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Original Research Article

Seroprevalence and the Incidence of Foot-and-Mouth Disease in Small Ruminant Farms in Sheep and Goats from the Northern Regions of Cameroon

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Abstract: Foot-and-mouth disease (FMD), is a highly contagious viral disease affecting livestock. It is manifested by fever and blisters in the mouth, on the teats, and between the hooves. This study was conducted in the Northern Cameroon, to assess the seroprevalence and economic impact of foot-and-mouth disease (FMD) in small ruminants. A total of 175 breeders were investigated and 63 serum samples were extracted from small ruminants for to detect antibodies against nonstructural proteins of the foot-and-mouth virus using the ELISA competition technique. The overall morbidity rate of foot-and-mouth disease was 96.13%. The estimated mortality rates were 20.05% in sheep and 24.22% in goats. Young lambs in the Far North had a high rate of morbidity (73.69%) and mortality (35.30%) rates compared to other regions. Total economic losses associated with the disease were high in the North and Far North regions, averaging of 433,526 ± 400,896 FCFA and 386,882 ± 577,742 FCFA respectively. Mortality losses were higher in the Far North, averaging 254 540 ± 391 655 FCFA which differs significantly from the other two regions ($P < 0.05$). Of the 63 analyzed, 30 were positive, resulting in an overall seroprevalence of 47.61%. The positive sample were susceptible to serotype O of aphtovirus. Due to the significant losses associated with FMD, it is crucial to rigorously implement the national program to combat this disease.

Keywords: Foot-And-Mouth Disease, Small Ruminants, Northern Regions, Cameroon.

INTRODUCTION

Foot-and-mouth disease (FMD) is a highly contagious viral disease affecting livestock and causing significant economic losses (Thompson *et al.*, 2002). It is caused by an aphthovirus belonging to the family Picornaviridea. The disease affects domestic and wild artiodactyl mammals. Due to a morbidity rate close to 100%, it has a significant impact on veterinary health and animal welfare, leading to decrease in animal production and mortality of young animals (Grubman M and Baxt B, 2004). Foot-and-mouth disease is listed in the Terrestrial Animal Health Code of the World Organization for Animal Health (OIE) which requires that it be reported to the organization. Additionally, it is the first animal infection for which the OIE has created an official list of free countries and zones, both vaccinated and unvaccinated (Kouato *et al.*, 2018). It does not cause a high mortality rate in adult animals. Therefore, it has been studied less to determine the responsible serotypes. However, a number of African countries including Cameroon, have realized that foot-and-mouth disease (FMD) is one of the transboundary diseases that must be controlled to ensure economic stability and access to lucrative international export markets for animals and animal products (Cottam EM, *et al.*, 2008). Economic losses specific to AF are rarely mentioned in the literature. The annual cost of FMD worldwide, in terms of production losses and prevention through vaccination has been estimated at approximately

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$ 4.45 USD (Chakraborty *et al.*, 2013). Therefore, it is clears that losses due to foot-and-mouth disease (FMD), including mortality and morbidity with reduced performance, result in lost income for the countries with affected livestock. This study aims to improve understanding of seroprevalence and economic losses due to FMD. More specifically, the study aims to evaluate the morbidity and mortality rates of small ruminants due to FMD; determine the costs of treating FMD-affected animals according to small ruminant category; evaluate losses due to FMD mortality of small ruminants in three regions of Cameroon; Determine the circulating serotype in small ruminants in these three regions.

MATERIALS AND METHODS

Study Area Selection and Characteristics

All experimental procedures performed on animals were approved by the Regional Delegation of Livestock, Fisheries and Animal industries in Ngaoundere (N°075/16/L/RA/DREPIA).

These three Northern Regions of Cameroon (Adamawa, North, and Far North) were chosen because they are not only production areas for ruminants, but also sites of frequent livestock trade with neighboring countries such as Chad, the Central African Republic, and Nigeria (Ziebe *et al.*, 2005).

The Far North region is located between 10° and 12° North Latitude and 14° and 15° East Longitude. It borders Chad and Nigeria. It covers 34,246 km^2 and has an estimated population of 3,111,792 inhabitants, with a density of 91 inhabitants/km^2. The climate is predominantly dry Sudano-Sahelian, with a dry season of seven to eight months and a rainy season of 6 months. Average annual rainfall varies range 800 to 9000 mm. The annual average temperature is 35 °C. Spiny steppes and periodically flooded meadows dominate the vegetation in this area. The population relies on agriculture, livestock breeding, and fishing for economic sustenance (MINEPAT, 2014).

The North region covers 66,090 Km^2. It extends between 6° and 10° North Latitude and 12° and 16° East Longitude. In 2012, the population was estimated at 2,152,750 inhabitants, with a density of 32.57 inhabitants/km^2. The climate is Sudanese with an average temperature of 31.5°C. The vegetation consists of dry grassy savannah and shrub and tree savanna. The main economic activities in this zone are agriculture, livestock breeding, and fishing (MINEPAT, 2014).

The Adamawa region borders the Central African Republic (CAR) and Nigeria. It has an area of 63,701 km^2 and an estimated population of more than 1,015,622, with a density of 16 inhabitants per km^2. The region located between 5° and 8° Latitude North and 11° and 14° Longitude East. The climate is of the Sudano-Guinean type with an average temperature of 22.6 °C. The predominant vegetation is the Guinean savannah, which becomes less wooded towards the North. The average annual precipitation ranges from 900 mm to 1,500 millimeters, decreasing further in the north. The main economic activities in this area are agriculture, livestock breeding, fishing, and beekeeping (MINEPAT, 2014).

Field Equipment

Field data was collected from a few actors involved in herd management, namely: breeders and agro-breeders from the three study regions.

The equipment used for this study included of a semi-structured survey form for each breeder, as well as a dry tube, a rack, a needle holder, a 21G needle, a cooler with ice packs, a GPS, device, and personal protective equipment (PPE) including a suit or blouse, boots, and latex gloves.

Laboratory Equipment

A set of equipment was used in the laboratory for the conservation and analysis of the samples including a freezer, a refrigerator, single-channel micropipettes, and multi-channel micropipettes, beakers, and test tubes. ELISA kits were used, including the PrioCHECK FMDV.NS brand® from Pronics Lelystad B.V. in the Netherlands, and ID brand kits. Vet (ID Screen® FMD Type O and Type A competition), and a Multiscan EX®brand spectrophotometer.

METHODS

Sampling and Data Collection

All chemicals used in the laboratory were purchased from Sigma Aldrich (Deisenhofen, Germany).

The sample size was depended on the availability of producers who had experienced FMD in their herds. Thus, a questionnaire was prepared and administered to 175 small ruminant breeders to collect data.

This information was collected using a semi-structured survey sheets, interviews and direct observations. The collected information related to the following: 1: The identification and sociodemographic characteristics of the interviewee which contain information on the geographical location of the herd, the breeder's identity of the breeder (name and first name, age, sex, marital status), the breeder's socio-economic group (religion); the breeder's operation of the farmer and finally the expenses related to foot-and-mouth disease.

Blood Sampling and Treatment for Serum Collection

Blood samples were randomly collected from some farms with more patients. This was done by puncturing of the jugular vein with using a 21G needle mounted on a dry and sterile 10 mL, vacutaner ND tube. The animal was held manually beforehand. Each blood sample was taken according to the species, sex, and age of the animal. After sampling, the samples were placed in an insulated box with ice packs, numbered, and labeled.

These samples were sent to the National Veterinary Laboratory (LANAVET) in Garoua in an insulated container with ice packs. On the same day, the samples were centrifuged at 35,00 rpm for 10 minutes. The resulting sera were distributed into labeled sterile Eppendorf® tubes, and stored at -4°C while awaiting the ELISA test.

Laboratory Analysis

ELISA

All collected sera were subjected to competitive ELISA, to detect of antibodies against the non-structural proteins of the foot-and-mouth disease virus regardless of responsible serotype for the infection. These tests were carried out using ID Vet Kits (ID Screen® FMD NSP-Competition), according to the manufacturers' protocols.

The analyses were carried out using ID Vet Kits via enzyme-linked immunosorbent assay (ELISA) with a range of commercial ID Screen® FMD NSP-Competition kits. Initially, all sera were subjected to the Elisa test for antibodies directed against non-structural proteins (NSP) of the FMD virus. These proteins are only synthesized only during viral multiplication. This test distinguishes antibodies generated by infection from those induced by vaccination (Leforban, 2003). NSP can thus be considered as indicators of infection regardless of the animal's vaccination status (Geoff *et al.*, 2023). Only animals positive to this test are subsequently considered seropositive.

Serotyping

The positive sera were then subjected to various ELISA NSP tests, as well as ELISA competition tests to identify the serotypes involved by searching for antibodies directed against the specific structural proteins of the foot-and-mouth virus. This blocking type, based on a competition between monoclonal antibodies and the antibodies present in the sample. The PRIOCHECK® FMDV Type O (Pronics Lelystad B.V., the Netherlands F190401L-0180102L) and ID Vet ID Sreen® FMD Type a Competition 10P (ID Vet) kits were used according to the manufacturers' protocols.

Estimation of Morbidity and Mortality Rates

In the interview, the breeders should describe the main epidemiological and clinical characteristics of FMD observed in their herds should be described by the breeders interviewed in order to continue with the questionnaire. The number of animals at risk, affected and killed by FMD during outbreaks will be recorded to determine morbidity and mortality rates by animal category using according to the following formulas.

$$\text{Morbidity rate} = \frac{\text{number of animals infected during outbreaks}}{\text{total number of animals at risk}} \times 100$$

$$\text{Mortality rate} = \frac{\text{number of animals that died from FMD during outbreak}}{\text{total number of animals at risk}} \times 100$$

Estimation of Economic Losses

The method used by Knight-Jones and Rushton in 2013 to assess, the economic impact of livestock diseases was used as a basis for evaluating the economic losses associated with foot-and-mouth disease (FMD). In the present work, the economic impact of FMD focuses on four main aspects.

Losses Due to Processing Costs

Economic losses due to foot-and-mouth disease (FMD) treatment costs were estimated as the algebraic sum of all losses from treating affected subjects in all categories (Knight-Jones and Rushton, 2013).

$\mathbf{PTrait} = \sum_{\mathbf{i=0}}^{\mathbf{n}}(\mathbf{Ti})$

PTrait = Total financial losses due to average processing costs;

Ti = average cost of treating sick animals in a herd i.

Losses Due to Mortality

The losses due to mortality equalled the market price of the animal that died. Thus, the financial loss due to mortality was calculated as follows:

$\mathbf{PMort} = \sum_{\mathbf{i=0}}^{\mathbf{n}}(\mathbf{Nm} * \mathbf{P})$

PMort = financial losses due to mortality.

Nm = number of dead animals;

P = The normal, average market price of an animal.

Total Economic Losses

Total economic losses will therefore be the sum of all losses from treatment costs and mortality.

$\mathbf{PET} = \sum_{\mathbf{i=0}}^{\mathbf{n}}(\mathbf{PTrait} + \mathbf{PMort})$

PET: total economic losses for all herds,

PETrait: Loss due to processing costs;

PEMort: Economic losses due to mortality.

The average economic loss per head of affected animal will be determined by dividing the total economic losses by the number of affected animals.

Statistical Analysis

The data collected through the survey sheets was entered into 'Sphinx Plus²' (version 5.0) the software to create tables and graphs. Statistical analyses that were carried out using SPSS® software (version 23.0).

The quantitative data were exported and processed using the Microsoft Excel® software which was also used for the descriptive analysis and automatic loss calculations according to the aforementioned formulas. The chi-square independence test with a significance threshold of $p < 0.05$, or the exact Fisher test when the expected numbers in the contingency table were less than 5, was used to test the association between seropositivity and the different variables, with a significance threshold of 0.05. Variables that were statistically related to the presence of the disease led us to estimate the odds ratio by simple logistic regression and the corresponding 95% confidence intervals.

A one-factor analysis of variance (ANOVA) was performed out to identify the significant factors contributing to variation in different economic losses. The Tukey test, was used for multiple comparisons; this test takes into account Student's range statistic to perform all pairwise group comparisons, was used for multiple comparisons. In each test, the dependent variable was the loss category and the independent variable was the farmer's socioeconomic characteristics.

RESULTS

Characteristics of the Surveyed Breeders

A total of 175 small ruminant farmers were interviewed during the survey, including 73 in the North (41.7%), 50 in the Far North (28.6%), and 52 in Adamawa (29.7%). Of these, the majority were over 30 years old are (82.9%). Furthermore, small ruminant breeding is much more prevalent among Muslims in Adamawa, accounting for 86.5% of surveyed breeders. This is followed by the North region, where 65.8% of the surveyed breeders, engage in this practice, and finally the Far North, where the figure stands at 80.0%.

The majority of surveyed breeders who were asked about the appearance of FMD outbreaks have not been to school, with 60% having not attended. Indeed, fewer than 45% of breeders reported having studied, at any level, be it primary, secondary or university. All of these data are presented in Table 1, which shows the sociodemographic characteristics of the surveyed breeders by region.

Table 1: Characteristics of the surveyed breeders (n.b. %)

Settings	Adamawa	North	Far North	Total
Age:				
< 30	11 (21.2)	9 (12.3)	10 (20.0)	30 (17.1)
> 30	41 (78.8)	64 (87.7)	40 (80.0)	145 (82.9)
Religion:				
Muslim	45 (86.5)	48 (65.8)	40 (80.0)	133 (76.0)
Christian	7 (13.5)	25 (34.2)	10 (20.0)	42 (24.0)
Level of study:				
None	34 (65.4)	46 (63.0)	25 (50.0)	105 (60.0)
Primary	12 (23.1)	18 (24.7)	22 (44.0)	52 (29.7)
Secondary	6 (11.5)	8 (11.0)	3 (6.0)	17 (9.7)
University	0 (0.0)	1 (1.4)	0 (0.0)	1 (0.6)

Clinical Signs of Disease

Table 2 shows farmers' knowledge of the main clinical signs of foot-and-mouth disease by farmers based on occurrence rates. Breeders declared that they had recognised lameness with at a rate of 99.4%. From this figure, it appears that the breeders recognised the presence of mouth ulcers on the hooves 97.7% of the time. The appearance of aphthae and oral mucosal erosions was recognised at a rate of 88.0%. These breeders recognised mastication disorders in 82.3% of case, nasal ulcers in 59.4% of cases, and mammary ulcers in 18.3% of cases.

Table 2: Knowledge of the main clinical signs of FMD by farmers, based on the percentages of occurrences

The main clinical signs of foot-and-mouth disease are:	Percentages of occurrences (%)
Intense and shooting salivation	1.1
Breast ulcers	18.3
Nasal ulcers	59.4
Chewing disorders	82.3
Aphthous ulcers and mucous erosions	88.9

The main clinical signs of foot-and-mouth disease are:	Percentages of occurrences (%)
Aphthous ulcers on the hooves	97.7
lameness	99.4

Mortality and Morbidity due to FMD, Classified by Region and Animal Category

According to the 175 breeders interviewed in our three study areas, the total herd comprised an estimated at 5,718 small ruminants including 3,356 sheep and 2,362 goats. Table 3 shows the mortality and morbidity due to FMD broken down by region and animal category. It appears from this table that a high morbidity and mortality were observed in the young lambs and cabris compared to the adults, with average rates of 56.86% and 60.42%, and 26.17%, and 30.49% respectively.

Table 3: Mortality and morbidity due to FMD by region and animal category

Categories	Settings	Adamawa	North	Far North	Total
Aries	Number	163	764	287	1 214
	Mortality (%)	10 (6.13)	93 (12.17)	34 (11.85)	137 (11.29)
	Morbidity (%)	71 (43.56)	270 (35.34)	117 (40.77)	458 (37.73)
Sheep	Number	129	593	252	974
	Mortality (%)	7 (5.43)	67 (11.30)	35 (13.89)	109 (11.19)
	Morbidity (%)	46 (35.66)	234 (39.46)	99 (39.29)	379 (38.91)
Lambs	Number	144	706	323	1173
	Mortality (%)	36 (25.0)	157 (22.24)	114 (35.30)	307 (26.17)
	Morbidity (%)	95 (65.97)	334 (47.31)	238 (73.69)	667 (56.86)
Goats	Number	98	412	177	687
	Mortality (%)	13 (13.27)	73 (17.72)	27 (15.25)	113 (16.45)
	Morbidity (%)	43 (43.88)	192 (46.60)	85 (48.02)	320 (46.58)
Goats	Number	127	451	189	767
	Mortality (%)	15 (11.81)	87 (19.29)	25 (13.23)	127 (16.56)
	Morbidity (%)	55 (43.31)	209 (46.34)	83 (43.92)	347 (45.24
Cabris	Number	104	495	303	902
	Mortality (%)	30 (28.85)	154 (31.11)	91 (30.03)	275 (30.49)
	Morbidity (%)	68 (65.38)	285 (57.58)	192 (63.37)	545 (60.42)

Direct Losses Related to Foot-And-Mouth Disease

Table 4 shows the direct losses associated with foot-and-mouth disease. He resorts to this table that the inherent morbidity rate for FMD was 96.13%, compared to 44.82% for sheep and an inherent morbidity rate of 51.31% for goats. The mortality rate of these flocks was 44.27%, compared to a mortality rate of 20.05% for sheep and a mortality rate of 24.22% for goats.

Table 4: Direct losses related to foot-and-mouth disease

Category	Initial number of animals	Animals present	Affected animals	Aborted animals	Dead animals
Aries	1 214	1 214	458	----	137
Sheep	998	974	379	214	109
Lambs	1 173	1 174	667	----	307
Goats	687	687	320	-----	113
goats	793	767	347	190	127
Cabris	902	902	545	----	275
Total	**5 767**	**5 718**	**2 716**	**404**	**1 068**

Morbidity Losses

Losses Related to the Cost of Treating Animals Affected by Foot-And- Mouth Disease (FMD)

Table 5 below shows that, from the economic point of view, the cost of treating 2,716 animals affected by foot-and-mouth disease (FMD) was estimated at 4,159,000 CFA francs (€6,398.5), with an average cost of 23,765 ± 30,811 CFA francs (€36.8) per head of small ruminant affected by the disease, depending on the category of animal and the region.

Table 5: Shows losses related to the cost of treating small ruminants affected by FMD, categorised by regions

Region/CMT	BE	BRE	AG	BO	CHE	CAB	BREGEST	CHEGEST	TOTAL
Adamawa	157,000	103,000	127,500	870,00	980,00	985,00	555,00	575,00	784,000
Far North	176,500	137,000	295,500	121,100	116,000	205,500	156,500	455,00	125,3600
North	357,700	341,200	370,500	239,700	275,400	305,600	128,500	102,800	212,1400
Total general	**691,200**	**581,200**	**793,500**	**447,800**	**489,400**	**609,600**	**340,500**	**205,800**	**415,9000**

CMT = Average cost of treatment; BE=Aries; BRE= Sheep; AG= Lambs; BO= Goats; CHE= Goat; CAB= Cabris; BREGEST= Pregnant sheep; CHEGEST= Pregnant goat

Total losses were highest in the North and Far North regions, averaging of 433,526 400,896 FCFA and 386,882 577,742 FCFA, respectively. Financial losses related to the cost of treatment were in the Northern region, averaging of 188,157,233,215 FCFA. Treatment losses vary by species; the average is 118,924,216 FCFA for sheep, compared to 69,232,128,002 FCFA for goats.

However, losses due to processing by livestock systems were higher in semi-intensive systems than in extensive systems with respective averages of 138,315,248,172 FCFA and 75, 028,71,968 FCFA. However, no significant difference ($P > 0.05$) was observed in overall losses between the semi-intensive, intensive system and the extensive systems (Table 6).

Farms where small ruminants were kept alongside cattle incurred greater considerable financial losses, averaging of 154,293,277,957 FCFA, whereas farms where small ruminants were kept separately incurred lower losses, averaging is 103,600,181,702 FCFA (Table 4). Variance analysis revealed a highly significant difference ($P < 0.05$) in the mean total financial losses by region.

However, there was no significant difference in losses between religions, level of study or according to the age of the breeders have no significant difference ($P > 0.05$). Table 6 summarises of losses based on the studied parameters.

Table 6: Summary of losses based on the studied parameters

	Processing losses (FCFA)		Mortality losses (FCFA)		Total losses (FCFA)	
Settings	**Mean ± SD**	**P-value**	**Mean ± SD**	**P-value**	**Mean ± SD**	**P-value**
Region						
Adamawa (52)	32,634 ± 26,882[a]	< 0.0001	53,940 ± 60,192[a]	< 0.0001	86,574 ± 80,580[a]	< 0.0001
North (73)	188,157± 233,215[b]		245,369 ± 209,782[b]		433,526 ± 400,896[b]	
Far North (50)	13,446 ± 30,5839[ab]		254,540 ± 391,655 [b]		386,882 ± 577,742[b]	
Religion						
Muslim (133)	125,433 ± 245,790	0.900	173,153± 216,446	0.2288	298,586 ± 412,271	0.296
Christian (42)	129,814 ± 17,840		247,974 ± 378,841		377,778± 470,185	
Level of study						
None (105)	140,547 ± 271,038		168,703 ± 199,867		309,251 ± 434,499	
Primary (52)	190,036± 113,372	0.602	221,932 ± 369,437	0.761	311,969 ± 425,117	0.926
Secondary (17)	148,700 ± 234,428		231,852 ± 261,924		380,552 ± 415,518	
University (1)	167,500 ± NC		248,000 ± NC		415,500 ± NC	
Age						
< 30 (145)	165,743 ± 382,377	0.5123	177,650 ± 264,304	0.7761	343,393 ± 557,328	0.717
> 30 (30)	118,362 ± 185,943		193,892± 266,559		312,254 ± 396,757	

The parameters affected by the same letters (a, b and c) do not differ significantly at the 5% threshold. SD: standard déviation

Losses Due To Mortality

Overall financial losses due to mortality were higher in the Far North region with at an average of 254,540,391,655 FCFA which differs significantly from the other two regions. There were variations in mortality losses by species with an average of 188,700,377,675 FCFA for sheep and 65,840,86,194 FCFA for goats. However, we note a significant difference ($P < 0.05$) was noted between the three regions and between species.

At the semi-intensive and extensive level livestock farming, the respective average losses due to mortality were 210,299,282,785 FCFA and 86,580,78 296 FCFA. On the other hand, the intensive system presents less damage 77,500,912,16 FCFA. Variations are observed at the individual level in each loss category. However, we note that no significant differences ($P > 0.05$) were observed in overall losses between the semi-intensive, intensive and extensive systems.

Farms where small ruminants were kept alongside cattle incurred greater financial losses, averaging 239,973,315,462 FCFA. While those who are not in associations showed fewer losses, so the average is 150 895 209 210 FCFA. No significant differences were observed (P > 0.05). Table 6 shows the losses by species region and farming system, as well as association with cattle.

Table 7: Losses by species, region and farming system, and in relation to cattle

Losses	Losses from treatment (FCFA)						Losses due to mortality (FCFA)					
	Sheep Mean ± SD	P-value	Gaots Mean ± SD	P-value	Total Mean ± SD	P-value	Sheep Mean ± SD	P-value	Gaots Mean ± SD	P-value	Total Mean ± SD	P-value
Region												
Adamawa (52)	20,134 ± 21,975[a]		125,00 ± 14,649[a]	0.054	32,634 ± 26,882[a]		27,969 ± 40,933[a]		25,971 ± 33,751[a]		53,940 ± 60,192[a]	
North (73)	118,924 ± 211,216[b]	0.0023	69,232 ± 128,002[a]		188,157 ± 233,215[b]	<0.0001	159,821 ± 184,810[b]	0.0011	85,547± 92,723[b]	<0.0001	245,369 ± 209,782[b]	<0.0001
Far North (50)	72,020 ± 130,608[ab]		62,026 ± 197,843[a]		13,446 ± 30,5839[ab]		188,700 ± 377,675[b]		65,840 ± 86,194[b]		254,540 ± 391,655[b]	
Breeding system												
Extensive (25)	37,604 ± 30,909		37,424 ± 53,550		75,028 ± 71,968		49,960 ± 46,750		36,620 ± 4,208		86,580 ± 78,296	
Intensive (2)	9,702 ± 2,041	0.342	32,500 ± 43,133	0.86	42,202 ± 45,534	0.0415	57,000 ± 62,225	0.191	20,500 ± 228,991	0.171	77,500 ± 9,121,6	0.0809
Semi-intensive(148)	85,581 ± 190,893		52,734 ± 146,143		138,315 ± 248,172		143,198 ± 261,595		67,101 ± 85,647		210,299 ± 2,827,85	
Cattle association												
Yes (79)	95,582 ± 184,098		58,711 ± 143,456		154,293 ± 277,957		162,638 ± 292,594		239,973 ± 315,462		239,973 ± 315,462	
Non (96)	60,192 ± 132,673	0.142	43,407 ± 120,440	0.46	103,600 ± 181,702	0.149	101,125 ± 191,132	0.0963	150,895 ± 209,210	0.0268	150,895 ± 209,210	0.0268

The parameters affected by the same letters (a, b and c) do not differ significantly at the 5% threshold. SD: standard deviation

Determination of the Serotypes Present in These Regions

Out of the 63 sera that were subjected to the serological ELISA competition test, 30 samples were found to be seropositive, giving with an overall seroprevalence of 47.61%. A farm is considered positive if it contains at least one positive test subject.

Serotyping tests carried out on the 30 positive sera identified the serotypes present and showed the marked predominance of the serotype O, which was present in all 30 sera.

DISCUSSION

The present study selected 175 breeders. Those whose herds were not affected by the FMD outbreaks were not taken into account. The majority of breeders (82.9%) were over 30 old, as revealed by this study. This is because to the fact that young people lack the financial resources to acquire small ruminants. Furthermore, the study found that, Muslim breeders were dominant in Adamawa, accounting for 86.5% of breeders, compared to 65.8% in the North and 80.0% in the Far North. The strong involvement of Muslim populations, notably the Fulani Mbororo, in livestock farming in northern Cameroon stems results from ancestral pastoral traditions, climate and cultural adaptation to the savannah climate. Their social organisation is centred on goats and sheep. These nomadic or semi-nomadic communities view livestock farming as a way of life. In terms of education, 9.7% of breeders have completed secondary school, while 0.6% have attended university. It appears that breeders who did not attend secondary school encountered FMD foci more frequently than those who did. This can be explained by uneducated farmers' inability to control this disease. The low level of education can be attributed to a historical delay in the introduction of formal schooling, which was initially perceived as a religious threat. This situation is perpetuated by a preference for traditional Koranic education, a lack of infrastructure, and the difficulty young people from these communities face in accessing higher education.

Almost all breeders (59.4% to 99.4%) described the main clinical signs of FMD: Lameness; the presence of mouth ulcers and oral mucosal erosions; chewing disorders; and so on. However, only 1.1% of breeders were able to recognise intense and shooting salivation. The majority of breeders' knowledge of the main clinical signs of FMD is explained by its endemic nature and socio-economic impact. Belsham *et al.,* (2025) evaluated the clinical signs in cattle, which include a fever of ~40°C followed by the development of vesicular lesions on the tongue, hard palate, dental pad, lips, gums, muzzle, coronary band, interdigital cleft and teats in lactating cows. Manoranjan *et al.,* (2015) described the

clinical signs of FMD in sheep and goats. Marked clinical lesions and severe forms of the disease have also been reported. Lameness is often the first clinical sign observed in sheep and goats. Affected animals develop a fever and show reluctance to walk, sometimes separating themselves from the rest of the flock.

The estimated morbidity rate was 96.13%. A total of 1,068 small ruminants were killed by FMD, giving an estimated mortality rate of 44.27%. This can be attributed to farmers' lack of awareness of the disease and their neglect of biosecurity measures on their farms. This result surpasses that of the epidemiological investigation into foot-and-mouth disease and plague of small ruminants in the Ghardaïa region during the epizootics of 2018 and 2019 by Ouafa Hadjadj and Ratiba Baazizz (2019), in which they obtained a mortality rate of 6% in sheep and no mortality in goats. Conversely, these results are lower than those reported in Wilaya, also in this region, where the mortality rate was found to be 58.3% in sheep and 22.6% in goats (Hadj and Guessoum, 2020). In Cameroon's northern zone, Mebanga *et al*., (2022) obtained a mortality rate of 2.2% in dairy cattle, which confirms the established fact that FMD is characterised by low mortality in adult animals (OIE, 2009). The high morbidity and low mortality rates demonstrated in this study can be explained by the small number of farmers surveyed per region and the low numbers of small ruminants reported by most of these farmers. Conversely, studies showing high mortality rates were conducted in all departments of the regions under study, at the national level and at the international level, and involved a large number of small ruminants.

From an economic perspective, the cost of treating 2,716 animals affected by foot-and-mouth disease (FMD) was estimated at 4,159,000 CFA francs (€6,398.5), with an average cost of 23,765 ± 30,811 CFA francs (€36.8) per animal. Losses varied by species; losses were higher in sheep (118,924 ± 216 FCFA) than in goats (69,232 ± 128,002 FCFA). In the northern region, sheep are more highly valued than goats for religious reasons, as they are the animal of choice for sacrifice, which gives them great importance in the eyes of breeders. This explains the higher treatment costs for sheep compared to goats. In the same area, Mebanga *et al.,* (2022) obtained a loss of 164,100 ± 18,436.8 FCFA in cattle in Cameroon. Losses due to processing in livestock farming systems were higher in semi-intensive systems than in extensive systems, with respective averages of 138,315 ± 248,172 FCFA and 75,028 ± 71,968 FCFA. Statistically, these losses differ from those in other systems ($P > 0.05$).

However, there is no significant difference in losses between religions or levels of study, nor according to the age of the breeders ($P > 0.05$).

Financial losses due to mortality were higher in the Far North region, at an average of 254,540 ± 391,655 FCFA, which differs significantly from the other two regions. Mortality losses varied by species, with an average of 188,700 ± 377,675 FCFA for sheep and 65,840 ± 86,194 FCFA for goats. However, we observe a significant difference ($P < 0.05$) between these three regions; the same is true for different species. Conversely, studies on cattle indicate higher mortality rates, averaging 720,000 ± 178,419.3 FCFA in the same area (Mebanga *et al.*, 2022). Some authors have assessed the economic losses in other countries. For example, Jemberu *et al.,* (2014) assessed the economic losses due to foot-and-mouth disease outbreaks in Ethiopia. They found that losses were on average USD 76 per affected herd and USD 9.8 per head of cattle in crop-livestock mixed systems, and USD 174 per affected herd and USD 5.3 per head of cattle in pastoral systems.

Total financial losses associated with this disease were high in the Northern and Far North regions, averaging 433,526 ± 400,896 and 386,882,577,742 FCFA, respectively. Financial losses in cattle in the same area were estimated at an average of 1,341,532.1 ± 180,926.7 FCFA (Mebanga *et al.*, 2022), which is higher than in small ruminants. Nampanya *et al.,* (2013) assessed economic losses in the Greater Mekong Subregion, finding that losses due to foot-and-mouth disease (FMD) per household varied between provinces ($P < 0.001$), amounting to USD 1,124, USD 862, and USD 381 in LPB, XK, and XYL, respectively. These figures represented 60%, 40%, and 16% of the annual household income. Kouato *et al.,* (2018) evaluated spatio-temporal patterns of FMD transmission in cattle and quantitatively assessed the economic impact of the disease in Niger. Their quantitative analysis showed that the average total cost of an FMD outbreak was 499 euros, while the average cost of vaccinating cattle against FMD during an outbreak was estimated to be more than 314 euros.

This study focused on the FMD virus serotype O. Studies conducted in Kenya and Pakistan showed serotype O prevalence rates of 89% (Anderson *et al.*, 1976) and 70% (Zulfiqar, 2003) in small ruminants, respectively. Between 2005 and 2015, serotype O was responsible for each foot-and-mouth disease epidemic in Israel, affecting 41% of small ruminants. (Elnekave *et al.*, 2016). The presence of serotype O in infected animal populations is said to be due to its cosmopolitan nature. This hypothesis is supported by the Pirbright Institute, the reference laboratory for foot-and-mouth disease, which received an annual average of 536 diagnostic samples for FMD from endemic areas, mainly in Africa and Asia, between 2000 and 2004. This is not similar to the 2016 epidemic in Ngaoundere involving cattle, in which four types were identified (A, O, SAT1 and

SAT2). A study by Miranda *et al.,* (2018) on serotypes circulating in cattle in Ngaoundere reported three serotypes (SAT2, O and A). Five serotypes (A, O, SAT1, SAT2 and SAT3) were reported to be circulating in cattle in the Far North Region of Cameroon (Ludi *et al*, 2014). A report on the foot-and-mouth disease situation in Cameroon from 2011 to 2016 indicates the presence of four serotypes: A, O, SAT1 and SAT2 (FAO, 2016). The presence of SAT3 remains doubtful. Mebanga *et al.,* (2022) highlighted the FMD virus serotypes O and A in dairy cattle in the northern regions of Cameroon.

CONCLUSION

This study aimed to evaluate the seroprevalence and economic impact of foot-and-mouth disease (FMD). It appears that FMD is endemic in the northern regions of Cameroon. The epidemiological and economic data of African horse sickness (AFS) were used to estimate the impact of AFS in the northern regions of Cameroon under endemic conditions. During the outbreak, some farmers lost at least one small ruminant. This led to significant economic losses for some farmers. These financial losses are of great importance to both livestock farmers and the nation. The monetary value of these losses across the three regions was estimated at 4,159,000 CFA francs (6,398.5 euros). Controlling FMD would be essential to limit losses, increase livestock farmers' income, and reduce the gap between production and national demand.

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