Seroprevalence of Foot and Mouth Disease Virus Infection in some Wildlife and Cattle in Bauchi State, Nigeria.

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Abstract

Background

Foot and mouth disease (FMD) is one of the most economically important transboundary animal diseases with devastating consequence on livestock production and wildlife conservation. The objectives of the study were: to determine the seroprevalence of FMDV in wildlife and cattle and identify circulating FMDV serotypes in wildlife and identify potential risk factors that will contribute to transmission of the disease at the wildlife-livestock interface in Yankari Game Reserve and Sumu Wildlife Park in Bauchi State, Nigeria.

Methods

Blood samples were collected between 2013 to 2015 from some wildlife and cattle respectively within and around Yankari Game Reserve (YGR) and Sumu Wildlife Park (SWP) in Bauchi State, Nigeria. The Wild animals were immobilized for blood collection using a combination of Etorphine Hydrochloride (M99® Krüger-Med South Africa) at 0.5-2 mg/kg and Azaperone (Stresnil®, Janssen Pharmaceuticals (Pty.) Ltd., South Africa) at 0.1 mg/kg using a Dan- Inject® rifle (Dan-Inject APS, Sellerup Skovvej, Denmark) fitted with 3 ml dart syringe and for reversal, Naltrexone (Trexonil® Kruger-Med South Africa) at 1.5 mg IM was used, cattle were restrained by the owners for blood collection. Harvested Sera from blood were screened for presence of Antibodies against FMDV using prioCHECK® 3 ABC NSP ELISA kit and positive samples from wildlife were serotyped using Solid-Phase Competitive ELISA, (IZSLER Brescia-Italy). Data obtained were analysed using Graphpad Prism version 7.

Results

The results showed that 197 (65.7%) of the 300 serum samples from cattle and 13 (24.5%) of the 53 serum samples from wildlife tested positive for antibodies to the highly conserved

non-structural 3-ABC protein of FMDV and statistically significant (P <0.05). Classification of cattle into breed and sex showed that detectable antibodies to FMDV were higher (P <0.05) in White Fulani 157 (72.8%) than red Bororo 23 (39.7%) and Sokoto Gudali 17 (33.3%) breeds of cattle whereas in females detectable FMDV antibodies were higher (P <0.05) 150 (72.8%) than in males 47 (50.0%). In the wildlife species, antibodies to FMDV were detected in waterbuck 2 (28.6%), elephant 1 (25.0%), wildebeest 4 (33.3%) and eland 6 (25.0%). Four serotypes of FMDV: O, A, SAT-1 and SAT-2 were detected from the 3-ABC positive reactors in waterbuck, elephant, wildebeest and eland. Contact of wildlife and cattle during utilization of the rich resources in the conservation areas is a potential risk factor for the spread of FMDV in the study area.

Conclusions

Presence of FMDV antibodies in cattle and some wildlife were observed and serotypes of FMDV: O, A, SAT-1 and SAT-2 were detected from the 3-ABC positive reactors in some of the wildlife. The study highlights the need for active surveillance of FMDV in wildlife and pastoral cattle within and around wildlife conservation areas in Nigeria. FMD surveillance system, control and prevention program that targets wildlife and livestock at the wildlife-livestock interface level will be beneficial to the livestock industry and wildlife conservation goals in Bauchi State, Nigeria.

Author summary

Foot and mouth disease (FMD) is an important trans-boundary viral disease of both domestic and wild cloven hoofed animals characterized by high morbidity with devastating consequence on the livestock worldwide. Despite the endemic nature of FMD in Nigeria, little is known about the epidemiology of the disease at the wildlife-livestock interface level. To address this gap, blood samples were collected between 2013 to 2015 from some wildlife and cattle respectively within and around Yankari Game Reserve (YGR) and Sumu Wildlife Park (SWP) in Bauchi State, Nigeria. Wild animals were immobilized using a combination of Etorphine Hydrochloride (M99® Krüger-Med South Africa) at 0.5-2 mg/kg and Azaperone (Stresnil®, Janssen Pharmaceuticals (Pty.) Ltd., South Africa) at 0.1 mg/kg using a Dan-Inject® rifle (Dan-Inject APS, Sellerup Skovvej, Denmark) fitted with 3 ml dart syringe and for reversal, Naltrexone (Trexonil® Kruger-Med South Africa) at 1.5 mg IM was used, cattle were restrained by the owners for blood collection. Harvested Sera from blood were screened for presence of Antibodies against FMDV using prioCHECK® 3 ABC NSP ELISA kit and positive samples were serotyped using Solid-Phase Competitive ELISA, (IZSLER Brescia-Italy). Out of the 300 and 53 sera collected from cattle and wildlife 197 (65.7%) and 13 (24.5%) (P <0.05) respectively tested positive for antibodies to the highly conserved non-structural 3-ABC protein of FMDV by the FMDV-NS blocking ELISA. Classification of cattle into breed and sex showed that detectable antibodies to FMDV were higher (P <0.05) in White Fulani 157 (72.8%) than red Bororo 23 (39.7%) and Sokoto Gudali 17 (33.3%) breeds of cattle whereas in females detectable FMDV antibodies were higher (P <0.05) 150 (72.8%) than in males 47 (50.0%). In the wildlife species, antibodies to FMDV were detected in waterbuck 2 (28.6%), elephant 1 (25.0%), wildebeest 4 (33.3%) and eland 6 (25.0%). Four serotypes of FMDV: O, A, SAT-1 and SAT-2 were detected from the 3-ABC positive reactors in waterbuck, elephant, wildebeest and elands. The results showed presence of

antibodies to FMDV in some wildlife and cattle and suggest that wildlife could equally play an important role in the overall epidemiology of FMD in Nigeria. FMD surveillance system, control and prevention program should be intensified in the study area.

Key words: Bauchi State, Cattle, Foot and mouth disease virus, Nigeria, Serotypes, Wildlife

Introduction

Foot and mouth disease (FMD) is one of the most economically important transboundary animal disease in the world caused by Foot and mouth disease virus (FMDV) a member of the genus *Aphthovirus* belonging to the *Picornaviridae* family (1). FMDV is a small non-enveloped virus and has a genome of 8.5 kb which encodes for structural proteins (VP1, VP2, VP3 and VP4) as well as non-structural proteins (NSPs) (2, 3).A structural protein produces antibodies to FMDV in vaccinated animals, whereas infected animals produce antibodies to both the structural and non-structural proteins (3) and assays to demonstrate antibodies against non-structural proteins have potential to differentiate infected from vaccinated animals (4,5,6,7). Seven immunologically different serotypes of the FMDV are known: O, A, C, Asia-1, South-African Territories (SAT) -1, -2 and -3, which comprise more than 65 subtypes (8).

The transmission of FMDV in sub-Saharan Africa is mainly driven by two epidemiological cycles: one in which wildlife plays a significant role in maintaining and spreading the disease to other susceptible wild and/or domestic ruminants (9,10). Whilst with the second cycle the virus is solely transmitted within domestic populations and hence is independent of wildlife (11). The disease is endemic in some parts of Europe, Africa, Middle East and Asia and has contributed to significant declines in wildlife and livestock populations in those regions (12, 13, 14, and 15). The first reported case of FMD outbreak in Nigeria was in 1924, which was

113 attributed to type O virus (16). Subsequently, other serotypes (A, SAT 1 and SAT 2) were
114 reported (17, 18, 19, 20, 21, 22) and recently SAT 3 serotype (23).
115
116 In spite of the annual FMD burden in Nigeria, sero-epidemiology and sero-typing studies for
117 FMD infections are inadequate. The current trend of FMD occurrence in Nigeria showed that
118 there are regular outbreaks, poor control measures and lack of enforcement of legislation
119 guiding disease reporting to veterinary authority (24, 25). The presence of antibodies to
120 FMDV in several wildlife species have been documented in studies conducted in different
121 countries of Africa mainly eastern and southern regions (26, 27, 28). There has been limited
122 monitoring of infectious diseases like FMD in wildlife in Nigeria. Domestic livestock
123 sometimes do share the same range with wildlife in YGR and SWP in Bauchi State, Nigeria
124 (29) and there is concern that wildlife may form a reservoir for FMDV. Consequently, there
125 is need to understand the potential role of wildlife as reservoir of FMDV to aid in the design
126 and implementation of the disease management programs. The aim of the study was to
127 determine the seroprevalence of FMDV in wildlife and cattle and identify circulating FMDV
128 serotypes in wildlife in YGR and SWP in Bauchi State, Nigeria.
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130 ## Materials and methods

131 ### The study area

132 The study locations were Yankari Game Reserve (YGR) and Sumu Wildlife Park (SWP) in
133 Bauchi State, Nigeria with human settlements surrounding them. YGR covers an area of
134 about 2,244 square kilometres, it is an important refuge for over 50 species of mammals and
135 over 350 species of birds and is one of the few remaining areas where wild animals are
136 protected in their natural habitat in Nigeria (30, 31). SWP covers about 40 square kilometer
137 area and habours species of wildlife including impala (*Aepyceros melampus*), springbok

(*Antidorcas marsupialis*), oryx (*Orynx gazelle*), eland (*Taurotragus oryx*), zebra *(Equus quagga crawshayi*) kudu (*Tragelaphus strepsiceros*), blue wildebeest (*Connochaetes taurinus*), and giraffe (*Giraffa camelopardalis*) and is located about 60 km north of Bauchi the State capital (29).

Serum sample collection

Field sampling was conducted between February 2013 to December 2015 and blood samples were collected from 300 cattle, and 53 wildlife including four elephant (*Loxodonta Africana*), eleven waterbuck (*Kobus ellipsiprymus*), one Hartbeest (*Alcelaphus buselaphus caama*) from YGR and twenty four eland (*Taurotragus oryx*), twelve blue wildebeest (*Connochaetes taurinus*) and one kudu (*Tragelaphus strepsiceros*) from SWP following chemical immobilization using Etorphine hydrochloride (M99® Krüger-Med South Africa) at 0.5-2 mg/kg and Azaperone (Stresnil®, Janssen Pharmaceuticals (Pty.) Ltd., South Africa) at 0.1mg/kg delivered intramuscularly (IM) using a Dan- Inject® rifle (Dan-Inject APS, Sellerup Skovvej, Denmark) fitted with 3ml dart syringe and barbed needles and for reversal Naltrexone (Trexonil® Kruger-Med South Africa) at 1.5mg IM was used. The serum samples were harvested from the blood into cryovials after spinning for 10 min at 1200 g and were divided into aliquots, labelled and kept at -20 ^{O}C until used.

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Detection of antibodies against FMDV non-structural proteins (NSPs) by ELISA

The ELISA was performed according to the manufacturer's instructions (PRIOCHECK® FMD-3ABC NS protein ELISA) for detection of antibodies to the non-structural polypeptide 3 ABC of FMDV in serum which detects infected animals regardless of their vaccination status and the FMDV serotype that caused the infection (32). Briefly, 80 µl of the ELISA buffer and 20 µl of the test sera were added to the 3ABC-antigen coated test plates. Negative, weak positive and strong positive control sera were added to designated wells on each test

plate, gently shaken and incubated overnight (18 h) at 22°C. The plates were then emptied and washed six times with 200 µl of wash solution and 100 µl of diluted conjugate was added to all wells. The test plates were sealed and incubated for one hour at 22ºC. The plates were then washed six times with 200 µl of wash solution and 100 µl of the chromogen (tetra-methyl benzidine) substrate was dispensed to all wells of the plates and incubated for 20 min at 22ºC following which 100 µl of stop solution was added to all the wells and mixed gently. Readings were taken on a spectrophotometer Multiskan® ELISA reader (Thermo Scientific, USA) at 450 nm and the OD 450 values of all samples was expressed as Percentage Inhibition (PI) relative to the OD 450 max using the following formula PI = 100 – [OD 450 test sample/OD450 max] × 100. Samples with PI = ≥ 50% were considered positive for FMD antibody while those with PI < 50% were declared negative for FMD antibody. Since the 3-ABC ELISA for FMD was = 100% specific and > 99% sensitive, the percentage prevalence was taken as true prevalence.

Detection of FMDV specific antibodies using solid-phase competitive enzyme linked immunosorbent assay

The 3ABC ELISA positive serum samples were analyzed for FMD-specific antibodies using a Solid-Phase Competitive ELISA (SPCE) as previously described for serotypes O, A, SAT 1 and SAT 2 (32, 33). The assays were performed using antibodies FMDV ELISA kits for serotypes O, A, SAT 1 and SAT 2 produced by IZSLER Biotechnology Laboratory (Italy). Briefly, 96 wells pre-coated with FMDV antigens captured by FMD serotypes O, A, SAT 1 and SAT 2 specific MAb flat-bottomed plates were used. Four dilutions of sera at 1/10, 1/30, 1/90 and 1/270 were made. Without washing, the conjugate (Horse-radish peroxidase) was added and incubated at room temperature for 1 h. The plate was washed and the substrate/chromogen solution (tetra-methyl-benzidine) was added and kept in the dark for 20

188 min. The reaction was stopped by the addition of a stop solution and the plates were read on a
189 MultiSkan® spectrophotometer ELISA plate reader (Thermo Scientific, USA) at 450 nm
190 wavelength. Serum end-point titre was expressed as the highest dilution producing 50%
191 inhibition, with serum having end point titre $\geq$ 50% being classified as positive for the
192 specific FMD antibody.
193 Data obtained were analysed using Graphpad Prism version 7. Results were summarized in
194 tables and expressed as percentages and levels of association between positivity and sex,
195 breed, age and animal species were derived using Chi-square. Values of $P \leq 0.05$ were
196 regarded as statistically significantly different.
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Results

Overall seroprevalence of FMDV in wildlife was 24.53% (Table 1). Detectable antibodies to FMDV were observed in waterbuck 2 (28.6%), elephant 1 (25.00 %), wildebeest 4 (33.3%) and eland 6 (25.0 %).

Table 1: Seroprevalence of foot and mouth disease virus in wildlife from Yankari game reserve and Sumu wildlife park in Bauchi State, Nigeria.

Wildlife	No. sampled (%)	No. +ve (%)	X^2	P value	Odds ratio	CI at 95%
Yankari park						
Waterbuck	11 (10.4)	2 (18.2)	1.395	0.943	0.373	0.899-0.327
Elephant	4 (3.8)	1 (25.0)				
Hartbeest	1(0.9)	0 (0.0)				
Sumu park						
Eland	24 (22.6)	6 (25.0)				
Wildebeest	12 (11.3)	4 (33.3)				
Kudu	1 (0.9)	0 (0.0)				
Overall	53 (100)	13 (24.5)				

Comparison of the overall seroprevalences of FMDV at the wildlife-cattle interface (Table 2) showed that detectable antibodies to FMDV were significantly higher ($P < 0.05$) in cattle 197 (65.67%) than in wildlife 13 (24%).

Table 2: Seroprevalence of foot and mouth disease at the wildlife-cattle interface in Yankari game reserve and Sumu wildlife park in Bauchi State, Nigeria.

Specie	No. sampled	No. +Ve (%)	X^2	P value	Odds ratio	CI at 95%
Wildlife	53	13 (24.53)	31.63	0.000	0.1699	0.087 - 0.332
Cattle	300	197 (65.67)				
Overall	353	210 (59.49)				

Antibodies to FMDV were significantly higher in female cattle than males (P <0.05) with Bunaji breed of cattle having high risk factor (odds ratio >5) of exposure to FMDV than the other breeds of cattle examined (Table 3).

Table 3: Seroprevalence of foot and mouth disease virus in cattle around Yankari game reserve and Sumu Wildlife Park in Bauchi State, Nigeria

Variables	No. sampled (%)	No +Ve (%)	X^2	P value	Odds ratio	CI at 95%
Breed						
Red Bororo	58 (19.3)	23 (39.7)	64.2	0.000		
Sokoto gudali	51 (17.0)	17 (33.3)			0.544	0.241 - 1.225
White Fulani	191 (63.7)	157 (82.2)			5.019	2.550 -9.878
Overall	300 (100)	197 (65.7)				
Sex						
Male	94 (31.3)	47 (50.0)	14.9	0.000	0.373	0.225 -0.620
Female	206 (68.7)	150 (72.8)				
Overall	300 (100.0)	197 (65.7)				

The detectable antibodies to FMD serotype were for serotypes O, A, SAT 1 and SAT 2 in waterbuck, wildebeest and eland whereas antibodies to serotypes A and SAT 2 were detected in elephant. Each of the serotypes A and SAT 1 were shown to have highest reactors of 10 (18.87%) whereas serotype O had the least reactors of 7 (13.21%) (Table 4)

Table 4: Foot and mouth disease virus serotypes detected in wildlife in Yankari game reserve and Sumu Wildlife Park in Bauchi State, Nigeria.

		Foot and mouth disease virus serotypes			
		O	A	SAT 1	SAT 2
Wildlife	No. tested (%)	No. positive (%)			
Waterbuck	11 (10.4)	2 (18.18)	2 (18.18)	3 (27.27)	1 (9.09)
Elephant	4 (3.8)	0	1 (25.0)	0	1 (25.0)
Hartbeest	1 (0.9)	0	0	0	0
Eland	24 (22.6)	3 (12.5)	6 (25.0)	4 (16.67)	4 (16.67)
Wildebeest	12 (11.3)	2 (16.67)	1 (8.33)	3 (25.0)	2 (16.67)
Kudu	1(0.9)	0	0	0	0
Overall	53 (100)	7 (13.21)	10 (18.87)	10 (18.87)	8 (15.09)

Discussion

The results of this study have shown that antibodies to FMDV were present in cattle (65.7%) and wildlife (24.5%). This is consistent with results of previous survey for FMDV antibodies in Nigeria in which a seroprevalence of 75.11% was reported in a study conducted in cattle in Kwara State (34). Also, seroprevalences of 64.3% and 70.98% respectively were reported in studies carried out in Plateau State (35, 36), and 64.7% in a study conducted at the Border States in Nigeria (21, 37). The similarities of findings of the present study with previous studies have shown that FMD is still an enzootic disease in Nigeria and this could be attributed to the lack of FMD vaccination campaigns in Nigeria (21, 37). There is unrestricted

259 herds mobility, continuous contact and intermingling of different cattle herds at water points,
260 communal grazing areas and porous borders.
261 The higher FMDV seroprevalence in female cattle during this study was consistent with the
262 findings of other investigators (34, 37) who reported a risk difference in association with sex
263 during FMDV studies in Kwara and Plateau States, Nigeria, respectively. Similarly, high
264 incidence of FMDV in females in Northwest Ethiopia was reported (38). However, most of
265 the cattle sampled during the study were females as opposed to males. The significant
266 association of seroprevalence with sex could be attributed to the preference for females to
267 males by the nomads for reproductive purposes and milk production and therefore females
268 are kept for longer period thereby having higher risk of exposure than males (8, 34, 37).
269 Significant association in seropositivity was observed in Bunaji breed of cattle, this could be
270 due to small number of other breeds (Sokoto gudali and Red bororo) sampled. However, all
271 the breeds of cattle are equally at risk.
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273 Results from the study have shown that antibodies to FMDV were present in elands,
274 wildebeests, waterbucks and elephants. This finding being the first of its kind in the study
275 area reveals that FMD could be a problem in wildlife in Nigeria. This is not surprising as
276 FMD is endemic in Nigerian livestock (18, 20, 39, 23). Presence of wildlife population along
277 the national park in Borgu Niger State Nigeria where cloven hoofed species come in contact
278 with live stock was shown to be the probable exposure factor that contributed to high FMD
279 sero-positivity in livestock observed in the area (37). The results from this study corroborate
280 with other studies in South Africa, Zimbabwe, Zambia, Botswana, Namibia, India, Chad and
281 Iran that demonstrated FMDV antibodies in wildlife (40, 10, 41, 42, 43, 28, 11, 44, 45). High
282 FMDV prevalence in waterbuck observed in this study reflects their ecology and living
283 ecosystem which is consistent with other findings in East Africa and Zimbabwe (41, 27, 46).

284 The study hitherto provided a picture of FMDV distribution in wildlife in Bauchi State,
285 Nigeria which was observed to be largely understudied (44).
286
287 The study confirms the presence of antibody to FMDV serotype O, A, SAT 1 and SAT 2 in
288 wildlife a finding probably first of its kind in Nigeria. Reported outbreaks affecting livestock
289 of West Africa since 2000 were caused by FMDV types O, A, and SAT 2 (44). Similarly,
290 FMDV serotypes O, A, and SAT 2 were the cause of most reported outbreaks in domestic
291 livestock in Nigeria from 2010 to 2016 (39, 34, 22). The result here showed that FMDV
292 serotypes observed in wildlife were equally previously observed in domestic livestock. The
293 possible source of FMDV serotypes infection for the wildlife could be from infected
294 livestock interacting with wildlife in the same environment. Transmission of FMDV between
295 wildlife and livestock, even in isolated areas, may be due to windborne infection or via
296 fomites (47, 48). Wildlife species often congregate at the natural 'salt lick' point in YGR (31)
297 similarly artificial salt lick points are also available in SWP. Therefore, dissemination of the
298 FMDV during wildlife activities at the salt-lick points is possible. Previous studies have
299 shown that FMDV can easily be disseminated in the soil and can persist in that environment
300 for a long period (28) .
301
302 The presence of FMDV antibodies in wildlife and cattle in this study might be driven by
303 direct contact at wildlife-livestock interface through sharing of water and pasture resources
304 observed to be a common activity in YGR and SWP in Bauchi State, Nigeria (31, 29). During
305 dry season wildlife and livestock in the study area do closely congregate at feed and water
306 points thus increasing the transmission likelihood of water-related infections like FMD (41,
307 13, 44). Studies conducted in Ethiopia and Zimbabwe found significant association between
308 cattle exposed to FMDV and their contact history with wildlife (50, 48, 11). It is unfortunate

309 that due to the endemic nature of FMD in Nigeria that outbreaks are not being investigated to
310 determine the primary source and hence the disease have continued to be a scourge to live
311 stock production in the Country.
312

313 ## Conclusion

314 According to the results presented, presence of FMDV antibodies in cattle and some wildlife
315 were observed with four serotypes of FMDV: O, A, SAT-1 and SAT-2 detected from the 3-
316 ABC positive reactors in some wildlife. This might have been driven by direct contact at
317 wildlife-cattle interface through sharing of water and pasture resources observed to be a
318 common activity in YGR and SWP in Bauchi State, Nigeria. The study highlights the need
319 for intensification of FMD surveillance system, control and prevention program among
320 wildlife and livestock within and around wildlife conservation areas in Nigeria.
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323

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328 **Conflict of interest**

329 The authors have declared that there is no conflict of interest

330 ## References

331 Abegunde, A.A., Ezeokoli, C.D., Umoh, J.U. and Addo, P.B (1988). Relationship between
332 recent FMD virus isolates from Nigeria and standard vaccine virus strain from the
333 African region. In: *Viral Diseases of Animals in Africa*. Williams, O. and Masiga, W.
334 N. (eds). OAU/STRC, Lagos, Nigeria.

335 Alexandersen, S., Zhang, Z. and Donaldson, A. I. (2002). Aspects of the persistence of foot-
336 and-mouth disease virus in animals—the carrier problem. *Microbes and Infection,*
337 4(10): 1099-1110.

338 Atuman, Y. J., Adawa, D.A.Y., Audu, S., Paul, M. P. and Bankole, O. A. (2014). Potential
339 risks for rabies spill-over from apparently healthy dogs to wildlife in Bauchi State,
340 Nigeria. *Journal of Veterinary Advances,* 4(4): 493-498.

341 Bastos, A., Boshoff, C.I., Keet, D.F., Bangis, R.G. and Thomson, G.R. (2000). Natural
342 transmission of foot-and-mouth disease virus between African buffalo
343 (*Synceruscaffer*) and impala (*Aepycerosmelampus*) in the Kruger National Park, South
344 Africa. *Epidemiol Infect*, 124:591.

345 Berger, H.G., Straub, O.C., Ahi, R., Tesar, M. and Marquardt, O. (1990). Identification of
346 foot-and-mouth disease virus replication in vaccinated cattle by antibodies to non-
347 structural virus protein. *Vaccine*, 8: 213-216.

348 Bengis, R., Kock, R. and Fischer, J. (2002). Infectious animal diseases: the wildlife-livestock
349 interface. *Revue Scientifique et Technique-Office International des Epizooties,* 21(1):
350 53-66.

351 Bengis, R.G., Leighton, F.A., Fischer, J.R., Artois, M., Morner, T. Tate, C.M. (2004). The
352 role of wildlife in emerging and re-emerging zoonoses. *Revue Scientifique et*
353 *Technique-Office International des Epizooties*, 23(2):497-511.

354 Bolortsetseg, S., Enkhtuvshin, S., Nyamsuren, D., Weisman, W., Fine, A. and Yang, A.
355 (2012). Serosurveillance for foot-and-mouth disease in Mongolian gazelles (*Procapra*
356 *gutturosa*) and livestock on the Eastern Steppe of Mongolia. *Journal of Wildlife*
357 *Diseases*. 48(1):33-38.

358 Bronsvoort, B., Parida, S., Handel, I., McFarland, S., Fleming, L., Hamblin, P. and Kock, R.
359 (2008). Serological survey for foot-and-mouth disease virus in wildlife in eastern
360 Africa and estimation of test parameters of a nonstructural protein enzyme-linked
361 immunosorbent assay for buffalo. *Clinical and Vaccine Immunology,* 15(6): 1003-
362 1011.

363 Brown, C. C. and Slenning, B. D. (1996). Impact and risk of foreign animal diseases. *Journal*
364 *of the American Veterinary Medical Association,* 208 (7): 1038-1040.

365 Chénard, G., Miedema, K., Moonen, P., Schrijver, R. S. and Dekker, A. (2003). A solid-phase
366 blocking ELISA for detection of type O foot-and-mouth disease virus antibodies
367 suitable for mass serology. *Journal of Virological Methods,* 107(1): 89-98.

368 Chukwuedo, A. and Nimzing, L. (2012). Field investigation of Foot and Mouth Disease
369 (FMD) virus infection in cattle in the northern states of Nigeria. *Nigerian Journal of*
370 *Biotechnology,* 24: 22-31.

371 Clavijo, A., Wright, P. and Kitching, P. (2004). Developments in diagnostic techniques for
372 differentiating infection from vaccination in foot-and mouth disease. *Veterinary*
373 *Journal*, 167: 9-22.

374 Daszak, P., Cunningham, A. A. and Hyatt, A. D. (2000). Emerging infectious diseases of
375 wildlife--threats to biodiversity and human health. *Science,* 287(5452): 443-451.

376 Dawe, P., Flanagan, F., Madekurozwa, R., Sorensen, K., Anderson, E., Foggin, C. and
377 Knowles, N. (1994). Natural transmission of foot-and-mouth disease virus from

African buffalo (*Syncerus caffer*) to cattle in a wildlife area of Zimbabwe. *The Veterinary Record,* 134(10): 230-232.

De-Diego, M., Brocchi, E., Mackay, D. and De Simone, F. (1997). The nonstructural polyprotein 3ABC of foot-and-mouth disease as a diagnostic antigen in ELISA to differentiate infected from vaccinated cattle. *Archives of Virology*, 142: 2021-2033.

Di Nardo, A., Libeau, G., Chardonnet, B., Chardonnet, P., Kock, R.A., Parekh, K., Hamblin, P., Li, Y., Parida, S. and Sumption, J.K. (2015). Serological profile of foot-and-mouth disease in wildlife populations of West and Central Africa with special reference to *Syncerus caffer* subspecies. *Veterinary Research*, 46(1): 77-93.

Durojaiye, A. (1981). Incidence of FMD in Oyo State of Nigeria, 1967- 1981. *Nigeria Veterinary Journal*. 10: 7-13.

Ehizibolo, D.O., Ajogi, I., Umoh, J.U., Kazeem, H.M., Ehizibolo, P.O., Perez, A.M. and Metwally, S. (2010). Serological survey of Foot and Mouth Disease (FMD) 3d Non-structural Proteins using virus-infection associated (VIA) Antigen assay in livestock animals from Plateau State, Nigeria. In: Book of Abstract 47th Annual Congress of the Nigerian Veterinary Medical Association, Benue, P 75.

Ehizibolo, D.O., Haegeman, A ., De Vleeschauwer, AR., Umoh ,J.U ., Kazeem, H.M., Okolocha, E.C., Van Borm, S. and De Clercq, K. (2017). Detection and molecular characterization of foot and mouth disease viruses from outbreaks in some states of northern Nigeria 2013-2015. *Transboundary and Emerging Diseases,* 64(6): 1979-1990

Esterhuysen, J.J., Thomson, G.R., Flammand, J.R. and Bengis, R.G. (1985). Buffalo in the Natal game parks show no serological evidence of infection with Foot and mouth disease virus, *Ondersteeport Journal of Veterinary Research*, 52 (2): 63-66

Fry, E.E., Stuart, D.I. and Rowlands, D.J. 2005. The structure of foot-and-mouth disease virus. *Current Topics in Microbiology and Immunology*, 288:71-101.

Hemmatzadeh, F., Boardman, W., Alinejad, A., Hematzade, A. and Moghadam, M.K. (2016). Molecular and Serological Survey of Selected Viruses in Free- Ranging Wild Ruminants in Iran. *PLoS ONE,* 11(12):1-14.

Lazarus, D.D., Schielen, W.J.G., Wungak, Y.S., Kwange, D.Y. 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., Adah, M.I., Ibu, J.O., Abenga, N., Ekong, P.S. and Ularamu, H.G. (2015). Serological response of commercial dairy cattle to inactivated foot-and-mouth disease vaccine (Type-O and A) in Nigeria. *Asian Journal of Medicine and Biological Research*, 1:163–168.

Libeau, J. (1960). Foot-and-mouth disease in Africa south of the Sahara the present situation. *Bulletin of Epizootic Diseases in Africa*, 8: 90-104.

Longjam, N., Deb, R., Sarmah, A., Tayo, T., Awachat, V. and Saxena, V. (2011). A brief review on diagnosis of foot-and-mouth disease of livestock: conventional to molecular tools. *Veterinary Medicine International,* 12: 123-129.

Mazengia, H., Taye, M., Negussie, H., Alemu, S. and Tassew, A. (2010). Incidence of foot and mouth disease and its effect on milk yield in dairy cattle at Andassa dairy farm, Northwest Ethiopia. *Agriculture and Biology Journal of America,* 1 (5): 969-973.

Miguel, E., Grosbois, V., Caron, A., Boulinier, T., Fritz, H., Cornélis, D. and de Garine-Wichatitsky, M. (2013). Contacts and foot and mouth disease transmission from wild to domestic bovines in Africa. *Ecosphere*, 4(4): 1-32.

Molla, B., Ayelet, G., Asfaw, Y., Jibril, Y., Ganga, G. and Gelaye, E. (2010). Epidemiological study on foot-and-mouth disease in cattle: seroprevalence and risk factor assessment in South Omo zone, south-western Ethiopia. *Transboundary and Emerging Diseases*, 57: 340–347

Nawathe, D.R and Goni, M. (1976). Foot-and-Mouth disease in Nigeria. *Bulletin of Animal Health and Production in Africa*. 24:1-4.

Odunlami, S. S. and Lake, B. (2003). An assessment of the ecotourism potential of Yankari national park, Nigeria. *Eco Club. Communication E paper Series NR, 7*.

Olabode, O., Kazeem, H., Raji, M. and Ibrahim, N. (2013). Seroprevalence of foot and mouth disease virus antibodies in trade cattle (*Bos indicus*) in Kwara state of Nigeria. *Veterinary World,* 6(10) :1-9.

Omondi, P., Mayienda, R., Mshelbwala, J. and Massalatchi, M. (2006). *Total aerial count of elephants, buffaloes, roan antelope and other wildlife species in Yankari ecosystem, Nigeria*. Technical report for CITES MIKE Programme, pp. 78-102.

Owolodun, B. (1971). Foot-and-mouth disease and virus types distribution in Nigeria. *Bulletin of Epizootic Diseases of Africa*, 12: 1-9.

Pedersen, A.B., Jones, K.E., Nunn, C.L. and Altizer, S (2007). Infectious diseases and extinction risk in wild mammals. *Conservation Biology*, 21(5): 1269-1279.

Rodriguez, A., Dopazo, J., Saiz, J.C. and Sobrino, F. (1994). Immunogenicity of non-structural protein of foot-and-mouth disease virus; differences between infected and vaccinated swine. *Archive of Virology*, 136:123-131.

Smith, M.J., Telfer, S., Kallio, E.R., Burthe, S., Cook, A.R. and Lambin, X. (2009). Host-pathogen time series data in wildlife support a transmission function between density and frequency dependence. Proceedings of National Academy of Science U S A, 106(19): 7905-7909

Sutmoller, P., Thomson, G. R., Hargreaves, S. K., Foggin, C. M. and Anderson, E. C. (2000). The foot-and-mouth disease risk posed by African buffalo within wildlife conservancies to the cattle industry of Zimbabwe. *Preventive Veterinary Medicine,* 44 (1): 43-60.

Thomson, G., Vosloo, W. and Bastos, A. (2003). Foot and mouth disease in wildlife. *Virus Research,* 91(1): 145-161.

Ularamu, H. G., Ibu J.O., Abenga, J. N., Lazarus, D. D., Wungak, Y. S., Chuckwuedu, A. A., Pam, B. L. and Adah, I. A. (2017). Improving laboratory capacity for foot and mouth disease diagnosis and control for sustainable livestock production in Nigeria. *Vom Journal of Veterinary Science,* 12: 1-10.

Ularamu, H.G., Ibu, J.O., Wood, B.A., Abenga, J.N., Lazarus, D.D., Wungak, Y.S., Knowles, N.J., Wadsworth, J., Mioulet,V., King, D.P., Shamaki, D. and M. I. Adah, M.I. (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 and Emerging Diseases,* 64(6): 1867-1876.

Vandenbussche, F., Mathijs, E., Ularamu, H.G., Ehizibolo, D.O., Haegeman, A., Lefebvre, D., De Vleeschauwer, A.R., Van Borm, S. and De Clercq, K. (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*, 6:e00039-18

Vosloo, W., De Klerk, L.M., Boshoff, C., Botha, B., Dwarka, R., Keet, D. and Haydon, D. (2007). Characterisation of a SAT-1 outbreak of foot-and-mouth disease in captive African buffalo (*Syncerus caffer*): clinical symptoms, genetic characterisation and phylogenetic comparison of outbreak isolates. *Veterinary Microbiology,* 120(3): 226-240.

Vosloo, W., Thompson, P., Botha, B., Bengis, R. and Thomson, G. (2009). Longitudinal study to investigate the role of Impala (*Aepyceros melampus*) in foot-and-mouth disease maintenance in the Kruger National Park, South Africa. *Transboundary and Emerging Diseases,* 56(1-2): 18-30.

Weaver, G. V., Domenech, J., Thiermann, A. R. and Karesh, W. B. (2013). Foot and mouth disease: a look from the wild side. *Journal of Wildlife Diseases,* 49(4): 759-785.

Williams, E., Yuill, T., Artois, M., Fischer, J. and Haigh, S. (2002). Emerging infectious diseases in wildlife. *Revue Scientifique et Technique-Office International des Epizooties,* 21(1): 139-158.

Wungak, Y. S., Olabisi, I. O., Olugasa, B. O., Lazarus, D. D. and Ularamu, H. G. (2015). Seroprevalence of foot and mouth disease (FMD) among sedentary cattle in northern Plateau, Nigeria. *Asian Journal of Medical and Biological Research,* 1(2): 169-174.

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

Yousef, M.R., Mazloum, K.S. and Al-Nakhli, H.M. (2012). Serological evidence of natural exposure of camels (*camelus dromedaries)* to foot-and-mouth disease virus. *Vet. World*, 5(4):197-200

Table 1: Seroprevalence of foot and mouth disease virus in cattle around Yankari game reserve and Sumu Wildlife Park in Bauchi State, Nigeria

Variables	No. sampled (%)	No +Ve (%)	X^2	P value	Odds ratio	CI at 95%
Breed						

Red Bororo	58 (19.3)	23 (39.7)	64.2	0.000		
Sokoto gudali	51 (17.0)	17 (33.3)			0.544	0.241 - 1.225
White Fulani	191 (63.7)	157 (82.2)			5.019	2.550 -9.878
Overall	300 (100)	197 (65.7)				
Sex						
Male	94 (31.3)	47 (50.0)	14.9	0.000	0.373	0.225 -0.620
Female	206 (68.7)	150 (72.8)				
Overall	300 (100.0)	197 (65.7)				

Table 2: Seroprevalence of foot and mouth disease virus in wildlife from Yankari game reserve and Sumu wildlife park in Bauchi State, Nigeria.

Wildlife	No. sampled (%)	No. +ve (%)	X^2	P value	Odds ratio	CI at 95%
Yankari park						
Waterbuck	11 (10.4)	2 (18.2)	1.395	0.943	0.373	0.899-0.327
Elephant	4 (3.8)	1 (25.0)				
Hartbeest	1(0.9)	0 (0.0)				
Sumu park						
Eland	24 (22.6)	6 (25.0)				
Wildebeest	12 (11.3)	4 (33.3)				

Kudu	1 (0.9)	0 (0.0)
Overall	53 (100)	13 (24.5)

570 **Table 3: Seroprevalence of foot and mouth disease at the wildlife-cattle interface in**
571 **Yankari game reserve and Sumu wildlife park in Bauchi State, Nigeria.**

Specie	No. sampled	No. +Ve (%)	X^2	P value	Odds ratio	CI at 95%
Wildlife	53	13 (24.53)	31.63	0.000	0.1699	0.087 - 0.332
Cattle	300	197 (65.67)				
Overall	353	210 (59.49)				

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580 **Table 4: Foot and mouth disease virus serotypes detected in wildlife in Yankari game**
581 **reserve and Sumu Wildlife Park in Bauchi State, Nigeria.**
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		Foot and mouth disease virus serotypes			
		O	A	SAT 1	SAT 2
Wildlife	No. tested (%)	No. positive (%)			
Waterbuck	11 (10.4)	2 (18.18)	2 (18.18)	3 (27.27)	1 (9.09)
Elephant	4 (3.8)	0	1 (25.0)	0	1 (25.0)
Hartbeest	1 (0.9)	0	0	0	0
Eland	24 (22.6)	3 (12.5)	6 (25.0)	4 (16.67)	4 (16.67)
Wildebeest	12 (11.3)	2 (16.67)	1 (8.33)	3 (25.0)	2 (16.67)
Kudu	1(0.9)	0	0	0	0

Overall	53 (100)	7 (13.21)	10 (18.87)	10 (18.87)	8 (15.09)

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