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Epidemiological Characteristics, Prevention and Control Policies of Brucellosis in Asia: A Comparative Analysis

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Abstract. Brucellosis, a highly prevalent zoonotic disease in Asia, faces significant challenges in prevention and control due to fragmented management and the insufficient effectiveness of traditional policy tools. This review examines the epidemiological characteristics and prevention and control policies of brucellosis in Asia, comparing the brucellosis prevention and control policies of five representative countries: Israel, India, South Korea, China, and Mongolia. It is found that each country enhances its prevention and control effectiveness through a combination of differentiated tools. However, there is still room for breakthroughs in free-range regulation, cross-border transmission, and cultural barriers. The research proposes an integrated governance framework under the concept of "One Health". Vertically, it establishes a three-tier national-regional-grassroots network. Horizontally, it promotes cross-departmental collaboration across agriculture, health, and other fields, and involves multiple stakeholders, including international organizations, communities, and private sectors. Policy tools need to focus on technological empowerment, such as strain tracing and Geographic Information System monitoring, as well as culturally sensitive interventions, exemplified by India's "Boiling Milk" initiative. In the future, researchers should promote regional cooperation in Asia, establish a technology-sharing platform, and coordinate policy tools and governance mechanisms. They should also build a three-dimensional prevention and control system to provide an Asian experience for the global management of zoonotic diseases.

Keywords: Brucellosis, Asia epidemiology, control policy, one health

1. Introduction

Brucellosis is one of the most common zoonotic diseases globally, with over 500000 new cases reported annually. While some developed countries have nearly eradicated the disease, Asia has emerged as the epicenter of the global brucellosis epidemic due to complex factors such as socio-economic development levels, animal husbandry practices, and geopolitical dynamics. This disease poses a dual threat to both public health and economic development in the Asian region. In terms of health, it can cause acute febrile illnesses in humans. If not treated promptly, these illnesses can easily become chronic, leading to recurrent episodes, disability, and even death [1]. Economically, most developing countries in Asia rely heavily on animal husbandry, with cattle and sheep being the primary hosts of Brucella. The epidemic not only hampers animal husbandry production and

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restricts international livestock trade, but also increases the economic burden on residents due to treatment costs [2,3]. Thus, brucellosis has become an urgent public health issue in Asia.

Over the past two decades, Asian countries have implemented diverse prevention and control plans, resulting in significant changes in the epidemic situation. For example, the incidence rate of human brucellosis in Syria dropped from 1603.4 per 100000 in 2006 to 47.26 per 100000 in 2017, and Mongolia's global ranking in the same period fell from second place (391.0 per 100000) to twentieth place (4.62 per 100000) [2]. However, the cross-departmental collaboration mechanism under the "One Health" concept has not been widely implemented, and epidemic data in Asia remains fragmented. This has led to insufficient comparative research on the prevention and control policies of various countries, preventing the full utilization of experiences from countries with successful "One Health" institutional mechanisms [4]. Against this backdrop, this review aims to summarize the prevalence of brucellosis across different regions of Asia and the prevention and control policies of typical Asian countries. By comparing the implementation and effectiveness of different policies, it seeks to fill the research gap on brucellosis prevention and control policies in Asia, provide references and insights for many developing countries in the region, and offer guidance for promoting the "One Health" concept and the integration of prevention and control institutions in Asia.

This review searched for keywords such as "Asian Brucellosis Prevention and Control Policies" on platforms like PubMed and Google Scholar, integrated 60 pieces of literature, and provided an overview of the prevalence and prevention and control policies of brucellosis in Asia based on the literature search results. Additionally, a comparative analysis was conducted on the prevention and control policies of typical countries, including Israel, India, South Korea, China, and Mongolia.

2. An overview of the epidemiological characteristics and prevention and control policies of brucellosis in Asia

As the core region for the global prevalence of brucellosis, Asia displays marked geographical heterogeneity and multidimensional disparities in its epidemic characteristics and prevention practices. These differences arise from variations in geographical environment, livestock structure, socioeconomic levels, and cultural customs. From the humid and rainy Southeast Asia to the arid and vast Central Asia, and from livestock-dependent Mongolia to the densely populated India, the epidemiological features of brucellosis vary significantly across countries: In terms of host range, brucellosis in different subregions of Asia primarily involves domestic animals such as cattle, sheep, and camels; In terms of pathogen lineages, many countries in Asia predominantly feature Brucella abortus (B. abortus) and Brucella melitensis (B. melitensis) as the dominant strains; In terms of epidemic intensity, there is a wide range, from countries that have eradicated brucellosis to those with human incidence rates exceeding 300 per 100000; In terms of transmission routes, most countries in Asia primarily experience contact transmission and foodborne spread, demonstrating distinct regional differentiation and a complex pattern.

This epidemiological landscape poses a chain of threats to public health, characterized by "acute fever—chronic progression—disabling and fatal" outcomes. It also has profound impacts on regional economies due to livestock losses and disruptions in international trade. Faced with this severe challenge, Asian countries have developed diverse prevention and control systems based on their national conditions. These include traditional strategies such as "testing—slaughtering—compensation", as well as modern approaches like vaccine innovation, interdepartmental collaboration, and cross-border epidemic linkage mechanisms. Over the past two decades, significant changes in the epidemiology of brucellosis have occurred due to the efforts made by

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Asian countries in prevention and control. While practices in typical countries such as Israel, India, South Korea, China, and Mongolia have significantly reduced the risk of outbreaks, most developing countries are still constrained by issues such as fragmented data, single management mechanisms, and insufficient vaccine coverage. This leaves room for improvement in their brucellosis prevention and control policies [1,2].

3. Epidemiological characteristics and prevention and control policies for brucellosis in Southeast Asia

The Southeast Asian region encompasses 11 countries, including Malaysia, Vietnam, Thailand, and Indonesia. Brucellosis in this region exhibits distinct host and regional variations. Cattle are primarily infected with Brucella abortus, with prevalence rates ranging from 1% to 2% in Thailand and Indonesia. In contrast, Malaysia and Myanmar experience higher rates of 4% to 5%, due to frequent importation of breeding stock and open farming practices [5]. Small ruminants, such as goats, are mainly affected by Brucella melitensis, with prevalence rates of approximately 1% in Malaysia and Thailand. High-prevalence areas are often linked to inadequate biosecurity measures and cross-border animal movements. This results in significant economic losses—approximately 200 million Malaysian ringgit annually in Malaysia—and poses threats to human health through untreated dairy products, leading to conditions such as undulant fever and arthritis [6].

In terms of control policies, Southeast Asian countries generally adopt comprehensive measures centered on "testing and culling". Initial screening of infected herds is conducted using the Rose Bengal Plate Test (RBPT), followed by confirmation of individual infections through the Complement Fixation Test (CFT). Animals that test positive are subject to mandatory culling, with economic compensation provided to the owners. This policy reduced cattle prevalence in Malaysia from 3.3% in 1979 to 0.23% in 1988. However, prevalence has recently risen to 5%, due to issues such as cross-border transmission [5]. Additionally, some high-risk areas supplement control efforts with attenuated live vaccines, enhanced quarantine and isolation at farms, harmless disposal of aborted materials, and pasteurization of dairy products as part of biosecurity measures. Notably, countries are increasingly promoting cross-sectoral collaboration among veterinary, public health, and agricultural departments. This involves improving diagnostic technologies and establishing hotspot surveillance maps to address challenges such as hidden transmission and import risks. The ultimate goal is to achieve the "One Health" approach in the management of zoonoses [7].

4. Epidemiological characteristics and prevention and control policies for brucellosis in central and North Asia

The Central Asian region includes five countries, namely Kazakhstan, Kyrgyzstan, and Uzbekistan, among others, while the North Asian region typically refers to Russia's Asian territories. In both Central and North Asia, brucellosis is a significant zoonotic disease that poses a threat to human and animal health, primarily caused by Brucella abortus and Brucella melitensis. Cattle, sheep, and goats are the main hosts, with cross-species transmission occurring [8]. Kazakhstan is a country with a relatively prominent epidemic situation. The prevalence rate among cattle is approximately 0.6%, and among small ruminants, it is around 0.4%. In 2004, the human incidence rate reached as high as 23.7 per 100000, particularly in the southern region. Due to miscarriages and decreased reproductive performance in infected animals, direct economic losses amounted to 45 million US dollars in 2015. Rural residents have become a key risk group for human infection, primarily due to their frequent consumption of homemade, unsterilized dairy products [9].

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Kyrgyzstan has the highest human incidence rate in Central Asia. In 2008, data indicated an incidence rate of 73.7 per 100000 people, with a serum-positive rate of 1.72% among small ruminants in the same year. In Russia, the epidemic is concentrated in southern federal regions such as Dagestan and the Tuva Republic in Siberia, with approximately 80% of human cases are caused by B. melitensis infection [10]. The spread of the disease is closely related to the transformation of regional animal husbandry models. Since the dissolution of the Soviet Union, small-scale family farming has increased rapidly, animal movement control has been relaxed, and cross-border trade has become more frequent, creating conditions conducive to pathogen spread. Although early large-scale use of vaccines such as the S-19 strain reduced animal miscarriage rates, the serological reactions triggered by these vaccines often interfere with epidemic diagnosis, posing challenges to precise prevention and control.

In terms of prevention and control policies, countries have implemented targeted measures. Kazakhstan has enforced a "testing and slaughter" policy since 2007, conducting two serological tests (RBPT and CFT) annually on cattle, sheep, and goats. Confirmed positive animals receive 30% compensation from the government and 70% from slaughterhouses for harmless treatment. However, due to the cumbersome compensation process and insufficient amounts, some farmers opt to conceal the epidemic [8,9]. Meanwhile, countries such as Russia and Uzbekistan widely use the Rev-1 strain vaccine for small ruminants. Russia has also developed weak agglutination vaccines, such as the Nevskii-13 strain, to reduce vaccine interference in serological testing [10].

Regarding monitoring systems, Kazakhstan has established a national-level veterinary laboratory network, and Russia has strengthened regional surveillance. However, issues such as the low registration rate of private farms and weak grassroots diagnostic capabilities remain prevalent. It is worth noting that the five Central Asian countries are promoting the establishment of the "Central Asian Animal Health Network", aimed at enhancing prevention and control coordination through cross-border epidemic information sharing [9,10]. Various countries are also promoting biosafety management, including the standardization of farm isolation, harmless treatment of aborted materials, and mandatory pasteurization of dairy products. However, regulatory gaps in homemade dairy products in rural areas and the lack of key data on farmers' consumption habits in Kazakhstan still affect the accurate construction of risk assessment and prevention models for transmission [8]. Overall, regional prevention and control efforts require further breakthroughs in cross-departmental collaboration, vaccine optimization, and data sharing to address the complex challenges of zoonotic disease transmission.

5. Epidemiological characteristics and prevention and control policies for brucellosis in West Asia (the Middle East)

The West Asia (Middle East) region encompasses 20 countries, including Saudi Arabia, Iran, and Israel. Brucellosis in this region is primarily caused by Brucella melitensis, while infections in camels are also reported in some countries[11]. The main hosts are sheep, goats, and cattle, with occasional infections in camels and pigs [12]. Human infections occur most frequently in Saudi Arabia, Iran, and Israel. In 1988, the incidence rate in Saudi Arabia reached 79.6 per 100000, and in Iran, it reached 132.4 per 100000. Transmission is mainly through the consumption of unsterilized dairy products and exposure to infected animals, with occupational groups at higher risk. Incidence peaks in spring and summer, correlating with lambing and increased dairy consumption [13].

The West Asia (Middle East) region, one of the highest incidence areas for brucellosis in Asia and globally, merits special attention for its low prevalence and effective prevention and control strategies in Israel. Israel's average incidence rate from 2004 to 2022 was only 1.6 per 100000,

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significantly lower than that of neighboring countries. This is primarily due to Brucella melitensis, which, since eradication in cattle, has made small ruminants the core source of infection. In terms of pathogens, 99.6% of confirmed cases are attributed to Brucella melitensis [12]. The epidemic situation in Israel shows significant ethnic differences: the incidence rate among the Arab (84.9%) and Druze ethnic groups is 6.6 per 100000 and 5.5 per 100000, respectively, due to family free-range breeding and raw milk consumption. The southern Arab settlement once reached 41.0 per 100000, while the Jewish ethnic group had only 0.18 per 100000 [12]. Over 80% of cases are related to the ingestion of raw goat milk, and laboratory infections have also been reported [13].

In terms of prevention and control policies, Israel has established a comprehensive system of "testing, slaughter, and vaccination". In 1993, the national eradication plan was launched, with positive animals being forcibly slaughtered and compensated through serological testing. During the pilot period, the epidemic situation significantly decreased. Since 1997, the Rev-1 vaccine has been administered to livestock under six months of age, effectively controlling the prevalence of small ruminants to a low level [13]. Public health interventions focus on high-risk communities, such as in northern Arab towns, where multiple departments collaborate to conduct pasteurization training and media campaigns [13]. The GINRON Veterinary Research Institute was established at the national level to unify strain identification and coordinate monitoring of human and animal epidemics [12]. Currently, challenges include the difficulty of eradicating household consumption of raw milk, insufficient vaccine coverage among nomadic populations (about 30% unvaccinated), and imported cases caused by cross-border illegal trade [13]. Israel's experience shows that culturally adapted interventions (such as mobile vaccine vehicles) and cross-departmental collaboration are key.

Other West Asian (Middle Eastern) countries also focus on "testing and slaughter" and vaccination in their prevention and control policies. For example, Kuwait's large-scale vaccination reduced the prevalence of sheep and goats from 5.8% to 2.02%. Iran uses the S19 vaccine for cattle, reducing the prevalence to below 1%. Countries have also implemented measures to strengthen biosecurity management, such as Iran's regulation of the handling of aborted materials on ranches [12]. Additionally, national laboratory networks and cross-departmental collaboration mechanisms have been established, and specialized prevention and control policies tailored to national conditions have been proposed, such as advocating for safe diets through religious leaders in high-risk communities in Saudi Arabia [13]. However, inadequate regulation of cross-border animal trade, lack of monitoring of nomadic populations, and potential side effects of vaccines remain major challenges. Epidemic prevention in West Asia (Middle East) still needs to strengthen the "One Health" strategy and enhance regional data sharing [12].

6. Epidemiological characteristics and prevention and control policies for brucellosis in South Asia

The prevalence and prevention policies of brucellosis in seven South Asian countries, including India and Pakistan, have long been neglected in research. Due to missing data, there are discrepancies and conflicts in the epidemiological data across multiple South Asian countries [1,2,14]. This makes it challenging to conduct a comprehensive analysis of the overall regional epidemic situation. As the most populous country in South Asia and the country with the world's largest number of cattle (307 million) and water buffalo (108 million), India has become a typical representative of the high burden of brucellosis, with the epidemic affecting all states and regions [15].

The epidemiological characteristics of brucellosis in India exhibit significant heterogeneity. The positivity rate of bovine serum varies widely among non-random samples (for example, 60% in

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Assam farms based on a history of miscarriage). However, 30437 random samples from 23 states across the country show an overall prevalence rate of ≤ 12%. Buffalo serum positivity rates range from 3% to 16.4%, with large-scale farms in Punjab reaching 17% to 21% [14]. Other important hosts include sheep (8.7%), goats (5.8%), pigs (6.3%–11.3%), and dogs (7.69% male). Cattle and water buffalo are primarily infected with Brucella abortus, while small ruminants are more susceptible to Brucella melitensis [15,16]. In terms of regional distribution, livestock positivity rates in agriculturally intensive areas such as Punjab are as high as 26.5%. Prevalence rates on large-scale farms near cities are two to three times higher than those in rural areas. In terms of climate distribution, miscarriage cases during the rainy season (July–September) in humid and hot regions account for 35% of the annual total [15]. The transmission routes of brucellosis in India are complex, with the localized livestock industry being one of the main transmission routes in rural areas. For example, the mixed farming model in rural areas increases the risk of cattle infection by two to three times, and only 12% of small-scale farmers use protective clothing. The government's vaccine subsidy coverage rate is 25%–50%, and 30%–40% of household infections come from drinking unpasteurized milk [14,16]. In terms of economic burden, India's annual total losses amount to 3.4 billion US dollars. This includes a 10%–15% decrease in milk production from cows and buffaloes (with Punjab farms experiencing an annual loss of 46%), a 6.8%–24% seropositivity rate among occupational populations, an annual medical loss of 10.46 million US dollars for the general population, and a loss of 177000 DALYs.

India's prevention and control policy is centered around the Brucellosis Control Plan (BCP), with the central government providing 90% of the funding. The focus is on vaccination, testing, isolation, and biosafety. From 2017 to 2018, approximately 20000 female cattle and water buffalo aged 4–8 months were vaccinated with the S19 vaccine. The pilot RB51 vaccine is predicted to reduce the cattle prevalence rate to 1.2% within 20 years [14]. Detection primarily relies on the Rose Bengal Plate Test (RBPT) and ELISA, with a pilot program of "one village, one laboratory" in Punjab. However, only 50% of county-level laboratories can perform ELISA, and 80% of states prohibit cattle slaughter, resulting in a compensation coverage rate for "detection and isolation" of less than 5% [15]. Biosafety measures include a 60% coverage rate for artificial insemination in Punjab, a 25% harmless treatment rate for aborted materials, a 15% occupational protection usage rate, and a 75% awareness rate for "boiling milk" in rural areas [16]. The country has introduced the FAO risk assessment model in international cooperation and is working on localizing the RB51 vaccine. In terms of effectiveness, the positivity rate of calves on large-scale farms has decreased from 21% in 2015 to 8% in 2023, and the vaccine coverage rate has increased from 15% to 40%. However, challenges remain, such as weak cold chain logistics (rural refrigerator penetration rate < 40%), lack of DIVA vaccines (serological misjudgment rate of 10%), a vaccination rate of only 30% for free-range households, and 20% of positive cattle being detained due to religious taboos [14].

7. Epidemiological characteristics and prevention and control policies for brucellosis in East Asia

The East Asian region encompasses five countries: China, Japan, South Korea, North Korea, and Mongolia. Japan has successfully eradicated brucellosis [2]. Meanwhile, North Korea is not considered valuable for research due to the lack of available data. South Korea, China, and Mongolia are the primary countries where brucellosis is prevalent. These three countries have implemented diverse brucellosis prevention and control policies, making them typical subjects for brucellosis research.

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The overall prevalence of brucellosis in South Korea has remained stable, with bovine brucellosis (caused by B. abortus) being the predominant form of the disease. From 2002 to 2009, there were 77082 cases of bovine brucellosis (with a prevalence rate of 13.3 per thousand) and 620 cases of human brucellosis (0.16 per 100000). The correlation coefficient between bovine and human outbreaks reached +0.985 [17]. The epidemic is concentrated in the southeast, with males (86.9%), individuals over 40 years old (86.1%), and farmers (47.9%) being the high-risk groups [18]. From 2014 to 2023, 45.2% of the isolates were imported B. melitensis, mainly from China and Saudi Arabia [18]. South Korea's prevention and control policies have become increasingly stringent. The core of its prevention and control strategy is "testing and slaughter" , which includes mandatory pre-sale and pre-slaughter testing since 2004, annual testing of entire herds and bi-monthly milk ring tests (MRT) implemented in 2008 and government compensation for culling infected livestock at 80% of the market price. Additionally, South Korea actively promotes cross-departmental collaboration, data sharing, and public education to enhance public awareness of protection. Although the increased detection intensity from 2004 to 2006 led to a temporary spike in the incidence rate to 225.1 per 10000 cases, it subsequently decreased to 59.5 per 10000 cases and remained stable in 2009 [18]. Meanwhile, the risk of imported brucellosis in South Korea continues to require monitoring.

Due to its large population and significant livestock industry, China has become another typical country for brucellosis prevention and control. The prevalence of brucellosis in China has exhibited distinct phases: the 1950s and 1960s were the peak epidemic periods, with a livestock infection rate of 41.27% and a population serum positivity rate of 3.56% in northern pastoral areas [19]. Vaccination efforts in the 1970s and 1980s reduced the livestock positivity rate to 0.55%. After the 1990s, the epidemic spread to North China and Northeast China. In the South, due to imported cases (such as 122 cases of goat milk infection in Guangxi in 2017), the average annual growth rate was 15%, although the overall epidemic situation has since declined [3, 20]. Since 2004, Inner Mongolia (25.80/100000) and Shanxi (7.33/100000) have emerged as high-prevalence areas, with Brucella melitensis outbreaks accounting for over 60% of cases [20]. In terms of prevention and control policies, China's system includes: since 1990, the establishment of 15 national monitoring points for surveillance, with annual testing of over 1 million serum samples; vaccination coverage, with an 80% S19 vaccine coverage rate in northern dairy farms and a 70% S2 vaccine coverage rate in southern flocks; early warning and culling of diseased livestock from 2004 to 2019, with compensation at 60%–80% of the market price and a 90% harmless treatment rate for large-scale farms; and medical intervention, with a 95% protective equipment rate for high-risk populations and a 90% cure rate for "doxycycline + rifampicin" treatment [3,19]. Thanks to these policies, public awareness has improved, with the rural awareness rate increasing to 78% in 2020. However, challenges such as a short vaccine protection period, imported drug resistance (with a 25% tetracycline resistance rate for Middle Eastern strains), and a 20% misdiagnosis rate at the grassroots level still persist [3,19].

Mongolia, one of the countries with the highest incidence of brucellosis globally, saw its incidence rate drop from second place (391.0/100000) to 20th place (4.62/100000) in 2017, making it another typical country for brucellosis prevention and control research. Intensive animal husbandry and occupational exposure among herders are the main risk factors for brucellosis prevalence in Mongolia [2,21]. After 2008, Mongolia reduced its herder population from 380000 to 290000 and increased its urbanization rate to 68% by promoting centralized breeding and improving livestock breeds, thereby reducing the occupational exposure population base. Additionally, the "White Disaster" in 2010 temporarily suppressed the epidemic, and long-term aridification

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effectively reduced animal density, indirectly blocking pathogen spread. Its prevention and control measures include the introduction of S19 and Rev-1 vaccines and the establishment of a culling compensation mechanism supported by the World Bank to further suppress brucellosis spread. In terms of international cooperation, the China-Mongolia border joint prevention and control mechanism uses electronic ear tags and Geographic Information System (GIS) technology to monitor cross-border livestock movement and strengthen prevention and control through joint exercises in 2013. These factors have collectively led to an overall improvement in Mongolia's epidemic situation. Although climate and social changes have reduced transmission, insufficient vaccine coverage and imperfect compensation mechanisms among nomadic populations still constrain prevention and control efforts.

8. The analysis and comparative evaluation of brucellosis prevention and control policies in Asia

Policy tools are the means by which governments translate policy objectives into concrete actions, and their selection directly impacts the effectiveness of policies. Peters has classified policy tools into four categories: command-based tools (laws, regulations, and administrative orders with preventive and control functions, as well as targeted controls on key links such as testing and slaughter, transportation, and isolation); incentive-based tools (including interest guidance and market leverage, commonly used in brucellosis prevention and control, such as economic compensation and subsidies, financial support, and cost-sharing); capacity-building tools (focusing on empowerment and system construction, mainly reflected in the research and development of detection and treatment technologies, infrastructure construction, as well as improvements in management quality and governance capacity, and international cooperation in brucellosis prevention and control); and information-based tools (primarily reflected in the promotion and education of brucellosis prevention and control policies). Efficient guidance and shaping through precise intervention of the target group, in conjunction with behavioral intervention, emphasize that tool selection should align with policy objectives, implementation environment, and stakeholder characteristics. Based on this, a policy analysis and comparison of brucellosis prevention and control policies in five typical countries, including Israel, India, South Korea, China, and Mongolia, will be conducted. By comparing the similarities, differences, advantages, and disadvantages of specific brucellosis prevention and control policies in each country across various types of policy tools, it will be beneficial to identify the optimal policy tool applications and governance system construction ideas, thereby providing references and examples for prevention and control policies and system construction in other countries [22].

Through the analysis and comparison of specific prevention and control policies in these five typical countries, important theoretical insights have been generated regarding these policy tools. First, in terms of tool adaptability, command-based tools are suitable for rapid loss mitigation during an epidemic outbreak; incentive-based tools can address the trust dilemma between the government and farmers; capacity-building tools are the core of establishing long-term mechanisms; and information-based tools need to be precisely designed in combination with cultural characteristics. Second, regarding tool combination logic, the experiences of these five countries collectively indicate that the effectiveness of a single tool is limited. A four-dimensional collaborative system of "command-based rapid response + incentive-based resistance reduction + capacity-building-based consolidation of foundations + information-based awareness cultivation" needs to be jointly constructed. Additionally, in terms of overcoming fragmented governance, Israel and China have initially formed a prototype of a "mechanism complex" through cross-departmental data sharing

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(capacity-building tools) and international joint defense and control (command-based tools), confirming the core logic of Peters' theory that "tool selection needs to match governance structure". These conclusions provide valuable practical reference suggestions: Asian developing countries can learn from the experiences of these five countries and prioritize the promotion of a "policy tool menu" in brucellosis prevention and control—dynamically combining tools based on the epidemic stage (epidemic period/stable period), socioeconomic conditions (mainly large-scale breeding/free-range), and cultural customs (dairy consumption habits) while strengthening cross-departmental cooperation and international technical assistance to address the issue of "fragmented" governance.

9. Conclusion

This review compares the prevention and control practices of Israel, India, South Korea, China, and Mongolia, highlighting the synergistic effects and fragmented governance challenges associated with the use of multiple policy tools in managing brucellosis. Experiences from various countries demonstrate that the rigid constraints of command-based tools, the interest guidance of incentive-based tools, the technological empowerment of capacity-building tools, and the cultural adaptation of information-based tools together form a four-dimensional support system, significantly enhancing the effectiveness of prevention and control efforts. However, issues such as the lack of supervision over free-range households, cross-border transmission risks, and resistance to cultural customs have exposed the difficulties faced by single countries or departments in addressing the challenges posed by cross-species and cross-border zoonotic diseases. There is an urgent need to develop a composite prevention and control system based on the concept of "One Health".

To address the complexity of prevention and control in the Asian region, it is essential to break through traditional models and integrate diverse governance resources under the guidance of the "mechanism complex" theory to innovate policy tools. At the vertical coordination level, a three-tiered national-regional-grassroots network should be established. For example, the combination of China’s national data platform with Mongolia’s border defense mechanism can help address issues related to scattered data and cross-border transmission. At the horizontal integration level, cross-sectoral cooperation among human, animal, and environmental sectors should be promoted at the national, regional, and grassroots levels. This can be achieved by learning from South Korea’s animal epidemic data exchange and India’s FAO risk assessment model, thereby enabling the linkage of monitoring, diagnosis, treatment, and supervision. At the level of diversified participation, international organizations such as the WHO and the World Bank, as well as communities and private sectors, should be incorporated. For example, Israel’s community leader training programs and the operation of special funds similar to the Global Fund can be emulated to form a "government-led + market-operated + community-participated" model. Policy tools should focus on technological empowerment, such as tracing MLVA strains in China, GIS tracking systems in Mongolia, and culturally sensitive interventions, to overcome the limitations of traditional vaccines and resistance mechanisms.

Looking ahead, Asian countries should work to upgrade regional cooperation mechanisms. It is recommended that ASEAN and the Shanghai Cooperation Organization include brucellosis prevention and control within the "One Health" cooperation framework, sign the "Convention on the Joint Prevention and Control of Asian Zoonotic Diseases" and clarify obligations such as epidemic notification, technology sharing, and emergency response. Additionally, the establishment of an "Asian Prevention and Control Technology Transfer Center" is proposed to promote the sharing of Israel’s precision testing technologies and China’s vaccine production experience within the region, thereby narrowing the gap in prevention and control capabilities among countries.The transition

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from "fragmented governance" to a "mechanism complex" essentially involves the organic integration of rigid legal constraints, economic interest guidance, technological innovation, and flexible cultural adaptation. The practice of brucellosis prevention and control in Asia has shown that only by breaking down barriers across departments, species, and borders can a three-dimensional prevention and control network be constructed—one that is vertically integrated, horizontally extensive, and collaboratively diverse. This approach can contribute to replicable Asian solutions to the global management of zoonotic diseases.

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