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Decision tree risk analysis for FMD outbreak prevention in Egyptian feedlots

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ABSTRACT

Foot and Mouth Disease (FMD) is one of the most contagious and economically influential viral diseases on animal health and productivity. Introduction of newly purchased animals to beef farms constitutes a greater risk for the FMD outbreaks in endemic countries. Physical examination of newly purchased animals in live animal markets and/or at the receiving farm, and the timing of preventative FMD vaccination may reduce the risk of FMD outbreaks under endemic conditions. Small (< 50 animals) and medium (50–500 animals) sized beef farms in Egypt constitute more than 60% of the country's beef industry where protocols for receiving newly purchased animals vary widely between farms. The current risk analysis aimed to build a decision tree model to reduce FMD outbreaks associated with introduction of replacement cattle on Egypt's medium sized beef farms. Management practices explored were the use of physical examinations and FMD vaccination and their timing for replacements with the goal of reducing losses due to FMD outbreaks. A producer survey revealed that more than 50% of the study herds relied on live animal markets as a source for replacements and reported more FMD outbreaks (P-value=0.09), FMD herd morbidity > 50% (p-value=0.05), and weight loss > 15 kg/animal in FMD clinical cases (P-value=0.01) in comparison to herds that received replacements from other farms, imported, or purchased from small stakeholders. More than 70% of the surveyed farms received replacements ≤ 1year old and reported significantly higher FMD outbreaks (P-value=0.02) in comparison to farms that received older animals. More than 80% of the surveyed farms performed physical examination of newly purchased animals before arrival at their premises. Of the surveyed farms, 73% reported FMD outbreaks with 67% of the outbreaks being reported during the Fall and Winter seasons. The decision tree identified physical examination of newly purchased animals prior to arrival and mixing with a premises beef herd followed by vaccination against FMD upon arrival as the intervention resulting in the lowest probability of FMD outbreak (8.9%). In contrast, herds that did not perform physical examination and delay the FMD vaccination for two or more weeks had the highest probability of FMD outbreaks (33.5%).

1. Introduction

Egypt's beef industry plays an important role in food security for a country with increased population growth and hence demand for animal protein (United Nations, 2019; CAPMAS, 2020). Egyptian beef farms are primarily small (< 50 animals) to medium (50 – 500 animals) sized with very few exceeding 500 animals. FMD is a highly contagious transboundary animal disease affecting cloven footed animals including cattle, buffaloes, sheep, goats, pigs and wild ruminants (Alexandersen and Mowat, 2005). The disease is caused by RNA virus of genus Aphthovirus, family Picornaviridae with seven immunologically distinct serotypes (A, O, C, SAT1, SAT2, SAT3 and Asia1) that make up more than 60 subtypes (Bachrach, 1968; Grubman and Baxt, 2004). There is no cross protection between FMD's different serotypes, however, there is some cross protection among the subtypes within the same serotype (Mahy, 2005). FMD is characterized by severe direct and indirect economic losses on both national and international levels as it affects the international trade of live animals and animal products from endemic countries (Krystynak and Charlebois, 1987; Sobrino and Domingo, 2001; Cairns et al., 2017). At a national level, FMD affects the economies of the endemic countries as otherwise limited funds are allocated for vaccination campaigns, surveillance programs, restriction of animal

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movement, and closure of the animal markets. At the farmer level, FMD is characterized by a high morbidity, loss in productivity, and increased costs of treatment and veterinary services. In addition, FMD can cause high mortality in young suckling calves due to a distinct heart pathology which is commonly known as tiger heart (Knight-Jones and Rushton, 2013; Jemberu et al., 2014; Tadesse et al., 2020).

The current epidemiologic situation of FMD in Egypt is endemic with three FMD serotypes, O, A and SAT2 (Diab et al., 2019). The first official reporting for the FMD in Egypt according to the World Reference Laboratory for Foot and Mouth Disease (WRLFMD) was in 1950 with serotype O and SAT2 (Aidaros, 2002; Sobhy et al., 2018). Subsequently, serotype A was reported in 1952 which disappeared since 1976 before its detection in a 2006 outbreak due to importation of live animals from Ethiopia. FMD serotype SAT2 also disappeared after 1950 until its detection in a 2012 FMD SAT2 outbreak with two new strains that were closely related to Sudan 2008 strain (Knowles et al., 2007; El-Ashmawy et al., 2013; Kandeil et al., 2013; Soltan et al., 2017). Recently new variants of serotype O and SAT2 were reported (El Nahas and Salem, 2020; Hassan et al., 2021).

Medium sized beef producers in Egypt are under high risk of FMD outbreaks due to the high turnover and continuous influx of replacements from live animal markets where biosecurity practices are limited due to budgetary reasons. As a result, management and biosecurity practices including vaccination protocols, physical examination of the new animals, and application of quarantine measures on new replacements vary greatly between beef farms in Egypt. To the best of our knowledge there are no previous studies that evaluated the effect of management practices such as physical examination (at the market and /or farm) and timing of FMD vaccination (upon arrival vs after 2 weeks) on the probability of occurrence of FMD outbreaks associated with the introduction of new replacements on medium sized Egyptian beef farms.

The objective of the current risk analysis was to specify a decision tree model that can educate management decisions on a convenience sample of medium sized beef farms in Egypt on physical examination and timing of FMD vaccination of replacements with the goal of minimizing the risk and losses due to FMD outbreaks. Our hypothesis was that beef farms that perform physical examination on replacements (at the live animal market and/or upon arrival at the farm) and vaccinate against FMD immediately upon arrival have a lower probability of FMD outbreaks and minimum losses compared to farms that neither perform physical examination at either location and delay FMD vaccination for at least two weeks after arrival on farm. The outcomes of the current study will guide medium sized beef producers to the best management practices related to new replacements and reduction of losses due to FMD outbreaks under endemic conditions. The study findings may be generalizable to other FMD endemic beef systems with similar biosecurity and management practices requiring minimal cost and risk-based guidelines that are locally relevant.

2. Material and methods

2.1. FMD management practices survey

The current study was approved by the Cairo University Institutional Animal Care and Use Committee (Protocol number VetCU01122022569). A convenience sample of 34 beef farms in Egypt was identified and their herd veterinarians interviewed using an in-person questionnaire conducted by a study author (MF) and others (see the acknowledgments). The questionnaire had 14 questions addressing herd demographics (breed, herd size, rate of receiving new replacements, source, and age of replacements), FMD control and prevention practices related to receiving new replacements (physical examination at live animal market or upon arrival to farm premises, time of vaccination, type of vaccine used), and history of FMD outbreaks (season, morbidity, mortality, and weight loss associated with a FMD outbreak). Chi square and Fisher exact tests were used to evaluate the associations between the occurrence of FMD outbreaks, FMD morbidity, and FMD mortality, and the predictors herd size, species (water buffalo: *Bubalus bubalis*, cattle: *Bos taurus*), time of vaccination (day of receiving, after 1 week, after 2 weeks, others), age of receiving new replacements (weaning, 6 months, 9 months, $\geq$ 1 year), rate of receiving replacements (weekly, every other week, monthly, other) animal source (markets, another farms, importation, other) and whether they performed physical examination of the replacements at the live animal market or upon arrival at the farm premises. The study survey is presented in Appendix A.

2.2. Multiple correspondence analysis (MCA)

Multiple correspondence analysis, an unsupervised multivariate analytical approach for categorical data (Costa et al., 2013; Rodriguez-Sabate et al., 2017), was specified on the survey responses' 14 categorical variables. The FactoMineR package (Lê et al., 2008) of the R software (R-4.1.2 version) was used for the MCA. The R code used for the analysis was MCA (X, ncp = 5, graph = TRUE) while X is the dataset of the survey (34 responses with 14 variables), ncp is the number of dimensions kept in the final results. The proportion of variances explained by each dimension was assessed through visualization of the Eigenvalues using the scree plot. The function dimdesc () dimension description was used to identify the most correlated variables within a given dimension and variables with correlation coefficients $\geq$ 0.4 or greater were retained for interpretation.

2.3. Risk analysis

Current management practices for FMD control in medium sized herds commonly rely on each owner's experience and sometimes on the herd veterinarian's advice. The risk of a FMD outbreak was analyzed given the effect of performing physical examination at the live animal market and/or at the farm upon arrival. While cattle purchased can be examined at the live animal market prior to purchase, it is also common for producers to receive cattle routinely from suppliers who deliver directly to farms, and hence physical examination can happen at the market or at the farm. In addition, cattle may have been examined at the live market by the suppler, prior to being examined a second time by the producer at the purchasing farm. The effect of physical examination was also considered in combination with the FMD vaccination protocol (immediately upon arrival or two weeks after arrival of replacements to farm premises) on reducing the losses due to FMD outbreaks from newly purchased animals under endemic conditions (Eq. (1)). Hence, eight different scenarios were evaluated to compare the risk of FMD outbreaks for each using a decision tree analysis (Fig. 1). The eight different scenarios were obtained by all possible combinations of applying physical examination (at the live animal market, upon arrival to the farm, both or none) and the timing of the first FMD vaccine shot (upon arrival or after 2 week) as in Fig. 1. The scenario with the minimum losses due to FMD outbreaks was identified as the lowest risk for FMD outbreaks and associated losses.

$$P(Y) = X - [X * (S) + X * (T)] \quad (1)$$

P(Y): Probability of FMD outbreaks.
X: Prevalence of FMD infected animals in the live animal market.
S: sensitivity of physical examination.
T: Time of first FMD vaccination dose (upon arrival, after 2 weeks).

2.3.1. Study population

The study was intended to target medium sized beef farms (50–500 animals) as they constitute more than 60% of the locally produced beef. In addition, medium sized beef farms in Egypt are under high risk of FMD outbreaks as the majority of these farms receive replacements more often (at least once per month) with live animal markets being the most

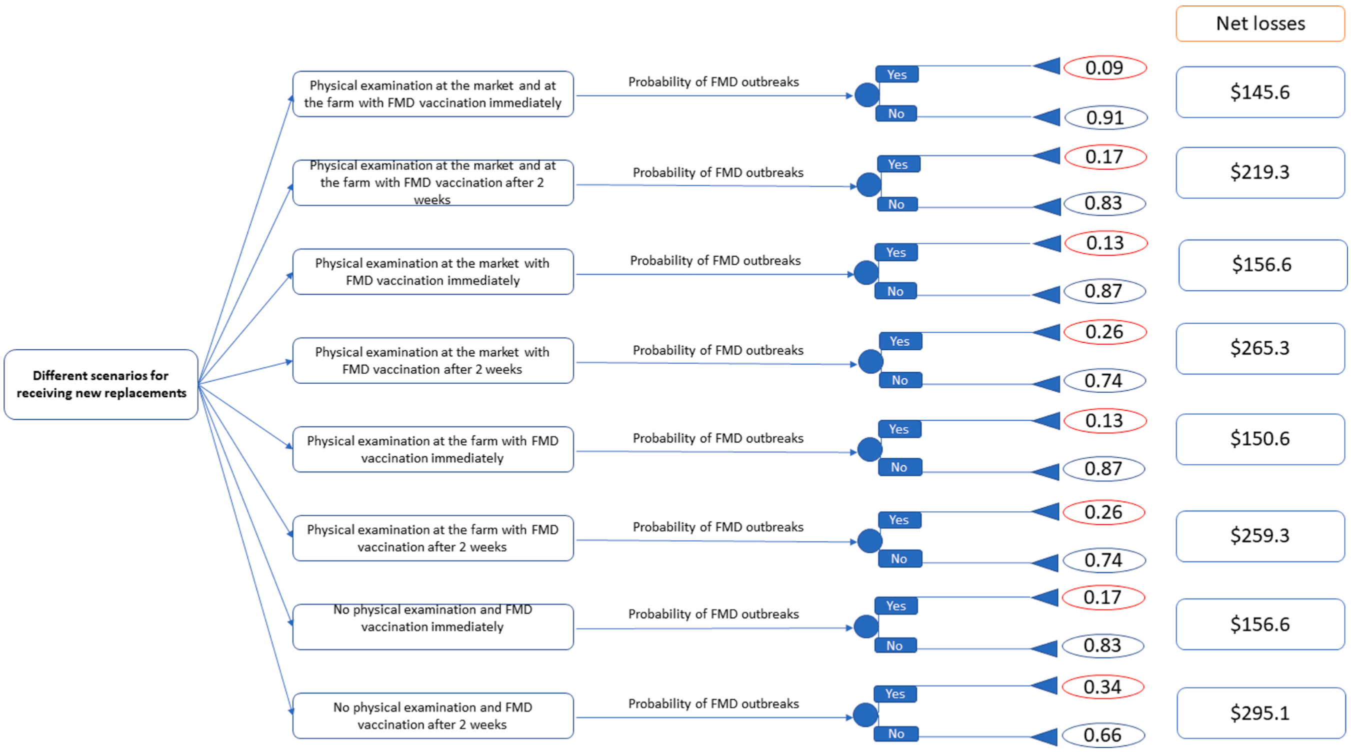

Fig. 1. Decision tree for the eight different scenarios for receiving animals in beef farms in Egypt and risk of Foot and Mouth Disease (FMD) outbreaks based on physical examination at live animal market and/or on farm, and timing of vaccination against FMD immediately upon or two weeks after arrival on farm premises. * Net losses are the sum of the losses due to FMD outbreak and the costs of physical examination and FMD vaccination for each scenario [Total (loss) = Treatment (cost) + Veterinary (cost) + Labor (cost) + Rent (cost) + Weight Loss (cost)].

common source resulting in increased probability of FMD outbreaks.

2.3.2. Decision tree model inputs

2.3.2.1. Prevalence of FMD in the animal markets. To the best of our knowledge, the prevalence of FMD in live animal markets in Egypt is unknown. Hence, the current study assumed the prevalence of FMD in an Egyptian live animal market to be similar to reported country's FMD prevalence. Previous studies reported that the prevalence of FMD in Egypt varied from 30% to 47.1% depending on the animal species and the FMD serotype (BenYousef, 2009; Orabi et al., 2017). In the current study, we assumed a stochastic parameter for prevalence using a uniform distribution with static value of 33.5% based on data from BenYousef, 2009 (Table 1).

2.3.2.2. Physical examination. Physical examination is one of the tools that can be used to reduce FMD outbreaks in endemic countries through exclusion of FMD clinically diseased animals before transport to a susceptible herd. Specifically, physical examination focused on FMD clinical signs (fever associated with salivation or lameness, vesicles or ruptured vesicles and associated ulcers) and examination of the common sites for FMD lesions (in the buccal cavity and muzzle, inter-digital space, and coronary band around the claws) usually occurs at the live animal market or at the farm upon arrival and prior to introducing the replacements to the main herd on the farm premises. A previous study reported that the sensitivity and specificity of physical examination as a tool for diagnosis of FMD at the market or farm were estimated at 30% and 99% respectively (Gonzales et al., 2014). Beta distributions were assigned for both sensitivity and the specificity Table 1.

2.3.2.3. Vaccination protocols. Vaccination is one of the main tools to control FMD outbreaks in endemic countries. Egypt is endemic with three main FMD serotypes (A, O, SAT2). The three main sources of FMD vaccines in Egypt are governmental, local private, and imported. In the decision tree model, two main scenarios exist for timing of FMD vaccination of animal replacements. The first relies on administering the first vaccine dose to replacements at the farm upon arrival on their first day, while the second involves administering the first FMD dose after two or more weeks of arrival. In the first scenario, FMD vaccination on the first day is assumed with at least 1 animal incubating FMD and an incubation period that ranges from 2 to 14 days (mean of 7 days) and that 50% of the newly introduced animals will develop protective immunity (Table 1). The estimate that 50% of vaccinates will have protective immunity was based on the calculation that for every 100 replacements with a FMD prevalence of 33%, an incubation period that ranges from 2 to 14 days (mean 7 days), and a vaccine efficacy of 80% would result in 5 protected animals ((100–33/100)* 0.8]= 0.53). In the second scenario, FMD vaccination of replacements at least two weeks after arrival to the premises is assumed with at least 1 animal incubating FMD, with a similar incubation period range and mean as in scenario 1, and that the FMD infection will be transmitted to 100% of the replacements. Stochasticity for FMD infections among the new replacements was added to the model assuming Uniform distribution Table 1. Vaccine efficacy of the three different vaccines was assumed to be equal.

2.3.2.4. Estimation of costs associated with physical examination and FMD vaccination

$$TC = (P \times n) + (V \times n) \quad (2)$$

TC: total costs of physical examination (live animal market, farm or both) and FMD vaccines.

P: costs of physical examination per animal.

V: cost of the FMD vaccine dose per animal.

n: number of new replacements.

Cost estimates for physical examination and FMD vaccination were calculated as shown in Eq. (2) and summarized in Table 1. Physical

Table 1
Distributions and parameters for variables in a decision tree model for risk of Foot and Mouth Disease (FMD) outbreaks after introduction of replacements on beef farms in Egypt.

Factor	Type of distribution	Distribution parameters	Source
Prevalence of FMD	Uniform	Min. (0.3), Max. (0.38)	(BenYousef, 2009; Orabi et al., 2017)
Number of animals received at a time	Triangle	-Min. 10, Max. 20, Most likely 12	Author (WE)
Clinical examination 1. Sensitivity 2. Specificity	Beta	α1 = 2, α2 = 2, Min. (0), Max. (1), Risk statistics (0.3) α1 = 2, α2 = 2, Min. (0), Max. (1), Risk statistics (0.99)	Gonzales et al. (2014)
Cost of FMD Vaccination/dose - Immediate OR ≥ 2 weeks	Triangle	Min. ($1), Max. ($3), Most likely ($1.5)	Author (WE)
Cost of clinical examination/ animal 1. At farm 2. At market	Triangle	- Min. ($1.5), Max. ($3.0), Most likely (2.0$) - Min. ($2.0), Max. ($4.0), Most likely (2.5$)	Author (WE)
Vaccination timing and FMD outbreaks 1. Immediate[a] 2. ≥ 2 weeks	Uniform	- Min. 0.35, Max. 0.75 - Min. 0.60, Max. 1.0	Author (WE)
Estimated cost of FMD outbreak/ animal 1. Cost of treatment 2. Cost of veterinary services 3. Cost of the place 4. Cost of the workers 5. Cost of reduction in body weight a. Reduction in body weight/ animal b. Price/kg BWT	Triangle	-Min. $5.7, Max. $9.5, Most likely $7.6 -Min. $3.2, Max. $6.3, Most likely $4.7 -Min. $0.63, Max. $1.27, Most likely $0.95 -Min. $44.30, Max. $7.59, Most likely $56.96 -Min. 5 kg, Max. 15 kg, Most likely 10 kg -Min. $3.42, Max. $4.18, Most likely $3.80	Author (WE)

[a] In the decision tree model, we assumed immediate vaccination will result in protection of 50% of the vaccinated animals at day 7. This assumption is the output of the calculation of 100 replacements with FMD prevalence of 33% given that the incubation period of FMD 2–14 days with 7 days average and 80% efficacy of FMD vaccine then [(100–33/100)* 0.8]= 0.53.

examination costs at the market were assumed to follow a triangular distribution with a minimum $ 1.5/animal, maximum $3/animal, and most likely $2/animal, while the physical examination costs at the farm level were assumed to follow a triangular distribution with a minimum $ 2.0/animal, maximum $4.0/animal, and most likely $2.5/animal based on lead author's experience. For FMD vaccination costs, Egypt's three FMD vaccine sources are priced differently. Hence, the estimate for the vaccination cost followed a triangular distribution to account for the variations in the vaccine prices Table 1.

2.3.2.5. *Estimation of losses associated with a FMD outbreak*

$$T(loss) = Tr(cost) + Ve(cost) + L(cost) + R(cost) + WL(cost) \quad (3)$$

T (loss): total losses associated with the occurrence of FMD outbreak due to receiving new replacements.

Tr (cost): cost of the medications given to FMD clinically infected animals.

Ve (cost): Cost of veterinary visits and follow up for FMD clinically infected animals.

L (cost): labor cost, during FMD outbreaks producers assign workers to and handle the sick animals and avoid contact with the healthy ones to minimize the spread of the disease through the workers.

R (cost): Rental cost for the space of FMD clinically infected animals. During FMD outbreaks producers tend to isolate the infected hence they specify a stall that is away from the main herd for the clinically infected animals as a way to minimize the contact between infected and health animals.

WL (cost): the cost for the loss in body weight associated with FMD in clinically infected animals.

Total losses associated with FMD morbidity (body weight loss, treatment costs) were calculated as in Eq. (3) and are summarized in Table 1. Losses associated with an FMD outbreak due to receiving new replacements were estimated by calculating the sum of the costs of treatment, veterinary supervision, labor effort, loss of useable pen space (rental cost) for housing sick animals, and morbidity-associated loss in animal weight. Stochasticity using Triangular distributions was specified for each of the aforementioned costs using minimum, maximum and most likely values for each parameter. All values included in the model were calculated according to the lead author's experience (Table 1).

2.3.3. *Risk analysis*

Decision tree analysis was used to identify the best scenario resulting in the minimum losses associated with introduction of replacement animals on medium sized beef farms (50–500 animals). The previously mentioned inputs including the prevalence of FMD, sensitivity and specificity of physical examination, vaccination and treatment costs were included in the decision tree model as stochastic inputs simulated using 5000 iterations in PrecisionTree @Risk 8.2 (Palisade, Ithaca, NY, USA). Eight different scenarios for the application of physical examination (at the farm level or at the live animal market or at both) in combination with the timing of FMD vaccination (upon arrival or after two weeks) were tested (Fig. 1). In addition, sensitivity analysis was done to determine the most influential factors of the losses due to FMD outbreaks for the different scenarios of receiving new replacements.

3. Results

3.1. *Survey*

Table 2 summarizes the demographics of the surveyed herds and the characteristics of the replacements. Most of the surveyed farms raised both cattle and buffaloes on the same premises with more than 60% of them raising less than 500 animals at any time. The most common sources of replacements were live animal markets (53%) and importation (20%). The majority of the farms received replacement animals that were ≤ 6 months of age (53%) and around 40% of the farms receive replacements at least once a month. Majority of the surveyed farms conducted physical examinations of replacements upon arrival (83%) with 53% of the examination done by their veterinarian.

Table 3 summarizes the results of the survey on FMD vaccines, vaccination protocols, and FMD outbreaks and the associated losses. Most of the surveyed farms (97%) vaccinated the newly received animals against FMD using local vaccines (67%), imported vaccines (23%) or both (7%). The local vaccines are manufactured locally either in the governmental vaccine manufacture facility (Veterinary Serum and Vaccine Research Institute, Abbassia, Cairo Egypt) or the private vaccine facility (Middle East for Veterinary Vaccines, Salihiyyah Al Jadidah, Ismailia, Egypt). Local FMD vaccines are oil adjuvant vaccines manufactured using local isolated strains (A, O, and SAT2) with PD50 ≥ 6 and the duration of immunity is 6 months after the booster dose. The imported vaccine (Aftovaxpur®, Boehringer Ingelheim Animal Health, Germany) contains the following FMD strains: A Iran05, A Saudi95, O Manisa, O 3039, SAT2 and Asia1 with $Al(OH)_3$ gel adjuvant and PD50 ≥ 6 while the duration of immunity is 4 months after the booster

Table 2
Descriptive statistics on 34 Egyptian beef herds surveyed for herds demographics and replacement practices.

Factor	Levels	Proportion	95% CI	
Animal species	Cattle	0.43	0.26	0.62
	Buffaloes	0.07	0.02	0.24
	Both	0.50	0.32	0.68
Herd size	≤ 100	0.40	0.24	0.59
	> 100 and ≤ 500	0.237	0.11	0.42
	> 500	0.37	0.21	0.56
Sources for replacements	Live animal markets	0.53	0.35	0.71
	Importation	0.20	0.16	0.24
	Farms	0.07	0.09	0.39
	Markets/Farms	0.13	0.05	0.32
	Markets/importation	0.03	0.004	0.22
	Small stakeholders	0.03	0.004	0.22
Frequency of receiving replacements	Every week	0.10	0.03	0.28
	Every 2 weeks	0.13	0.05	0.32
	Every month	0.17	0.07	0.35
	All in all out	0.20	0.09	0.39
	≤ 6 months and < 1 year	0.30	0.16	0.49
	Depends on the market	0.10	0.03	0.28
Age of replacements	≤ 6 months	0.53	0.35	0.71
	> 6 months and < 12 months	0.27	0.14	0.46
	≥ 12 months	0.20	0.09	0.39
Physical examination for replacements	Yes	0.83	0.65	0.93
	No	0.17	0.07	0.35
Physical examination personnel	Veterinarian	0.53	0.35	0.71
	Owner	0.23	0.11	0.42
	Both	0.03	0.004	0.22
	Other	0.03	0.004	0.22
	None	0.17	0.07	0.35

Table 3
Foot and Mouth Disease (FMD) vaccine source, vaccination protocols, and losses associated with FMD outbreaks on 34 Egyptian beef farms.

Factor	Levels	Proportion	95% CI	
FMD vaccines	Local	0.67	0.48	0.82
	Imported	0.23	0.11	0.42
	Both	0.07	0.02	0.24
	None	0.03	0.004	0.22
Time between receiving replacements and first vaccine shot	Within the first week	0.27	0.14	0.45
	> 1 and ≤ 2 weeks	0.45	0.29	0.62
	> 2 and ≤ 4 weeks	0.12	0.04	0.29
	Other[a]	0.15	0.06	0.32
Annual FMD outbreaks	1–2 outbreaks	0.73	0.54	0.86
	None	0.27	0.14	0.46
Seasons of FMD outbreak	April to September	0.33	0.17	0.55
	October to March	0.67	0.45	0.83
FMD morbidity	less than 10%	0.54	0.34	0.73
	10–20%	0.08	0.02	0.30
	21–50%	0.04	0.01	0.26
	> 50%	0.33	0.17	0.55
FMD mortality	No mortality	0.42	0.24	0.62
	≤ 1%	0.23	0.10	0.44
	2–5%	0.12	0.04	0.32
	6–10%	0.19	0.08	0.40
	> 10%	0.04	0.005	0.25
Average weight loss due to FMD infection	< 5 kg	0.04	0.01	0.26
	5–10 kg	0.21	0.09	0.43
	10–15 kg	0.125	0.04	0.34
	> 15 kg	0.625	0.41	0.80

[a] Other, vaccinate the first shot of FMD vaccine after receiving all animals (all in all out).

dose. FMD outbreaks were reported at least once in the previous year in 73% of the farms (70% vaccinate against FMD, 3% did not vaccinate against FMD) with more than 67% of the outbreaks reported between October and March (Fall and Winter seasons). More than 30% of the farms reported FMD morbidity greater than 50% while 23% reported FMD mortality greater than 5%. More than 60% of the surveyed farms (n = 34) reported body weight loss greater than 15 kg per clinically diseased animal during the FMD outbreak.

FMD outbreaks, morbidity and weight loss varied by herd size, age of replacements, and source of replacements Table 4. Herd size was significantly associated with weight loss of more than 15 kg due to FMD infection (P-value < 0.01). Small size herds (≤ 100 animals) suffered from body weight loss greater than 15 kg in comparison to 60% for medium size herds (101–500 animals) and 33.3% for herds greater than 500 animals. Only a borderline association was observed between herd size and FMD morbidity > 50% (P-value=0.05) where 16.7% of large size herds (>500 animals) had FMD morbidity > 50% in comparison to 40.0% in medium size herds and 66.6% in small size herds. Occurrence of FMD outbreaks was associated with age of replacements (P = 0.02) where 37.5% of farms that received replacements > 1 year old had FMD outbreaks in comparison to 84.0% of farms that receive replacements less than 1 year old. All the farms that reported receiving replacements > 1 year old had weight loss due to FMD infection greater than 15 kg/FMD-infected animal in comparison to 54.5% of farms that receive replacements ≤ 1 year old (P-value=0.02). Source of replacements was associated with FMD outbreaks (P-value=0.09), FMD morbidity > 50% (P-value=0.05), and weight loss of > 15 kg due to FMD infection (P = 0.01). Of the farms that receive replacements from live animal markets, 82.6% had FMD outbreaks in comparison to 50% of farms that relied on replacements from other sources (farms, importation, or small stakeholders). None of the farms that received replacements from sources other than live animal markets experienced FMD morbidity > 50% and only 16.7% experienced weight loss of > 15 kg due to FMD infection in comparison to 75.0% of farms that received their replacements from live animal markets.

3.2. Multiple correspondence analysis

The MCA analysis of the survey questionnaire revealed that 32.4% of the variability in the responses were explained by the first three dimensions which were labeled as closely as possible to their component variables (12.02% for dimension 1, FMD outbreaks; 10.78% for dimension 2, herd management; and 9.61% for dimension 3, replacement practices) Table 5. Responses to FMD outbreaks and its outcomes (outbreak season, FMD associated morbidity, mortality, and weight loss) were highly correlated and represented the major variability for the first dimension. Sources of replacements and herd size represent the variability of the second dimension while animal species, frequency of receiving of replacements and the source of FMD vaccines represent most of the variations on the third dimension.

3.3. Decision tree model

The results of the decision tree model comparing the different scenarios for receiving replacement animals at medium sized beef farms (50–500 animal) are summarized in Table 6 and Fig. 1. The best identified scenario resulted in minimum losses due to FMD outbreaks and involved physical examination of replacements at both the live animal market and upon arrival to the farm followed by FMD vaccination immediately upon arrival at the farm before mixing with the main herd. The best scenario also resulted in the lowest probability (8.91%) of FMD outbreaks. Specifically, physical examination either at the live animal market or on the farm followed by immediate vaccination against FMD reduced the probability of FMD outbreaks to 13.15% in comparison to 16.78% for farms that did not conduct physical examination on replacement animals. The highest risk for FMD outbreaks was associated

Table 4
Risk factors associated with Foot and Mouth Disease (FMD) outbreaks, morbidity, and weight loss identified from a survey of 34 Egyptian beef herds surveyed for replacement practices.

Variable	Levels	FMD outbreaks			FMD morbidity > 50%			FMD weight loss > 15 kg		
		% (SE)	95% CI	P-value	% (SE)	95% CI	P-value	% (SE)	95% CI	P-value
Herd size	≤ 100 (n = 12)	66.6 (0.14)	36.4 – 87.4	0.17	66.6 (0.16)	31.7– 89.5	0.05	**100 (0.00)**		< 0.01
	101–500 (n = 9)	55.5 (0.17)	24.1 – 83.0		40.0 (0.22)	9.2 – 81.3		**60 (0.22)**	18.6–90.7	
	> 500 (n = 12)	91.7 (0.08)	56.7 – 98.9		16.7 (0.11)	3.8 – 49.6		**33.3 (0.14)**	12.4–63.8	
Age at receiving	≤ 1 year (n = 25)	**84.0 (0.07)**	63.3 – 94.1	0.02	36.4 (0.10)	18.6–58.7	0.62	**54.5 (0.11)**	33.1–74.3	0.02
	> 1 year (n = 8)	**37.5 (0.17)**	11.9 – 72.6		50 (0.25)	11.3–88.6		**100 (0.00)**		
Source of Replacements	Live animal markets (n = 23)	82.6 (0.08)	60.7 – 93.5	0.09	50 (0.11)	28.4–71.5	0.05	**75 (0.10)**	50.8–89.6	0.01
	Others (n = 10)	50.0 (0.16)	21.6 – 78.3		0.00			**16.7 (0.15)**	2.0–65.6	

Table 5
Results of a Multiple correspondence analysis based on responses to an in -person survey of 34 Egyptian beef farms on Foot and Mouth Disease (FMD) outbreaks and replacement practices.

Identified component	Variation Percent (%)	Component variables	Correlation
FMD outbreaks	13.2	Season of FMD outbreak	0.91
		FMD mortality	0.91
		Average weight loss due to FMD	0.90
		FMD morbidity	0.89
		Occurrence of FMD outbreaks	0.83
Herd Management	9.80	Source of replacements	0.61
		Herd size	0.49
Replacement practices	7.78	Frequency of receiving replacements	0.62
		Animal species	0.53
		FMD vaccine used	0.53

with denying the application of any physical examination on the new replacements in conjunction with waiting for at least two weeks before initiating the FMD vaccination protocol (probability of FMD outbreaks 33.5%).

Sensitivity analysis showed that immediate vaccination against FMD upon arrival was the most influential factor followed by specificity of the physical examination, price of the live weight, total cost associated with weight loss associated with FMD, total body weight loss associated with FMD outbreak, performing physical examination at the farm and sensitivity of the physical examination as shown in supplement S-Table 3.

4. Discussion

Live animal markets represent a major risk for FMD in endemic countries due to the mixing of healthy and FMD infected animals from different sources and regions (Wiratsudakul and Sekiguchi, 2018). The current study found that, beef farms that are conducting physical examinations on new replacements at the market and upon arrival at the farm had the lowest probability (8.91%) of FMD outbreaks. In contrast, farms that denied performing any physical examination on the new replacements and waited for at least two weeks before the first FMD vaccination shot had the highest probability of FMD outbreaks (33.5%). Animals can acquire FMD infection at live animal markets through direct contact with infected animals or indirect contact by ingestion of contaminated feed in shared mangers or fomites including transportation vehicles (Colenutt et al., 2020). In addition, FMD may easily spread between animals in live animal markets through individuals who were in contact with FMD infected animals or fomites (Wiratsudakul and Sekiguchi, 2018). Furthermore, live animal markets in Egypt are meeting grounds for animals from different governorates. Such transport of animals is associated with stress and weakened immunity and hence increased susceptibility to diseases including FMD. Physical examination of replacements and excluding those with clinical signs before introduction and mixing with the main herd can prevent clinically ill animals from entering the herd. Of the surveyed herds, 83% performed physical examination either at the market or upon arrival at the farm with 53% of exams conducted by the herd veterinarian and 29% conducted by the owner or other farm personnel. Sensitivity of clinical diagnosis is influenced by the experience of the examiner (Osti et al., 2019). In FMD endemic countries, livestock veterinarians and producers are commonly experienced in diagnosis of clinical FMD cases (Knight--Jones and Rushton, 2013). The decision tree model revealed that physical examination either at the animal market and/or at the farm reduced the probability of FMD outbreaks through preventing clinically sick animal access to the main herd. Previous studies reported that the maximum transmission rate of FMD virus occurs after the appearance of clinical signs which increases the risk of disease transmission to animals in contact (Charleston et al., 2011; Chase-Topping et al., 2013). Preventing clinically diseased animals from entering the farm will reduce the occurrence of FMD outbreaks (Charleston et al., 2011; Chase-Topping et al., 2013).

Vaccination is a major tool to control FMD outbreaks in endemic countries (Hussain et al., 2019). More than two thirds of the surveyed beef producers used locally produced FMD vaccines and 23% relied on imported FMD vaccines. Only 3% of the producers did not vaccinate against FMD as they raised previously vaccinated adult animals (3 or 4 times prior to arrival) for approximately two months before being sent to slaughter. During that short period of time, in response to an FMD outbreak sick animals would be symptomatically treated, and their contacts would be immediately culled for slaughter to avoid financial losses. Vaccination protocols against FMD varied among the surveyed farms with the majority (45%) vaccinating new replacements between 1 and 2 weeks after receiving while 27% vaccinated immediately after receiving within the first week, and the remaining producers vaccinated their replacements after 2 weeks. The MCA reported a correlation between the source of the FMD vaccine (local, imported) and the variability explained on the third dimension of the study herds.

Fifty percent of surveyed farms raised both water buffaloes and cattle on the same facility, the remaining 43% raise only cattle and 7% raised only buffaloes. Cattle and water buffaloes vary in their susceptibility to FMD strains (Donaldson, 2004) which may explain why 50% of beef farms raise both cattle and buffaloes to reduce the losses to FMD outbreaks in addition to satisfying market demand In addition, MCA identified herd size as a major variable that is correlated with the variability

Table 6
Decision tree outputs on the probability and estimated losses of FMD outbreaks using eight management scenarios for receiving new replacements in medium sized beef herds in Egypt.

Management scenario	Probability of occurrence of a FMD outbreaks (%)	Estimated losses if FMD outbreaks occurred ($)	Probability of No FMD outbreaks (%)	Estimated costs if FMD outbreaks did not occurred ($)
1. Clinical examination at both the live animal market and at the farm, and all animals were vaccinated immediately upon arrival.	8.91	897.94	91.08	72
2. Clinical examination at the live animal market and all animals were vaccinated immediately after receiving.	13.15	867.95	86.85	42
3. Clinical examination at the farm and all animals were vaccinated immediately after receiving.	13.15	873.94	86.85	48
4. Clinical examination at both the live animal market and at the farm, and all animals were vaccinated after 2 weeks of receiving.	17.83	897.95	82.17	72
5. Clinical examination at the live animal market and all animals were vaccinated after 2 weeks of receiving.	26.31	867.95	73.69	42
6. Clinical examination at the farm and all animals were vaccinated after 2 weeks of receiving.	26.31	873.95	73.69	48
7. No clinical examination at live animal market nor at the farm and all animals were vaccinated immediately upon arrival.	16.78	843.95	83.22	18
8. No clinical examination at live animal market nor at the farm and all animals were vaccinated after 2 weeks of receiving.	33.55	843.95	66.45	18

explained on the second dimension between the surveyed farms. Hence, small, and medium size beef farms are at high risk of FMD outbreaks with greater losses in comparison to large herds, that may be attributed to their limited ability to apply biosecurity measures, early detection of sick animals, providing quarantine measures for replacements, and seeking veterinary guidance.

Occurrence of FMD outbreaks may be impacted by climatic conditions. More than 73% of the surveyed farms reported FMD outbreaks in 2020 with two thirds of the outbreaks having occurred in the fall and winter seasons. The MCA estimated a high correlation (0.91) between the season of FMD outbreak with the variability explained on the first dimension of the study herds. The higher frequency of FMD outbreaks were in Fall and Winter seasons in Egypt which may be attributed to the lower temperature and wet conditions which increases the FMD virus survivability and favors air borne transmission (Hagerman et al., 2018). However, the increased calving rate during winter season in Egypt and its associated increase in susceptible animals, primarily number of newborns, may have also contributed to the increase in FMD outbreaks.

The best decision tree scenario for receiving new replacements was through application of physical examination of replacements at the market and upon arrival at the farm combined with vaccination against FMD upon arrival which is explained by the benefits of vaccinating non-clinical animals on reducing the probability of FMD outbreaks (Schley et al., 2012). Previous studies reported that a protective immune response to a booster dose of FMD may start as early as 4 days post vaccination (Grant et al., 2017). Given that replacements are most likely exposed to either FMD vaccination or previous infection, a vaccine dose upon arrival most likely serves as a booster that initiates a rapid immune response that may help protection against FMD outbreaks (Schley et al., 2012). Delaying FMD vaccination by two or more weeks after arrival for replacements, that are FMD infected but not clinical, may increase the probability of FMD outbreaks. A delay in FMD vaccinations by at least two weeks exceeds the disease incubation period resulting in clinical disease development before initiation of the vaccination protocol (Callahan, 2014) thereby introducing the disease into the main herd.

Losses due to FMD infections can be detrimental. On the international level FMD affects international trade while on the local level it affects meat prices by altering the volume and consistency of beef supplies given the FMD-associated morbidity, mortality, production losses, and treatment costs in endemic countries (Tadesse et al., 2020). At the producer level, 33% of the surveyed farms reported morbidity $\geq$ 50% and 23% reported mortality $\geq$ 6%. Herds that received replacements $>$ 1 year old reported less FMD outbreaks (37.5%) in comparison to herds that received younger replacements (84%) which could be attributed to preexposure of older animals to FMD vaccinations or natural infections providing protection against FMD infections (Schley et al., 2012). More than 60% of the surveyed farms reported a weight loss of more than 15 kg per FMD-infected animal which constitutes most of the losses in addition to treatment costs. All the herds that received replacements $>$ 1 year old reported weight loss of greater than 15 kg per animal due to FMD infection in comparison to 54.5% for herds received replacements $\leq$ 1 year old which may be explained by the differences in age. Recent studies reported tiger heart lesions in adult animals associated with FMD infection which may explain the higher reported mortality (El-Ashmawy et al., 2013; Sobhy et al., 2018). Foot and mouth disease clinically infected animals suffer from mouth lesions (vesicles, erosions, and ulcers) and/or foot lesions (vesicles, ulcers at the coronary band and in the interdigital space) which affects dry matter intake and results in body weight loss (Hussain et al., 2019; Limon et al., 2020).

Limitations.

The current survey included a sample size of 34 farms which may have contributed to absence of statistical significance in some of the associations. Future studies that include large number of herds are needed to generalize the results on the whole country. The survey findings may not represent other herds that differ from the survey respondents in cattle demographics and management. In addition, the decision tree model did not account for the loss in the daily gain that would happen if the animal was not clinically infected with FMD. Further long-term studies are required to explore other management factors including the feasibility of quarantining newly purchased animals, pen stocking density, distance between farms, and between farms and the live animal markets as risk factors for FMD outbreaks and its economic impacts. In our study we assumed that the efficacies of all three vaccines were equal. Hence, further studies are needed to study the effect of heterogenous vaccine efficacies on impact of physical examination and FMD vaccination as preventive measures for FMD outbreaks.

5. Conclusions

Conducting physical examinations on beef replacements to exclude animals with clinical FMD before introduction into the main herd and vaccination against FMD upon arrival was associated with the lowest risk for FMD outbreaks and associated losses.

Conflict of interest

The authors declare no conflict of interest.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2022.105820.

References

Aidaros, H.A., 2002. Regional status and approaches to control and eradication of foot and mouth disease in the Middle East and North Africa. Rev. Sci. Tech. 21, 451–458.
Alexandersen, S., Mowat, N., 2005. Foot-and-mouth disease: host range and pathogenesis. Curr. Top. Microbiol. Immunol. 288, 9–42.
Bachrach, H.L., 1968. Foot-and-mouth disease. Annu. Rev. Microbiol. 22, 201–244.
BenYousef, A.B., 2009. FMD situation in Egypt. In: EuFMD, F. (Ed.) FAO, FAO, Appendix 13, p. 74.
Cairns, A., Tolhurst, T., Poon, K., Ker, A.P., Duff, S., Jacques, D., Yang, L., 2017. The economic impact of a foot-and-mouth disease outbreak for Ontario's beef sector. Can. J. Agric. Econ. 65, 159–183.
Callahan, 2014. Basic Veterinary Immunology: Chapter 13, Adaptive Immune Responses to Infections and Immunological Memory. University Press of Colorado.
CAPMAS, E., 2020. Statistical YearBook 2020. In: Statistics, C.A.f.P.M.a. (Ed.) Central Agency for Public Mobilisation and Statistics, Egypt.
Charleston, B., Bankowski, B.M., Gubbins, S., Chase-Topping, M.E., Schley, D., Howey, R., Barnett, P.V., Gibson, D., Juleff, N.D., Woolhouse, M.E.J., 2011. Relationship between clinical signs and transmission of an infectious disease and the implications for control. Science 332, 726–729.
Chase-Topping, M.E., Handel, I., Bankowski, B.M., Juleff, N.D., Gibson, D., Cox, S.J., Windsor, M.A., Reid, E., Doel, C., Howey, R., Barnett, P.V., Woolhouse, M.E., Charleston, B., 2013. Understanding foot-and-mouth disease virus transmission biology: identification of the indicators of infectiousness. Vet. Res. 44, 46.
Colenutt, C., Brown, E., Nelson, N., Paton, D.J., Eble, P., Dekker, A., Gonzales, J.L., Gubbins, S., 2020. Quantifying the transmission of foot-and-mouth disease virus in cattle via a contaminated environment. mBio 11.
Costa, P.S., Santos, N.C., Cunha, P., Cotter, J., Sousa, N., 2013. The use of multiple correspondence analysis to explore associations between categories of qualitative variables in healthy ageing. J. Aging Res. 2013, 302163.
Diab, E., Bazid, A.H.I., Fawzy, M., El-Ashmawy, W.R., Fayed, A.A., El-Sayed, M.M., 2019. Foot-and-mouth disease outbreaks in Egypt during 2013-2014: molecular characterization of serotypes A, O, and SAT2. Vet. World 12, 190–197.
Donaldson, A., 2004. Clinical signs of foot-and-mouth disease. In: Sobrino, F., Domingo, E. (Eds.), Foot and Mouth Disease: Current Perspectives. Horizon Bioscience. British Library Cataloguing-in-Publication Data, pp. 104–114.
El Nahas, A.F., Salem, S.A.H., 2020. Meta-analysis of genetic diversity of the VP1 gene among the circulating O, A, and SAT2 serotypes and vaccine strains of FMD virus in Egypt. J. Vet. Res. 64, 487–493.
El-Ashmawy, W., Mousa, S., Ibrahim, E., Korany, R., 2013. Clinical study on Egyptian cattle affected with recent isolate of foot and mouth disease virus SAT2/2012. Int. J. Livest. Res. 52–63.
Gonzales, J.L., Barrientos, M.A., Quiroga, J.L., Ardaya, D., Daza, O., Martinez, C., Orozco, C., Crowther, J., Paton, D.J., 2014. Within herd transmission and evaluation of the performance of clinical and serological diagnosis of foot-and-mouth disease in partially immune cattle herds. Vaccine 32, 6193–6198.
Grant, C.F.J., Carr, B.V., Kotecha, A., van den Born, E., Stuart, D.I., Hammond, J.A., Charleston, B., 2017. The B cell response to foot-and-mouth disease virus in cattle following sequential vaccination with multiple serotypes. J. Virol. 91.
Grubman, M.J., Baxt, B., 2004. Foot-and-mouth disease. Clin. Microbiol. Rev. 17, 465–493.
Hagerman, A.D., South, D.D., Sondgerath, T.C., Patyk, K.A., Sanson, R.L., Schumacher, R. S., Delgado, A.H., Magzamen, S., 2018. Temporal and geographic distribution of weather conditions favorable to airborne spread of foot-and-mouth disease in the coterminous United States. Prev. Vet. Med. 161, 41–49.
Hassan, A.M., El-Mayet, F.S., El-Habbaa, A.S., Shahein, M.A., Zowalaty, M.E.E., Hagag, N.M., Sharawi, S.S.A., 2021. Molecular characterization of newly emerging foot-and-mouth disease virus serotype SAT2 of Lib-12 lineage isolated from Egypt. Virus Res., 198651
Hussain, A., Abubakar, M., Shah, H., Arshed, M.J., Batool, S., Afzal, M., 2019. Impact assessment of ring vaccination to control economic losses of foot and mouth disease in Pakistan. Pak. J. Agric. Sci. 56, 929–935.
Jemberu, W.T., Mounts, M.C.M., Woldehanna, T., Hogeveen, H., 2014. Economic impact of foot and mouth disease outbreaks on smallholder farmers in Ethiopia. Prev. Vet. Med. 116, 26–36.
Kandeil, A., El-Shesheny, R., Kayali, G., Moatasim, Y., Bagato, O., Darwish, M., Gaffar, A., Younes, A., Farag, T., Kutkat, M.A., Ali, M.A., 2013. Characterization of the recent outbreak of foot-and-mouth disease virus serotype SAT2 in Egypt. Arch. Virol. 158, 619–627.
Knight-Jones, T.J., Rushton, J., 2013. The economic impacts of foot and mouth disease - what are they, how big are they and where do they occur? Prev. Vet. Med. 112, 161–173.
Knowles, N.J., Wadsworth, J., Reid, S.M., Swabey, K.G., El-Kholy, A.A., Abd El-Rahman, A.O., Soliman, H.M., Ebert, K., Ferris, N.P., Hutchings, G.H., Statham, R.J., King, D.P., Paton, D.J., 2007. Foot-and-mouth disease virus serotype A in Egypt. Emerg. Infect. Dis. 13, 1593–1596.
Krystynak, R.H.E., Charlebois, P.A., 1987. The potential economic-impact of an outbreak of foot-and-mouth-disease in Canada. Can. Vet. J. 28, 523–527.
Lê, S., Josse, J., Husson, F., 2008. FactoMineR: an R Package for multivariate analysis. J. Stat. Softw. 25, 1–18.
Limon, G., Ulziibat, G., Sandag, B., Dorj, S., Purevtseren, D., Khishgee, B., Basan, G., Bandi, T., Ruuragch, S., Bruce, M., Rushton, J., Beard, P.M., Lyons, N.A., 2020. Socio-economic impact of foot-and-mouth disease outbreaks and control measures: an analysis of Mongolian outbreaks in 2017. Transbound. Emerg. Dis. 67, 2034–2049.
Mahy, B.W., 2005. Introduction and history of foot-and-mouth disease virus. Curr. Top. Microbiol. Immunol. 288, 1–8.
Orabi, A., Mansour, S., Megahed, A., Saleh, A., 2017. Epidemiological insights of foot and mouth disease virus infection among cattle and buffaloes in Sharkia Governorate, Egypt. Zagazig Vet. J. 45, 165–176.
Osti, M.H., Sokana, O., Gorae, C., Whitfeld, M.J., Steer, A.C., Engelman, D., 2019. The diagnosis of scabies by non-expert examiners: a study of diagnostic accuracy. PLoS Negl. Trop. Dis. 13 e0007635-e0007635.
Rodriguez-Sabate, C., Morales, I., Sanchez, A., Rodriguez, M., 2017. The multiple correspondence analysis method and brain functional connectivity: its application to the study of the non-linear relationships of motor cortex and basal ganglia. Front. Neurosci. 11, 345.
Schley, D., Tanaka, R.J., Leungchavaphongse, K., Shahrezaei, V., Ward, J., Grant, C., Charleston, B., Rhodes, C.J., 2012. Modelling the influence of foot-and-mouth disease vaccine antigen stability and dose on the bovine immune response. PLoS One 7.
Sobhy, N.M., Bayoumi, Y.H., Mor, S.K., El-Zahar, H.I., Goyal, S.M., 2018. Outbreaks of foot and mouth disease in Egypt: molecular epidemiology, evolution and cardiac biomarkers prognostic significance. Int. J. Vet. Sci. Med. 6, 22–30.
Sobrino, F., Domingo, E., 2001. Foot-and-mouth disease in Europe - FMD is economically the most important disease of farm animals. Its re-emergence in Europe is likely to have consequences that go beyond severe alterations of livestock production and trade. EMBO Rep. 2, 459–461.
Soltan, M.A., Negmaldin, A.H., El-Diasty, M.M., Mansour, S.M.G., Elbadry, M.A., Wilkes, R.P., 2017. Molecular characterization of circulating Foot and mouth disease virus (FMDV) serotype O topotype EA-3 and serotype A (African topotype) genotype IV in Egypt, 2016. Vet. Microbiol. 208, 89–93.
Tadesse, B., Tesfahun, A., Molla, W., Demisse, E., Jemberu, W.T., 2020. Foot and mouth disease outbreak investigation and estimation of its economic impact in selected districts in northwest Ethiopia. Vet. Med. Sci. 6, 122–132.
United Nations, 2019. World Population Prospects 2World Population Prospects 2019: Highlights (ST/ESA/SER.A/423). Department of Economic and Social Affairs, P.D. (Ed.), United Nations New York, 2019.
Wiratsudakul, A., Sekiguchi, S., 2018. The implementation of cattle market closure strategies to mitigate the foot-and-mouth disease epidemics: a contact modeling approach. Res. Vet. Sci. 121, 76–84.