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FUTURE PREDICTION OF FOOT-AND-MOUTH DISEASE (FMD): AN INDUSTRIAL PERSPECTIVE

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ABSTRACT

The global livestock industry is significantly threatened by foot-and-mouth disease (FMD). The re-emergence of FMD outbreaks in Indonesia is one example of the epidemiological cycle in a region. This study aimed to analyze the future industry of foot-and-mouth disease. This qualitative study used a secondary data processing that includes the collection, analysis, and interpretation of information to identify trends, challenges, and opportunities that may emerge by using the foresight industry analysis approach and the Generic Foresight Process (GFP) stage framework. Industry foresight analysis identified changing trends of technological, regulatory, geopolitical, demographic, and lifestyle. Several possibilities were identified through the GFP framework, which was conducted by identifying several possibilities based on looking and analyzing what is happening, what is really happening, what might happen in the future, what we would like to happen, and what we might need to do. The results of the industry foresight analysis showed that an FMD vaccine was essential for farmers to open international market access and as a sustainable disease control strategy. The technology aspect played a vital role as the key to competition in the industry in the future. The industry will compete to create an FMD vaccine that best suits the existing market challenges. The results of the GFP framework analysis showed that eradicating FMD worldwide still requires a long and extensive process and is predicted to continue until 2050.

KEYWORDS *foot-and-mouth disease (FMD), foresight industry, technology, vaccine.*

INTRODUCTION

Foot-and-mouth disease (FMD) is an infectious disease that affects cloven-hoofed animals such as cattle, buffalo, pigs, sheep, goats, and other wildlife (Truong et al., 2018). One of the main factors causing the spread of FMD is the trade or mobility of live animals and its product across regions with very high intensity (Blacksell et al., 2019; Udahemuka et al., 2020). FMD is a severe challenge for the world's livestock industry that can threaten a country's economy.

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FMD is caused by an RNA virus that belongs to the family Picornaviridae with the genus Aphthovirus. FMD has 7 virus serotypes: O, A, C, Asia 1, SAT 1, SAT 2, and SAT 3 (Jones et al., 2017). The FMD virus has three epidemiological clusters based on its epidemiological classification. The three clusters cover the continents of Africa, Asia and South America (Roeder et al., 2013).

FMD continues to be a significant issue in Asia. Asia is the world's central pillar of cattle and buffalo farming. Data shows that the Asian region has about 39% of global livestock population concentrated in East, South, and Southeast Asia. Therefore, many countries in the Asian region still have FMD endemic status (Roche et al., 2020). FMD can be controlled using effective vaccination. Vaccination has been commonly used in FMD-endemic countries and is the only reliable method to combat the disease. However, vaccination still has limitations due to antigenic diversity in FMD viruses that tend to evolve very quickly (Ranaweera et al., 2019; Paton et al., 2021).

Evidence of FMD virus evolution can be seen from the re-emergence of FMD disease in Indonesia in 2022. Indonesia has been declared FMD-free in 1990. The first re-emergence of FMD in Indonesia after >30 years of being declared FMD-free provides evidence that a disease has an epidemiological cycle. The problem of outbreaks will persist due to the recurring disease cycle and may continue albeit with a lower incidence. This study was conducted to predict future FMD trends to create the reliable strategy for combat the disease.

RESEARCH METHOD

Study Period and Location

The study was carried out within a period of 3 months from October 2023 to January 2024. The process of collecting and processing data was carried out at the School of Business, IPB University (SB-IPB) and Veterinary Public Health and Epidemiology Division, School of Veterinary Medicine and Biomedicine, IPB University (SKHB-IPB).

Source of Data

The study was conducted using a literature study based on theoritical framework in the context of the animal health to determine the future needs for FMD vaccines and provide a comprehensive analysis of foot-and-mouth disease trends. The study includes the collection, analysis, and interpretation of information to identify trends, challenges, and opportunities that may emerge.

The future needs analysis for FMD vaccine were conducted using industry foresight analysis by considering various aspects. FMD disease tren analysis was performed using the Generic Foresight Process (GFP) stage framework. The analysis presents the identification of FMD disease in 2024 and prediction in 2050.

This qualitative research examines and explores a social problem by providing a broad and detailed perspective (Creswell and Cresswell, 2018). The data used was secondary data from a literature review relevant to the research, external documents such as reports, credible websites, articles and regulations or legislative policies, and decrees belonging to government agencies.

Data Analysis

The data was processed using the industry foresight analysis concept approach that refers to the theory of Voros (2003). The industry foresight analysis was conducted by identifying changing trends in various aspects. These aspects included technology, regulatory, geopolitics, demographic, and lifestyle. A comprehensive industry foresight formulation encompassed the combined formulation of these changing trends

The results of the industry foresight analysis were then identified using the Generic Foresight Process (GFP) stage framework. According to Voros (2003), the GFP stage is conceptualized as a set of methodologies that combine all stages, starting from the input stage or input collection, which is reviewed based on "look and see what is happening", the analysis stage by examining "what seems to be happening?", the interpretation stage which reviews based on "what might happen in the future?", and the prospecting stage which reviews "what might happen in the future?". The research framework flow is presented in Fig.1.

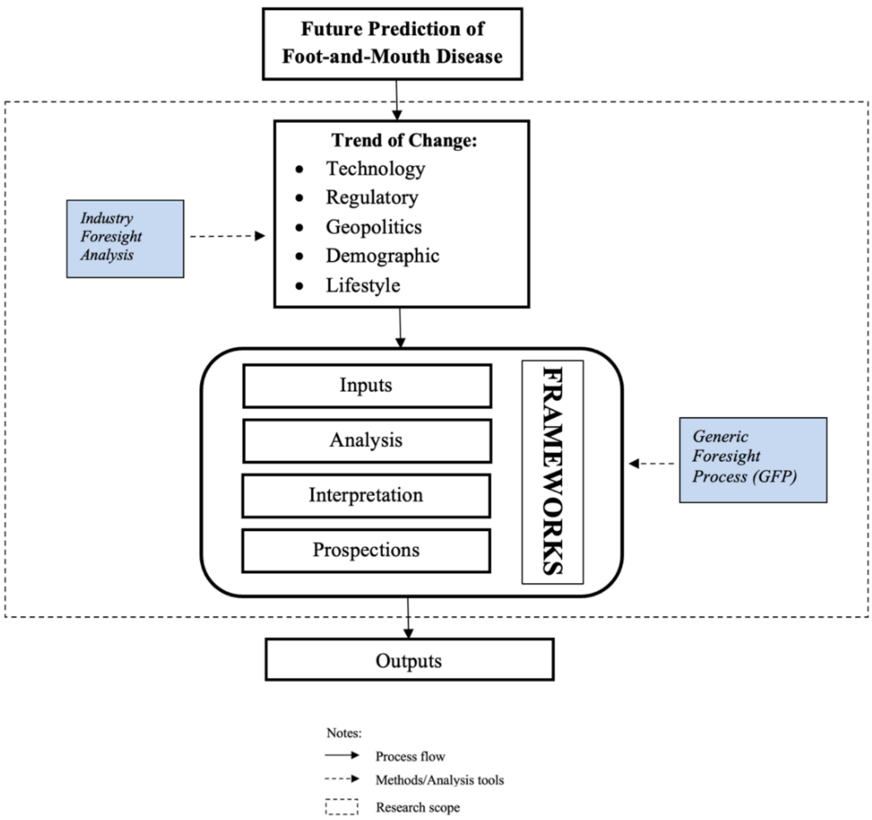

Figure 1. Research Framework Flow

RESULT AND DISCUSSION

Foresight Industry

Over the past few decades, industry foresight analysis has been widely used as a long-term endeavour to anticipate the future of society, economy, technology, and science. The industry foresight is described as a strategic approach that involves the systematic and participatory collection of current facts and intelligence based on trends, phenomena, and cycles. Consequently, it is capable of accommodating traditional forecasting that is both historical and well-known. Through industry foresight, future predictions can be clearly depicted in a broader perspective in an era of challenging and dynamic change (Adegbile et al., 2017, Marinkovic et al., 2022). Furthermore, industry foresight has been used in the veterinary service as a brainstorming analysis tool to determine policies and strategic efforts to be taken by policy makers (Grace, 2021).

FMD is an animal disease that causes substantial economic losses. Therefore, FMD is categorized as a strategic disease. Indonesia is one example of a country that has first re-emerged FMD outbreak with a distance of >30 years. This is a factual phenomenon that cannot be ignored. Therefore, it is necessary to analyze the development of future trends of FMD disease by identifying changing trends derived from technology, regulatory, geopolitics, demographics, and lifestyle. The data was presented in Table 1.

Table 1. Formulation of industry foresight analysis on the trends of foot-and-mouth disease

Aspects	Trend of Change	Industry Foresight
Technology	Encouragement of technological innovation through safer, cheaper, easy-to-apply mRNA-based vaccines to boost immunity.	FMD vaccine is an essential requirement for farmers. Innovation is the key to successful future competition in the FMD vaccine production market. All manufacturer compete to create FMD vaccines that are safer, cross-protective, effective, easy to apply, efficient, and economical to influence the international standard of vaccine product.
Regulatory	Regulations on foot-and-mouth disease management and control.	
Geopolitics	National interest in trading live animals and its derivative products influences import-export policies.	
Demographic	The increase in demand for meat consumption has led to increased livestock productivity.	
Lifestyle	Awareness of the need for good quality animal protein and the relationship between livestock and the socio-cultural life.	

Technology. Technology plays the most crucial role in the development of FMD vaccine production. This is due to the rapid growth of biomolecular technology, which is highly applicable to the production of vaccines. Vaccine products must have good quality and safety since vaccines are instrumental in the sustainable control and prevention of diseases. Therefore, a vaccine must provide good immunity and safety and be effective for combat the disease. Figure 2 explains time map of vaccine manufacturing technology development.

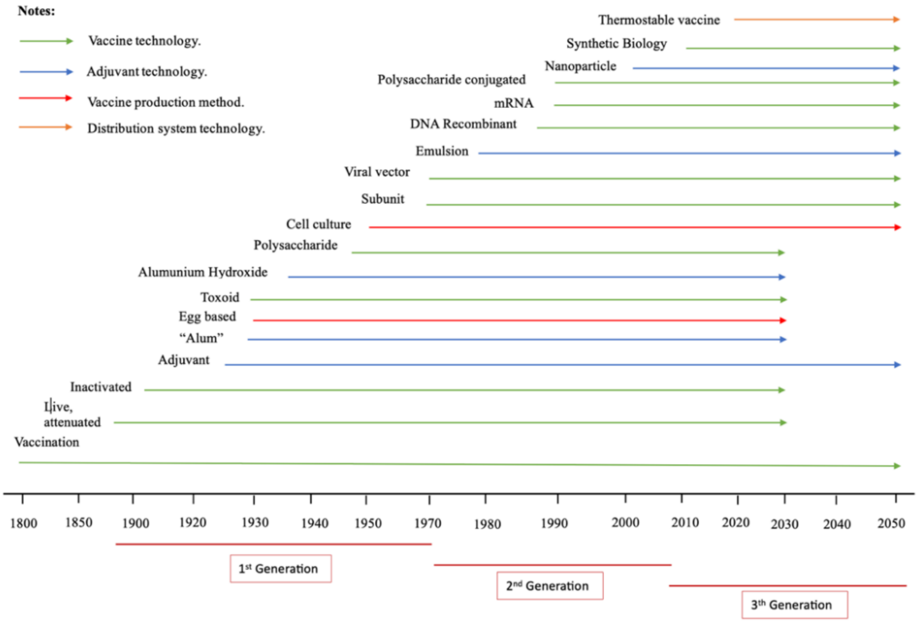

Figure 2. Time map of vaccine manufacturing technology development

FMD vaccines should be produced to have the capacity to verify DIVA vaccination diagnostics or DIVA compatible. The fundamental concept of DIVA diagnostics is to distinguish between antibodies produced by animals naturally affected with FMD virus and antibodies created from vaccination. Thus, disease control and FMD eradication status can be determined based on the results of these antibody testing (Hardam et al., 2020, Erdem et al., 2022).

A DIVA-compatible vaccine can be produced by eliminating the non-structural protein (NSP) in the FMD virus, which is the main composition of the vaccine. However, commercial FMD vaccines use inactivated vaccines containing oil emulsions and the chemical compound binary-ethylenimine (BEI) to eliminate NSP protein. This process is unsafe and does not provide good long-term immunity potential for vaccinated animals. Therefore, biomolecular developments can be maximized by making vaccines based on DNA/mRNA. This technology is predicted to be the future for the FMD vaccine industry in producing safe products with excellent immunity potential (Kamel et al., 2019).

mRNA technology has developed rapidly since the 1990s. It was invented to overcome the limitations in the generation of other types of vaccines. mRNA technology has been extensively utilized in the development of human vaccines due to its rapid production and ease of design. The use of mRNA is expected to expand in the animal health and care industry. Thus, mRNA is predicted to become the standard for making or producing veterinary vaccines for the future by 2050.

Nano-adjuvants are predicted to become the standard adjuvant technology in vaccine production. Nano-adjuvant involves nanoparticle material technology whose size ranges from 1-1000 nanometers (1 mm). This technology is present to overcome the limitations of an effective and controllable antigen delivery system. Through nanoparticles, active ingredients known as an antigen in vaccine products can be delivered to target tissues very quickly and can better stimulate the immune system (Nooraei et al., 2023).

Vaccine are biological products. Biological products require cold storage at 2°-8° C temperatures on an ongoing basis. This was carried out so that the active ingredients are not damaged, which can reduce product quality. Cold storage is needed in production, administration, distribution, transportation, and for the application processes.

Vaccine itself requires a cold chain system in their distribution system. However, the system is highly dependent on a stable electricity supply. This is particularly impactful in low- and middle-income countries that do not have widespread access to a stable and adequate electricity supply and, therefore, cannot store vaccine products for some time and where the business size may be relatively small in different regions (Beazley, 2022). The manufacturer should invest in a solution by adapting thermostable vaccine technology. Thermostable vaccines are vaccines that can be stored above 8° C, and are not damaged by freezing temperatures (<0° C) (Fanelli et al., 2022). In other words, the product do not require a cold chain system. Thermostable vaccines have been developed in many commercial veterinary vaccines and are expected to proliferate until 2050.

Regulatory. FMD is still a severe challenge in many countries around the world, especially in Southeast Asian countries. The livestock industry is at significant risk due to FMD, which results in substantial economic losses. Countries have struggled for years to achieve FMD-free status. Therefore, FMD control require the role and commitment of the Government.

Stamping out, and test & slaughter are the two most frequently used methods for combating FMD through depopulation. Stamping out has been effectively implemented in numerous European countries during FMD outbreaks. Based on the history, the UK culled 6.5 million livestock, the Netherlands 2.85 million, France 63,000, Ireland 53,000 within 24 hours. Through this, Europe did not encounter any FMD case in 2001 (Harikumar et al., 2021). However, stamping out are not suitable for the Southeast Asian region. This is due to the dynamic movement of live animals across the region, making it more difficult to detect the presence of FMD-infected and suspected animals. In addition, stamping out is considered culturally contradictory for backyards and requires a lot of funding for compensation costs for stamping out actions taken.

Referring to the history of FMD control programs in Indonesia (1983) and the Philippines (2011), both countries implemented phased control by dividing areas based on risk management, known as the progressive zoning approach. The progressive zone in the Philippines is complemented by a buffer zone that monitors vaccine performance based on post-vaccination serology testing results. In the last control stage, the Philippines took stamping out in buffer zones to raise public awareness. Philippines was declared FMD-free in 2011 (Blacksell et al., 2019)

Although Indonesia and the Philippines are archipelagic countries, which is possible to divide their territories using the zoning approach, it does not rule out the possibility that in the future, policymakers can also adapt the strategy for countries that are in the continental component.

Geopolitics. The livestock industry is one of the fastest-growing agricultural sub-sectors in the world. Data recorded that livestock has contributed to 40% of the global value of agricultural products. As such, the industry has successfully supported livelihoods, food security and nutrition for 1.3 billion people worldwide (The World Bank, 2021). Livestock market share in the world is increasing along with the demand for livestock due to the surge in consumption demand caused by urbanization, rising incomes in developing countries, and changes in trade policies or economic liberalization (Thornton, 2010; Enahoro et al., 2021). These circumstances have led to high global trade in live animals and its derivative products, both exports and imports. However, the emergence of FMD is a significant challenge that has caused market instability and changes to beef trade patterns. Compared to live animals, dairy products, germplasm, leather, and bone, beef is the most valuable commodity.

Therefore, several countries are focusing their attention on FMD disease and implementing various control strategy to obtain official recognition of FMD-free status. This status offers commercial advantages. These advantages are manifested in the form of re-established access to international markets. This access contributes to the country's economic growth by generating valuable foreign exchange. Consequently, the export profile will shift to a higher value than countries that have not experienced a FMD outbreaks. According to research conducted by Enahoro et al., (2021), there is a trade rule that countries with FMD-free status tend to import countries with similar status. There are two categories of FMD-free status worldwide: free status with vaccination and free status without immunization. Compared to countries with FMD-free status with vaccination, those with FMD-free status without vaccination will typically have higher export prices. Subsequently, each livestock exporting nation is striving to achieve FMD-free status.

Demographic. Urbanization has been a global phenomenon over the past two decades. Urbanization is defined as the proportion of the urban population in the total population that comes from rural areas. The phenomenon is generally undertaken for more decent jobs, education, and better life opportunities. Data recorded that urbanization accounts for about 40-60% of global annual population growth in cities (Ghirotti, 2010; Regmi et al., 2010). In the next decade, a massive increase in African and Asian urban communities is projected (Thornton, 2010).

The growth in national income influences the ability to purchase or spend on livestock products to increase. This is reinforced by Ghirotti (2010), who states that livestock products are the preferred source of protein for people with higher incomes. Urbanization is also associated with changes in people's consumption patterns. The consumption patterns are more diversified, Urban communities tend to favour foods based on animal protein and fat, such as meat, poultry, milk, and dairy products. The urbanization can also be linked to changes in people's consumption patterns, the increase in human population and the income growth. This can be an input to the demand for livestock products globally and influence changes in consumption patterns (Ghirotti, 2010; Hatab et al., 2019). These changes significantly impact the demand for livestock products and its derivatives product.

Lifestyle. Open access to technology triggers people to obtain information on the origin of the meat they will consume. This is carried out to mitigate the risk of infectious diseases found in meat. Hence, the requirement for FMD disease-free certificates has been implemented, particularly for meat import activities. In the future, the certificates may also be required more widely in domestic trade. Based on information from the World Organization for Animal Health (WOAH) (2020), seven Southeast Asian countries require livestock traders to conduct FMD vaccination activities before shipment, while five countries require commercial farmers to submit FMD vaccination reports to veterinarians or local authorities. The need for FMD vaccination will be a must and a priority that can be pursued in the current and future industry.

In addition, livestock such as cattle and buffalo strongly influence the socio-cultural life of developing countries. For the example in Indonesia. This connection has formed into a social system that cannot be separated from people's lives. People's perception of beef and buffalo meat has been widely studied. Research shows that beef and buffalo meat have been widely used as cultural customs to complete Eid dishes and menus at certain events such as weddings, circumcisions, and other celebrations. However, in particular community groups, ox meat has a deep meaning (Permata et al., 2018).

In Merangin communities, a district in Jambi Province, Indonesia, there is a tradition or culture called the Bebantai Kerbau Tradition. The tradition involves the slaughter of hundreds of cattle such as cows and buffaloes to welcome the holy month of Ramadan in the local area. The slaughtered meat can be enjoyed by all groups, so the price of meat is set at a low cost. The implementation of the tradition has social value and religious values. Social values include cooperation, mutual cooperation, togetherness, solidarity, friendship and harmony between communities. Meanwhile, the spiritual value is the slaughter of livestock as an expression of gratitude in welcoming the month of Ramadan (Hariandi et al., 2022).

Generic Foresight Process (GFP) Stages

The GFP stages framework is a practical tool that can be used to identify how a strategy can be implemented in accordance with the foresight approach. This stages is conceptualized as a series of methodologies that combine all stages starting from the input collection, analysis, interpretation, and prospecting (Voros, 2003). By using this framework, this study can identify the FMD trends in 2024 compared to 2050. The data was presented in Table 2.

Table 2. Comparison results of FMD trends identification in 2024 and 2050.

GFP Stages	Identification 2024	Identification 2050
Inputs	FMD control in the Southeast Asia region.	Focus on FMD control in developing and underdeveloped countries such as the African continent region uses the successful approach of Rinderpest eradication.
Analysis	FMD vaccine demand is high in some Southeast Asia countries.	Strengthen regional coordination in implementing FMD control strategies in least-developed countries.
Interpretation	Focus and prioritize local FMD vaccine production.	Climate change, regular monitoring of FMD virus strains.
Prospection	Provide FMD vaccine according to the virus circulating in the country of origin, known as a vaccine matching.	Provide biomolecular-based and thermostable FMD vaccines that do not require cold chain systems.

Input. The input stage in the GFP framework refers to observing things that are seen or appear to be happening. In 2024, it is evident that WOAH will continue prioritizing the control of FMD on the Asian continent. The FMD virus has three epidemiological clusters based on its epidemiological classification. The three clusters cover the continents of Africa, Asia and South America. The African continent, particularly the sub-Saharan region, known as "The Greater Horn of Africa", has six of the seven FMD virus serotypes in circulation. These serotypes are A, O, C, SAT-1, SAT-2, SAT-3. The Asian continent is known to have four of the seven circulating serotypes, including serotypes A, O, ASIA-1 and C. The South American region has three serotypes: A, O, and C, which can currently only be found in Venezuela. No FMD cases were found in Europe since the last eradication in 2011. The sub-Saharan or "The Greater Horn of Africa" and the Asian region are FMD endemic areas (Roeder et al., 2013).

The Asian region is the world's central cattle and buffalo production pillar. Based on data released by FAO (2020), the Asian region has a global livestock population of around 39% or equivalent to >650 million head of population concentrated in South, Southeast, and East Asia. WOAH focuses on FMD control and eradication in the Asian region through a regional document/campaign called "The SEACFMD Roadmap".

Control and eradication towards FMD eradication can be based on the successful eradication of Rinderpest. Rinderpest is the most lethal disease in the history of the livestock industry. It also affects cloven-hoofed animals such as cattle, feral pigs, domestic pigs, deer, giraffes and camels (Caceres, 2011, Mourant et al., 2018). Rinderpest eradication was successfully carried out globally in 2011 and is considered the first collaborative effort that successfully applied multiple approaches. In fact, FAO and WOAH have now started to implement a progressive control pathway (PCP) similar to that of Rinderpest (Roeder et al. 2013, FAO 2022). The PCP is a guiding framework for FMD-endemic countries to conduct risk-based control to reduce disease (FAO, 2022). However, the control is still implemented in the Asian Region. This because Africa has much more significant challenges for controlling the disease. Thus, it is not impossible that by 2050, FMD control will be more focused on the African region. The region has yet to fully implement a reasonable FMD control and eradication strategy. This is based on unrestricted animal movement, vaccination strategies, vaccine-related problems, and the absence of stamping out regulations (Roeder et al., 2013).

Analysis. The analysis stage in the GFP framework refers to identifying "what seems to be happening". Several Southeast Asian countries urgently need an appropriate or matching FMD vaccine. This is stated in the document campaign agenda "The SEACFMD Roadmap", which is related to FMD prevention through the DIVA vaccination strategy. Therefore, the required FMD vaccine must support for the diagnostic of DIVA vaccination (DIVA compatible).

Coordination is equally vital in the process of controlling and eradicating a disease. This requires effective coordination of high national commitment at the political, policy, and scientific or technical levels. Coordination is essential to strategically and nationally align global strategies and issues when implementing a program. Organizations at the regional level should have full ownership and control of the coordination of implementation strategies. Oversight and planning in national programs must involve livestock farmers and traders associations and require multi-donor funding and global technical support. Regional coordination is underway for Southeast Asia, China and Mongolia through "The SEACFMD Roadmap" campaign.

Funding for FMD control and diagnosis in the Southeast Asia, China and Mongolia region has been established over the past 30 years through several bilateral and multilateral projects despite unique technical and political challenges. The projects were managed by WOAH, the Australian Centre for International Agricultural Research (ACIAR), the Australian Aid Program (AusAid and AIDAB), the European Union, the Government of South Korea, and the Japan Trust Fund and have been funded by the Australian Government through the Department of Foreign Affairs and Trade (DFAT) since 2011. Through the project, FMD control has proven to provide many benefits. However, funding must be increased for field technical capabilities, vaccines, surveillance, awareness raising, biosecurity and emergency response capabilities (Roeder et al., 2013; Blacksell et al., 2019).

Such initiatives will undoubtedly severely impact control and eradication efforts towards global FMD eradication. Thus, it is not unlikely that by 2050, the strategies to be pursued in underdeveloped countries such as the African region will adapt Southeast Asia's implementation by strengthening regional coordination through political commitment, bilateral and multilateral cooperation, and strengthening project funding from various donors or multi donors.

Interpretation. The interpretation stage in the GFP framework refers to identifying "what might happen in the future". In Southeast Asia, FMD vaccines are obtained from imports and local production. Countries that have been produced locally are only Thailand and Vietnam. Thailand started producing FMD vaccines in 1960 using isolates O/BKK/60 (serotype O), A/BKK/60 (serotype A) and Asia1/BKK/60 (serotype Asia-1). Furthermore, four other serotypes, such as O/Udonthani/1987, Asia1/Petchburi/1985, A/Sakolnakorn/1997 and A/Lopburi/2012 have been used in FMD control in Thailand. However, these vaccines have not adequately controlled FMD in Thailand. This is because the serotype A and Asia-1 FMD viruses in Thailand were found to be different or not homologous to the existing vaccines, requiring the development of new, and more suitable vaccine (Blacksell et al., 2019). Vaccination effectiveness is reliable when the vaccine products have homology matching or match the FMD virus serotypes circulating in the country of origin. Therefore, what is really happening is that national FMD vaccine production should focus on creating effective vaccine formulations. In 2018, Vietnam also produced a monovalent local FMD vaccine with serotype O to meet domestic demand (WOAH, 2021).

The FMD virus is a virus that has RNA genetic material. The virus can mutate quickly. Climate change is one of the triggers for genetic mutations in the virus. FMD virus RNA in some endemic areas can be detected at temperatures >27°C. The detection increased by 45% when the temperature increased to 37°C and RH 86%. Furthermore, researcher states that there is a strong correlation between warming temperatures and FMD outbreaks in Mongolia temporally and spatially (Mun et al., 2023). The spread of FMD viruses can be very dynamic worldwide due to the influence of increasing earth temperatures. In addition, FMD is also known to spread through the air. The virus can spread as far as 100 m from as few as 10 infected cattle under ideal circumstances (Mielke et al., 2023).

In response, improved veterinary services are needed to anticipate and manage the spread of disease due to climate change. This is done to globally maintain the food security (Stephen and Soos, 2021). However, vaccination is not considered optimal in controlling FMD. This is because the FMD virus has antigenic diversity. FMD viruses have characteristics that change rapidly in the structure of the virus or its RNA genome, which called mutation. The mutation phenomenon causes changes in the antigenicity of FMD viruses. This causes rejection of the immune response provided by a vaccine, leading to the emergence of other FMD virus variants that are immunologically different. Therefore, issues related to vaccine matching need to be followed up on. Periodic monitoring of FMD virus strains has begun. This is conducted to monitor the relationship between FMD vaccines available in the market and isolates that match the field or place where the outbreak occurred (Mahapatra and Parida, 2018).

Prospection. The interpretation stage in the GFP framework refers to identifying "what might happen in the future”. The future of FMD vaccine production will involve biomolecular-based vaccine manufacturing technologies, product distribution systems, adjuvant technologies, antigen delivery systems, and administration routes. Computational biomolecular-based vaccine manufacturing technology and reverse genetics in the manufacture of DNA vaccines and thermostable vaccines that do not require cold chain distribution systems. Thermostable vaccine can be easily accessed in any area. These technologies are considered more capable of creating vaccines with DIVA diagnostic markers, excellent potency, safety for vaccinated animals, and biosafety because the vaccine did not use all components and structures of the FMD virus in the production process. This is the future of FMD vaccine production requirements that can be used to design strategies for vaccine manufacturers (Kamel et al., 2019).

It is suitable to be applied when the focus of control and eradication towards FMD eradication is based on the history of Rinderpest eradication, one of the strategies of which is through vaccine development. Based on the history in 1960, a Rinderpest vaccine was developed using tissue culture technology. The vaccine is the TCRV vaccine known as tissue culture rinderpest vaccine. The TCRV vaccine is known to have successfully eradicated Rinderpest throughout Africa region. The vaccine can protect against all types of Rinderpest virus or known as a cross-protection, provide lifelong immunity in livestock or long-term seroprotection with no adverse immune reactions and is immunogenic. The TCRV vaccine is a significant milestone in rinderpest control. In 1986, the Faculty of Veterinary Medicine and the United States Department of Agriculture developed a thermostable TCRV vaccine formulation that can be stored for up to 8 months at 37°C 10 days at 56°C. In addition, the ThermoVax commercial vaccine emerged as a thermostable vaccine that does not require a cold chain system. This makes applying the vaccine easier (Roeder et al., 2013).

CONCLUSION

The Global of foot-and-mouth disease is predicted to continue until 2050. The eradication requires a long and extensive process. FMD can be sustainably controlled through vaccination. Vaccination is also considered important to open an international market access in the trade of meat, live cattle, and other derivative products. Several driving factors contribute to foot-and-mouth disease becoming highly dynamic. Therefore, FMD vaccines must be provided by relevant technological innovations to address the various challenges and problems in the market.

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