©Kashere J. Anim. Sci. Volume 1 Issue 1 151-168 ISSN: 3115-6479
Date received: 8th October 2025
Date accepted: 22nd October 2025
Date published: 7th December 2025

# CLINICAL SIGNS, SEROPREVALENCE AND SEROTYPE COMPARISON OF FOOT AND MOUTH DISEASE VIRUS IN MIXED HERDS IN GOMBE STATE

**[1]Madu, H.K., [2]Okaiyeto, S. O., [2]Mohammed, F. U. [3]Kia, G. S. and [4]Ularamu, H. G.**
[1]Department of Animal Health and Production Technology, Federal College of Horticulture, Dadin Kowa, Gombe State, Nigeria
[2]Department of Veterinary Medicine, Faculty of Veterinary Medicine, Ahmadu Bello University, Zaria, Nigeria
[3]Department of Veterinary Public Health and Preventive Medicine, Faculty of Veterinary Medicine, Ahmadu Bello University Zaria, Kaduna State, Nigeria.
[4] Foot-and-Mouth Disease Research Laboratory, National Veterinary Research Institute, Vom, Plateau State, Nigeria

## ABSTRACT
*Small ruminants (Sheep and Goats) constitutes a significant revenue generation component for small-scale livestock farmers across the globe especially in most developing nations including Nigeria. However, the role of small ruminant animals in FMD epidemiology in the study area is still underestimated and poorly understood. FMD causes severe economic losses due to reduced productivity, trade restrictions, and control measures. This study was aimed at investigating the seroprevalence and epidemiological role of small ruminants in foot and mouth disease transmission in mixed herds in Gombe State, Nigeria. The clinical signs of FMD observed in sheep and goats in the present study were inappetence, panting, pyrexia (≥40 °C), distress, congestion of mucus membrane and lameness. In addition, in sheep there were vesicular lesions in the inter-digital cleft and on the bulb of the heels. Temperature of Small ruminant suspected to be infected with FMDV showed a mean value of 40.2°C. A total of six hundred and thirty (630) sera samples were collected and subjected to Bio vet® FMDV NSP-3B bELISA kit (multi-species). The result showed that out of 630 sera tested, 71 (41.0%) of sheep, 40 (41.2%) of goats and 230 (63.9) of cattle were evident of NSP-FMD antibodies. FMD structural protein serotypes, A, O and SAT 2 was screened using a solid-phase competitive ELISA (ID Screen ®) for FMDV serotype O and IZSLER: Brascia, Italy for FMDV serotype A and SAT2 respectively 75% of goats were serotype A positive, 60% of cattle were positive for serotype SAT2 and 80% of sheep were serotype O positive. In conclusion, the high seropositivity of small ruminants to FMD observed in this study may be associated with non-vaccination of small ruminants which is a salient signal to infection and viremia. This poses a great risk to indigenous cattle as the small ruminants lead the cattle on their trek routes. We recommended that movement-controlled measure and the use of multivalent vaccines comprising the three local circulating serotypes as the control option.*

**Keywords**: Small ruminants, Epidemiological, FMD, Seroprevalence, ELISA, Serotype, Gombe.

## INTRODUCTION
Ruminants are hoofed herbivorous grazing or browsing mammals that are able to acquire nutrients from plant-based food by fermenting it in a specialized stomach (rumen) prior to digestion, principally through microbial actions (Clauss and Rossner, 2014). The roughly 200 species of ruminants include both domestic and wild species (Fernández and Vrba, 2005). Ruminating mammals include cattle, all domesticated and wild bovines, goats, sheep, giraffes, deer, gazelles, and antelopes (Fowler, 2010).
Ruminant production has been recognised for its contribution to livestock production in Nigeria. Ruminants form a significant proportion of the livestock production in Nigeria and possess obvious advantage over other livestock such as playing significant roles in the life of rural households (Aruwayo, *et al.,* 2015).
Small ruminants (sheep and goats) are sometimes preferred by farmers compared to large ruminants because of the small space they occupy and less fodder requirement. Small ruminant production has been described as one of the fastest growing agricultural subsectors in developing countries. Its share of agricultural gross domestic product (GDP) has been reported as 33% and is rapidly increasing (Delqado, 2005; Thornton, 2010). In addition, goats have high adaptability to harsh climates which makes them suitable for husbandry in marginal areas (Kosgey, *et al.,* 2008; Wanyoike, 2009). They are veritable sources

of income generation, household consumption, and hobby and as security against crop failure. Lebbie (2004) reported that sheep and goats play a significant role in the food chain and overall livelihoods of rural households, where they are largely the property of women and their children. Rearing of SR plays a very important role in the lives of households in developing countries.

In Nigeria, the role of SR farming in poverty alleviation for the common people cannot be overemphasized; it has become an integral part of the socio-economic life of most rural dwellers. SR production is an immense benefit to livestock farmers in the areas of meat and milk production, hides and skin, manure income generation, cultural and religious ceremonies and festivals, they also serve as a source of ready cash to small farmers in emergency situation (Al-khaz'leh *et al.,* 2005; Nwachukwu and Berenidu, 2020). Other advantages include lack of social and religious barrier to its production and consumption (Yusuf *et al.,* 2018). Infectious diseases are the major constraints in SR production (Nyariki and Amwata, 2019).

Foot and mouth disease (FMD) are an acute highly contagious, transboundary, disease caused by foot and mouth disease virus (FMDV). It affects cloven-hoofed domestic ruminants such as `cattle, swine, sheep and goats as well as cloven-hoofed wild ruminants (Arzt *et al.,* 2011). It severely affects livestock production leading to disruption of trade in animals and their products at regional and international level. A global strategy for the control of FMD was endorsed in 2012 to minimize the burden of FMD in endemic settings and maintain free status in FMD-free countries (OIE, 2018). About 77% of the global livestock population is affected by the disease, mainly in Africa, the Middle East and Asia, and some few areas in South America (OIE, 2018). This is coupled with the possibility of disease incursion in countries which are currently free (OIE, 2018).

The FMDV is classified into the *Picornaviridae* family and the genus Apthovirus. It is a small non-enveloped virus with an icosahedral capsid and a positive sense RNA consisting of a large open reading frame encoding for four structural proteins and ten nonstructural proteins (Mason *et al.,* 2003). The FMDV exists in seven immunologically distinct serotypes; A, O, C, Asia 1, SAT 1, SAT 2 and SAT3; all with distinct lineages except SAT 1 and SAT 2 which have unresolved clades (Yoon *et al.,* 2011). The disease is among the World Organisation for Animal Health (OIE) listed diseases which are transmissible with serious potential to spread across national borders and which require immediate reporting in order to control their spread (OIE, 2018). The incubation period for foot-and-mouth disease virus is between one and 14 days in cattle (Arzt, *et al.,* 2010), 3-8 days in small ruminants (Mahmoud *et al.,* 2019). The disease in cattle is characterized by high fever within two to three days, formation of vesicles inside the mouth leading to drooling of saliva. Vesicles are also on the nose, teats and when on the feet may rupture and cause lameness. It also causes weight loss in adults and significant reduction in milk production which sometimes fails to return to normal even after recovery. Morbidity rate can be as high as 100% though mortality rate is low in adults but high in neonates due to myocarditis. About 50% of infected ruminants remain asymptomatic carriers in the oropharynx. In cattle the virus can persist for 3-5 years, in sheep up to nine months, in goats up to six months and in the African buffalo up to five years. Pigs do not become carriers (Stenfeldt *et al.,* 2014). Viral excretion in carrier animals is intermittent and declines over time and the risk of transmission from the African buffalo to cattle exists (Bengis *et al.,* 1986). Foot and mouth disease in adult sheep and goats are frequently asymptomatic, but can cause high mortality in young animals (Mahmoud *et al.,* 2019). Lameness is a significant feature characterized by unwillingness to rise or move (Donaldson *et al.,* 2000; Mahmoud *et al.,* 2019). The disease can easily be missed unless individual animals are carefully examined for disease lesions. Small ruminants can therefore be responsible for the introduction of FMD into previously disease-free herds (Kitching *et al.,* 2002). The mortality rate in sheep and goats is generally less than 1% in adult animals. Clinical disease in young lambs and kids is characterized by death due to heart failure without the appearance of vesicles (Barnett and cox 1999).

Although FMD may be suspected based on clinical signs and post-mortem findings, it cannot be differentiated clinically from other vesicular diseases. Confirmation of any suspected case through laboratory tests is therefore essential. The richest source of virus in diagnosis is vesicular fluid or epithelium from fresh lesions (Radostits *et al.,* 2007). Serum is used for antibody detection where lesions are not fresh and also in epidemiological surveys. Differential diagnosis for FMD in small ruminants includes Peste des petit ruminantium (PPR) which can be ruled out by signs of pneumonia and diarrhea, Bluetongue disease (atypical signs are facial oedema and nasal ulceration), Capripox (which is ruled out by presence of pock lesions), Contagious ecthyma is also ruled out because of lacks of vesicular stomatitis and lameness which are characteristic in FMD), Pneumonic Pasteurellosis and Contagious Caprine Pleuropneumonia (CCPP) are characterized by respiratory illness alone (Radostits *et al.,* 2007).

FMD is widely distributed in the developing world, in particular Africa, Asia, Middle East and South America, where livestock farming forms the backbone of rural economies that supports approximately 70% of the world's poor (Maree *et al.,* 2014). FMD outbreaks particularly affects vulnerable individuals such as women and children in rural areas since approximately 75% of livestock in Africa are raised under the pastoral systems for sustainable livelihoods (Scoones *et al.,* 2010; Ferguson *et al.,* 2013; Miguel *et al.,* 2013). The lack of veterinary infrastructure, human resources, movement controls, and appropriate vaccines render many developing countries particularly exposed to the spread of FMD (Doel, 2003; Sutmoller *et al.,* 2003; Perry and Rich, 2007). In sub-Saharan Africa, two transmission cycles of FMD occur: one in which FMDV circulates between wildlife and domestic animals and the other in which the virus spreads among domestic animals. The cycle between wildlife and domestic animals occurs in southern and eastern Africa, but due to the low populations of wildlife in West Africa, the disease is maintained mainly in domestic animals (Fasina *et al.,* 2013).

In Africa, the diversity of circulating field strains of FMDV makes the selection of sufficiently cross-protective FMD vaccines a challenge. There is a need for risk-based surveillance to determine endemic areas and factors that influence disease dissemination, to assist the design of targeted, area-wide, or ecosystem-based disease control strategies, as most African regions adopt the Food and Agriculture Organization of the United Nations (FAO)-OIE Progressive Control Pathway (PCP) for the Control of FMD (Rweyemamu *et al.,* 2008). Also, the efficiency of FMD surveillance and control programmes in developing countries is often challenged by the issue of underreporting (Madin, 2011; Bellet *et al.,* 2012). However, FMD is known to cause significant financial losses for small scale producers, making it a threat to the livelihood and food security of the poorest communities (Bellet *et al.,* 2012). The seroprevalence of between 50 and 78% have been reported in cattle population (Lazarus *et al.,* 2012; Wungak *et al.,* 2015) with serotypes A, O, SAT 1 and SAT 2 among currently circulating strains in Nigeria (Wungak *et al.,* 2017; Ularamu *et al.,* 2016; Vandenbussche *et al.,* 2017).

Four serotypes of FMD (O, A, SAT 1 and SAT 2) are known to be circulating in Nigeria (Chukwuedo, and Nimzing, 2012; Fasina *et al.,* 2013; Ehizibolo *et al.,* 2014; Olabode *et al.,* 2014; Wungak *et al.,* 2015). The 3ABC competition antibody ELISA which has high sensitivity and specificity can deliver same-day results when using the short protocol and is routinely applied for general screening FMD (Parida, *et al.,* 2007; Parida, *et al.,* 2009).

Sheep and goats form a substantial proportion of the global FMD-susceptible livestock population. However, these species have not been studied with regard to their epidemiological role and significance in the spread of FMD. Unlike cattle, sheep and goats are not included in vaccination control programs in Study area. In spite of their potential infection, though all species are subject to the normal quarantine measures in disease outbreak. Thus, the present study was to investigate the sero-prevalence of FMD in small domestic small ruminants in Gombe state and to investigate potential risk factors associated with FMD occurrence in these animals.

## MATERIALS AND METHOD

### Study area

The study was conducted in Gombe State, Nigeria. Gombe state is located on longitude 11° 10‘ E and latitude 10° 15′ and situated in the north eastern part of Nigeria. Being located within the expansive savannah allows the state to share common borders with the states of Borno, Yobe, Taraba, Adamawa and Bauchi. It has an area of 20,265 km$^2$ and a population of about 2,353,879 million people (NPC, 2006).

Gombe state has two distinct climates, the dry season (November – March) and the rainy season (April – October) with an average rainfall received of 850mm/annum. Administratively the state is made up of 11 local Government Areas and 14 traditional chiefdoms (GSG, 2013). The state has an estimated cattle population density of 1 million and 2.5 million small ruminants (GSG, 2013). The savannah vegetation as well as the present of Dadin-kowa dam, Cham dam, Balanga dam and Wawa Zange grazing reserve makes the state suitable for livestock rearing. The state comprises of different ethenic groups which include Fuifulde, Tera, Tangale, Babur, Kanuri, Waja, Hausa, Bolewa, Jukun, Cham, Tula, Dadiya, Pero, Lunguda, Awak and Kamo.

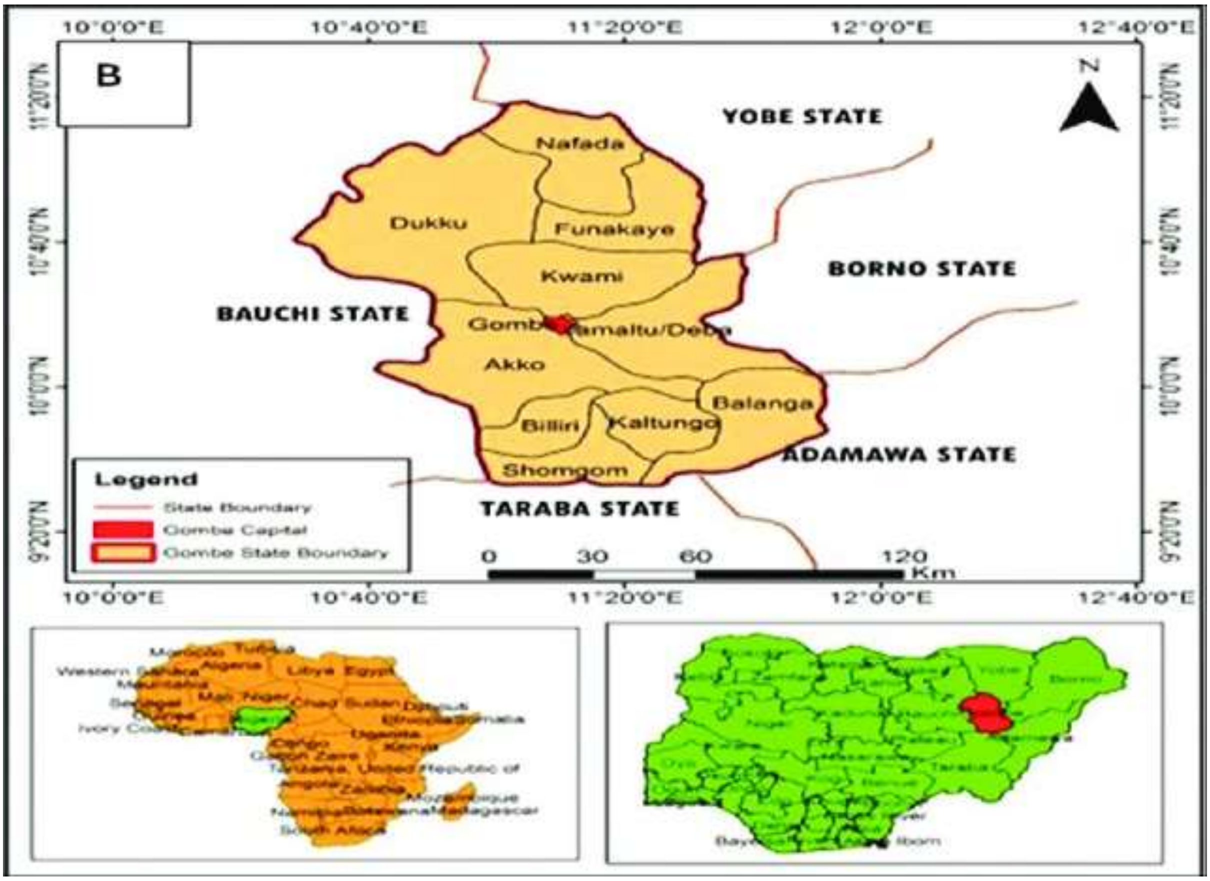


**Figure 1. Map of Gombe State showing the study area (Source: Adamu and Saidu 2015)**

**Study Design**

The study was a cross-sectional study, combining field observation, serological testing, molecular characterization, and assessment of knowledge, attitude and practices. The study population included animals: Sheep and goats in mixed herds with cattle: Farmers and livestock handlers of the Gombe region. A multistage cluster sampling was employed to select sampling units. A semi-structured closed ended questionnaire was developed and administered to the herders immediately after sample collection. These questions were deployed via KoBoToolbox, using the KoBoCollect mobile app on Android phones, to enable both offline data collection and online data submission (Aruwayo, *et al.,* 2015) by trained field assistants.

**Sample size Determination**

The sample size was determined by the formula for the estimation of prevalence using random sampling as provided in (Thrusfield, 2005). Substituting expected prevalence of 9.3% for small ruminants (Olabode, *et al.,* 2014) and 57.7% for cattle (Atuman, 2020), a 95% level of confidence and a ±5% desired level of precision in the formula;

$$n = \frac{Z^2 \times P_{exp}(1-P_{exp})}{d^2}$$

Where n = required sample size,

$P_{exp}$ = expected prevalence = 9.3%

$d^2$ = desired absolute precision =0.05

Z = standard normal distribution at 95% confidence interval = 1.96

$$\text{Therefore } n = \frac{1.96^2 \times 0.093 \times (1-0.093)}{0.005}$$

$$n = \frac{3.84 \times 0.093 \times 0.907}{0.0025}$$

$$n = \frac{0.3239}{0.0025}$$

n = 129.56 n = 130

For cattle: $n = \frac{Z^2 \times P_{exp}(1-P_{exp})}{d^2}$

Where n = required sample size,

$P_{exp}$ = expected prevalence =65.7%

$d^2$ = desired absolute precision =0.05

Z = standard normal distribution at 95% confidence interval = 1.96

$$\text{Therefore } n = \frac{1.96^2 \times 0.657 \times (1-0.657)}{0.005}$$

$$n = \frac{3.84 \times 0.657 \times 0.343}{0.0025}$$

$$n = \frac{0.8653}{0.0025}$$

n = 346.14 n = 346

Therefore, sample sizes of 130 sheep, 130 goats and 346 cattle were used for the study

**Sampling Techniques**

Stratified sampling procedure was used to select the sampling location.

Gombe state agricultural development program (GSADP) stratified the eleven Local Government Areas (LGAs) of the state into three agricultural zones as follows: Gombe North, Gombe Central and Gombe South. Gombe North is having 5 LGA (Dukku, Funakaye, Gombe, Kwami and Nafada), Gombe Central is having 2 LGA (Akko and Yamaltu Deba) while Gombe South is having 4 LGA (Balanga, Billiri, Kaltungo and Shongom). Simple random sampling techniques was used to select two LGAs each from Gombe North and Gombe South and One LGA was selected from Gombe Central agro-ecology. Three wards were randomly selected from each selected LGAs and three house hold herds were also selected from each ward. A total of sixteen animals comprising of ten cattle, three sheep and three goats were sampled from each house hold herd.

The physical examination was conducted to gather essential information for assessing the health status of the animals. This information, combined with the history obtained from the farmer or herdsman, enabled us to identify specific signs of disease and helped localize the disease process to particular organ systems.

Initial observations were made from a distance, focusing on the animal's posture, gait, behavior, and general physical condition. Observing other members of the flock or herd helped differentiate normal from abnormal characteristics within the specific management system, as what is considered "normal" may vary from farm to farm. Additionally, the owner's or herdsman's perception of normal may actually reflect abnormal conditions. This comparative observation was valuable for assessing the incidence of diseases or disorders linked to management practices.

**Physical examination of the animals**

Vital parameters including respiratory rate, pulse rate, and body temperature, were recorded. As more animals across different herds were examined, a broader understanding of management-related deficiencies was developed, allowing for more reliable assessments. With the animal properly restrained, the physical examination progressed to specific body parts. Clinical signs were checked on the limbs, dental pad, coronary band, and interdigital spaces for any lesion's indicative of foot and mouth disease.

**Blood/Serum Sample Collection**

Blood samples was collected from the jugular vein of individual animals, using sterile plain vacutainer tubes. About six millilitres of blood was withdrawn from each animal. The samples were coded, stored overnight at room temperature for serum separation and transferred into sterile cryovials after separation. The sera samples were stored at −20°C until laboratory test is performed.

**Table 1: Showing the sampling approach and proportionate distribution of sample**

| Agricultural Zone | Selected LGAs | Wards in the selected LGAs | House Hold Herd | Sample SR | Allocated Cattle |
|---|---|---|---|---|---|
| Gombe north | Kwami | Doho | 3 | 6 | 8 |
| | | Kwami | 3 | 6 | 8 |
| | | Malleri | 3 | 6 | 8 |
| | Funakaye | Bajoga East | 3 | 6 | 8 |
| | | Kupto | 3 | 6 | 8 |
| | | Kupto | 3 | 6 | 8 |
| Gombe Central | | Hinna | 3 | 6 | 8 |
| | | Kuri/Lano/Lambam | 3 | 6 | 8 |
| | | Zambuk/Kwali | 3 | 6 | 8 |
| Gombe South | Balanga | Gelengu/Balanga | 3 | 6 | 8 |
| | | Cham | 3 | 6 | 8 |
| | | Mona | 3 | 6 | 8 |
| | Kaltungo | Awak | 3 | 6 | 8 |
| | | Kaltungo West | 3 | 6 | 8 |
| | | Ture | 3 | 6 | 8 |

Key: LGAs = local Government Areas, SR = Small Ruminant

**Procedure for blood sample collection in cattle**

The animal was restrained using rope and halter with head elevated and jugular vein exposed and was clean with gauze containing antiseptic to remove superficial dirt and debris. This also assist in visualizing raised vein, then the jugular vein was occluded by applying pressure at the base of the jugular groove, 18 guage needle was inserted firmly into skin and into vein at 20° angle once needle inserted, after the needle was stabilize, the vacutainer tube was then push into hub, blood flowed freely into tube. As the collection completed, the vacutainer tube was then removed, and pressure was applied over injection site, before removing the needle as described by SOP. (2017).

**Procedure for blood sample collection in small ruminant**

The animal was restrained with head elevated and jugular vein exposed the animal was stand with its back against the handler's legs. The head of the animal was held at about a 30° angle to the side to extend neck and expose jugular, with the animal set between handler's legs, the head was then tucked under the arm, and access jugular from above, a small area was clipped over the jugular groove, and clean with antiseptic gauze to remove superficial dirt and debris. This assisted in visualizing raised vein. Then the jugular vein was occluded by applying pressure at the base of the jugular groove, 21 guage needle was inserted firmly into skin and into vein at 20° angle as the needle inserted, stabilize needle and push the vacutainer tube into hub, blood flowed freely into tube. As the collection completed, the vacutainer tube was then removed, and pressure was applied over injection site, before removing the needle as described by SOP. (2017).

**Laboratory Diagnosis**

The collected serum samples were subjected to FMDV NSP – 3B bELISA (multi - speces / multi – spacies) at the National Veterinary Research Institute Vom Plateau State. The diagnostic test kit has a sensitivity of 91.7% and specificity of 99.5% (Roche, *et al.,* 2014). This test detects only antibodies produced against non-structural proteins and can hence differentiate vaccinated animals from unvaccinated animals. The tests were done according to the manufacturers recommendation and the procedure provided by the OIE manual of diagnostic tests and vaccines for terrestrial animals (OIE, 2008). FMDV serotyping was done using ID Screen ® FMD Competition, a competitive ELISE for detection of FMDV serotype O antibody in serum or plasma from bovine, ovine, caprine, porcine and all susceptible species and IZSLER: Brascia, Italy solid – phase competitive ELISA (SPCE) for antibodies to FMDV serotype A and SAT2 respectively as detailed by Ularamu *et al.* (2017).

**Data Management**

Data generated from laboratory investigations was recorded and coded using a Microsoft Excel spreadsheet and analyzed using STATA version 14. Descriptive analyses were used to assess the seroprevalence, and knowledge and control practices of farmers. The seroprevalences was calculated as a proportion of seropositive to the total number of animals tested, and 95% confidence intervals was given for the estimates. Standard errors for the seroprevalence confidence intervals was calculated using the cluster sandwich variance estimator which accounts for the cluster correlated nature of the data (Williams, 2000). The true prevalence (TP) was derived from the apparent prevalence (AP) based on the sensitivity (Se) and specificity (Sp) of the diagnostic test as: TP = AP+Sp-1Se+Sp-1 (Thrusfield, 2005). Age stratified seroprevalence was used to estimate the annual occurrence of FMD outbreak. Seroprevalence difference between cattle and small ruminants was compared using the chi-squared test.

**Data Analysis**

Both data sets were then brought together in a Microsoft Excel Spreadsheet, cleaned and coded before being exported to Statistical Package for Social Science (SPSS) Version 20 for analysis. Analysis included descriptive analysis of the variables to generate means, medians, proportions and confidence intervals. Chi-squared test as recommended by Campbell (2007) and Richardson (2011) was used to compare proportions while the confidence intervals of the proportions was calculated using the method recommended by Atuman *et al.* (2020). The test of crude association between risk factors (both individual animal and herd level) and FMD sero-positivity was done using chi-square test.

**RESULTS**

**Clinical Sign**

The clinical signs of Foot and Mouth Disease (FMD) observed in sheep, goats and cattle in this study showed 90.0% of cattle, 66.7% of goats and 57.1% of sheep are exhibiting a sign of inappetence, all the observed sheep are having lameness and 23% of cattle present drooling of saliva from their mouth. 66.7% of goats are having vesicular like lesions on their lip while 57.1% of sheep presents a vesicular like lesions in the inter-digital cleft and 42.9% of sheep have vesicular like lesions in the bulbs of the heels respectively. No vesicular lesions were observed on the tongue, dental pad, buccal cavity and hoof coronet (Table 4.1 and Plate I to X.).

**Vital parameters of small ruminant animal suspected to be infected with FMD**

The vital parameters recorded for small ruminants suspected to be infected with Foot and Mouth Disease Virus (FMDV) in Gombe showed a mean body temperature of 40.2ºC, pulse rate of 62.88bpm and respiratory rate of 17.75bpm, respectively (Table 2).

**Seroprevalence of FMD in Sheep, Goat and Cattle kept in close contact in Gombe**

These findings indicate that the variation in seroprevalence across species was unlikely due to random chance. It reflects a real variation in exposure or susceptibility among these species. This suggest that cattle may be more exposed to FMD virus or more susceptible to the infection compared to small ruminants. The differences could be attributed to factors such as herd size, movement patterns, management practices, or species-specific immune responses.

**Seroprevalence of Foot and Mouth Disease (FMD) by Animal Species in Gombe State**

A total of 630 animals comprising sheep (n = 173), goats (n = 97), and cattle (n = 360) were sampled to determine the seroprevalence of FMD. The results showed that cattle had the highest seroprevalence at 63.9%, followed by goats at 41.2%, and sheep at 41.0%. To assess whether the observed differences in FMD seroprevalence among species were statistically significant, a Chi-square test of independence was conducted. The test revealed a statistically significant association between animal species and FMD seroprevalence ($\chi^2$ =0.000, p = 0,000) (Table 3)

**Table 2: The clinical signs of Foot and Mouth Disease (FMD) observed (no. Sheep 7, Goats 6 and Cattle 30)**

| Clinical Signs | Sheep (%) | Goats (%) | Cattle (%) |
|---|---|---|---|
| Inappetence | 4(57.1) | 4 (66.7) | 27(90.0) |
| Distress | 5 (71.4) | 3 (50.0) | 23(76.7) |
| Lameness. | 7(100) | 2(33.3) | 15(50.0) |
| Drooling of saliva | 0(0.0) | 0(0.0) | 7(23.3) |
| Vesicular like lesions on the lip | 0(0.0) | 4 (66.7) | 8(26.7) |
| Vesicular like lesions in the inter-digital cleft | 4(57.1) | 1 (16.7) | 9(30.0) |
| Vesicular like lesions in the bulbs of the heels | 3 (42.9) | 0(0.0) | 0(0.0) |
| Vesicular lesions on the tongue | 0(0.0) | 0(0.0) | 11(36.7) |
| Vesicular lesions on the dental pad | 0(0.0) | 0(0.0) | 9(30.0) |
| Vesicular lesions in the buccal cavity | 0(0.0) | 0(0.0) | 8(26.7) |
| Vesicular like lesions on the hoof coronet | 0(0.0) | 0(0.0) | 7(23.3) |

**Table 3: Vital Parameters of Small Ruminants Suspected to be Infected with FMDV in Gombe State**

| Parameter | Number of Animals | Mean Value | Unit |
|---|---|---|---|
| Temperature | 8 | 40.20 | °C |
| Pulse Rate | 8 | 62.88 | beats/min |
| Respiratory Rate | 8 | 17.75 | breaths/min |

(P-value for temperature = 0.000)

**Seroprevalence of Foot and Mouth Disease (FMD) in Small Ruminant by Local Government Area**

A total of 270 animals were sampled across five LGAs in Gombe State. The highest FMD seroprevalence was recorded in Kaltungo (25.9%) sheep and (25.9%) goat, followed by Yamaltu Deda (25.9%) sheep and (9.3%) goat, Balanga (25.9%) sheep and (7.11%) goat,, Funakaye (20.4%) sheep and (14.8%) goat,, and Kwami (20.4%) sheep and (14.8%) goat,. A Chi-square test of independence was conducted to determine whether the differences in FMD seroprevalence across LGAs were statistically significant. The result showed a Chi-square value of 20.709 with a P-value of 0.000, indicating that the variation in seroprevalence among LGAs was statistically significant at the 0.05 level, although it was marginally close to significance (Table 4)

**Seroprevalence of Foot and Mouth Disease (FMD) in Cattle by Local Government Area**

A total of 360 animals were sampled across five LGAs in Gombe State. The highest FMD seroprevalence was recorded in Yamaltu Deba (84.7%), followed by Balanga (65.5%), Kaltungo (59.7%), Funakaye (59.7%) and Kwami (50.0%). A Chi-square test of independence was conducted to determine whether the differences in FMD seroprevalence across LGAs were statistically significant. The result showed a Chi-square value of 20.709 with a P-value of 0.000, indicating that the variation in seroprevalence among LGAs was statistically significant at the 0.05 level, although it was marginally close to significance (Table 4)

**Distribution of FMD Serotype A in Sheep and Goats**

Among the five LGAs sampled, Balanga had the highest prevalence of FMD Serotype A at 42.2%, while Kwami recorded the lowest at 23.9% (Table 4).

**Distribution of FMD Serotype O in Sheep and Goats**

The highest prevalence of FMD Serotype O was observed in Yamaltu Deba LGA at 92.9%, whereas Kwami LGA had the lowest at 69.2% (Table 4).

**Distribution of FMD Serotype SAT 2 in Sheep and Goats**

Yamaltu Deba LGA showed the highest prevalence of FMD Serotype SAT 2 at 70.0%, while Funakaye LGA had the lowest at 30.8% (Table 4).

**Table 4: Seroprevalence of FMD in Sheep, Goat and Cattle kept in close contact in Gombe (n = 630)**

| Animal Species | Total tested | Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|
| Sheep | 173 | 71 (41.0) | 29.019 | 0.000 |
| Goat | 97 | 40 (41.2) | | |
| Cattle | 360 | 230 (63.9) | | |

**Table 5: Seroprevalence of FMD in Small Ruminants kept in close contact with Cattle in Gombe (n = 270)**

| LGAs | Total tested | Sheep Positive (%) | Goat Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|---|
| Balanga | 54 | 14 (25.9) | 4 (7.1) | 20.709 | 0.000 |
| Funakaye | 54 | 11(20.4) | 8(14.8) | | |
| Kaltungo | 54 | 14 (25.9) | 14 (25.9) | | |
| Kwami | 54 | 11(20.4) | 8(14.8) | | |
| Yamaltu Deba | 54 | 14 (25.9) | 5(9.3) | | |

**Table 6: Seroprevalence of FMD in Cattle kept in close contact with Small Ruminants in Gombe (n = 360)**

| Animal Species | Total tested | Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|
| Balanga | 72 | 47 (65.3) | 20.709 | 0.000 |
| Funakaye | 72 | 43 (59.7) | | |
| Kaltungo | 72 | 43 (59.7) | | |
| Kwami | 72 | 36(50.0) | | |
| Yamaltu Deba | 72 | 61(84.7) | | |

**Table 7: Distributions of FMD Serotype A in Sheep and Goat kept in close contact with Cattle in Gombe (n = 65)**

| LGA | No. Tested | No. Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|
| Balanga | 13 | 6 (46.2) | 0.577 | 0.131 |
| Funakaye | 13 | 5 (38.5) | | |
| Kaltungo | 13 | 3 (23.9) | | |
| Kwami | 13 | 3 (23.9) | | |
| Yamaltu Deba | 13 | 3 (23.9) | | |

**Table 8: Distributions of FMD Serotype O in Sheep and Goat kept in close contact with Cattle in Gombe (n = 65)**

| LGA | No. Tested | No.Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|
| Balanga | 13 | 11 (84.6) | 0.575 | 0.857 |
| Funakaye | 13 | 11 (84.6) | | |
| Kaltungo | 13 | 12 (92.3) | | |
| Kwami | 13 | 9 (69.2) | | |
| Yamaltu Deba | 13 | 12 (92.3) | | |

**Table 9: Distributions of FMD Serotype SAT2 in Sheep and Goat kept in close contact with Cattle in Gombe (n = 65)**

| LGA | No. Tested | No. Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|
| Balanga | 13 | 8 (61.5) | 0.575 | 0.854 |
| Funakaye | 13 | 4 (30.8) | | |
| Kaltungo | 13 | 8 (61.5) | | |
| Kwami | 13 | 9 (69.2) | | |
| Yamaltu Deba | 13 | 7 (70.0) | | |

**Table 10: Comparation between Viral serotype found in small Ruminant and the one found in Cattle in Gombe State**

| Serotypes | Animal Species | No Tested | No. Positive (%) | Chi-Square | P – Value |
|---|---|---|---|---|---|
| **Serotype A** | Sheep | 20 | 4 (20.0) | 0.178 | 0.079 |
| | Goat | 20 | 5 (75.0) | | |
| | Cattle | 20 | 11 (55.0) | | |
| **Serotype O** | Sheep | 20 | 16 (80.0) | 0.418 | 0.360 |
| | Goat | 20 | 15 (75.0) | | |
| | Cattle | 20 | 3 (15.0) | | |
| **Serotype SAT2** | Sheep | 20 | 9 (45.0) | 0.418 | 0.360 |
| | Goat | 20 | 12 (60.0) | | |
| | Cattle | 20 | 15 (75.0) | | |

**Comparison of Circulating FMDV Serotypes Between Small Ruminants and Cattle in Gombe State**

The comparison of circulating FMDV serotypes between small ruminants and cattle in Gombe State revealed notable differences. Goats exhibited the highest prevalence of FMDV serotype A at 75.0%, compared to 55.0% in cattle. For FMDV serotype O, sheep showed the highest prevalence at 80.0%, while cattle had a significantly lower prevalence of 15.0%. Interestingly, FMDV serotype SAT 2 cattle showed the highest prevalence at 75.0%, while sheep had a significantly lower prevalence of 45.0% (Table 4.9)

## DISCUSION

The clinical signs of FMD observed in Sheep and goats in the study area were inappetence, panting, pyrexia (≥40 °C), distress, and lameness. In addition, in sheep there is a presence of vesicular lesions in the inter-digital cleft and on the bulb of the heels. This finding is in line with the finding Madhanmohan *et al.* (2020) who reported that sheep and goats infected through coronary band route showed clinical signs of FMD such as inappetence, panting, pyrexia (≥40 °C), lameness and vesicles in foot and mouth at 2–5 dpc. This finding was also in accordance with the earlier experiments in sheep (Dellers and Hyde 1964; Burrows, 1968; Ryan *et al.,* 2007; Madhanmohan *et al.* 2020) and goats (Onozato, *et al.,* 2014). Hughes *et al.* (2002) reported intra nasal inoculation of FMDV which resulted in generalized infection in sheep. Sheep and goats inoculated by both intra-dermo-lingual/coronary band routes also showed FMD clinical signs whereas sheep and goats inoculated by intra-dermo-lingual route did not produce clinical signs of FMD (Madhanmohan *et al.,* 2020). Furthermore, Lazarus, *et al.* (2019) presented that indigenous South African goats manifested FMD clinical signs by challenging intra-dermo-lingual route with SAT1 virus pool. Clinical signs of FMD in sheep and goats are usually mild compared to cattle and pigs (Pay, 1988)

The clinical signs of FMD observed in cattle in the present study are acute pyrexia (≥40 °C), anorexia, lameness, development of vesicular lesions in the mouth, tongue, buccal cavity, dental pad and feet. This is in agreement of the finding of Meyer and Knudsen (2001), who reported that clinically, FMD is typically marked by acute pyrexia, development of vesicular lesions in the mouth, tongue, buccal cavity, dental pad, nares, feet, udder, and teats, in appetence or anorexia, lameness, and occasionally mastitis (Meyer and Knudsen 2001).

On vital parameters, the increase in Temperature in the positive animals could be due to high fever which is primarily caused by viral infection and subsequent inflammatory response and may be a direct result of the body's immune response to the virus (Table 4.2)

The increase in pulse rate of the positive sample in the present study could be due to the feverish nature of Foot and Mouth Diseases in ruminant can lead to a tachycardia. Variation in pulse rate has been reported to reflect the rate at which the heart pumps blood through the body (Adetunji *et al.,* 2002). However, the higher values found in this study indicated of greater stress at that period as reported by Badru *et al.* (2009) that rectal temperature and pulse rates are both used to determine the health status and adaptability of domestic animals to stressful condition. Respiratory rate increase in the positive animals may be due to the tachypnoea as a result of stress and pain.

These findings indicate that the variation in seroprevalence across species was unlikely due to random chance. It reflects a real variation in exposure or susceptibility among these species. This suggest that cattle may be more exposed to FMD virus or more susceptible to the infection compared to small ruminants. The differences could be attributed to factors such as herd size, movement patterns, management practices, or species-specific immune responses.

Additionally, clinical cases of FMD are unreported or underreported (Verma *et al.,* 2010). In terms of species, Goat had a higher prevalence (41.2%) than Sheep (41.0%) (Table 4.3). The findings of 41.0% sero-prevalence in sheep in the present study is in line with n 41.66% recorded in Bauchi State (Lazarus *et al.,* 2012) but higher than 31.0% reported by Olabode *et al.* 2019 and 9.3% documented by Ehizibolo *et al.*(2010) in Plateau State using virus infection associated (VIA) antigen assay, indicating that ELISA is more sensitive and specific (Sorensen *et al.,* 1998) as earlier suggested (Lazarus *et al.,* 2012). The finding of this study is lower than the work of Adeiza, *et al*. (2022) who reported 74.2% positive in sheep and 85.8% in goat respectively.

Consequently, the occurrence of NS-positive antibodies in sheep further confirms FMD endemicity and poor vaccination control attempts amongst the common susceptible Nigerian livestock breeds of cattle (Olabode *et al.,* 2013) usually co-herd with sheep as earlier reported by Olabode *et al.* (2014c). Earlier studies (Parida, *et al.,* 2008; Madhanmohan, *et al.,* 2010b) revealed antibodies against 3ABC in sheep at 10 days after inoculation of FMDV. In the current experiment, must of the sheep were positive for NSP antibodies This finding is in accordance with the earlier experiment in sheep and goats (Madhanmohan, *et al.,* 2010a; Madhanmohan, *et al.,* 2010; Adeiza, *et al*. 2022).

The observed differences in FMD seroprevalence across LGAs also as the previous suggest potential variation in exposure risk, animal movement, or local management practices. Although the statistical test did not confirm a significant association at the conventional 5% level, the p-value (0.0542) was close to the threshold, indicating a possible trend worth further investigation. Future studies with larger sample sizes or stratified analysis may help clarify these LGA differences.

The current investigation reported the FMD seropositivity in all study locations, Tables 4.4 display various serological data addressing the relationship between risk factors such as species and sex. Yamaltu Deba LGA was found to be having the highest sero-prevalence of FMD (25.9%) sheep and (84.7%) cattle, followed by Balanga LGA (25.9%) sheep and (65.3%) cattle, Kaltungo LGA (25.9%) sheepand (59.7%) cattle, Funakaye LGA (20.4%) sheep and (59.7%) cattle, and lastly K LGA (20.4%) sheep and (50.0%) cattle respectively. These differences in prevalence among LGA could be explained by the fact that the placement of farms in each LGA differs, as do the places where outbreaks are prevalent as well as the agroecological conditions of the various areas. All the five LGAs of Gombe State were at higher risk of FMD indicating the impact of biotic and abiotic factors on the disease prevalence. Temperature and relative humidity are considered as crucial environmental factors for the development and transmission of disease as the virus can travel up to 250 km (Constable *et al.,* 2017). The primary source of the spread of transboundary disease is the movement of animals for their trade (Fevre *et al.,* 2006).

With a total sero- prevalence of 58.0% in this study indicating the endemicity of FMD virus in all the LGA of Gombe State. The presence of antibodies against the FMD virus Non-Structural proteins in the sera samples of small ruminant indicates that the animals had exposure to the FMD virus (OIE 2019). The high prevalence of FMD in the present study could be attributed to geographical location of the area, no vaccination of the animals, poor management practices, movement of animals from neighbourhood LGA or states, contact of animals to the stray animals roaming in the area, where they can get infections from disease affected animals. This in line with the work of Adeiza, *et al*. (2022). Who reported that 80% of the small ruminants (sheep and goats) slaughtered in Karu Abbatoir, Federal Capital Territory, Nigeria tested positive to FMD antibodies. The high seropositivity of small ruminants to FMD sometimes associated with non-vaccination of small ruminants considered relatively expensive by their owners, is a salient signal to infection and viremia. This poses a great risk to indigenous cattle as the small ruminants lead the cattle on their trek routes. With inapparent clinical signs, these leading small ruminants shed the viruses and possibly infecting other animals (Arzt, *et al.,* 2011; Fasina, *et al.,* 2013).

The significant variation in Serotype O and SAT2 across LGAs may also reflect differences in animal movement patterns, herd management, or environmental factors influencing virus transmission. The uniformity of Serotype A suggests it may be more endemic or less influenced by local factors. These findings underscore the importance of targeted surveillance and control strategies tailored to regional serotype dynamics.

The present study showed that FMDV serotypes A, O and SAT 2 are co-circulating in all the three agricultural zones of the Gombe State Nigeria. This has a great implication in vaccine formulation, as only a multivalent vaccine will be appropriate for use in such situation (Wungak, *et al.* 2017). As reported by several authors, FMD serotype O has been observed to be the predominant serotype from this study.

The three FMDV serotypes detected in the course of these studies (serotype O, A and SAT2) along with previous reports in Nigeria establish the facts that these are the most prevalent serotypes circulating among ruminants' animals in the country (Fasina, *et al.,* 2013, Olatunde, *et al.,* 2014, Lazarus, *et al.,* 2015, Wungak, *et al.,* 2015,). However, to the best of our knowledge, this study has provided the first comprehensive base line data of FMDV serotypes in Gombe State, North-eastern Nigeria. From the available information, none of the animal herd sampled ever practiced FMD vaccination and since routine prophylactic vaccination of cattle is not a common practice in the country, these results tend to present evidence of viral exposure.

In this study, analyses of serotype-specific antibodies to FMDV indicate that FMD serotypes O, A, and SAT 2 are widely distributed and co-circulated within the study areas during the period of the study. The wide distribution of the FMDV serotypes in the region could be attributed to unrestricted movement of cattle, sheep and Goats within the zone, frequent contacts of different herds at watering and feeding points, lack of any meaningful control measure in place, and husbandry management system that is being practiced by the pastoralists. In the present study Cattle are mostly affected than Sheep and Goats. This finding is also in consistent with the previous study conducted between 2007 and 2015, where FMD serotypes A, O, and SAT 2 have been reported to cause disease outbreaks among pastoral and sedentary herds in Nigeria (Fasina, *et al.,* 2013, Ehizibolo, *et al.,* 2014, Olatunde, *et al.,* 2014, Wungak, *et al.,* 2015, Ularamu, *et al.,* 2015 and Ehizibolo, *et al.,* 2016,). And the present findings also are in agreement with the work of Wungak, *et al.* (2017) who reported FMD serotype A, O, SAT1 and SAT2 from the research conducted at North Central part of Nigeria.

These current findings revealed that serotype O is the most prevalent serotype in the region. FMDV serotype O has been known to be the most dominant and most widely distributed serotype. It has the ability to be the most invasive serotype (Kitching and Thrusfield, 2005, Wungak, *et al.* 2017). Depa *et al.* (2012), reported that serotype O was most prevalently recorded in most of the FMD outbreaks worldwide. This is also consistent with a study conducted in Somali Ecosystem in Kenya by Chepkwony *et al.* (2012), where they reported a higher prevalence of serotype O as compared to the other serotypes. In this study, serotype SAT2 was the second in terms of prevalent and the serotype A was the lowest. This finding did not agree with finding of Wungak *et al.* (2017) where he reported that FMD serotype A was second in terms of prevalent.

The evidence of multiple exposures to viruses among herds might be an indication of continuous and silent propagating transmission. This could also be attributed to recent infections with multiple serotypes or reinfection with different serotypes of FMDV over time. This has a great implication for control, as farmers and livestock owners will not have the knowledge of the virus circulating in their herds (Wungak *et al.,* 2017). This finding is consistent with a study conducted in Uganda where concurrent high antibody titres against serotypes O, SAT 2, SAT 1, and SAT 3 were demonstrated in the same serum samples in cattle herds (Mwiine, *et al.,* 2010). Infection or vaccination with one FMD serotype has been known not to confer immune protection against the other serotypes, as such following exposure to a single virus serotype does not provide immunity against the other serotypes of the virus (Doel, 2005). Another reason is the fact that the presence of antibodies to different serotypes of FMDV is an indication of repeated infection with different serotypes. Alexandersen *et al.* (2002), reported that a number of cattle populations exposed to FMDV become carriers, in which the animal continues to produce antibodies against the FMDV(s) without showing any clinical sign.

**Ethical Approval**

Ethical approval for this study was obtained from the Animal Use and Care Committee of Ahmadu Bello University, Zaria. The approval reference number is ABUCAUC/2025/050

**REFERENCES**

Aruwayo, A; Tiri, GD; Yahaya, MA; Akinyemi, M. (2015). An Emperical Analysis of Ruminant Production In Dutsinma Local Government Area, Katsina State, Nig *International Journal of Inov. Agriculture & Biological Research* 3(2):34-40.

Arzt, J., Baxt, B., Grubman, M. J., Jackson, T., Juleff, N., Rhyan, J. and Rodriguez, L. L. (2011). The pathogenesis of foot-and-mouth disease II: viral pathways in swine, small ruminants, and wildlife; myotropism, chronic syndromes, and molecular virus–host interactions. *Transboundary and emerging diseases*, 58(4), 305-326.

Arzt, J., Pacheco, J. M. and Rodriguez, L. L. (2010). The early pathogenesis of foot-and-mouth disease in cattle after aerosol inoculation. Identification of the nasopharynx as the primary site of infection. *Veterinary Pathology*. 2010; 47 (6): 1048–1063.

Atuman, Y. J., Kudi, C. A., Abdu, P. A., Okubanjo, O. O. Abubakar, A. Wungak, Y. and Ularamu, H. G. (2020). Seroprevalence of Foot and Mouth Disease Virus Infection in Some Wildlife and Cattle in Bauchi State, Nigeria. *Veterinary Medicine International* Volume 2020, Article ID 3642793, 8 pages https://doi.org/10.1155/2020/3642793

Barnett, P. V. and Cox, S. J. (1999). The role of small ruminants in the epidemiology and transmission of foot-and-mouth disease. *Veterinary Journal*. 1999; 158: 6-13.

Bellet, C., Vergne, T., Grosbois, V., Holl, D., Roger, F. and Goutard, F. (2012). Evaluating the efficiency of participatory epidemiology to estimate the incidence and impacts of foot-and-mouth disease among livestock owners in Cambodia. *ActaTropica*, 123: 31–38.

Bengis, R. G, Thomson, G. R., Hedger, R. S., De Vos, V. and Pin, A. (1986). Foot –and –mouth disease and African buffalo (Syncerus Caffer) carriers as a source of infection for cattle. *Onderstepoort Journal of Veterinary Research*. 1986; 53(2): 69-73.

Campbell, I. (2007). Chi-squared and Fisher-Irwin tests of two-by-two tables with small sample recommendations. *Statistic Medicine*. 2007; 26:3661–3675.OpenUrlCrossRefPubMedGoogle Scholar

Chukwuedo, A. A. and Nimzing, A. (2012); Field investigation of Foot and Mouth Disease (FMD) virus infection in cattle in the northern states of Nigeria. *Nigerian Journal of Biotechnology,* 24: 20–26.

Clauss, M. and Rossner, G. E. (2014). "Old world ruminant morphophysiology, life history, and fossil record: exploring key innovations of a diversification sequence" (PDF). Annales Fernández, Manuel Hernández; Vrba, Elisabeth S. (2005-05-01). "A complete estimate of the phylogenetic relationships in Ruminantia: a dated species-level supertree of the extant ruminants". *Biological Reviews*. 80 (2): 269–302. doi:10.1017/s1464793104006670. ISSN 1469-185X. PMID 15921052. S2CID 29939520.

Doel, T. R. (2003). Foot and mouth disease vaccines. *Virus Research,*91(1): 81–99.

Donaldson, A. I., Sellers, R. F., Martin, W. B. and Aitken, I. D. (2000). Foot-and-mouth disease. Diseases of sheep. Oxford: *Blackwell Science*; 2000. p. 254–258.

Ehizibolo, D. O., Ijomanta J. O.,Michael, C. A., Wungak, Y. S. Lazarus D. D., Ularamu, H. G., Meseko, C., and Umoh, J. U. (2016);Serological survey of foot and mouth disease virus antibodies in apparently healthy domestic pigs in Nigeria. *African Journal of Microbiology Research.*,10:87–92.

Ehizibolo, D. O., Perez, A. M., Carrillo, C., Pauszek, S., AlKhamis, M., Ajogi, I.,Umoh, J. U., Kazeem, H. M., Ehizibolo, P. O., Fabian, A., Berninger, M., Moran, K., Rodriguez, L. L. and Metwally, S. A. (2014): Epidemiological analysis, serological prevalence and genotypic analysis of foot-and-mouth disease in Nigeria 2008–2009. *Transboundry Emerging Diseases,* 63, 500– 510.

FAO, (1981). *Production Yearbook*, Food and Agriculture Organization, Rome, Italy. Vol. 34, 1981.

Fasina, F. O., Connell, D. R., Talabi, O. A., Lazarus, D. D., Adeleke, G. A., Olusanya, T. P. And Hernandez, J. A. (2013). Foot-and-mouth disease virus strains and examination of exposure factors associated with seropositivity of cattle herds in Nigeria during 2007–2009.*Preventive Veterinary Medicine,* 109: 334– 342.

Ferguson, K. J., Cleaveland, S., Haydon, D.T., Caron, A., Kock, R.A., Lembo, T., Hopcraft, J.G., Chardonnet, B., Nyariki, T., Keyyu, J., Paton, D.J. and Kivaria, F.M. (2013). Evaluating the potential for the environmentally sustainable control of foot and mouth disease in sub-Saharan Africa.*Ecohealth*,10(3): 314–322.

Fernández, M. H. and Vrba, E. S. (2005). "A complete estimate of the phylogenetic relationships in Ruminantia: a dated species-level supertree of the extant ruminants". *Biological Reviews.* 80 (2): 269–302. doi:10.1017/s1464793104006670. ISSN 1469-185X. PMID 15921052. S2CID 29939520.

Fowler, M. E. (2010). "Medicine and Surgery of Camelids", Ames, Iowa: Wiley-Blackwell. Chapter 1 General Biology and Evolution addresses the fact that camelids (including camels and llamas) are not ruminants, pseudo-ruminants, or modified ruminants. *Zoologici Fennici*. 51 (1–2): 80–94. doi:10.5735/086.051.0210. S2CID 85347098

G.S.G. (2013), Gombe State Government: General Information. Adapted On 30/01/2014, from; [http://www.gombestate.gov.ng/geni nformatio n.html](http://www.gombestate.gov.ng/geninformation.html)

Kitching, R. P. (2002). Clinical variation in foot and mouth disease: Cattle. *OIE Revue Scientifique et Technique,* 21(3), 499–504.

Kosgey, I. S. (2004). Breeding objectives and breeding strategies for small ruminants in the tropics. PhD Thesis, Wageningen University, *The Netherlands,* p. 272, 2004.

Kosgey, I. S., Rowlands, G. J., van Arendonk, J. A. M. and Baker, A. L. (2008). Small ruminant production in smallholder and pastoral/extensive farming systems in Kenya. *Small Ruminants Research*. 2008; 77(1):11–24.

Lazarus, D. D., Schielen, W. J. G., Wungak, Y., Kwange, D. and Fasina, F. O. (2012). Sero-epidemiology of foot-and-mouth disease in some Border States of Nigeria, *African Journal of Microbiology Research*,6(8):1756-1761.

Lazarus, D. D., Wungak Y. S. and Adah M. I. (2015). Serological response of commercial dairy cattle to inactivated foot-and-mouth disease vaccine (type-O & A) in Nigeria. Asian *Journal of Medical and Biological Research.* 2015;1(2):163–168. doi: 10.3329/ajmbr.v1i2.25606.

Lebbie, S. H. B. (2004). Goats under Household Conditions. *Small Ruminant Research* 51: 131 – 136

LiveGAPS (2022). Small ruminant production in Nigeria. *https//researchcsiro.au.livegaps*

Madin, B. (2011). An evaluation of foot-and-mouth disease outbreak reporting in mainland South-East Asia from 2000 to 2010.*Preventive Veterinary Medicine*,102:230–241.

Mahmoud, M. A. E., Ghazy, A. A. and Shaapan, R. M. (2019). Diagnosis and control of foot and mouth disease (FMD) in dairy small ruminants; sheep and goats. *International Journal of Dairy Science.* 2019; 14: 45-870 52.

Maree, F. F., Kasanga, C. J., Scott, K. A., Opperman, P. A., Chitray, M., Sangula, A. K., Sallu, R., Sinkala, Y., Wambura, P. N., King, D. P., Paton, D. and Rweyemamu, M. (2014). Challenges and prospects for the control of foot-and-mouth disease: An African perspective. Veterinary Medicine: *Research and Reports*, 5, 119–138.

Mason, P.W., Grubman, M.J. and Baxt, B. (2003). Molecular basis of pathogenesis of FMDV. *Virus Research,* 91, 9–32.

Miguel, E., Grosbois, V. and Caron, A. (2013). Wildlife-livestock contacts: frequency of interactions contact and foot-and-mouth disease dynamic in cattle populations at the periphery of Transfrontier Conservation Areas in Southern Africa. *Ecosphere*,4(4):51.

N.P.C. (2006), Annual Statistical Abstract on Nigeria Population Census, Abuja: *NPC,* pp 22

NASS (2011). National Bureau of Statistics/Federal Ministry of Agriculture and Rural Development *Collaborative Survey on National Agriculture Sample Survey* (NASS), 2010/2011

NPC (2006). PHC Priority Tables – NATIONAL POPULATION COMMISSION". *population.gov.ng.* Archived from the original on 2018-10-16. Retrieved 2017-10-10.

Nyariki, D. M. and Amwata, D. A. (2019). The value of pastoralism in Kenya: Application of total economic value approach. *Pastoralism.* 2019; 9: 9.

OIE (2008). *Manual of Diagnostic Tests and Vaccines for Terrestrial Animals* (Mammals, Birds and Bees). 6th ed., Vol. I. Paris: World Organization for Animal Health (OIE) (2008), 192–200.

OIE (2018). Manual of Diagnostic Tests and Vaccines for Terrestrial Animals 8th Edition. 2018. *https://www.oie.int/standard-setting/terrestrial-manual/861*

Olabode, H.O., Makajoula, K., Abiola,R. Dogongiginya I., and Daniel, N. (2014). Geo-spatial distribution of serologically detected bovine Foot and Mouth Disease (FMD) serotype outbreaks in Ilesha Baruba, Kwara State-Nigeria. *Journal of Advanced Veterinary and Animal Research.* 2014;1: 1.

Olabode, O. H., Kazeem, H. M., Raji, M. A. and Ibrahim, N. D. (2013). Seroprevalence of foot and mouth disease virus antibodies in trade cattle (Bos indicus) in Kwara state of Nigeria. *Veterinary World*. 6: 828–832

Parida, S. (2009). Vaccination against footand-mouth disease virus: strategies and effectiveness. *Expert review of vaccines*, 8(3), 347-365.

Perry, B. D. and Rich, K. M. (2007). Poverty impacts of foot-and-mouth disease and the poverty reduction implications of its control. *Veterinary Record*, 160(7): 238–241.

Radostits, O. M., Gay, C. C., Hinchcliff, K. W. and Constable, P. D. (2007). *Veterinary medicine:* A textbook of the diseases of cattle, horses, sheep, pigs and goats. 10th ed. Philadelphia: W.B. Saunders; 2007.

Richardson, J. T. E. (2011). The analysis of 2 × 2 contingency tables - Yet again. *Statistic Medicine*. 2011; 30:890. OpenUrl PubMed Google Sch

RIMS, (1992). Nigerian livestock resources. National Synthesis. *Resource Inventory and Management Ltd.,* RIMS, Jardin House, St. Helier, Jersey, UK., Vol. 2.

Roche, M., Donnet, F., Malzac, M. and Comtet, L. P. (2014). New competitive ELISAs for detection of non-structural or structural FMDV antibody. In: *Open Session of the Standing Technical and Researah Committees of the EUFMD,* 29–31 October 2014 (Cavtat).

Rweyemamu, M., Roeder, P., Mackay, D., Sumption, K., Brownlie, J., Leforban, Y., Valarcher, J. F., Knowles, N. J. and Saraiva, V. (2008): Epidemiological patterns of foot-and-mouth disease worldwide. *Transboundry Emerging Diseases,* 55, 57– 72.

Scoones, I., Bishi, A., Mapitse, N., Moerane, R., Penrith, M. L., Sibanda, R., Thomson, G. and Wolmer, W. (2010). Foot-and-mouth disease and market access: *challenges for the beef industry in southern Africa.* Development, 1(2): 135-164.

SOP, (2017). *Blood collection in cattle*. Developed by the Office of the University Veterinarian and reviewed by Virginia Tech IACUC to provide a reference and guidance to investigators during protocol preparation and IACUC reviewers during protocol review.

Stenfeldt, C, Pacheco, J. M., Rodriguez, L. L and Arzt J. (2014). Early events in the pathogenesis of foot- and-mouth disease in pigs; identification of oropharyngeal tonsils as sites of primary and sustained viral replication. *PLoS ONE.* 2014; doi:10.1371/journal.pone.010685

Sutmoller, P., Barteling, S. S., Olascoaga, R. C. and Sumption, K. J. (2003). Control and eradication of foot-and-mouth disease. Virus Research., 91(1), 101-144.

Thrusfield, M. (2005). Veterinary Epidemiology. 2nd ed. Oxford, UK: *Blackwell Science Ltd.* (2005). p.232.

Ularamu, H. G. Wungak, Y. S., Lazarus, D. D., Woma, T. Y., Ehizibolo, D. D., Dogonyaro, B. B., Bwala, D. G., Bakari, D. G., Agom, D., Onoja, M. A., Ibu, J. O. and Shamaki, D. (2015). Serological evidence of foot-and-mouth disease virus (FMDV) in camels (Camelus dromedaries) in Nigeria. *Journal of Veterinary Medicine and Animal Health.,* 7, 261–264

Ularamu, H. G., Ibu, J. O., Wood, B. A,, Abenga, J. N,, Lazarus, D. D,, Wungak, Y. S, (2016) Characterization of foot-and-mouth disease viruses collected in Nigeria between 2007 and 2014: evidence for epidemiological links between West and East Africa. *Transboundary Emerging Disieases*. (2017) 64:1867–76. doi: 10.1111/tbed.12584

Ularamu, H. G., Ibu, J. O., Wood, B. A,, Abenga, J. N,, Lazarus, D. D,, Wungak, Y. S, (2017) Characterization of foot-and-mouth disease viruses collected in Nigeria between 2007 and 2014: evidence for epidemiological links between West and East Africa. *Transboundary Emerging Disieases*. (2017) 64:1867–76. doi: 10.1111/tbed.12584

Vandenbussche F., Mathijs E. and Ularamu H. G. (2018). Complete genome sequences of five foot-and-mouth disease viruses of serotype a isolated from cattle in Nigeria between 2013 and 2015. Genome Announcements. 2018;6 (7) doi: 10.1128/genomea.00039-18. e00039-18

Vandenbussche, F., Lefebvre, D.J., De Leeuw, I., Van Borm, S. and De Clercq, K. (2017). Laboratory validation of two real-time RT-PCR methods with 5'-tailed primers for an enhanced detection of foot-and-mouth disease virus. *Journal of Virological Methods*. (2017) 246:90–4. doi: 10.1016/j.jviromet.2017.04.014



Madu *et al.,*

Wanyoike, S. (2009). The epidemiology and socio-economics of contagious bovine pleuropneumonia and its control by vaccination in Narok District of Kenya [*dissertation*]. Reading (UK): University of Reading; 2009.

Williams, R. L. (2000). A note on robust variance estimation for cluster-correlated data. *Biometrics*. (2000) 56:645–6.

Wungak, Y. S., Ishola, O. O., Olugasa, B.O., Lazarus, D. D., Ehizibolo, D. O. and Ularamu, H. G. (2017). Spatial pattern of foot-and-mouth disease virus serotypes in North Central Nigeria Veterinary World, EISSN: 2231-0916 Available at www.veterinaryworld.org/Vol.10/April-2017/13.pdf

Wungak, Y. S., Lazarus, D. D., Agom, D. and Ularamu, H. G. (2015); Serological evidence of foot-and-mouth disease virus (FMDV) antibodies in pigs from northeastern Nigeria. *Journal of Veterinary Medicine and Animal Health.,* 7, 237–260.

Wungak, Y. S., Olugasa, B. O., Ishola, O. O., Lazarus, D. D. and Ularamu, G. H. (2016). Foot-and-mouth disease (FMD) prevalence and exposure factors associated with seropositivity of cattle in north-central, Nigeria. *African Journal of Biotechnology,* Vol. 15(24), pp. 1224-1232, 15 June, 2016

Wungak, Y. S., Olugasa, B. O., Ishola, O., Lazarus, D. Chukwuedo, A. A. and Ularamu, H. G. (2019). Isolation and Serotyping of Foot-and-Mouth Disease Virus in Cattle collected from North Central, Nigeria. *Nigerian Veterinary Journal* 40 (3). ISSN 0331-3026

Yoon, S. H., Park, W., King, D. P and Kim, H. (2011). Phylogenomics and molecular evolution of foot- and-mouth disease virus. *Mol. Cells*. 2011; 31: 413–421

Yusuf, A., Aruwayo, A. and Muhammad, I. R. (2018). Characterisation of Small Ruminant Production Systems in Semi-Arid Urban Areas of Northern Nigeria. *Journal of Applied Science an Environmental Management* Vol. 22 (5) 725 – 729 May 2018