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Assessment of communal farmers' knowledge of foot-and-mouth disease (FMD) within the FMD protection zone with vaccination of Limpopo and Mpumalanga Provinces, South Africa

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A R T I C L E I N F O

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A B S T R A C T

Foot-and-mouth disease (FMD) is a highly contagious disease affecting domestic livestock and its control in South Africa depends on methods including event-based surveillance and the reporting of disease by farmers. This study assessed FMD knowledge level among small-scale, communal livestock farmers in South Africa's FMD zone with vaccination. A cross-sectional study was conducted with 629 farmers from 44 dip-tanks (animal assembly points). A FMD knowledge score was derived from 25 yes/no questions with scores above the median classified as high FMD knowledge. Mixed-effects logistic regression was used to evaluate predictors of high FMD knowledge with associations reported as odds ratios (OR) and their corresponding 95 % confidence intervals (CI). Eighty percent of the participants were male and 65 % aged 60 or older. The most common livestock raised was cattle (98.1 %). Sixty-six percent (415/629) of the interviewed farmers reported that they were aware of the existence of FMD. Formal education (OR 2.0, 95 % CI, 1.4–2.9, $P < 0.001$), poultry ownership (OR 1.7, 95 % CI 1.1–2.5, $P = 0.006$), livestock farming as the main occupation (OR 1.6, 95 % CI 1.1–2.3, $P = 0.026$) and the total livestock units of their farm (OR 1.5, 95 % CI 1.1–1.9, $P = 0.002$) were significant predictors of FMD recognition. Most respondents (54 %) that claimed to be aware of the existence of FMD did not know that African buffalos were a source of FMD virus. Also, less than half of the respondents cited lameness (38 %) and excessive salivation (37 %) as the main FMD clinical signs. Only a small proportion (2.4 %) of these respondents were aware that movement of infected animals can cause FMD virus to spread to new areas. FMD knowledge scores were calculated for the 415 respondents claiming to be aware of the existence FMD with 174 (42 %) having a total knowledge score greater than the median (hereafter referred to as "high FMD knowledge" compared to the rest of the farmers). Farmers from Vhembe District in Limpopo had an odds of high FMD knowledge four times higher than those in Ehlanzeni District in Mpumalanga (OR 4.0, 95 % CI 1.7–9.4, $P = 0.002$). Farmers that owned more than 15 cattle (OR 1.7, 95 % CI 1.0–2.8, $P = 0.035$) and farmers that supervised their own cattle during grazing (OR 1.6, 95 % CI 1.0–2.5, $P = 0.043$) also had a significantly higher odds of high FMD knowledge. Communal farmers in South Africa have gaps in their FMD knowledge and specifically were not aware that movement of infected animals and their products pose a threat for the spread of FMD. Comprehensive information, education and training for communal livestock farmers are essential for improving event-based surveillance and FMD prevention and control in the region.

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1. Introduction

South Africa is an upper middle-income country, located at the southern tip of the African continent and covers a land area of 1.22 million square kilometers (WBG, 2021). The country shares borders with six countries (Namibia, Botswana, Zimbabwe, Mozambique, Eswatini, and Lesotho, which is landlocked within its territory) and has a population of around 63 million people (WBG, 2023). South Africa has a mix of urban and rural communities, many of whom depend on agriculture for their livelihoods. Livestock production is the largest agricultural sub-sector with diverse animal populations including 12.2 million cattle, 21.4 million sheep, 5.1 million goats, and 1.3 million pigs (WAHIS, 2023). The beef industry is the country's second largest individual agricultural industry with a gross value of R48 billion ($2.7 billion) and contributes 13 % to the total gross value of agricultural products (USDA and GAIN, 2022). Despite the improvements in profitability, beef production has declined over the past decade due to several challenges including animal disease outbreaks (BFAP, 2018; RMIS, 2024). Foot-and-mouth disease (FMD) is one of the most contagious diseases of domestic livestock with severe implications for agricultural productivity and economic stability. African buffaloes carry and maintain the Southern African Territories (SAT) serotypes of the FMD virus (FMDV) in the Kruger National Park (KNP) causing occasional outbreaks in cattle from the bordering communal farming areas (Grubman and Baxt, 2004). In southern Africa, infections due to SAT serotypes of FMDV are often unapparent causing a mild disease in both domestic animals and wildlife (Kitching, 2002; Grubman and Baxt, 2004; Hughes et al., 2017; Sobrino and Domingo, 2017). However, in East Africa (Lyons et al., 2015) and other regions (Ahmed et al., 2012; Ehizibolo et al., 2020) SAT infections have been reported to cause more severe clinical signs.

When clinically affected, animals typically develop blisters and lesions in the mouth and on the tongue that can cause hypersalivation. Feet can also be affected, which can cause lameness. Lesions can cause feeding problems with subsequent weight loss and up to a 75 % drop in milk production (Jemberu et al., 2014). The virus can persist in animal products such as milk, meat and hides with movement of animals and their products increasing the risk of FMDV spread.

In South Africa, FMD is a controlled animal disease as defined in the Animal Diseases Act (1984), and the country is divided into three controlled areas including the infected zone, the protection zone, and the (formerly) free zone of the country (majority of the country). The infected zone includes the Kruger National Park (KNP), and surrounding game reserves where FMD is endemically maintained by African buffalo (*Syncerus caffer*). The protection zone is the buffer area between the infected and non-infected zones. The control of FMD in South Africa relies on compulsory slaughter of infected animals (when FMD outbreaks occur in the designated FMD-free zone), vaccination, disease control fencing (which is a physical separation of livestock and wildlife), movement control and surveillance strategies (DAFF, 2014). A type of surveillance commonly used to detect FMD outbreaks is passive surveillance, which includes both indicator-based surveillance (IBS) and event-based surveillance (EBS). Indicator-based surveillance relies on laboratory test results, whereas event-based surveillance depends on the spontaneous observation and reporting of clinical signs of disease in animals at the farm level (Garner et al., 2016).

Livestock keepers are key elements of FMD event-based surveillance and early warning due to their proximity to the animals and their active involvement in the day-to-day management of livestock. Their vigilance, reporting, and collaboration with veterinary professionals are vital in early disease detection and control. However, reporting of disease by farmers is limited by a number of factors including inability to recognize the disease (Hopp et al., 2007; Garner et al., 2016). Despite the critical role of farmers in disease control, limited research has been conducted to evaluate FMD knowledge among small-scale, communal cattle producers within southern Africa.

This study aims to assess the level of FMD knowledge and identify predictors of high knowledge among small-scale, communal cattle producers within the FMD protection zone with vaccination of South Africa.

2. Materials and methods

2.1. Study area

This study was conducted in the FMD protection zone with vaccination (PZV) in Mpumalanga and Limpopo Provinces, adjacent to the Kruger National Park (KNP) at the domestic-wildlife interface (Fig. 1). The FMD protection zone in KwaZulu-Natal Province was excluded from the study, as it is a recently designated protection area (2014). Livestock farming, primarily cattle (78 %), is the main agricultural activity in these communal grazing areas owned by the state (Lazarus et al., 2017). There were an estimated 56 845 registered farmers, together owning a total of 600 384 heads of livestock of which 77.4 % were cattle, 15.6 % goats, 5 % pigs, and 1.6 % sheep. (Jongh, 2018). The KNP and the surrounding areas are a declared FMD controlled area in terms of the Animal Diseases Act (1984) regulations (DAFF, 2014) with restrictions on livestock movement and marketing.

2.2. Ethics approval

The study protocol was approved by the local Research Ethics Committees (blinded for per review) (Ethics reference number: REC166–20). Only participants aged 18 years or older, who agreed to participate after providing informed consent were included in the study. Personal information disclosed by the famer during the administration of the questionnaire was treated as strictly confidential.

2.3. Study design

A cross-sectional study was conducted using a two-stage selection process. In the first stage, available dip-tanks (livestock inspection points) were listed, stratified by province, and randomly selected. A total of 205 dip-tanks are located in the PZV with 55 in Limpopo (with 33 and 22 respectively in Vhembe and Mopani districts) and 150 Mpumalanga (all in Ehlanzeni district). The sample size was calculated using StatCalc within the EpiInfoTM version 7.2.1.0 software (CDC, Atlanta, GA, USA) assuming a proportion of 50 % of livestock farmers with FMD knowledge assessed as high (no prior information was available), a 10 % margin of error, a confidence level of 95 % and a design effect of 1.5 to account for a clustered sampling design related to dip-tank. The required sample size was then increased by 10 % to account for possible missing data and subsequent exclusions. The final sample size was 158 farmers, and it was expected that three farmers per dip-tank would consent to the in-person questionnaire and therefore the number of dip-tanks to be sampled was determined by dividing the sample size by three (number of required participants per dip-tank) yielding a total of 44 dip-tanks. Simple random sampling was used to select dip-tanks proportional to the total within each province, with 12 and 32 selected in Limpopo and Mpumalanga respectively.

2.4. Questionnaire development

The questionnaire comprised three sections: demographics, livestock management, and FMD knowledge (recognition, clinical signs, transmission, and prevention). The questionnaire was pre-tested and revised based on feedback from a herd health expert (blinded for per review) and a pilot study (n = 5) in a communal area in Limpopo Province but outside the PZV.

A survey design feature (skip logic) was used to allow respondents to skip certain questions based on previous responses. For example, only respondents who reported being aware of the existence of FMD were asked subsequent questions about FMD causes, clinical signs, mode of spread, and prevention.

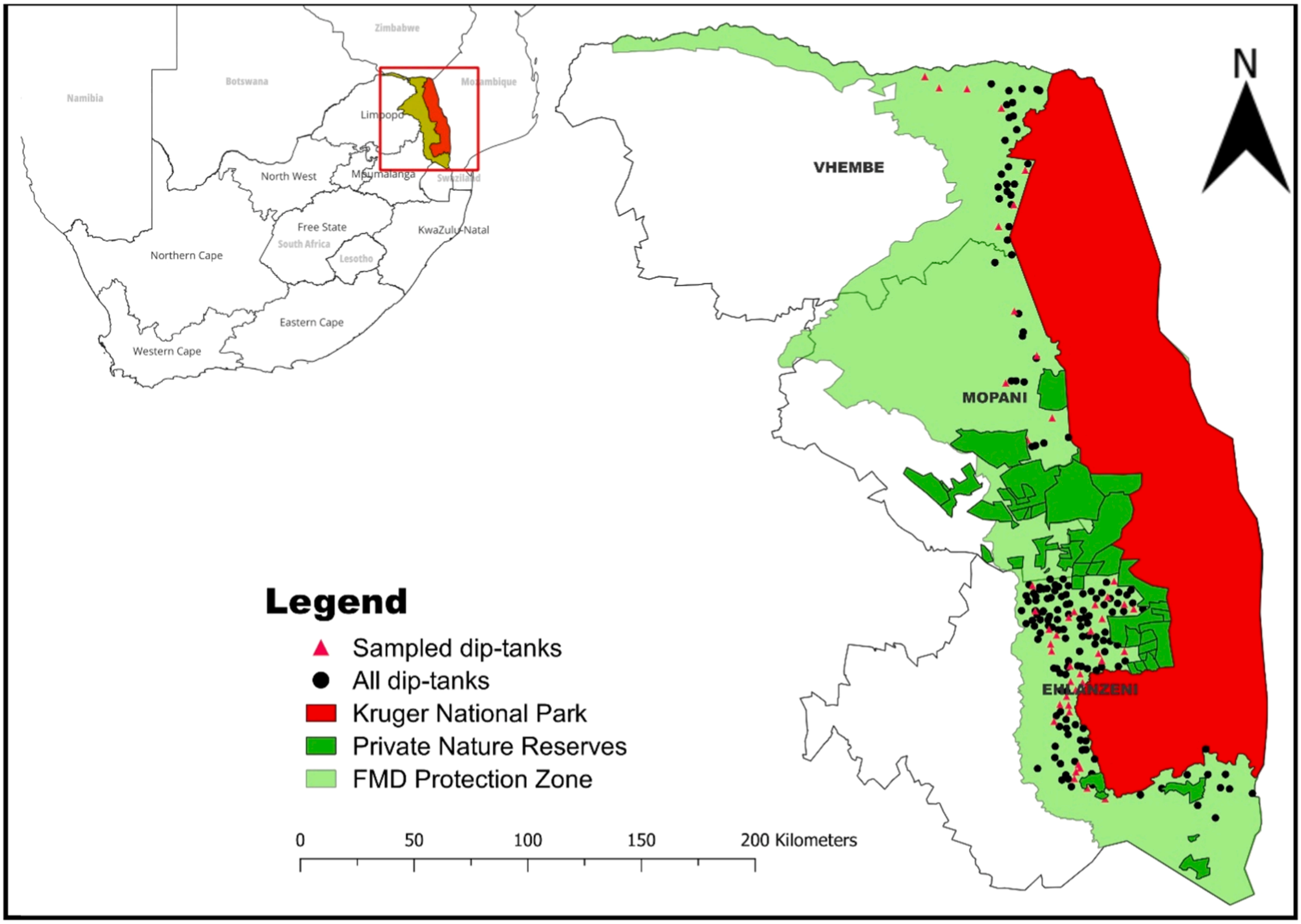

Fig. 1. Foot-and-mouth disease control area with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

2.5. Questionnaire administration

The questionnaire (Supplemental material) was administered in-person to cattle owners aged 18 years or older, who agreed to participate after providing informed consent. Livestock farmers were enrolled as they presented their animals for FMD surveillance and dipping at the randomly-selected dip-tanks. Farmers were selected in sequential order with the first three who agreed included in the study. Other owners who were also interested to participate were subsequently enrolled. To ensure that the interviewed farmers were the actual cattle owners, the cattle ownership card (cattle stock card) was requested for verification. Each participating farmer received a small incentive (a baseball-style cap). Two locally residing animal health technicians were trained and used as enumerators for data collection. The interviews were conducted in a local language (Tsonga) and each lasted 20 minutes on average. Data were collected using electronic tablets with the questionnaire implemented in the Kobo Collect (Version 2023.1.2) Android application and subsequently downloaded, cleaned, and validated in Excel (Microsoft® Excel® for Microsoft 365 MSO, Version 2308 Build 16.0.16731.20542).

2.6. Data manipulation

Total livestock units (LU) were calculated from the livestock species and numbers present on each farm using coefficients based on the nutritional or feed requirement of each animal (EUROSTAT, 2023). Cattle, goats, sheep, pigs and poultry were considered for LU calculations.

FMD knowledge scores were calculated by the simple summations of scored responses within the questionnaire. Twenty-five yes/no questions were used to calculate the total FMD knowledge score, which theoretically ranged between -25 and 25. Correct responses were scored as + 1, incorrect responses as −1 and unsure/missing coded as 0. Scores greater than the median were classified as high FMD knowledge**.**

2.7. Data analysis

2.7.1. Descriptive analysis

The socio-demographic characteristics of the communal livestock farmers were summarized using frequencies and proportions. The percentage of households engaged in livestock farming was calculated and the mean herd size, median herd size, and inter-quartile ranges for different types of livestock species raised were computed. Frequencies, proportions and their corresponding 95 % confidence intervals (CI) were used to summarize questionnaire responses related to the recognition of FMD causes, clinical signs, mode of spread and prevention.

2.7.2. Mixed-effects logistic regression analysis

Based on the questionnaire responses, two outcomes were analysed: the yes/no FMD knowledge claim and a high FMD knowledge score. The FMD knowledge claim model included respondents who reported that they were aware of the existence of FMD against those who were not aware of FMD. The FMD high knowledge score model was based on an FMD knowledge score greater than the median (yes/no) and only included individuals that initially claimed to be aware of the existence of FMD.

For both outcome variables, potential risk factors were evaluated using a mixed-effect logistic regression model. To account for clustering of farmers in each selected village, dip-tank was entered as a random effect assuming a variance components covariance structure. Quantitative predictors were categorized into four groups using percentiles, dichotomized at the median, and evaluated as continuous variables when approximately linear in the log odds. Univariate models were used to screen each potential risk factor and Spearman's rank correlation coefficient (rho) was used to assess collinearity among predictors. Variables with a Spearman's rho > 0.7 or < -0.7 were considered collinear and only the variable with the strongest apparent association with the outcome variable was considered for multivariable modelling. All non-collinear variables with significant Wald statistics at the P < 0.2 level were added into a multivariable logistic regression model. Final multivariable models were constructed using a backward-stepwise approach through the removal of variables with the largest Wald P-value. Variables were excluded one-by-one until all remaining variables in the model had P-values less than 0.05. Interaction terms were not investigated. Statistical modelling was performed using commercial software (IBM SPSS Statistics Version 27, International Business Machines Corp., Armonk, NY, USA) and P < 0.05 used as the criterion for predictor significance.

3. Results

3.1. Description of the study population

A total of 629 farmers from 44 dip-tanks within the FMD PZV participated in the questionnaire investigation with the majority (69 %) being from Mpumalanga Province (Table 1). Eighty percent were male and 65 % aged 60 or older. The most commonly raised livestock was cattle (98.1 %) with an average herd size of 13.6 head (Table 2).

3.2. Predictors of FMD recognition

Of the 629 participating farmers, 415 (66 %) reported being aware of the existence of FMD. Six evaluated variables were significantly associated with reportedly being aware of FMD in the univariate analyses (Supplemental Table 1). In the final multivariable model, formal education, poultry ownership, the total livestock units of their farm and livestock farming were significant predictors of FMD recognition (Table 3).

3.3. Predictors of high FMD knowledge

The median calculated FMD knowledge score for respondents who reported being aware of FMD was 2 (absolute range [-3;7]) (Fig. 2). Most respondents (54 %) did not know that African buffalos were a source of FMD. Fewer respondents cited lameness (38 %) and excessive salivation (37 %) as main FMD clinical signs. A small proportion (2.4 %) of respondents were aware that the movement of infected animals can cause FMDV to spread to new areas (Table 4). Of the respondents who reported being aware of FMD, 42 % (174/415) had a total knowledge score greater than the median (hereafter referred to as "high FMD knowledge"). Seven variables were significantly associated with a high FMD knowledge score on univariate analyses (Supplemental Table 2). In the final multivariable knowledge score model, livestock farmers from Vhembe District in Limpopo Province were four times more likely to have a high FMD knowledge score compared to those in Ehlanzeni District in Mpumalanga (OR 4.0, 95 % CI 1.7–9.4, P = 0.002) (Table 5). Owning more than 15 cattle (OR 1.7, 95 % CI 1.0–2.8, P = 0.035) and grazing their own cattle (versus another person or unsupervised grazing) were also significantly associated with having high FMD knowledge (OR 1.6, 95 % CI 1.0–2.5, P = 0.043).

Table 1
Socio-demographic characteristics and frequency distribution of communal livestock farmers (n = 629) interviewed between (2022–2023) in the FMD protection zone with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

Variables	Category	Frequency (%)		
		Limpopo	Mpumalanga	Total (%)
Gender of respondent	Male	143 (28.4)	360 (71.5)	503 (79.8)
	Female	55(43.6)	71(56.3)	126 (20.0)
District of respondents	Vhembe	126	-	126 (20.0)
	Mopani	72	-	72 (11.4)
	Ehlanzeni	-	431	431 (68.4)
Age of respondent	18–28 years	3 (60.0)	2 (40.0)	5 (0.8)
	29–40 years	6 (20.6)	23 (79.3)	29 (4.6)
	41–50 years	16 (25.3)	47(74.6)	63 (10.0)
	51–60 years	44 (36.6)	76 (63.3)	120 (19.0)
	> 60 years	127 (30.9)	283 (69.0)	410 (65.1)
Level of education	Professional	2 (33.3)	4 (66.6)	6 (1.0)
	Bachelor	2 (22.2)	7 (77.7)	9 (1.4)
	College	3 (50.0)	3 (50.0)	6 (1.0)
	Secondary school	39 (20.42)	143 (78.5)	182 (28.9)
	Middle school	5 (4.3)	109 (95.6)	114 (18.1)
	Elementary	59 (98.3)	1 (1.6)	60 (9.5)
	No formal education	82 (33.3)	164 (66.6)	246 (39.0)
Cattle grazing management	Primary owner	92 (30.8)	206 (69.1)	298 (47.6)
	Hired herdsmen	74 (26.4)	206 (73.5)	280 (44.7)
	Other family member	24 (58.5)	17 (41.4)	41 (6.5)
	Cattle graze unattended	6 (85.7)	1 (14.2)	7 (1.1)
Respondent's occupation	Crop farming	0 (0.0)	8 (100)	8 (0.5)
	Government employee	16 (59.2)	11 (40.7)	27 (4.3)
	General employee	6 (11.1)	48 (88.8)	54 (8.6)
	Own business	11 (47.8)	12 (52.1)	23 (3.7)
	Household keeper	8 (88.8)	1 (12.5)	9 (1.4)
	Livestock farming	90 (21.0)	338 (78.9)	428 (67.9)
	Pensioner	64 (83.1)	13 (16.8)	77 (12.2)
	Student	1(100)	0.(0.0)	1 (0.2)

Table 2
The percentage of household, mean herd size, median and the inter-quartile ranges of livestock species types raised by communal livestock farmers (n = 629) interviewed between (2022–2023) in the FMD protection zone with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

Species	Household Frequency (%)			Herd size	
	Limpopo	Mpumalanga	Total	Mean (SD)	Median (IQR)
Cattle	186	430	616 (98.1)	13.6 (19.1)	9 (5–15)
Goats	65	153	218 (34.6)	10.2 (9.9)	7 (4–12)
Sheep	7	4	11(1.7)	8.7 (10.3)	6 (2–9)
Pigs	6	47	53 (8.4)	7.5 (9.1)	5 (3–8)
Poultry	26	216	242 (38.9)	23.2 (40.0)	15 (10–25)
Donkey	6	0	6 (1.0)	7.67 (2.7)	7 (5–11)

SD = standard deviation. IQR = inter-quartile range

4. Discussion

This study evaluated the knowledge of FMD and identified predictors of high FMD knowledge among small-scale, communal livestock farmers within the FMD control zone with vaccination of South Africa. The majority of communal farmers involved in livestock farming were older

Table 3
Multivariable analysis of factors significantly associated with FMD yes/no knowledge claim among communal farmers (n = 629) interviewed between (2022–2023) in the FMD protection zone with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

Variables	Slope parameter	Odds ratio	95 % CI	p-value
Education level of respondent				
None	Referent			
Some school level	0.698	2.04	1.41–2.4	< 0.001
Own poultry				
Yes	0.542	1.71	1.16–2.53	0.006
No	Referent			
Occupation of respondents				
Livestock farming	0.451	1.57	1.05–2.33	0.026
Work outside livestock	Referent			
Total livestock units (LU) (per 10 LU continuous)	0.414	1.51	1.16–1.95	0.002

males.

The dominance of males in our study could be due to the focus on cattle farmers; pig and poultry production are more often women-driven activities (Assan, 2014; Dione et al., 2020). Male dominance in livestock production has also been reported in other studies of smallholder livestock farmers in Mpumalanga (Mupfunya et al., 2021) and in Vhembe District of Limpopo Province (Chaminuka et al., 2014). Another possible explanation as to why few females were involved in livestock farming in our study is that in sub-Sahara Africa, women's roles in livestock production are strongly determined by gender and cultural norms (Galiè et al., 2019). These norms place limits on women's ability to make decisions about livestock raising and ownership (Alkire et al., 2013; Baltenweck et al., 2024). Gender can also influence access to resources including land, animal health services, credit and training, which are essential to livestock production (Price et al., 2018; Baltenweck et al., 2024). Such gender-based inequalities in the livestock sector likely explains the higher representation of male participants in our study.

The most common livestock raised was cattle. In addition, goats, pigs and poultry were also reportedly raised by participants in this study. The dominance of cattle farmers in our study could be due to the fact that interviewed farmers were selected at the dip-tank where only cattle farmers are required to be present. However, other studies also reported this cattle dominance within the FMD protection zone of South Africa (Lazarus et al., 2021; Ngoshe et al., 2022). Mean herd size of cattle was also similar to that reported in the Mnisi communal farming area in Bushbuckridge, Mpumalanga Province (Van Rooyen, 2016).

Most respondents (66 %) reported that they are aware about FMD contrasting with a greater proportion (94 %) of respondents who claimed FMD knowledge among small-scale dairy farmers in Kenya (Nyaguthii et al., 2019). The finding that 34 % of the respondents in this study were not aware of the existence of FMD was unexpected given that all respondents were selected from dip-tanks within the FMD PZV where regular inspection for FMD clinical signs are conducted once a week. One possible explanation of this lack of FMD recognition among some farmers is that while the dip-tank is a hub for information sharing and knowledge dissemination, farmers irregularly attend dip-tank sessions. Poor attendance can be a concern especially in locations where the dip-tank is not functioning due to infrastructure problems, lack of water or dipping medication. Inconsistent attendance might negatively impact communication and information dissemination between farmers and veterinary officials. For example, a previous study in the PZV reported that 39 % of interviewed farmers never had contact or communicated with the animal health technician (AHT), 21 % reported contact once in 3–5 months and only 18 % had weekly contact with the AHT (Moerane, 2013).

Another possible explanation is the presence of trust issues, which

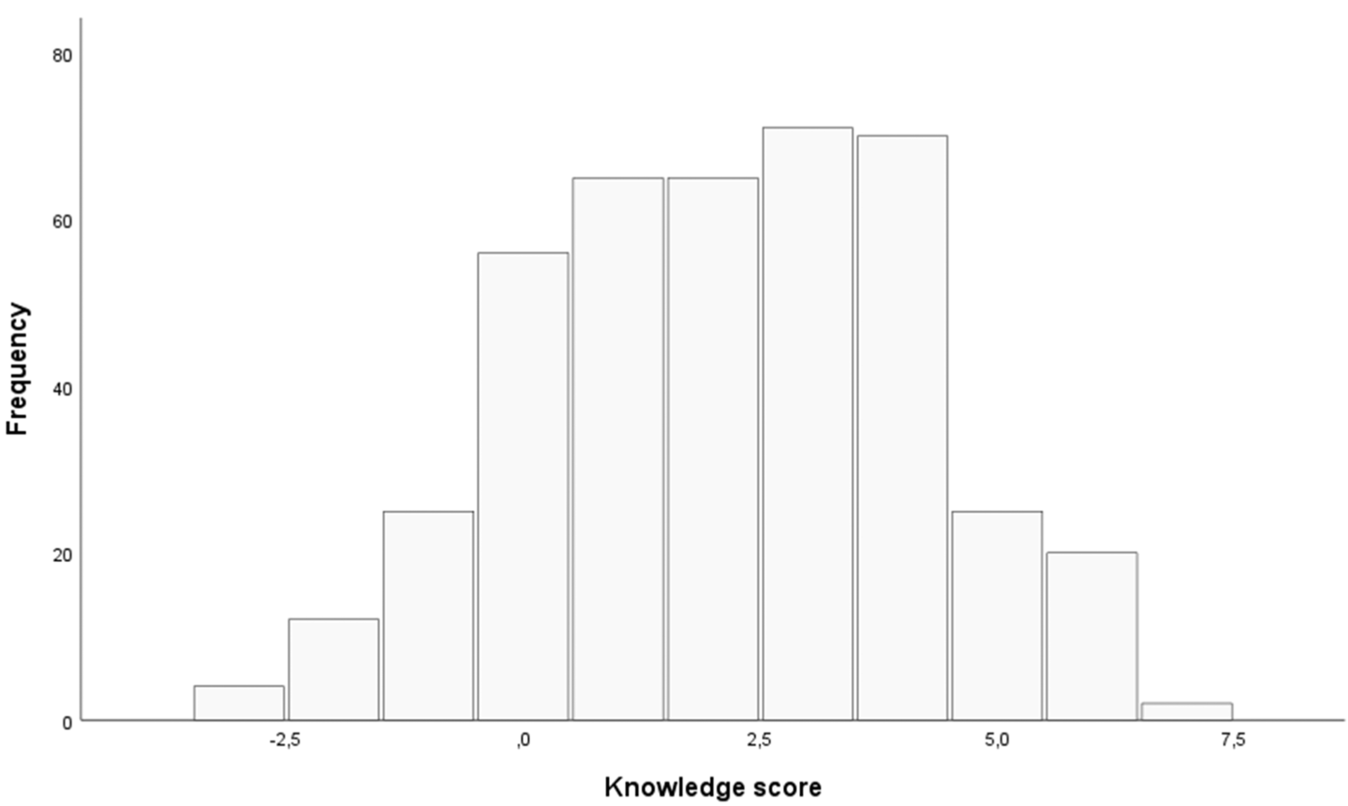

Fig. 2. Distribution of the epidemiology FMD knowledge score (Mean score =2.13) and Std. Dev = 2.053) obtained by smallholder communal farmers (n = 415) interviewed between (2022–2023) in the FMD protection zone with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

Table 4
Descriptive presentation of questionnaire responses related to the recognition of FMD causes, clinical signs, mode of spread and prevention reported by smallholder communal farmers (n = 415) interviewed between (2022–2023) in the FMD protection zone with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

Variables	Correct response	Responses		Percentage (95 % CI) for correct responses
		Yes	No	
FMD causes				
Ticks	No	18	396	95.7 (93.3, 97.6)
Worms in cow faeces	No	9	405	97.8 (96.4, 99)
Virus	Yes	10	403	2.4 (1.0, 3.9)
Buffalo/wildlife	Yes	191	224	46.0 (40.0, 50.7)
Clinical signs				
Ticks on the skin	No	16	398	95.6 (94, 97.8)
Lameness	Yes	156	258	38.0 (33.1, 41.8)
Excessive salivation	Yes	155	259	37.4 (32.9, 41.8)
Weight loss	Yes	33	381	7.9 (5.6, 10.9)
Watery eye	No	2	412	99.5 (98.8, 100)
Decrease in milk production	Yes	1	413	0.2 (0.0, 0.7)
Mode of FMD spread				
Co-grazing	Yes	166	249	40.0 (35.4, 44.6)
Contaminated feed	Yes	88	327	21.2 (17.3, 25.3)
Contact with buffalo	Yes	62	353	15.0 (11.6, 18.3)
Infected animal movement	Yes	10	405	2.4 (1.2, 4.1)
External parasite e.g., ticks	No	4	411	99.0 (98.0, 99.8)
Airborne disease	Yes	7	408	1.7 (0.5, 3.1)
Manure of infected cattle	Yes	2	413	0.5 (0.0, 1.2)
Urine of infected cattle	Yes	2	413	0.5 (0.0, 1.2)
Meat or milk of infected cattle	Yes	0	415	0.0 (0.0, 0.0)
Too much rain	No	1	414	99.8 (0.0, 0.7)
FMD prevention				
Avoid buffalo	Yes	41	374	9.9 (6.9, 13.0)
Dipping the cattle	No	11	404	97.3 (95.7, 98.8)
Antibiotic injection	Yes	50	365	12.0 (8.9, 15.4)
Vaccination	Yes	215	200	51.8 (46.0, 56.6)
FMD is a zoonotic disease	No	204	211	50.8 (46.0–55.9)

Table 5
Multivariable analysis of factors significantly associated with FMD high knowledge score among communal farmers (n = 415) interviewed between (2022–2023) in the FMD protection zone with vaccination in Limpopo and Mpumalanga Provinces of South Africa.

Variables	Slope parameter	Odds ratio	95 % CI	p-value
District of respondents	Referent	1.51	0.56–4.08	0.408
Ehlanzeni	0.417	4.01	1.69–9.47	0.002
Mopani	1.387			
Vhembe				
Herd grazing	Referent	1.59	1.01–2.50	0.043
management	468	1.69	1.03–2.77	0.035
Other grazing methods	Referent			
Grazing by the owner	0.529			
Number of cattle on farm				
≤ 15 cattle				
> 15 cattle				

might have led farmers to withhold or deny being aware of the existence of FMD, particularly when interviewed in the presence of government AHT. Such presence could have influenced their responses. Studies conducted in other regions have emphasized the role of trust in shaping farmers' willingness to report diseases (Wright et al., 2018; Gates et al., 2021; Scutt et al., 2023). Respondents who had formal education in our study were significantly more likely to make this FMD yes/no knowledge claim. These respondents might be more likely to access educational materials including media, farm magazines or other information sources to learn about the disease. Total livestock units were also a significant predictor of FMD recognition in the study. Many farmers within the South African FMD protection zone are subsistence smallholder farmers (Gwiriri et al., 2019). Farmers of this type employ family labour and have irregular cattle sales, mainly to raise capital to meet immediate household needs. A smaller group of "emerging" farmers have acquired between 5 and 100 ha of farmland, on either a freehold or leasehold basis and are more commercially-focused producers. These farmers produce above subsistence and much of their incomes are derived from cattle sales (Gwiriri et al., 2019). Some farmers in this group have attended livestock production courses or possess professional agricultural qualifications (Gwiriri et al., 2019), and had access to technical support including livestock herd management (MacLeod et al., 2008). Often, emerging farmers are affiliated to groups or cooperatives with access to information including animal diseases, livestock marketing and the financial resources needed for livestock businesses. These farmers keep various livestock species and might invest more resources in disease prevention, detection, and management because of their commercial orientation and the resulting higher anticipated economic impact of an FMD outbreak on their income compared to other farmers. They might also be more aware of the potential economic risks associated with FMD and thus be more motivated to learn about recognizing and responding to the disease. This might explain why farmers with more livestock units were more likely to be aware of FMD.

Respondents who reported livestock farming as the main occupation were more likely to make the FMD knowledge claim. Our findings are consistent with a recent study assessing the knowledge, attitudes and perceptions of livestock diseases among communal livestock farmers in the FMD controlled zone at the wildlife-livestock interface in northern KwaZulu-Natal (Ngoshe et al., 2022). This previous study reported that respondents who identified their occupation as livestock rearing had higher livestock disease knowledge scores compared to those engaged in crop farming or other employment (Ngoshe et al., 2022). The possible explanation for this association is that farmers who rely on livestock farming as their main source of income have a greater incentive to learn about animal diseases due to the economic implications associated with outbreaks. Livestock diseases, such as FMD, can have important economic consequences, including decreased productivity, increased mortality, and reduced market value of animals (Jemberu et al., 2014; Knight-Jones et al., 2017). Therefore, understanding and effectively managing these diseases is crucial for mitigating economic losses and protecting livelihoods. Furthermore, farmers who are heavily dependent on livestock farming might invest more time and effort into acquiring knowledge about animal diseases as a means of safeguarding their livelihoods. This could involve participating in training programs, accessing information through extension services or veterinary professionals, and actively seeking resources to enhance their understanding of disease prevention and management strategies.

Respondents who owned poultry were significantly more likely to report being aware of the existence of FMD. The reason for this association is unclear and poultry ownership might be associated with an unmeasured variable truly related to FMD awareness. An alternative explanation for this observed association could be that poultry farming requires special attention to housing conditions, cleaning systems, access to fresh water and nutrition (Zhou et al., 2020). Poultry are highly susceptible to infectious diseases in general, including Newcastle disease, infectious laryngotracheitis, acute fowl cholera, infectious bursal disease and highly pathogenic avian influenza (HPAI) (Alders et al., 2014). The perception of the consequences associated with HPAI infection in chickens has been reported to not only influence poultry farmers motivation to take action including information seeking (Gupta et al., 2021), but also to adopt preventive strategies (Cui et al., 2019). Cross-species disease awareness might therefore influence awareness of cattle diseases among these farmers.

Despite evidence that buffaloes carry and maintain FMDV and have been associated with outbreaks in cattle in communal farming (Grubman and Baxt, 2004), most respondents (54 %) in our study did not know that African buffalos were a source of FMD and therefore lacked awareness concerning their role in FMD spread. This is probably the reason why most respondents did not link buffalo contact to FMD occurrence and only a few knew that buffalo should be avoided to reduce FMD spread. To mitigate the risks of disease transmission from wildlife to livestock, attention has been increasingly focused on adapting proactive livestock husbandry practices (Ward et al., 2006; Miguel et al., 2013). For example, pastoralists in Kenya, adopted improved herding practices to avoid or minimise contact with wildlife and limit disease outbreaks (Mizutani et al., 2005). Such improved herding practices have been also reported in Zimbabwe (Miguel et al., 2017). In Kenya, the Maasai people herd cattle away from grazing areas frequented by wildebeest during high-risk periods of the year to prevent malignant catarrhal fever transmission (Bedelian et al., 2007).

Wildlife avoidance strategies adopted by cattle owners in Zimbabwe and pastoral communities in Kenya might be challenging in communal farming systems in South Africa because of uncoordinated herding (drop and fetch herding) and livestock roaming unattended are common practices (Van Rooyen, 2016). Planned grazing, and wildlife contact management are essential for improved husbandry practices at the wildlife-livestock interface of South Africa (Van Rooyen, 2024).

Less than half of the respondents recognized lameness (38 %) and excessive salivation (37 %) as main FMD clinical signs. A study among small-scale dairy farmers in Kenya reported that 77 % of participants correctly identified hypersalivation and 54 % identified lameness as a common FMD clinical signs (Nyaguthii et al., 2019). The observed difference in knowledge between our study and the Kenyan study could be attributed to several factors, one of which is the high prevalence of FMD reports in Kenya. For example, a nationwide Kenyan survey reported a seroprevalence of 53 %, with certain counties reaching 100 % prevalence (Kibore et al., 2014). Kenya is also known to be endemic for FMDV serotypes A, O, SAT1, and SAT2 among domestic species (Namatovu et al., 2013; Wekesa et al., 2014b). These serotypes can vary in their virulence and impact on livestock populations. For example, outbreaks in Kenya are predominantly caused by serotype O (Chepkwony et al., 2012), SAT1 (Wekesa et al., 2014a), SAT2 (Lyons et al., 2015) and serotype A (Wekesa et al., 2014b). Serotypes A and O belong to the Eurasian lineage of FMDV (Grubman and Baxt, 2004) and typically cause highly contagious infections with high morbidity in domestic animals (Grubman and Baxt, 2004). Serotype O has been principally detected from clinical cases in East Africa including Ethiopia (WRLFMD, 2017), and Kenya (WRLFMD, 2018) and has been associated with severe disease characterized by high morbidity and up to an 75 % drop in milk production (Jemberu et al., 2014). In southern Africa in contrast, infections due to SAT serotypes are often less apparent, causing a sub-clinical infection in both domestic and wild animals (Kitching, 2002; Grubman and Baxt, 2004; Sobrino and Domingo, 2017). This difference in disease severity might influence farmers' perceptions and awareness of FMD between areas.

The relatively small proportion of the respondents in the current study that were able to recognize excessive salivation and lameness as common clinical signs of FMD suggests a lack of awareness and is a potential limitation to FMD event-based surveillance in South Africa. Event-based surveillance is a critical component of FMD control. It is defined as a spontaneous and continuous system of event reporting (e.g. clinical signs in an animal or unusual mortality) matching a pre-established definition by animal owners to health authorities for early detection and rapid reaction (Hernández-Jover et al., 2011; Caporale et al., 2012; Gates et al., 2021). Farmers' knowledge and awareness of livestock diseases have been successfully used in various disease control programs, including FMD (Hussain et al., 2005; Jost et al., 2007; Ndahi et al., 2012; Truong, 2017). FMD event-based surveillance has proven effective for the control of FMD in both endemic and non-endemic countries (McLaws and Ribble, 2007), and remains an indispensable tool for disease control efforts worldwide. For example, studies across FMD-free regions, including Europe, South America, Asia, and Africa, revealed that 53 % of outbreaks were identified as a result of a farmer notifying private veterinarians or authorities of clinically suspicious cases (McLaws and Ribble, 2007). In the United Kingdom, early detection was more likely when cases were reported by farmers during the 2001 FMD outbreak (McLaws et al., 2006).

A small proportion (2.4 %) of respondents were aware that the movement of infected animals can cause FMDV to spread to new areas, while none of the respondents were knowledgeable about the potential for meat and milk to contribute to the spread of the FMD. This finding suggests that people might be involved in movements of potentially infected animals (or their products) out of the protection zone without any awareness of the potential contribution of these movements to FMD spread. Such lack of awareness of the risk of uncontrolled livestock movements has been reported in a recent study that evaluated goat movement patterns within the FMD protection zone of South Africa (Lazarus et al., 2021). This recent study reported that the undocumented movement of goats extended beyond the FMD protection zone to locations within the formerly FMD-free zone of the country (Lazarus et al., 2021). Previous studies have extensively reviewed unregulated movements of livestock or wildlife and its implications for disease spread (Fèvre et al., 2006). Many countries in Africa, including southern Ethiopia and Uganda, are confronted with the issue of illegal livestock movements. For instance, in southern Ethiopia, a higher prevalence of FMD has been linked to herd mobility from transhumance movements of livestock in pastoral systems (Megersa et al., 2009). Similar findings, indicating movement patterns of herds as risk factors for FMD, have been reported in the South Omo Zone of south-western Ethiopia (Molla et al., 2010). Studies conducted in Uganda have similarly identified animal movements as a significant risk factor for FMD outbreaks (Ayebazibwe et al., 2010). In South Africa, the movement of livestock from the FMD protection zone recently led to the introduction and spread of FMDV to disease-free areas in the North West Province of the country (DALRRD, 2023b).

Only approximately half of the current respondents believed vaccination can prevent FMD. The authors of a previous study in Mpumalanga Province reported that cattle farmers had a positive perception of FMD vaccination (Lazarus et al., 2017). However, sporadic FMD outbreaks continued despite vaccination (WOAH, 2024), raising concerns about the effectiveness of FMD vaccination. Several factors have been reported to affect vaccination effectiveness including the vaccine potency and antigenic payload, the match of the vaccine strain to the circulating virus, and the vaccination regime (timing, frequency, proportion) (Jori et al., 2009; Knight-Jones et al., 2014; Jori and Etter, 2016; Lyons et al., 2016). Lower vaccination proportions and longer vaccination intervals increase the likelihood of FMD outbreaks and compromise FMD control efforts. Vaccinated cattle in the FMD protection zone with vaccination have been reported to have a low proportion of cattle with high levels of detectable antibodies against circulating FMDV serotypes (Lazarus et al., 2017). In the same study, the reported inter-vaccination interval ranged between 7 and 12 months. A recent study also reported poor FMD vaccination proportions and large vaccination intervals in the PZV of Limpopo Province (Sirdar et al., 2024). These findings suggest an increased risk of FMD outbreaks. The occurrence of FMD outbreaks despite vaccination might negatively influence farmers' perceptions of vaccine effectiveness.

Farmers who owned more than 15 cattle and farmers who grazed their own cattle rather than employing a hired herdsman were more likely to have a high FMD knowledge score. The association between larger herd sizes and better FMD knowledge might be due to these farmers being more motivated to learn about diseases in effort to protect their investment. Furthermore, there is a belief that the risks associated with the introduction and spread of FMD, as well as its perceived impact, are higher in larger herds compared to smaller ones. Farmers who do not personally supervise their cattle during grazing might have an occupation other than livestock farming and therefore might not be able to monitor their animals daily. They might also have insufficient time to learn about diseases or lack regular contact with veterinarians compared to farmers who graze their own animals. These factors might explain why farmers who graze their own cattle were more likely to have better FMD knowledge. However, the causal link might be reversed, i.e., farmers with better FMD knowledge might decide to supervise their cattle themselves during grazing to reduce the risk of FMD transmission to their herd. Cross-sectional studies have the limitation of not being able to investigate temporal relationships. Unsupervised grazing also poses a risk of undetected and unreported cases of FMD, which could weaken the FMD event-based surveillance system.

Respondents from Vhembe District in Limpopo were significantly more likely to have high FMD knowledge compared to Ehlanzeni District in Mpumalanga whereas respondents from Mopani District did not. According to disease reporting data from the Department of Agriculture Land Reform and Rural Development (DALRRD, 2023a) and the World Animal Health Information Database (WAHIS) (WOAH, 2024), between January 2020 and December 2022, a total of 60 FMD outbreaks were reported in the FMD protection zone of Limpopo and Mpumalanga provinces. Most 48/60 (80 %) of these outbreaks occurred in Limpopo Province with 33 and 15 outbreaks reported in the Vhembe and Mopani districts respectively. The remaining few (20 %) outbreaks were reported in Mpumalanga and were all clustered in a single area (Bushbuckridge Municipality). Therefore, respondents from Vhembe District might have been more likely to observe the disease in cattle and possibly have access to veterinarians who might have explained the disease to them. Furthermore, in response to the increasing FMD outbreaks in Vhembe District, the government might have initiated FMD awareness campaigns in affected areas. Such awareness campaigns might also explain why these farmers were more likely to have high FMD knowledge.

The findings of this study should be interpreted with caution because of several potential limitations. Livestock owners were not randomly selected but conveniently sampled after providing informed consent, which might have caused selection bias. Also, FMD knowledge data were based on questionnaire administration to respondents in the presence of government animal health technicians and this approach might have caused respondents to withhold their true opinions leading to social desirability bias (Kaine and Wright, 2024). It was not possible to verify opinions and views of participating farmers by other methods. Other potential limitations of this study included the cross-sectional design preventing the investigation of temporal relationships and the inability to adjust for confounding by unmeasured factors.

5. Conclusion

Communal livestock farmers in South Africa have gaps in their FMD knowledge and specifically were not aware that the movement of infected animals and their products poses a threat for the spread of FMD. Such knowledge gaps are critical in small-scale communal livestock farming systems at the domestic/wildlife interface where FMD is endemic in wild African buffaloes. This lack of knowledge might influence illegal movements of livestock out of the protection zone. The limited recognition of key FMD clinical signs and routes of transmission indicate gaps in knowledge dissemination efforts. Furthermore, suspicious FMD cases might be undetected and therefore unreported reducing the sensitivity of the event-based system for FMD control. Comprehensive information, education and training are essential for communal livestock farmers to raise awareness and ensure an effective event-based system to improve FMD prevention and control in the region. Communication efforts should specifically target farmers who have not had access to a formal education. Tailored training programs and improved access to veterinary services are essential to empower farmers and enhance event-based systems, thereby mitigating FMD outbreaks in southern Africa.

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CRediT authorship contribution statement

Chaminuka Petronella: Writing – review & editing, Supervision. **Kiayima Kibambe Daddy:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Etter Eric:** Writing – review & editing, Funding acquisition, Conceptualization. **Delabouglise Alexis:** Writing – review & editing, Supervision. **Fosgate Geoffrey:** Writing – review & editing, Validation, Supervision, Methodology, Funding acquisition, Formal analysis, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2025.106468.

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