALP = Alkaline phosphatase; Na^+= sodium ion; K^-= Potassium ion. **(Latimer, 2011; Weiss, 2010)

DISCUSSION

The outcome of this present study further confirmed the endemicity of FMD, with variations in susceptibility regarding breed, sex, and age of cattle. The high incidence of 50% FMDV infection in the White Fulani breed compared to other indigenous breeds observed in the study agrees with the earlier observation of Atuman *et al*. (2020), who also observed the highest seroprevalence of FMD of 72.8% in the White Fulani breed compared to other breeds of cattle using the PrioCHECK® 3ABC NSP Ab ELISA kit. Though this present study was based on clinical signs and confirmation with the FMD rapid diagnostic kit. This could be said to have confirmed the

authenticity of the FMD rapid diagnostic kit as well. The highest incidence may be associated with the probably larger population of White Fulani and being the most predominant cattle in the Nigerian cattle population in general (Charles and Adedayo, 2018). It might also be due to their long history of existence in Nigeria, as they are part of the foremost indigenous breeds still in existence in Nigeria. The higher incidence of FMDV in females compared to males observed in this present study is in conformity with the observation of previous reports in Nigeria (Olabode *et al*., 2013; Wungak *et al*., 2016; Atuman *et al*., 2020), who all observed a risk variation in association with sex during FMDV studies in Bauchi, Kwara, and Plateau states, Nigeria, respectively. The reason for the high incidence of females may be attributed to the preference for females over males by cattle owners for reproductive and milk production purposes, which may necessitate keeping females for a longer period, which may put them at higher risk (Longjam *et al*., 2011). This may also be due to the relatively hardy trait of males compared to females generally in a population. This finding, however, contradicts the work of Megersa *et al*. (2009) in Ethiopia, who posited that there were no sex variations in susceptibility to FMD. This difference in result may be due to differences in the location of the study, different methods of diagnosis, and the breeds of cattle studied. The higher incidence in adult cattle compared to young cattle as seen in this present study is in complete agreement with the earlier observations of previous researchers (Megersa *et al*., 2009; Mohamoud *et al*., 2011), who both reported higher likelihood and prevalence of FMDV in adults than in calves in their various studies, respectively. Beyene *et al*. (2015) also observed a higher likelihood of seropositivity as the animal advances in age. This could be due to the presence of circulating antibodies to FMD in the young, which often wane with age. However, this contradicts the report of Olabode *et al*. (2013), who stated that the young were more susceptible to FMD than the adults. Notably, all breeds showed a significant decrease in MCV, MCH, platelets, and lymphocytes when compared to reference levels; other measures, based on the data available, were within the normal reference range.

The White Fulani breeds possessed the lowest of these erythrocytic parameters, while the Red Bororo recorded the highest of these parameters. This may imply that FMD infection has the highest impact on the erythrocytic parameters of white Fulani breeds of cattle. This could be due to their predominance as an indigenous breed, which would have resulted in their having the highest exposure to FMD per generation cycle. Therefore, consistent breed exposure favored by the increased population may have encouraged their susceptibility to the virus. The hematological findings as observed in this present study disagree with the earlier report of Ghanem *et al*. (2010) who reported reduced RBC and a trend in the direction of reduced PCV indicating anemia, and a generalized significant decrease in total leukocytes and absolute counts of neutrophils, lymphocytes, and monocytes in FMDV- infected calves. The dissimilarity may be due to differences in location, breed, age, and nature of the study. The present study is a natural FMDV infection, while the previous study was an experimental study on FMDV infection. The Red Bororo breeds of cattle were observed to record the lowest leucocyte count, while the Sokoto Gudali had the highest leucocyte count in response to FMD infection. This suggests that the Red Bororo has a comparatively stronger immune response to FMD infection as opposed to the other breeds. The lack of a significant difference in the hematological parameters of the breeds tested in this present study agrees with the observation of Saravanan *et al*. (2020), who also observed no significant difference in the hematological indices of FMD-infected calves in all breeds tested in India.

Serum biochemical analyses reveal a low total serum protein concentration when compared to the normal reference range, with no significant differences when comparisons were made within the breeds. This also agrees with the findings of Saravanan *et al*. (2020) who also observed no significant differences in the biochemical parameters of FMD-infected calves in all the breeds tested in India. However, among all the breeds analyzed, the Red Bororo recorded the highest concentration of total serum protein and glucose, while the White Fulani recorded the lowest concentration. The general hypoproteinemia and hypoglycemia associated with all the breeds could be attributed to malnutrition. The oral lesions that the FMD virus causes make feeding difficult. This could account for the decreased serum concentrations of glucose and proteins. The Red Bororo recorded the highest concentrations of cholesterol and triglycerides, and the Crosses recorded the lowest concentrations of cholesterol and triglycerides. This once again could be attributed to the malnutrition FMD incites because of the difficulty in eating caused by the lesions in the oral cavities of infected cattle. The Red Bororo also recorded the highest concentrations of serum creatinine and serum AST, ALT, and ALP enzymes, while the White Fulani had the lowest concentrations. This probably suggests that the white Fulani may have the least organ damage with respect to FMD infection, while the Red Bororo had the most organ involvement. This could be because White Fulani breeds of cattle are reputed to be the hardest and probably the breed with the highest resilience of all the indigenous Zebu-type breeds of cattle in Nigeria (Kubkomawa, 2017). The general leucocyte counts appeared to be higher in the females than in the males. This may be attributed to the peculiar effects of male sex hormones compared to female sex hormones on immune mechanisms. Female animals are reported to have stronger immunity than male animals (Giefing-Kröll *et al*., 2015). This is also supported by the findings of Klein and Flanagan (2016) and Ghosh and Klein (2017), who reported using mouse and human models, respectively, that females produce greater antibodies and are better equipped with innate immunity against pathogens in general.

The biochemical parameters appeared better in cows compared to bulls naturally infected with FMDV; this is in conformity with the earlier observation of higher FMD antibodies in cows compared to bulls (Atuman *et al*., 2020). Further findings in this present study showed that the adults had comparatively higher haematological parameters (PCV, Hb conc., RBC count, MCV, MCH,

and MCHC) when compared to the young, except for the RBC count and MCHC. This, therefore, could be suggestive of the fact that the adult cattle are poorly hydrated. This explains why there is a comparatively higher PCV in adults, even when the total RBC count is lower. This sub-hydrated' status could have resulted from the poor, extensive husbandry systems often practiced in Nigeria. This generally reduces the access of adult cattle to sufficient water and feed. The leucocyte counts in adults present a higher lymphocyte, neutrophil, and monocyte count than in the young. This may be associated with a more developed and mature immune system in adults than in the young, probably due to previous infections. Even healthy young animals tend to be relatively less immune-competent than adults. Also, the immune systems of young animals respond less effectively to diseases than those of adult animals. This agrees with the observation of Chase *et al*. (2008), who also reported that young animals have a weaker immune response to disease than adult animals.

Higher levels of serum protein, glucose, cholesterol, and triglycerides were observed in the adults compared to young FMDV-infected animals, as observed in this present study. This could be because older animals have effective body reserves that could be used when there is depletion of the serum concentrations of these metabolites during FMDV infection. This agrees with the work of Orihuela and Galina (2019), who reported an observation that older animals have a larger body nutrient reserve than young animals.

Findings showed that there were relatively higher values of serum creatinine, AST, ALT, and ALP levels in the adults compared to those of young FMDV-infected cattle. This may probably be because of more organ involvement (i.e., enteropathies, hepatic, and renal damage) in adults than in young animals while FMDV infection. This may also be attributed to the presence of circulating maternal antibodies to FMDV that persist in the young, which might suppress the damaging effects of the virus.

Findings from this study also indicate generalized hyponatraemia. These observations are in tandem with the report of Mohamoud *et al*. (2011) who reported reduced Na^+ and increased K- values in Egyptian cattle naturally infected with FMDV. Hyponatraemia might be attributed to the probable reduction in cortisol level in FMDV infection because cortisol is essential to inhibit the loss of sodium and chloride ions from the intestine.

The study concluded that the highest occurrence of FMDV infection was in White Fulani breed, cow, and adult cattle compared to other breeds, bull and young cattle, respectively. Red Bororo breed, Cow and adult cattle possessed better haematological and biochemical parameters in natural FMDV infection. Further studies are therefore recommended to uncover the genetic traits or factors that may be responsible for the relatively better hematological and biochemical features possessed by the Red Bororo breed of cattle naturally infected with FMDV in Nigeria.

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Conflict of Interest

The authors have no conflict of interest to declare.

Authors' Contribution

S.C.O. and O.O.A. conceived and designed the research study. S.C.O., O.O.A., O.A. and P.S.A. performed the experiments and collected the data. S.C.O., O.A. and A.A. analyzed and interpreted the data. S.C.O. and O.O.A. wrote the initial draft of the manuscript. All authors reviewed, edited, and approved the final version of the manuscript.

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