Study on the epidemiology of foot and mouth disease in Ethiopia

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Summary

This study was designed to describe the status of foot and mouth disease (FMD) in Ethiopia, through analysis of FMD outbreak reports and the detection of antibodies, to address the possibility of establishing a disease-free zone. Serum samples collected from cattle between 2003 and 2006 for the serosurveillance of rinderpest were used for this study. The records of the Ministry of Agriculture and Rural Development from 2002 to 2006 indicate that FMD outbreaks occurred each year in Ethiopia during this period, with the highest number in 2004, when 134 outbreaks took place. The highest rates were from the North Shoa zones of both the Oromia and Amhara regions.

The serum samples were tested using the 3ABC enzyme-linked immunosorbent assay kit, to identify antibodies against FMD. From a total of 4,465 sera, 10.5% (n = 467) tested positive. The highest seroprevalence was detected in samples from the Eastern zone of Tigray with 41.5%; followed by the Guji zone of Oromia and Yeka district of the city of Addis Ababa, with 32.7% and 30%, respectively. Antibodies specific to FMD virus were not detected in Gambella or Benishangul. The effects of cattle, sheep and goat density, both separately and together, were analysed with a spatial regression model, but did not have a significant effect on seroprevalence. This indicates that other factors, such as farming systems and livestock movement, play a significant role in the occurrence of FMD. Based on these study findings, it might be appropriate to establish disease-free zones in Gambella and Benishangul.

Keywords

Cattle – Disease-free zone – Epidemiology – Ethiopia – Foot and mouth disease.

Introduction

The dominant economic feature of Ethiopia is its agricultural sector, of which livestock is an essential component. Ethiopia has the largest livestock population in Africa, with approximately 43.1 million cattle, 23.6 million sheep and 18.4 million goats (3). The highlanders raise livestock and cultivate crops for their livelihood, whereas the lowlanders or pastoralists subsist mainly on livestock and livestock products. Consequently, the government gives due attention to the livestock sector, to take advantage of its contribution to economic growth and to meet the needs of an expanding population (8).

While the livestock sector makes a significant contribution to the national economy, a huge amount of work is required to maximise this contribution. It is accepted that livestock products such as meat, milk, honey, eggs, cheese and butter provide much-needed animal protein to improve the nutrition of the people. Livestock also play an important role in providing export commodities, such as live animals, hides and skins, to earn foreign exchange. In addition, livestock provide the draught power to cultivate smallholdings and thresh crops. Livestock also confer security in times of crop failure, as a 'near-cash' capital stock. Moreover, livestock provide farmyard manure, commonly used for both soil fertility and as a source of energy (8).

In Ethiopia, many of the known infectious diseases of animals occur commonly and are poorly controlled. Foot and mouth disease (FMD) has a great impact on economic development, causing both direct and indirect losses. It is a highly contagious viral disease of cloven-hoofed domestic and wild animal species, characterised by fever, salivation and vesicular eruptions on the feet and mouth (2, 16). Morbidity can rise to 100% in susceptible animal populations but mortality is low, particularly in adults. Infected animals show a spectrum of responses to FMD, ranging from inapparent infection to severe disease and death (16).

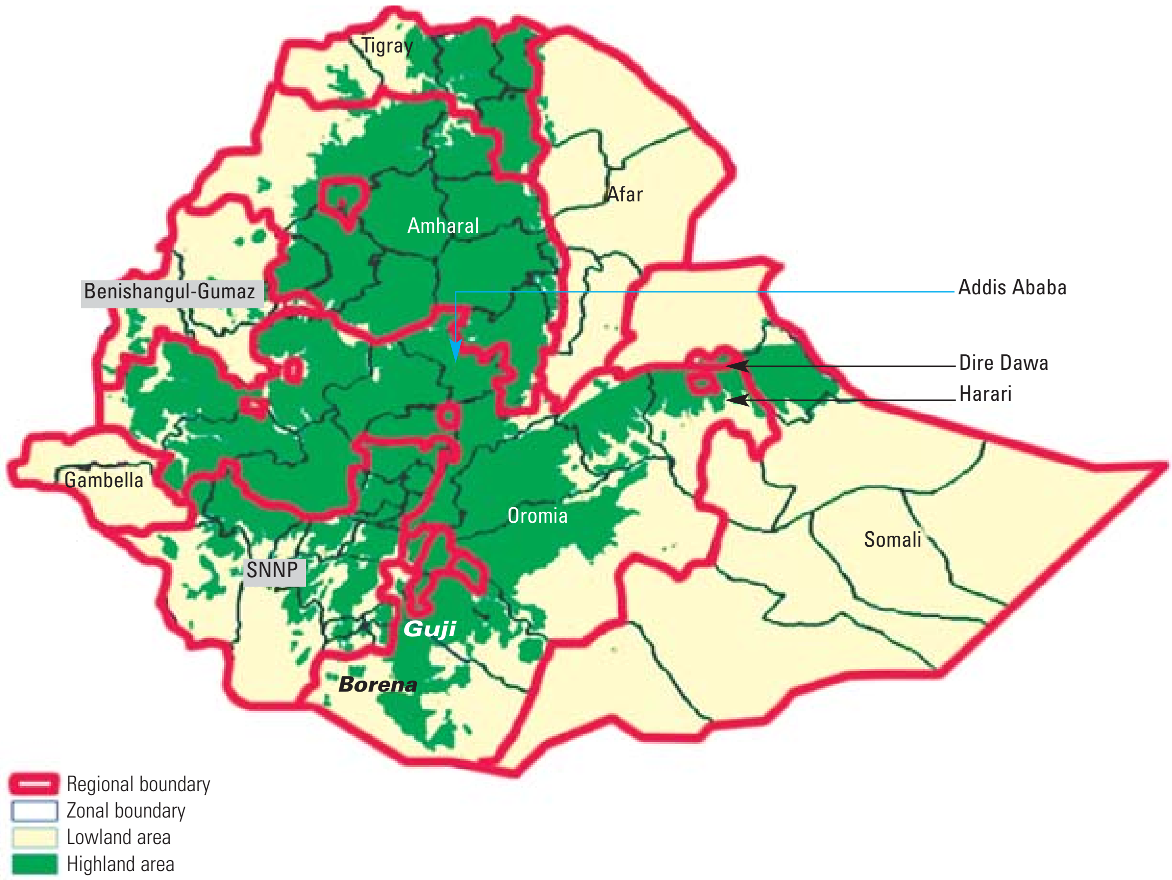
Foot and mouth disease was first recorded in Ethiopia in 1957, when serotypes O and C were found (6, 7). Type A and Southern African Territories 2 (SAT 2) were not identified until 1969 and 1989, respectively (7, 10).

In terms of potential livestock exports from Ethiopia, FMD is seen as a major hindrance to international trade. In part, this perception is based on the assumption that national freedom from FMD is required before exports are possible. At present, the Ethiopian government is hoping to establish a disease-free zone for export purposes – an approach that is supported by the World Organisation for Animal Health (OIE) (8). However, before this can occur, high-quality information that indicates the distribution, prevalence and impact of FMD on animal production in Ethiopia must be gathered. This initial study describes the status of FMD, using outbreak reports and serosurveillance of samples collected from cattle throughout Ethiopia. The objective of this study is to address the need for reliable information and to indicate the possible areas for the establishment of a disease-free zone.

Materials and methods

Study area

Ethiopia is divided into 11 administrative regions. Each region is divided into zones, which are further divided into districts (Fig. 1). There are three major agro-ecological climate zones in Ethiopia:
– the dry climate zone
– the tropical, rainy zone
– the temperate zone.



SNNP: Southern Nations, Nationalities and People's Region
Source: Ministry of Agriculture and Rural Development of Ethiopia, 1999

Fig. 1
Map of Ethiopia showing farming systems
The agro-ecological zones of Ethiopia
The green area is the highlands where mixed farming is practised, while the yellow area is the lowlands, where pastoralism is practised

Classification of the country into agro-ecological zones or administrative regions is of limited value in understanding the epidemiology of FMD. However, classification according to farming systems is probably more useful as the type of farming system influences the transmission and spread of the disease (12).

The two major farming systems in Ethiopia are:

– the communal (pastoral) farming system, conducted mainly by nomads in lowland areas (less than 1,500 m below sea level), in a dry climate

– the semi-intensive and intensive farming system (sedentary), carried out mainly in highland and mid-altitude areas, with a tropical rainy or temperate climate (Fig. 1).

Sample collection

Retrospective data

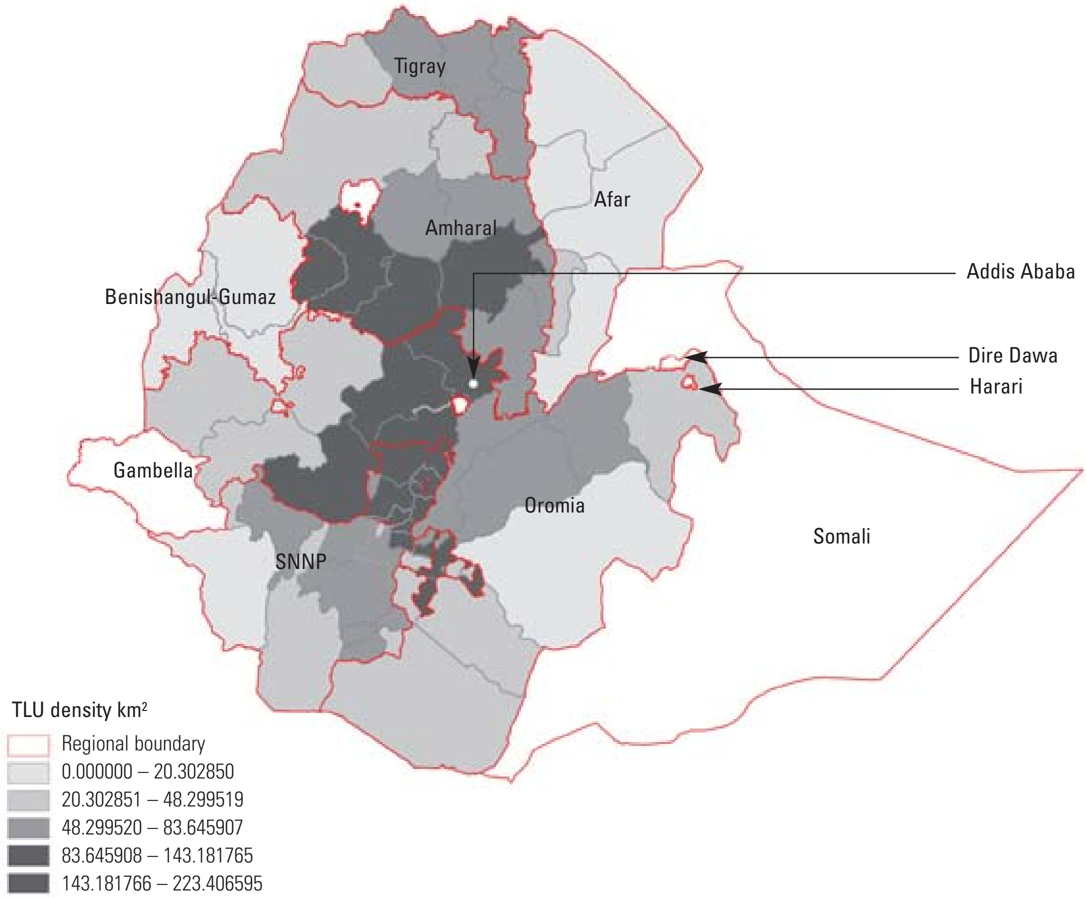
Foot and mouth disease outbreak records from 2002 to 2006, from the Ministry of Agriculture and Rural Development (MOARD), were used to identify areas with frequent outbreaks and to estimate yearly outbreak rates.

Serum samples

Serum samples collected from cattle between one and three years old, for the serosurveillance of rinderpest, between 2003 and 2006, were supplied by the National Animal Health Diagnostic and Investigation Center in Sebeta for use in this study. During rinderpest serosurveillance, 20 sera were collected from each randomly selected village. Since these samples were collected from all parts of the country, using multi-stage sampling techniques, they were considered appropriate for an FMD seroprevalence study.

Study design

A cross-sectional study was carried out to investigate the seroprevalence of FMD in cattle in Ethiopia. The sample size was based on simple random sampling techniques with the following predetermined parameters, i.e. a prevalence of 20% (11), a confidence level of 90% and a specified error of 1%.



SNNP: Southern Nations, Nationalities and People's Region
Source: Food and Agriculture Organization of the United Nations (5)

Fig. 2
Livestock distribution in Ethiopia, expressed in tropical livestock units (TLU)
Cattle = 0.7 TLU; sheep and goats = 0.1 TLU

$$n = \frac{1.96^2 Pexp(1 - Pexp)}{d^2}$$

Where n = required sample size; *Pexp* = expected prevalence (%); and d = desired absolute precision (%)

A minimum of 4,329 samples were expected to be included. The number of villages (217) was determined by dividing the total number of samples by 20, since 20 sera samples were collected from each village during rinderpest serosurveillance. Villages were selected with a simple lottery random sampling technique. Accordingly, 73 villages were selected from Oromia, 33 villages from the State of Southern Nations, Nationalities and Peoples (SNNP), 24 from Amhara, 20 from Tigray, 18 from Addis Ababa, 18 from Afar, 15 from Somali and 8 villages each from Benishangul and Gambella. In each village, a team went to the communal grazing land, placed animals into specific age groups, then randomly selected animals for sampling from the appropriate age groups. However, in Addis Ababa, kebeles (neighbourhoods) were considered as village equivalents and farms were picked with the help of the local veterinary department in various districts. In total, 4,465 sera were processed, since more than 20 sera were obtained from some of the villages.

Risk factors for foot and mouth disease

Ethiopia has the largest livestock population in Africa, with about 43.1 million cattle, 23.6 million sheep and 18.4 million goats (3). The Central Statistical Agency (3) livestock census report was used to determine the cattle, sheep, goat and tropical livestock unit (TLU) density of each zone (Fig. 2). The TLU was calculated by considering that cattle = 0.7 TLU, while sheep and goats = 0.1 TLU (5).

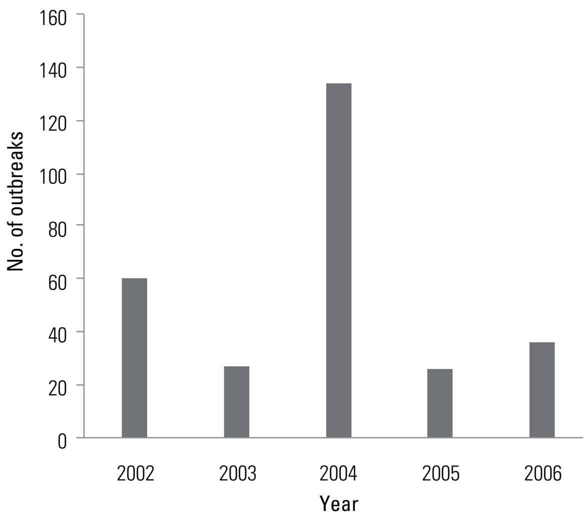
The main objective of this part of the study was to identify any association of livestock density (cattle, sheep and goat density, both separately and combined) with the occurrence of antibodies against FMD in different parts of the country. The livestock density data and serological results were first coded and transferred into Microsoft Excel before being analysed using Statistical Package for Social Sciences (SPSS) software, version 15, using a multiple logistic regression statistical test.

Serological test

A total of 4,465 sera were tested, using the Bommeli Diagnostics FMD virus (FMDV) non-structural 3ABC enzyme-linked immunosorbent assay (ELISA), with 95% sensitivity and 97% specificity, for identifying previously infected animals (4). All the reagents, buffers, microplates and reactive and non-reactive control sera were supplied by the manufacturer (Bommeli Diagnostics, Switzerland). Briefly, the test or reference sera were diluted 100-fold and added in duplicate to 96-well ELISA plates (which had been pre-coated with 3ABC antigen), then incubated for 60 min at 37°C. After incubation, the plates were washed. An enzyme conjugated to anti-species antibody was added to the plate and incubated for another 60 min. After incubation the plates were washed again and developed with tetramethylbenzidine (TMB) substrate solution stopped with 1 M sulphuric acid. The results of the test sera were expressed as an index, derived by dividing the absorbance value of the serum tested by that of the cut-off control.

The formula is as follows, where OD = optical density:

$$Value\ \% = \frac{OD\ sample - OD\ neg \times 100}{OD\ pos - OD\ neg}$$



Source: Ministry of Agriculture and Rural Development of Ethiopia

Fig. 3

Number of foot and mouth disease outbreaks per year, in various parts of Ethiopia, between 2002 and 2006

This is the number of outbreaks reported to the Ministry of Agriculture and Rural Development each year. Disease reported from one site is considered as one outbreak

Table I

Comparison of the prevalence of foot and mouth disease in pastoral livestock systems and highland mixed farming

Farming system	No. of sera tested	No. testing positive	Apparent prevalence (95% confidence interval)	True prevalence
Mixed farming	2,224	142	6.38% (0.054–0.073)	3.67%
Pastoral	2,241	325	14.50% (0.132–0.158)	12.50%
Total	**4,465**	**467**	**10.50% (0.096–0.113)**	**8.15%**

True prevalence (TP) = AP – 1 – Se/Sp – 1 – Se, where AP = apparent prevalence; Se = sensitivity; Sp = specificity (95% confidence interval); test sensitivity = 95% and test specificity = 97%
For total tested:
Positive predictive value = 73.76%
Negative predictive value = 99.54%

Interpretation of the results: a percentage value of less than 20% is negative, 20% to 30% is ambiguous and greater than 30% is positive.

Statistical analysis

The 3ABC test results for each animal and its origin (village, district, zone and administrative region) were recorded in a Microsoft Excel spreadsheet. Descriptive statistical analysis and multiple logistic regressions were carried out using Stata software version 9 (State Corp., College Station, Texas, USA). The maps were generated using ArcGISv9.0 (ESRI, Redlands, California, USA). The true prevalence was calculated using a Win Episcope 2.0 (University of Edinburgh, UK).

Results

Retrospective results

Ministry of Agriculture and Rural Development records between 2002 and 2006 indicate that FMD outbreaks occurred every year, with the highest number in 2004 (134 outbreaks) (Fig. 3). Foot and mouth disease outbreaks were reported from most zones and regions, with the highest rate of up to 128 outbreaks from the North Shoa zones of the Oromia and Amhara regions (Fig. 4).

Serological results

Of the 4,465 sera tested, 10.5% (n = 467) tested positive for the presence of antibodies against FMD, using the 3ABC ELISA test. The true prevalence was calculated at 8.15%, with the positive and negative predictive values being 73.76% and 99.54%, respectively (Table I). The highest seroprevalence was detected in samples from Oromia (20.7%); however, no FMDV-specific antibodies were detected in Gambella or Benishangul. From the administrative zones, the highest seropositivity was obtained from the Eastern zone of the Tigray region, with 41.5%; followed by the Guji zone of Oromia and the Yeka district of Addis Ababa, with 32.7% and 30%, respectively (Table II). A prevalence of 14.8% (n = 325) was obtained ($p < 0.05$) from 2,241 samples collected from the pastoral areas of the country (Table I).

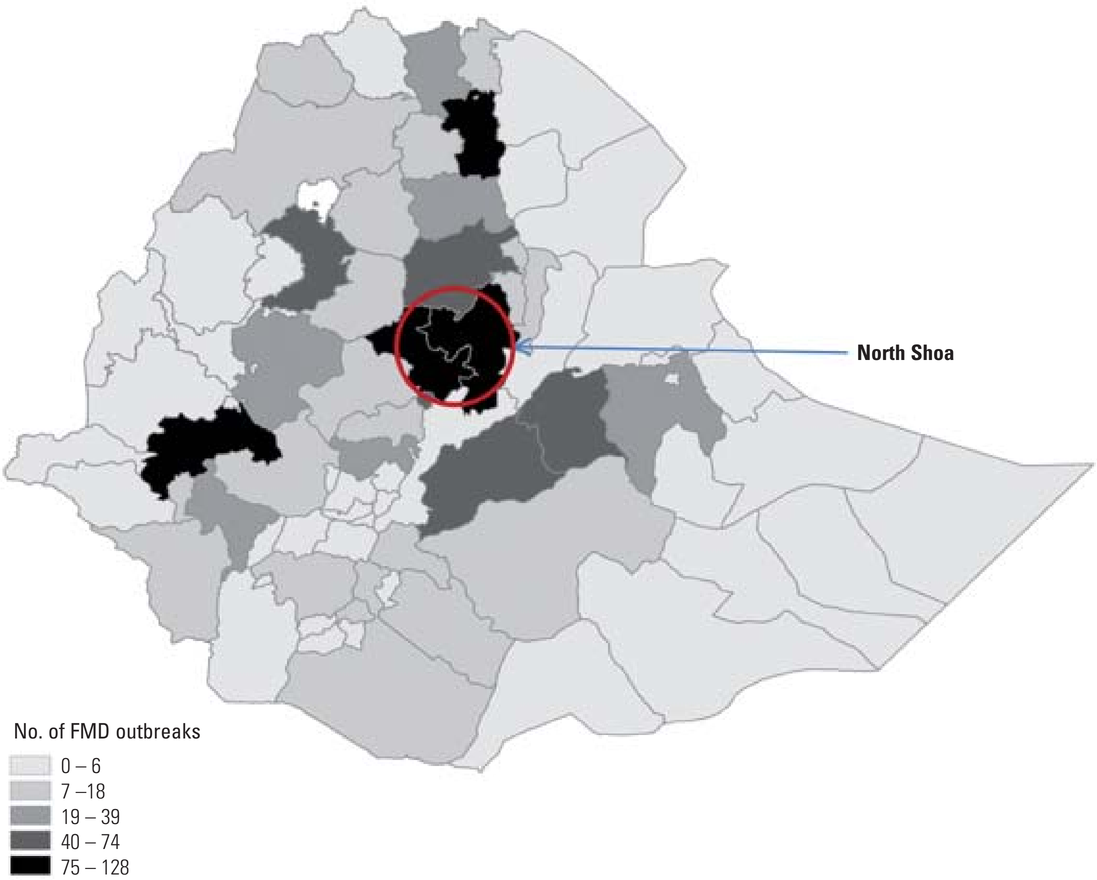


Fig. 4

Map showing the number of foot and mouth disease (FMD) outbreaks and their spatial distribution in various parts of Ethiopia, between 2002 and 2006

The dark shaded area is where a high number of FMD outbreaks were reported, while the lighter areas represent fewer reported outbreaks

Table II
The seroprevalence of foot and mouth disease in the geographic zones of Ethiopia
Tests were conducted using the 3ABC enzyme-linked immunosorbent assay

Region	Zone	No. of sera tested	No. testing positive	Proportion testing positive	95% confidence interval	
Addis Ababa	Addis Ketema	40	0	0	–	–
	Arada	40	1	0.025	-0.026	0.076
	Bole	40	5	0.125	–	–
	Gulele	40	5	0.125	0.017	0.233
	Kirkos	40	2	0.05	-0.02	0.12
	Kolfe Keranyo	40	6	0.15	0.037	0.263
	Lideta	40	2	0.05	-0.02	0.12
	Nefasiklafto	40	4	0.1	0.003	0.197
	Yeka	40	12	0.3	0.15	0.45
Afar	Zone 1	58	0	0	–	–
	Zone 4	299	14	0.047	0.024	0.07
Amhara	Awi	189	8	0.042	0.014	0.071
	North Gonder	101	0	0	–	–
	North Wollo	103	2	0.019	-0.007	0.046
	South Wollo	93	4	0.043	0.001	0.085
Benishangul	Meteket	160	0	0	–	–
Gambella	Itang	160	0	0	–	–
Oromia	Arsi	19	0	0	–	–
	Borena	585	157	0.268	0.233	0.304
	East Harerge	45	4	0.089	0.002	0.176
	East Shoa	80	1	0.013	-0.012	0.037
	Guji	349	114	0.327	0.279	0.374
	Ilubabor	301	10	0.033	0.013	0.053
	North Shoa	173	3	0.017	-0.002	0.037
SNNP	Bench Maji	100	10	0.1	0.047	0.153
	Gomugofa	40	0	0	–	–
	Hadya	160	2	0.013	-0.005	0.03
	South Omo	200	24	0.12	0.077	0.163
	Sidama	160	1	0.006	-0.006	0.019
Somali	Jijiga	66	1	0.015	-0.015	0.045
	Shinile	224	5	0.022	0.003	0.042
Tigray	Central zone	139	37	0.266	0.193	0.339
	Eastern zone	41	17	0.415	0.255	0.574
	Western zone	220	12	0.055	0.025	0.084
Total		**4,465**	**467**	**0.105**	**0.096**	**0.113**

SNNP: State of Southern Nations, Nationalities and Peoples

This study shows that FMD is endemic in most parts of the country, occurring most frequently in the pastoral areas, particularly in the Borena and Guji zones of Oromia. Importantly, however, samples collected from Benishangul and Gambella tested negative for the presence of FMDV (Fig. 5).

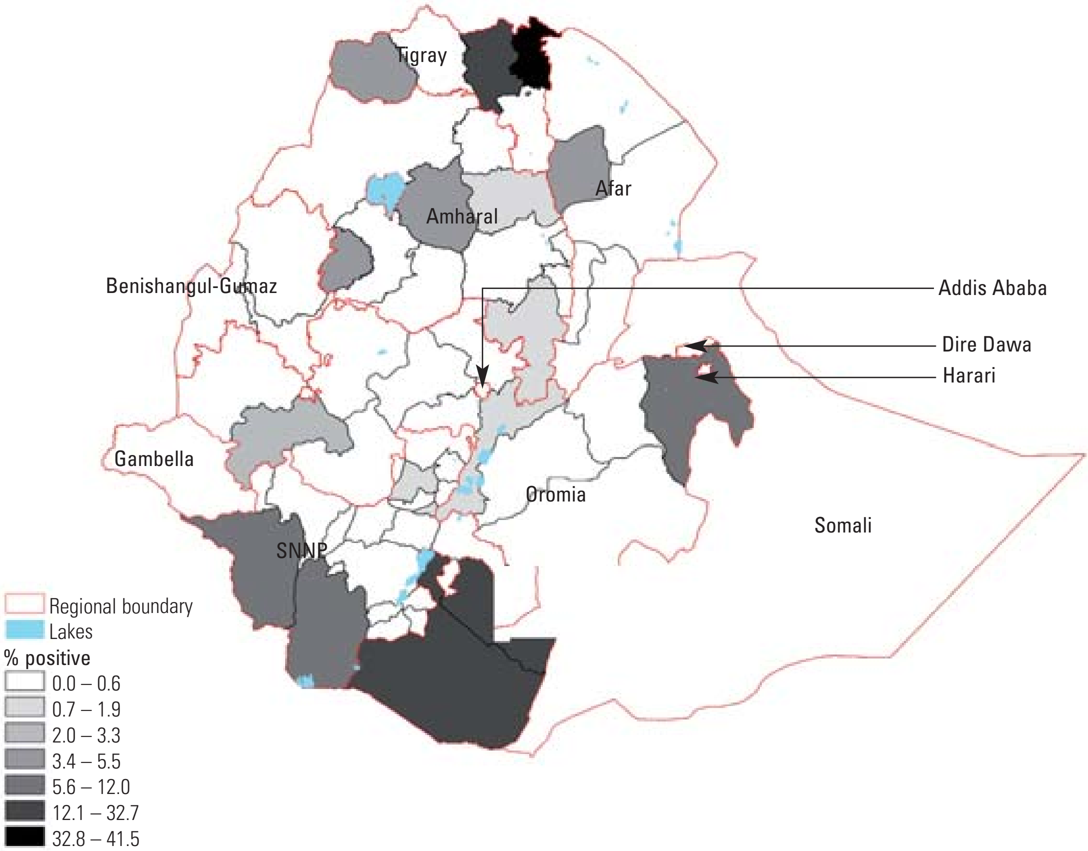
Analysis of risk factors

The densities of cattle, sheep and goats were analysed, separately and together as TLU, for their association with

Table III
Spatial regression analysis of livestock density in relation to the seroprevalence of foot and mouth disease in Ethiopia
Source: Food and Agriculture Organization of the United Nations (5)

Variables	Odds ratio	Standard error	*p*-value	95% confidence interval	
TLU density	1.00	0.01	0.92	0.98	1.02
Goat density	1.07	0.10	0.45	0.90	1.28
Sheep density	1.02	0.10	0.82	0.85	1.23
Cattle density	1.03	0.04	0.54	0.95	1.11

TLU: tropical livestock unit (cattle = 0.7 TLU, while sheep and goats = 0.1 TLU)



SNNP: Southern Nations, Nationalities and People's Region

Fig. 5
Map showing seroprevalence of foot and mouth disease in various parts of Ethiopia
The darker shaded areas represent those regions where a high percentage of seroprevalence was found, while the lighter areas represent a lower seroprevalence

FMD seroprevalence, using SPSS logistic regression. This revealed that none of these densities has a statistically significant correlation as a risk factor for FMD seropositivity (Table III). However, the pastoral method of animal rearing was statistically associated with FMD seropositivity (Table I).

Discussion

Foot and mouth disease is enzootic in most parts of Africa, and only a few countries on the continent have managed to control the disease to allow access to lucrative export markets for live animals and animal products (12, 13). Ethiopia has a large livestock population, including both domestic and wild animals (11, 12), and an FMD outbreak has been reported every year. This disease remains largely uncontrolled in Ethiopia, as prophylactic vaccination is generally not practised, being used for only a few dairy herds containing exotic animals. This retrospective study indicates that frequent FMD outbreaks occur in Ethiopia every year, with the highest number taking place in 2004 (n = 134) (Fig. 3), which is consistent with previous reports (1).

In a country such as Ethiopia, where FMD is endemic, and where large numbers of susceptible domestic and wild ruminants exist, with limited vaccination and disease reporting and investigation, serological surveys are very useful for understanding the epidemiology of the disease. To build up an epidemiological profile of the endemic occurrence of FMD in Ethiopia, 4,465 sera of cattle from various regions were investigated, using the 3ABC ELISA, and a prevalence of 10.5% was obtained. A prevalence of 14.8% (n = 325) was obtained from 2,241 samples collected from pastoral areas of the country. This figure is significantly higher than the prevalence found in settled livestock systems ($p < 0.05$). These seroprevalence rates are lower than those given in the study of Sahle (12), who reported 26.25%, and Rufael *et al.* (11), who reported 21% seroprevalence in the Borena zone. The differences might be due to a decrease in FMD outbreaks. For instance, there were 176 outbreaks in 2001 but this decreased to 26 in 2005 (8).

Spatial analysis has been used retrospectively to assess the 2001 FMD epidemics in Great Britain (15), herd demography in Argentina (14) and goat density in Pakistan (9). During this study, cattle, sheep, goat and TLU densities were analysed for their relationship with FMD seroprevalence in Ethiopia, but no significant association was found. This might be due to the dominance of other factors, such as the pastoral livestock husbandry system, which allows mixing of large numbers of herds at watering points and on grazing pastures.

This study has demonstrated that the Gambella and Benishangul regions are serologically free from FMD, which indicates that these might be suitable areas for establishing disease-free zones. Stamping out FMD in countries like Ethiopia is unlikely. The alternative option of applying vaccination could be suitable, particularly in those areas which have a high seroprevalence. Other control methods, including movement restrictions, especially in pastoralist areas, would need to take account of pastoralist production systems and the efficiency of mobile, opportunistic grazing systems in dry land environments with erratic rainfall. The cross-border movement of herds is customary in much pastoralism and so harmonising control efforts between countries is also essential.

Acknowledgements

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Étude épidémiologique de la fièvre aphteuse en Éthiopie

G. Ayelet, E. Gelaye, H. Negussie & K. Asmare

Résumé

Les auteurs décrivent une étude visant à déterminer la situation de la fièvre aphteuse en Éthiopie ; il s'agissait, à partir de l'analyse des notifications de foyers de fièvre aphteuse et des résultats des tests de détection des anticorps, d'apprécier la possibilité de mettre en place une ou plusieurs zones indemnes de maladie. L'étude sérologique a porté sur des échantillons de sérum bovin qui avaient été prélevés entre 2003 et 2006 lors des opérations de surveillance sérologique de la peste bovine. Les données enregistrées entre 2003 et 2007 par le ministère éthiopien de l'Agriculture et du développement rural (MOARD) font état de la survenue de nouveaux foyers chaque année dans le pays, l'année 2004 étant celle ayant connu le plus grand nombre de foyers signalés (134 foyers). Les taux les plus élevés ont été constatés dans les zones du Shoa-Nord dans les régions d'Oromia et d'Amhara.

L'épreuve sérologique utilisée pour l'étude était une épreuve immuno-enzymatique (ELISA) 3ABC (kit commercial) visant à détecter la présence d'anticorps dirigés contre le virus de la fièvre aphteuse. Les résultats ont été positifs pour 467 échantillons sériques (soit 10,5 %) sur les 4 465 échantillons analysés. La prévalence sérologique la plus élevée se rapportait aux échantillons provenant de la zone orientale de Tigray (41,5%) ; suivaient ensuite les districts de Guji et de Yeka de la communauté urbaine d'Addis-Abeba (32,7 % et 30 %, respectivement). Aucun anticorps dirigé contre le virus de la fièvre aphteuse n'a été décelé dans les échantillons provenant de Gambella ou de Benishangul. Les influences spécifique et cumulée de la densité des populations de bovins, d'ovins et de caprins ont été évaluées au moyen d'un modèle de régression spatiale ; aucune corrélation significative n'a été mise en évidence entre ces densités et la prévalence sérologique. Il en ressort que d'autres facteurs interviennent de manière significative dans l'apparition de la fièvre aphteuse, parmi eux les différents systèmes d'élevage et les déplacements de bétail. Compte tenu de ces observations, les auteurs préconisent la mise en place de zones indemnes de fièvre aphteuse, respectivement à Gambella et à Benishangul.

Mots-clés
Bovins – Épidémiologie – Éthiopie – Fièvre aphteuse – Zone indemne de maladie.

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Estudio de la epidemiología de la fiebre aftosa en Etiopía

G. Ayelet, E. Gelaye, H. Negussie & K. Asmare

Resumen
Los autores describen un estudio encaminado a determinar la situación sanitaria de Etiopía en relación con la fiebre aftosa por el expediente de analizar los informes sobre brotes y sobre detección de anticuerpos, con el fin de estudiar la hipotética creación de una zona libre de esta enfermedad. En el estudio se emplearon muestras de suero de ganado extraídas entre 2003 y 2006 con fines de serovigilancia de la peste bovina. Los registros del Ministerio de Agricultura y Desarrollo Rural (MOARD) entre 2003 y 2007 indican que en Etiopía, durante ese periodo, hubo brotes de fiebre aftosa cada año, con un pico de 134 brotes en 2004. Los índices más elevados se registraron en las zonas de North Shoa, pertenecientes a las regiones de Oromia y Amhara.
Para detectar anticuerpos contra la fiebre aftosa se sometieron las muestras séricas al kit de ensayo inmunoenzimático (ELISA) para la proteína 3ABC. De un total de 4.465 sueros, el 10,5% (n = 467) dieron resultado positivo. La seroprevalencia más elevada (un 41,5%) se observó en muestras de la zona oriental de Tigray, seguida de dos distritos de Addis Abeba, Guji y Yeka, con un 32,7% y un 30% respectivamente. Ni en Gambella ni en Benishangul se detectaron anticuerpos específicos contra el virus de la fiebre aftosa. También se analizaron con un modelo de regresión espacial los efectos de la densidad de bovinos, ovinos y caprinos, tanto por separado como juntos, pero no se observó que tuviera una incidencia significativa en la seroprevalencia. Esto indica que otros factores, como los sistemas de producción o los movimientos del ganado, influyen sustancialmente en la aparición de fiebre aftosa. A tenor de las conclusiones del estudio, quizá fuera conveniente definir zonas libres de fiebre aftosa en Gambella y Benishangul.

Palabras clave
Epidemiología – Etiopía – Fiebre aftosa – Ganado bovino – Zona libre de enfermedad.

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References

1. Asfaw W. & Sintaro T. (2000). – The status of FMD in Ethiopia, a growing concern. Addis Ababa, Ethiopia. *Ethiop. vet. Epidemiol. Newsl.*, **1** (2), 1–5.

2. Brooksby J.B. (1982). – Portraits of viruses: foot-and-mouth disease virus. *Intervirology*, **18**, 1–23.

3. Central Statistical Agency [Ethiopia] (CSA) (2007). – Agricultural sample survey 2006/07 [1999 EC], Vol. II, report on livestock and livestock characteristics. CSA, Addis Ababa.

4. Engel B., Buist W., Orsel K., Dekker A., de Clercq K., Grazioli S. & van Roermund H. (2008). – A Bayesian evaluation of six diagnostic tests for foot-and-mouth disease for vaccinated and non-vaccinated cattle. *Prev. vet. Med.*, **86** (1–2), 124–138, doi: 10.1016/j.prevetmed.2008.03.009.

5. Livestock and Environment Toolbox (1999). – Livestock, Environment and Development Initiative (LEAD). Animal Production and Health Division, Food and Agriculture Organization of the United Nations. Available at: www.fao.org/ag/againfo/programmes/en/lead/toolbox/Index.htm (accessed on 24 October 2012).

6. Martel J.L. (1974). – Foot and mouth disease in Ethiopia. Distribution of foot and mouth disease virus serotypes. *Rev. Elev. Méd. vét. Pays trop.*, **27** (2), 169–175.

7. Martel J.L. & Gallon C. (1975). – Comparative serological study of the principal foot and mouth disease virus strains isolated in Ethiopia, 1969–1974. *Rev. Elev. Méd. vét. Pays trop.*, **28** (3), 287–295.

8. Ministry of Agriculture and Rural Development (MOARD) [Ethiopia] (2005). – Annual report on diseases of livestock in Ethiopia. Veterinary Services Department, MOARD, Addis Ababa, 2–8.

9. Perez A.M., Thurmond M.C. & Carpenter T.E. (2006). – Spatial distribution of foot-and-mouth disease in Pakistan estimated using imperfect data. *Prev. vet. Med.*, **76**, 280–289.

10. Roeder P.L., Abraham G., Mebratu G.Y. & Kitching R.P. (1994). – Foot-and-mouth disease in Ethiopia from 1988 to 1991. *Trop. anim. Hlth Prod.,* **26**, 163–167.

11. Rufael T., Catley A., Bogale A., Sahle M. & Shiferaw Y. (2008). – Foot-and-mouth disease in the Borana pastoral system, southern Ethiopia and implications for livelihoods and international trade. *Trop. anim. Hlth Prod.,* **40**, 29–38.

12. Sahle M. (2004). – An epidemiological study on the genetic relationships of foot and mouth disease viruses in east Africa. PhD thesis submitted to the Department of Veterinary Tropical Diseases, Faculty of Veterinary Science, University of Pretoria, South Africa.

13. Vosloo W., Bastos A.D.S., Sangare O., Hargreaves S.K. & Thomson G.R. (2002). – Review of the status and control of foot and mouth disease in sub-Saharan Africa. *In* Foot and mouth disease: facing the new dilemmas (G.R. Thomson, ed.). *Rev. sci. tech. Off. int. Epiz.,* **21** (3), 437–447.

14. Ward M.P. & Perez A.M. (2004). – Herd demographics correlated with the spatial distribution of a foot-and-mouth disease epidemic in Buenos Aires province, Argentina. *Prev. vet. Med.*, **65**, 227–237.

15. Wilesmith J.W., Stevenson M.A., King C.B. & Morris R.S. (2003). – Spatio-temporal epidemiology of foot-and-mouth disease in two counties of Great Britain in 2001. *Prev. vet. Med.*, **61**, 157–170.

16. World Organisation for Animal Health (OIE) (2008). – Manual of standards for diagnostic tests and vaccines. OIE, Paris, 77–86.