The Seroprevalence of Chlamydia Infection in Sheep in Shanxi Province, China

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Simple Summary: Chlamydiosis is an important zoonotic disease, which can cause significant harm and economic losses to animal husbandry. So far, there are 15 species in the genus Chlamydia, some of which can infect humans and many mammals including sheep, yaks, pigs, equine animals, and some wild animals. In this study, the indirect hemagglutination assay (IHA) and indirect enzyme-linked immunosorbent assay (ELISA) were used to conduct an epidemiological survey of Chlamydia and Chlamydia abortus (C. abortus) infection in sheep in Shanxi Province, China. The results showed that the overall seroprevalence of Chlamydia infection in sheep in Shanxi Province was 35.67%, and the seroprevalence was associated with the geographical location and management mode. This study provides baseline information for the prevention and control of Chlamydia infection in sheep in Shanxi Province, China.

Abstract: Chlamydia, an obligate intracellular bacterium, can cause chlamydiosis in humans and animals worldwide and also leads to serious economic losses to the sheep industry. However, the information on Chlamydia infection in sheep was limited in Shanxi Province, northern China. In the present study, a total of 984 serum samples of sheep were collected from 11 regions in Shanxi Province, northern China in the autumn of 2020. The antibodies against Chlamydia and Chlamydia abortus were examined by the indirect hemagglutination assay (IHA) and indirect enzyme-linked immunosorbent assay (ELISA), respectively. The result showed that 351 (35.67%, 95% CI 32.68–38.66) of 984 serum samples were positive for Chlamydia, and the seroprevalence ranged from 6.67% to 70.79% among the different regions. In addition, antibodies to C. abortus infection were detected in 78 (7.93%, 95% CI 6.24–9.61) of 984 serum samples, and the seroprevalence ranged from 6.24% to 14.81% among the different regions. This is the first report on the seroprevalence of Chlamydia and C. abortus in sheep in Shanxi province, northern China. The findings provide baseline information for preventing and controlling Chlamydia infection in sheep in Shanxi Province, China.

Keywords: Chlamydia; Chlamydia abortus; seroprevalence; sheep; China

1. Introduction

Chlamydia is a globally distributed obligate intracellular bacterium, which has an extensive host spectrum and can cause various clinical symptoms in humans and animals, such as endemic blindness, bacterial sexually transmitted disease, respiratory infections, and even death [1,2]. The Chlamydiaceae only has one genus, Chlamydia, and contains 15 species [3], and some of these pathogens, such as C. abortus, C. pecorum, C. psittaci, and C. suis, can infect sheep [4]; C. psittaci can cause a variety of inflammatory and respiratory symptoms, which can be life-threatening to humans and birds [5]. C. abortus can induce pneumonia and inflammation in sheep and is also an important cause of late-term abortion.
in goats and sheep, especially in the 2–3 weeks before delivery. *C. abortus* is endemic among ruminants, and sheep are the animals susceptible to *C. abortus* [6–8]. Although the live vaccine (*C. abortus* 1B strain) has been used for preventing the outbreaks of *C. abortus* in some regions of Europe, it still carries the risk of causing miscarriage in the sheep, and its safety remains to be clarified [9].

In pregnant women, contact with ruminants infected with *C. abortus* could cause flu-like symptoms of systemic infection, and even miscarriage [10]. Moreover, breeders and veterinarians who have more opportunities to come into contact with sheep are more likely to be infected by *C. abortus* [11]. *C. abortus* has also been widely reported in China; for example, the seroprevalence of *C. abortus* ranges from 1.76 to 15.29% in sheep in the south of China [12]. China is a large agricultural country, and animal husbandry is an important economic source for people in some regions of China. Sheep is closely related to human life, and it can provide mutton, milk, and sheepskin for humans; at the same time, sheep are also one of the most common hosts of *Chlamydia*, including *C. abortus*, so the epidemiological investigation of *Chlamydia* infection in sheep has become particularly important. However, to date, information on *Chlamydia* and *C. abortus* infection in animals has been very limited in Shanxi Province, China, seriously affecting the correct assessment of chlamydiosis in economic animals in Shanxi Province. The seroprevalence of *Chlamydia* was 13.94% (95% CI: 9.66–18.22) in alpacas in Shanxi Province [13], which was the first and the only report of *Chlamydia* infection in animals in Shanxi Province.

The objective of the present study was to investigate the seroprevalence of *Chlamydia* and *C. abortus* in sheep in Shanxi Province, and to explore the risk factors associated with *Chlamydia* and *C. abortus* infection, which could provide useful data to improve the precautionary measures for preventing *Chlamydia* and *C. abortus* infection in sheep in China.

### 2. Materials and Methods

#### 2.1. Ethics Approval

The experimental procedures of the study were reviewed and approved by the Experimental Animal Ethics Committee of Shanxi Agricultural University (Approval No. 2019IACUCSXAU002A01, approved on 17 June 2019). The animals were handled in accordance with good animal practice as defined by the relevant Animal Ethics Procedures and Guidelines of the People’s Republic of China.

#### 2.2. Investigation Sites

This study involved 11 regions throughout Shanxi Province, north China, including three cities located in Northern Shanxi, four cities located in Central Shanxi, and four cities located in Southern Shanxi, respectively (Figure 1). Shanxi Province (34°36′–40°44′ N, 110°15′–114°32′ E) is located in the north of China, which has a temperate continental monsoon climate with distinct differences in the four seasons; the temperature discrepancy between the north and the south is large, and the average temperature is 11 °C in autumn.

#### 2.3. The Collection of Serum Samples

984 serum samples were randomly collected from sheep from 11 regions in Shanxi Province in the autumn of 2020, including Datong City (n = 90), Shuozhou City (n = 90), Xinzhou City (n = 90), Taiyuan City (n = 85), Lvliang City (n = 90), Jinzhong City (n = 90), Yangquan City (n = 90), Changzhi City (n = 90), Jincheng City (n = 90), Linfen City (n = 89), and Yuncheng City (n = 90); with 270, 355, and 359 serum samples being collected from Northern Shanxi, Central Shanxi, and Southern Shanxi, respectively (Table 1). At least three farms were sampled in each city and a total of 43 farms were sampled in this study. These 43 farms include 32 household animal farms (n = 682) (in each of these farms, the annual stock is no more than 300 sheep), six animal farming cooperatives (n = 120) (each farming cooperative is composed of multiple household animal farms), and five large-scale animal farming companies (n = 180) (in each of these companies, the annual stock is more than 1000 sheep) (Table 2). The serum samples were transported to the laboratory and stored at −40 °C.
Figure 1. Map showing the geographical locations and seroepidemiological distribution of *Chlamydia* and *C. abortus* infection in sheep in Shanxi Province, China. Northern Shanxi: Datong City, Shuozhou City, and Xinzhou City; Central Shanxi: Taiyuan City, Yangquan City, Lvliang City, and Jinzhong City; Southern Shanxi: Linfen City, Changzhi City, Yuncheng City, and Jincheng City.

Table 1. The seroprevalence of *Chlamydia* infection in sheep in different cities of Shanxi Province, China.

| Geographical Location | City        | No. Examined | No. Positive | Prevalence (%) |
|-----------------------|-------------|--------------|--------------|----------------|
| Northern Shanxi       | Datong      | 90           | 43           | 47.78          |
|                       | Shuozhou    | 90           | 30           | 33.33          |
|                       | Xinzhou     | 90           | 51           | 56.67          |
|                       | Taiyuan     | 85           | 19           | 22.35          |
|                       | Lvliang     | 90           | 6            | 6.67           |
|                       | Jinzhong    | 90           | 18           | 20.00          |
|                       | Yangquan    | 90           | 15           | 16.67          |
|                       | Changzhi    | 90           | 25           | 27.78          |
|                       | Jincheng    | 90           | 41           | 45.56          |
| Central Shanxi        | Linfen      | 89           | 63           | 70.79          |
|                       | Yuncheng    | 90           | 40           | 44.44          |
| Total                 |             | 984          | 351          | 35.67          |

2.4. Serological Tests

The specific antibodies against *Chlamydia* at genus level from sheep were detected by indirect hemagglutination assay (IHA) using a commercially available kit (Lanzhou Veterinary Research Institute, Chinese Academy of Agricultural Sciences, Lanzhou, China) according to the manufacturer’s instructions, and this kit can be used to detect antibodies against *Chlamydia* at genus level in all mammals [14–16]. Briefly, the serum was diluted by serial fourfold from 1:4 to 1:64, and the positive and negative serum were separately added to each plate. The serum samples were considered positive if agglutinated layers of erythrocytes formed in a dilution of 1:16 or higher. The results between 1:4 and 1:16 were considered as “doubtful” and were retested. The antibodies against *C. abortus* were
determined by using a commercially available ELISA kit (Innovative Diagnostics, Grabels, France) in accordance with the manufacturer’s recommendations [17–20]. Before the antibody detection, the kits and serum samples were placed at room temperature (20 °C) for one hour. Samples with \( \text{OD}_{\text{sample}} / \text{OD}_{\text{positive}} \times 100\% (\text{S/P}) \geq 60\% \) or \( \leq 50\% \) were positive or negative, respectively, and 50 < S/P% < 60% were considered as “doubtful” and were retested.

Table 2. The seroprevalence of *Chlamydia* infection in sheep in three geographical locations and management modes in Shanxi Province, China.

| Variable                  | Category            | No. Examined | No. Positive | Prevalence (%) (95% CI) | p-Value | OR (95% CI) |
|---------------------------|---------------------|--------------|--------------|-------------------------|---------|-------------|
| Geographical location     | Northern Shanxi     | 270          | 124          | 45.93 (39.98–51.87)     | <0.01   | 4.55 (3.21–6.46) |
|                           | Central Shanxi      | 355          | 58           | 16.34 (12.49–20.18)     |         | Reference   |
|                           | Southern Shanxi     | 359          | 169          | 47.08 (41.91–52.24)     |         | 3.86 (2.66–5.59) |
| Management mode           | Household animal farms | 684        | 258          | 37.72 (34.09–41.35)     | <0.05   | 2.48 (1.59–3.89) |
|                           | Animal farming cooperatives | 120      | 29           | 24.17 (16.51–31.83)     |         | Reference   |
|                           | Large-scale animal farming companies | 180  | 64           | 35.56 (28.56–42.55)     |         | 1.73 (1.03–2.91) |
| Total                     |                     | 984          | 351          | 35.67 (32.68–38.66)     |         |             |

2.5. Statistical Analyses

A chi-square test was performed for seroprevalence and potential risk factors (geographic location and management mode) of *Chlamydia* and *C. abortus* infection in sheep in Shanxi Province, China using SPSS 26.0 software (Chicago, IL, USA). The odds ratios (ORs) and the 95% confidence interval (95% CI) of each factor were analyzed in this study; \( p \) value < 0.05 was considered statistically significant.

3. Results

In this study, antibodies to *Chlamydia* infection were detected in 351 (35.67%, 95% CI 32.68–38.66) of the 984 sheep serum samples by IHA, with the seroprevalence ranging from 6.67% to 70.79% among the different regions (Table 1). Furthermore, the geographical location (\( p < 0.01 \)) and management mode (\( p < 0.05 \)) were revealed as risk factors for *Chlamydia* infection in sheep in Shanxi Province (Table 2).

In this study, antibodies to *C. abortus* infection were detected in 78 (7.93% 95% CI 6.24–9.61) of the 984 sheep serum samples by ELISA with the seroprevalence ranging from 1.11% to 21.11% among the different regions (Table 3). Moreover, geographical location (\( p < 0.01 \)) was revealed as a risk factor for *C. abortus* infection in sheep in Shanxi Province (Table 4).
Table 3. The seroprevalence of *C. abortus* infection in sheep in different cities of Shanxi Province, China.

| Geographical Location | City     | No. Examined | No. Positive | Prevalence (%) |
|-----------------------|----------|--------------|--------------|----------------|
| Northern Shanxi       | Datong   | 90           | 15           | 16.67          |
|                       | Shuozhou | 90           | 6            | 6.67           |
|                       | Xinzhou  | 90           | 19           | 21.11          |
|                       | Taiyuan  | 85           | 13           | 15.29          |
|                       | Luliang  | 90           | 3            | 3.33           |
|                       | Jinzhong | 90           | 5            | 5.56           |
|                       | Yangquan | 90           | 1            | 1.11           |
|                       | Changzhi | 90           | 1            | 1.11           |
| Central Shanxi        |          |              |              |                |
|                       |          |              |              |                |
|                       |          |              |              |                |
|                       |          |              |              |                |
| Southern Shanxi       | Linfen   | 89           | 4            | 4.49           |
|                       | Yuncheng | 90           | 1            | 1.11           |
| Total                 |          | 984          | 78           | 7.93           |

Table 4. The seroprevalence of *C. abortus* infection in sheep in three geographical locations and management modes in Shanxi Province, China.

| Variable             | Category                  | No. Examined | No. Positive | Prevalence (%) (95% CI) | p-Value | OR (95% CI) |
|----------------------|---------------------------|--------------|--------------|-------------------------|---------|-------------|
| Geographical location| Northern Shanxi           | 270          | 40           | 14.80 (10.58–19.52)     | <0.01   | 3.72 (2.04–6.82) |
|                      | Central Shanxi            | 355          | 22           | 6.20 (3.69–8.71)        | <0.01   | 1.42 (0.73–2.74) |
|                      | Southern Shanxi           | 359          | 16           | 5.93 (3.11–8.74)        | <0.01   | Reference   |
| Management mode      | Household animal farms    | 684          | 48           | 7.02 (5.10–8.93)        | <0.01   | Reference   |
|                      | Animal farming cooperatives| 120         | 10           | 8.33 (3.39–13.28)       | >0.05   | Reference   |
|                      | Large-scale animal farming companies | 180   | 20           | 11.11 (6.52–15.70)      | >0.05   | 1.21 (0.59–2.45) |
|                      | Total                     | 984          | 78           | 7.93 (6.24–9.61)        |         |             |

4. Discussion

In the present study, the seroprevalence of *Chlamydia* infection in sheep in Shanxi Province was 35.67% based on IHA (Table 1), which was higher than that in black-boned sheep in Yunnan Province, China (22.76%) [16], but lower than that in sheep in Shandong Province, China (52.78%) [10]. The seroprevalence of *Chlamydia* infection in sheep has been widely reported around the world, such as 15.23% in sheep in Germany [21], and 8.9% in sheep in India [22]. Furthermore, the seroprevalence of *C. abortus* in sheep in Shanxi Province was 7.93% based on ELISA (Table 3), which was lower than that in most provinces in China; for example, it is slightly lower than that in goats in Hunan Province (8.45%) [23], and also lower than that in sheep in Gansu Province (18.65%) [8]. The seroprevalence of *C. abortus* infection also has been reported in sheep worldwide, such as 7.98% in sheep in southern Ethiopia [24], and 19.2% in sheep in Australia [25]. The different seroprevalences may be due to the living environment, geographic location, and climatic conditions.

The distance between the northern Shanxi Province and the southern Shanxi Province is more than 680 km, and the large temperature differences and different local conditions and customs may affect the infection of animals with different pathogens. In the present study, the seroprevalence of *Chlamydia* in sheep was different in different regions, ranging from 6.76% in Luliang City located in Central Shanxi, to 56.67% in Xinzhou City located in Northern Shanxi, and 70.79% in Linfen City located in Southern Shanxi (Table 1). The geographical location was revealed as a risk factor for *Chlamydia* infection in sheep in Shanxi Province (*p* < 0.01) in that higher seroprevalence of *Chlamydia* infection in sheep...
was detected in Northern and Southern Shanxi, and lower seroprevalence was detected in Central Shanxi (Table 2). Compared with sheep in Central Shanxi (16.34%), sheep in Northern Shanxi (45.93%) and Southern Shanxi (47.08%) had more than four times (OR = 4.55, 95% CI = 3.21–6.46) and nearly four times (OR = 3.86, 95% CI = 2.66–5.59) higher risk of acquiring Chlamydia infection, respectively. These results indicated that sheep had the lowest risk of acquiring Chlamydia infection in Central Shanxi. Compared with Southern and Northern Shanxi, the temperature and humidity in Central Shanxi are at the middle level, but the seroprevalence of Chlamydia was lower than that in Southern and Northern Shanxi, so the results indicated that climatic conditions do not seem to be the main factor affecting Chlamydia infection in sheep in Shanxi Province.

In order to explore the possible causes of this phenomenon, the seroprevalence of Chlamydia infection in sheep under different management modes was analyzed. The results showed that compared with sheep in animal farming cooperatives (24.17%), sheep in household animal farms (37.72%) and large-scale animal farming companies (35.56%) had more than two times (OR = 2.48, 95% CI = 1.59–3.89) and nearly two times (OR = 1.73, 95% CI = 1.32–2.91) higher risk of acquiring Chlamydia infection, respectively. These results indicated that management mode was a risk factor for Chlamydia infection in sheep in Shanxi Province (p < 0.05). The capital and the core area of economic development of Shanxi Province are located in Central Shanxi which has led the economic development of Shanxi Province. In animal husbandry, the management mode of animal farming cooperatives with standardized management has been established in Central Shanxi, which may be the main reason for the lower seroprevalence of Chlamydia infection in sheep in Central Shanxi.

The Chlamydiaceae family only has one genus but contains 15 species [3], and different species of Chlamydia may have different transmission characteristics. To explore the seroprevalence of C. abortus in sheep in Shanxi province, the antibodies against C. abortus were tested by ELISA. A total of 78 of 984 (7.93%, 95% CI 6.24–9.61) examined sheep serum samples were positive for C. abortus infection, accounting for 22.22% (78/351) of all Chlamydia infections in this study. C. abortus infection in sheep was distributed in all examined cities in Shanxi Province with different seroprevalences, ranging from 1.11% to 21.11% (Table 3). Xinzhou City (21.11%) and Datong City (16.67%) located in Northern Shanxi had higher C. abortus seroprevalence in sheep, which was consistent with the infection trend of Chlamydia in Shanxi Province. However, in some regions, very low levels of C. abortus infection in sheep was detected, such as in Changzhi City (1.11%) and Yuncheng City (1.11%) located in Central Shanxi, which was quite different from the overall Chlamydia prevalence in these regions, suggesting that C. abortus may not be the dominant species of Chlamydia infection in sheep in these regions, which warrants further investigation. By analyzing the potential risk factors (geographical location and management mode) of C. abortus infection, only the geographical location was revealed as a risk factor for C. abortus infection in sheep in Shanxi Province (p < 0.01) (Table 4). Among these three geographical locations, sheep in Southern Shanxi (5.93%, 95% CI 3.11–8.74) had the lowest seroprevalence of C. abortus, which was similar to sheep in Central Shanxi (6.20%, 95% CI 3.69–8.71), but far lower than that in Northern Shanxi (14.80%, 95% CI 10.58–19.52). Sheep in Northern Shanxi had approximately four times (OR = 3.72, 95% CI = 2.04–6.82) higher risk of acquiring C. abortus infection than that in Southern Shanxi.

The overall seroprevalence of Chlamydia infection in sheep in Shanxi Province was 35.67%, while the seroprevalence of C. abortus infection was only 7.93%. The difference was more obvious in Southern Shanxi (47.08% versus 5.93%). These results suggested that C. abortus is not the dominant species of Chlamydia infection in sheep in Shanxi Province. According to the result of another study, the main Chlamydia species infecting sheep are C. abortus and C. pecorum [26]; therefore, it is likely C. pecorum is the dominant species of Chlamydia in Shanxi Province. However, more studies are needed to detect the main species of Chlamydia in sheep in Shanxi Province.
Overall, both Chlamydia and C. abortus infections appear to be severe in sheep in Northern Shanxi, and low temperatures in Northern Shanxi may facilitate the long-term survival of Chlamydia in the environment, including C. abortus [27]. In addition, most areas of Shanxi Province lie between the Lvliang Mountains and Taihang Mountains which isolate Shanxi Province from Shaanxi, Hebei, and Henan Provinces; only the northern part of Shanxi Province directly borders the Inner Mongolia grasslands, and the living habits are closer to the people in Inner Mongolia Autonomous Region (IMAR). The seroprevalence of Chlamydia in pigeons in Tongliao City of IMAR was 35.14%, which could facilitate the spread of Chlamydia to susceptible animals through direct contact or fecal contamination [28], and the seroprevalence of C. abortus in commercial dairy and beef cattle in IMAR was 12.96% [29]. According to the above results and the actual situation in Shanxi Province (the production type is mainly mutton), in addition to improving the management mode in the sheep industry, it is also imperative to strengthen the prevention and control of animal diseases between the boundaries to avoid cross-infection. In addition, a limitation of the present study is that more potential risk factors, such as gender, age, other co-infections, or vaccination programs, were not included in the analysis, because such information was incomplete and could not be unified among the 43 sampling sites. Further analysis of other potential risk factors and the continuous detection of Chlamydia infection in sheep herds are the directions of our future efforts.

5. Conclusions

The present investigation revealed that the overall seroprevalence of Chlamydia infection in sheep in Shanxi Province is high (35.67%, 351/984), and the seroprevalence of C. abortus infection in sheep in this province is 7.93%. Geographical location and management mode were the risk factors associated with Chlamydia infection in sheep in Shanxi Province, China. This is the first report of the seroprevalence of Chlamydia and C. abortus in sheep in Shanxi Province, which provides baseline data for the prevention and control of Chlamydia and C. abortus infection in sheep in Shanxi Province.

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References
1. Elwell, C.; Mirrashidi, K.; Engel, J. Chlamydia cell biology and pathogenesis. Nat. Rev. Microbiol. 2016, 14, 385–400. [CrossRef] [PubMed]
2. Pagliarani, S.; Johnston, S.D.; Beagley, K.W.; Dief, H.; Palmieri, C. The occurrence and pathology of chlamydiosis in the male reproductive tract of non-human mammals: A review. Theriogenology 2020, 154, 152–160. [CrossRef]
3. Chaiwattanarungruengpaisan, S.; Thongdee, M.; Anuntakarun, S.; Payungporn, S.; Arya, N.; Punchukrang, A.; Ramasoota, P.; Singhakaew, S.; Atithep, T.; Sariya, L.A. A new species of Chlamydia isolated from Siamese crocodiles (Crocodylus siamensis). PLoS ONE 2021, 16, e0252081. [CrossRef] [PubMed]
4. Borel, N.; Polkinghorne, A.; Pospischil, A. A review on chlamydial diseases in animals: Still a challenge for pathologists? Vet. Pathol. 2018, 55, 374–390. [CrossRef] [PubMed]

5. Knittler, M.R.; Sachse, K. Chlamydia psittaci: Update on an underestimated zoonotic agent. Pathog. Dis. 2015, 73, 1–15. [CrossRef]

6. Arif, E.D.; Saeed, N.M.; Rachid, S.K. Isolation and identification of Chlamydia abortus from aborted ewes in Sulaimani Province, Northern Iraq. J. Microbiol. 2020, 69, 65–71. [CrossRef] [PubMed]

7. Zhang, H.; Deng, X.; Cui, B.; Shao, Z.; Zhao, X.; Yang, Q.; Song, S.; Wang, Z.; Wang, Y.; Wang, Y.; et al. Abortion and various associated risk factors in dairy cow and sheep in ill, China. PLoS ONE 2020, 15, e0232568. [CrossRef]

8. Qin, S.Y.; Yin, M.Y.; Cong, W.; Zhou, D.H.; Zhang, X.X.; Zhao, Q.; Zhu, X.Q.; Zhou, J.Z.; Qian, A.D. Seroprevalence and risk factors of Chlamydia abortus infection in Tibetan sheep in Gansu province, northwest China. Sci. World J. 2014, 193464. [CrossRef]

9. Caspe, S.G.; Palarea-Albaladejo, J.; Underwood, C.; Livingstone, M.; Wattegedera, S.R.; Milne, E.; Sargison, N.D.; Chianinni, F.; Longbottom, D. Distribution and severity of placental lesions caused by the Chlamydia abortus 1B vaccine strain in vaccinated ewes. Pathogens 2021, 10, 943. [CrossRef] [PubMed]

10. Pichon, N.; Guindre, L.; Laroucau, K.; Cantalouby, M.; Nallatamby, A.; Parreau, S. Chlamydia abortus in pregnant woman with acute respiratory distress syndrome. Emerg. Infect. Dis. 2020, 26, 628–629. [CrossRef] [PubMed]

11. Baud, D.; Greub, G. Intracellular bacteria and adverse pregnancy outcomes. Clin. Microbiol. Infect. 2011, 17, 1312–1322. [CrossRef] [PubMed]

12. Zhou, J.; Li, Z.; Lou, Z.; Fei, Y. Prevalence, diagnosis, and vaccination situation of animal chlamydiosis in China. Front. Vet. Sci. 2018, 5, 88. [CrossRef] [PubMed]

13. Li, J.; Ma, Y.T.; Liang, Q.L.; Li, R.L.; Zheng, F.G.; Liu, Q. Serological evidence of Toxoplasma gondii and Chlamydia infection in alpacas (Vicugna pacos) in Shanxi Province, northern China. Microb. Pathog. 2020, 149, 104399. [CrossRef] [PubMed]

14. Li, M.H.; Yang, B.T.; Yin, Z.W.; Wang, W.; Zhao, Q.; Jiang, J. A seroepidemiological survey of Toxoplasma gondii and Chlamydia infection in chickens, ducks, and geese in Jilin Province, northeastern China. Vector Borne Zoonotic Dis. 2020, 20, 825–830. [CrossRef]

15. Ni, X.; Qin, S.; Lou, Z.; Ning, H.; Sun, X. Seroprevalence and risk factors of Chlamydia infection in domestic rabbits (Oryctolagus cuniculus) in China. Biomed. Res. Int. 2015, 2015, 460473. [CrossRef]

16. Sun, L.X.; Liang, Q.L.; Hu, X.H.; Li, Z.; Yang, J.F.; Zou, F.C. First report of Chlamydia seroprevalence and risk factors in domestic black-boned sheep and goats in China. Front. Vet. Sci. 2020, 7, 363. [CrossRef]

17. Anderson, I.E.; Herring, A.J.; Jones, G.E.; Low, J.C.; Greig, A. Development and evaluation of an indirect ELISA to detect antibodies to abortion strains of Chlamydia psittaci in sheep sera. Vet. Microbiol. 1995, 43, 1–12. [CrossRef]

18. Liu, S.S.; Chu, J.; Zhang, Q.; Sun, W.; Zhang, T.Y.; He, C. Development of a novel pmpD-N ELISA for Chlamydia psittaci infection. Environ. Sci. 2016, 29, 315–322.

19. Chen, W.; Liu, Y.; Chen, J.; Ma, Y.; Song, Y.; Cen, Y.; You, M.; Yang, G. The Notch signaling pathway regulates macrophage polarization in liver diseases. Int. Immunopharmacol. 2021, 99, 107938. [CrossRef]

20. Merdja, S.E.; Khaled, H.; Aaziz, R.; Voriomore, F.; Bertin, C.; Dahanani, A.; Bouyoucef, A.; Laroucau, K. Detection and genotyping of Chlamydia species responsible for reproductive disorders in Algerian small ruminants. Trop. Anim. Health Prod. 2015, 47, 437–443. [CrossRef]

21. Runge, M.; Binder, A.; Schotte, U.; Ganter, M. Investigations concerning the prevalence of Coxiella burnetii and Chlamydia abortus in sheep in correlation with management systems and abortion rate in Lower Saxony in 2004. Berl. Munch. Tierarztl. Wochenschr. 2012, 125, 138–143. [PubMed]

22. Chahota, R.; Gupta, S.; Bhardwaj, B.; Malik, P.; Verma, S.; Sharma, A.M. Seroprevalence studies on animal chlamydiosis amongst ruminants in five states of India. Vet. World 2015, 8, 72–75. [CrossRef] [PubMed]

23. Hu, S.F.; Li, F.; Zheng, W.B.; Liu, G.H. Seroprevalence and risk factors of Chlamydia abortus infection in goats in Hunan Province, subtropical China. Vet. Borne Zoonotic Dis. 2018, 18, 500–503. [CrossRef] [PubMed]

24. Tesfaye, A.; Sahele, M.; Sori, T.; Guyassa, C.; Garoma, A. Seroprevalence and associated risk factors for chlamydiosis, coxiellosis and brucellosis in sheep and goats in Borana pastoral area, southern Ethiopia. BMC Vet. Res. 2020, 16, 145. [CrossRef]

25. Bommana, S.; Jeelocnik, M.; Borel, N.; Marsh, I.; Carver, S.; Polkinghorne, A. The limitations of commercial serological assays for detection of chlamydial infections in Australian livestock. J. Med. Microbiol. 2019, 68, 627–632. [CrossRef]

26. Rodolakis, A.; Laroucau, K. Chlamydiaceae and chlamydial infections in sheep or goats. Vet. Microbiol. 2015, 181, 107–118. [CrossRef]

27. Sachse, K.; Bavoil, P.M.; Kaltenboeck, B.; Stephens, R.S.; Kuo, C.C.; Rossello-Mora, R.; Horn, M. Emendation of the family chlamydiaeae: Proposal of a single genus, Chlamydia, to include all currently recognized species. Syst. Appl. Microbiol. 2015, 38, 99–103. [CrossRef]

28. Wang, X.; Zhang, N.Z.; Ma, C.F.; Zhang, X.X.; Zhao, Q.; Ni, H.B. Epidemiological investigation and genotype of Chlamydia exposure in pigeons in three provinces in northern China. Vet. Borne Zoonotic Dis. 2018, 18, 181–184. [CrossRef]

29. Sun, W.W.; Meng, Q.F.; Cong, W.; Shan, X.F.; Wang, C.F.; Qian, A.D. Herd-level prevalence and associated risk factors for Toxoplasma gondii, Neospora caninum, Chlamydia abortus and bovine viral diarrhea virus in commercial dairy and beef cattle in eastern, northern and northeastern China. Parasitol. Res. 2015, 114, 4211–4218. [CrossRef]