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Research article

Coxiella burnetii seroprevalence, risk factors, and health hazards in sheep and goats in Upper Egypt

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Abstract

Query fever (Q fever) or coxiellosis is a serious bacterial infection caused by *Coxiella* (*C.*) *burnetii* and affects various animals and humans. Clinically, Q fever ranges from various degrees of fever to abortion, either in infected animals or humans. Such infection is especially important in cattle and small ruminants industry, particularly sheep and goats. Thus, the current study aimed to recognize the prevalence of specific antibodies against *C. burnetii* in serum samples collected from sheep and goats in Sohag governorate, Upper Egypt, using a commercially available enzyme-linked immunosorbent assay (ELISA). The overall seroprevalence was found against *C. burnetii* (25.6%; 56/219), subdivided as 22.8% (23/101) in sheep and 28% (33/118) in goats. Animals used for this study are representative of different small ruminants (sheep and goats), age (various ages), sexes (males and females), locations (different localities in Sohag governorate), physiological and pathological conditions, and many other factors related to animals, farm, and the environment. Female animals exhibited a higher rate of *C. burnetii* antibodies than males ($p = 0.0637$). Also, females in the dry period showed a higher seropositive rate than those pregnant females ($p < 0.0001$). In addition, the breeding system was reported as a risk factor for infection because animals bred in smallholders demonstrated a lower prevalence rate than those reared in individual breeding ($p = 0.010$) and mass farming ($p = 0.006$). Clinical and biochemical variables were estimated to recognize the health impact of seropositivity. Seropositive animals exhibited marked alterations in the selected clinical parameters and alanine transaminase (ALT) compared to the seronegative ones. Determining the exact occurrence of Q fever in sheep and goats might assist in developing a control policy for this infection and thus improve the income of the small ruminants industry and protect humans from infection.

Keywords: Q fever, *Coxiella burnetii*, ELISA, Antibodies, Egypt, Ruminants

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Introduction

A global public health concern, query fever (Q fever or coxiellosis) is a broadly distributed infection with various vulnerable hosts. The disease is caused by *Coxiella burnetii* (*C. burnetii*), a Gram-negative, obligatory intracellular bacterium (Seshadri et al., 2003). Humans and numerous animals, including domestic pets, farm animals, wild mammals, arthropods (mostly ticks), and birds, are susceptible to infection by *C. burnetii*. The wild cycle, which includes ticks and wild animals, and the domestic cycle, which largely depends on ruminants and other animal species like dogs and cats as reservoirs, are the two cycles that *C. burnetii* can be sustained in nature (Lang, 1990; Arricau Bouvery et al., 2003). Since the domestic cycle has been determined to be the main source of human infection, the link between the two proposed cycles is now unclear. Cattle, goats, and sheep are examples of domesticated ruminants that are major reservoirs of *C. burnetii* (Masala et al., 2004).

The two most notable clinical signs of *C. burnetii* infection in pregnant small ruminants are stillbirth and abortion. The majority of abortions take place without any preceding clinical symptoms close to the end of the pregnancy (Arricau-Bouvery and Rodolakis, 2005). When *C. burnetii* infection results in an abortion, the foetuses often look normal and fresh, but they can also occasionally become autolytic. Placentitis can appear macroscopically and is usually recognized by a purulent yellow-brownish discharge that covers the intercotyledonary zones that have swollen significantly (van den Brom et al., 2012).

Epidemiological and experimental studies have shown that individuals are primarily exposed to *C. burnetii* by inhaling aerosol when interacting with sick animals, their young, or other animal products such as wool and hides (Eldin et al., 2017). Another way to spread this infection is by consuming raw milk and dairy products manufactured from contaminated raw milk, though it is unclear if these foods act as sources of infection (Pexara et al., 2018). The pathogen is shed through vaginal mucus and feces for several months following abortion or parturition and even during the succeeding parturition (Berri et al., 2007; Joulié et al., 2015; Álvarez Alonso et al., 2018). During abortions or healthy delivery, infected females can release significant amounts of bacteria into the environment through birth products (Angelakis and Raoult, 2010).

Ruminants have been reported to transmit *C. burnetii* sexually and vertically (Kruszewska and Tylewska-Wierzbanowska, 1997). Sexual transmission to humans has occasionally been documented (Miceli et al., 2010). Later, *C. burnetii* was also found in the semen of rams (Ruiz-Fons et al., 2010). So, breeding transmission can occur not only by sexual intercourse but also by semen containing *C. burnetii*. Over 40 different tick species are naturally infected with *C. burnetii*. As a result, significant quantities of the bacterium are excreted in their feces and applied to their animal hosts' skin when fed (Maurin and Raoult, 1999).

Molecular and serological assays are effective means of detecting *C. burnetii*. Polymerase chain reaction (PCR) tests can

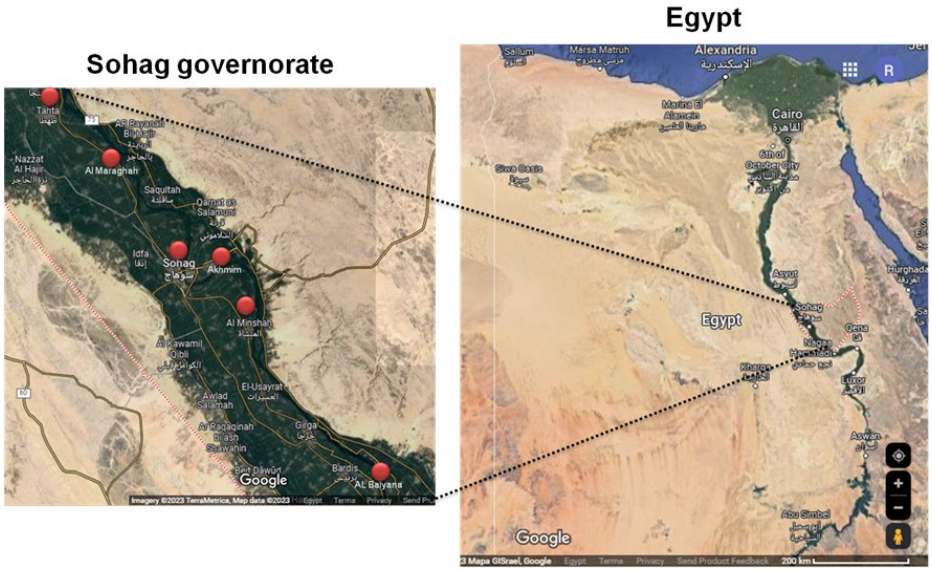

Figure 1: Collection sites for tested samples. The landscape on the right shows the geographic location of the Sohag governorate in Egypt, and on the left are the different cities of Sohag where samples were collected, as indicated in dark red circles.

target distinct regions of the bacterial genome. Several PCR-based diagnostic techniques have been applied, including nested PCR, real-time PCR, and conventional PCR (Van den Brom et al., 2015). In terms of serology, several assays can be used to show the existence of antibodies against *C. burnetii*, including microagglutination (MAT), complement fixation test (CFT), immunofluorescence assay (IFA), and enzyme-linked immunosorbent assay (ELISA). On the other hand, mass prevalence and epidemiological studies greatly benefit from using ELISA. Compared to immunofluorescence assay, ELISAs have a sensitivity of 82% to 100% and a specificity of 93% to 96% for small ruminants (Jaspers et al., 1994).

In Egypt, seroprevalence of *C. burnetti* antibodies was reported from several animals and regions with variable seropositive rates. In recent studies, the high seroprevalence reaching 50% of *C. burnetii* in sheep was reported in northern Egypt (Hegazy et al., 2021) and in southern Egypt (37.5%) (Kamaly et al., 2022). Similarly, the high seroprevalence of *C. burnetii* in goats was reported in various Egyptian regions, e.g., 51.4% (Abbas et al., 2020) and 12% (Saleh et al., 2021). However, the current study provided a comprehensive report on *C. burnetii* infection in sheep and goats in the Sohag governorate, Upper Egypt. This report included seroprevalence rate, numerous risk factors analysis, and the associated clinical and biochemical variations among the seropositive and seronegative animals.

Materials and methods

Ethical statement

This study complied with the guidelines established by the Research Board of the Faculty of Veterinary Medicine, South Valley University, Qena, Egypt. The study was approved by the Research Bioethics Committee at South Valley University Number 99/11.2022 and VM/SVU/23(2)-01. Informed consent was obtained orally from all farm owners before the study.

Animal population and geographic locations

A total of 219 blood samples were randomly collected from various cities in the Sohag governorate, southern Egypt. Sohag is a governorate with one of the highest animal population densities in Egypt, particularly in the southern part (Figure 1). Samples were collected from small ruminants (sheep and goats), sexes (male and female), and locations (Six cities: Sohag, Tahta, Akhmim, Al Balyana, Al Minshah, and Al Maraghah) during the period of one year from March 2022 to February 2023.

Case history and clinical examination

A specified questionnaire was designed to record the information and complaints of the animal owner, the exhibited clinical signs, and management practices. The collected data were organized with our recorded signs and observations on each animal and breeding site. Routine clinical examination of these studied cases was performed according to previously described methods (Constable et al., 2016). Complete clinical examination (visual inspection of the skin, teeth, all mucous membranes, ears, external palpation of the limbs, neck, abdominal organs, and lymph nodes; abdominal and thoracic auscultation) was performed on each animal.

Serum sample collection and preparation

Blood samples were obtained through jugular vein puncture using glass tubes without anticoagulant agents. Sera were separated from blood samples by centrifugation at 3000 rpm for 10 min. Then, collected samples were transferred to the South Valley University laboratory (Faculty of Veterinary Medicine, South Valley University, Qena, Egypt) and were stored at -20°C until use in ELISA testing.

iELISA testing and interpretation of results

In *C. burnetii* antibody detection, serum samples were analyzed with an indirect multi-species ELISA for Q fever (ID.vet, Grabels, France). Serum samples and controls were diluted 1:50. The optical densities (ODs) obtained were used to calculate the percentage of sample (S) to positive (P) ratio (S/P%) for each of the test samples according to the following formula:

$$S/P\% = \frac{\text{OD sample - OD negative control}}{\text{OD positive control - OD negative control}} \times 100$$

Using an Infinite® F50/Robotic ELISA reader (Tecan Group Ltd., Männedorf, Switzerland), the ODs of all ELISA data were read at 450 nm and quantified.

Biochemical investigations

Serum samples were used to estimate total protein by gram per deciliter (g/dl), albumin (g/dl), globulin (g/dl), alanine transaminase (ALT) by unit per liter (U/l), aspartate transaminase (AST) (U/l), using colorimetric methods and commercial kits (Mira Lab, Cairo, Egypt) according to the manufacturer's instructions. Values were read using a Rock 120 full automatic chemistry analyzer (BioElab, Nanjing, China). Globulin concentration was calculated by subtracting albumin from the corresponding total protein value. The albumin/globulin ratio was estimated by dividing the albumin value by globulin (Fereig et al., 2023).

Table 1: Seroprevalence of *C. burnetii* antibodies among sheep and goats from Sohag governorate, southern Egypt.

Animal species	No. of tested	No. of negative (%)	No. of doubtful (%)	No. of moderate positive (%)	No. of strong positive (%)	No. of total positive (%)	95% CI*
Sheep	101	70 (69.3)	8 (7.9)	21 (20.8)	2 (2)	23 (22.8)	15.3-32.4
Goat	118	79 (66.9)	6 (5.1)	16 (13.6)	17 (14.4)	33 (28)	20.3-37.1
Total	219	149 (68)	14 (6.4)	37 (16.9)	19 (8.7)	56 (25.6)	20-32

*95% CI; Confidence interval is calculated according to the method described by (http://vassarstats.net/ accessed on 5-10 November 2023).

Table 2: Animal factors-wise and the seroprevalence of *C. burnetii* antibodies among small ruminants at Sohag governorate, southern Egypt.

Analyzed factor		No. of tested	No. of negative (%)	No. of positive (%)	Odds ratio (95% CI)*	*p-value*#
Animal species	Sheep	101	78 (77.2)	23 (22.8)	Ref	Ref
	Goat	118	85 (72)	33 (28)	1.3 (0.7-2.4)	0.438
Age	<1 year	30	21 (70)	9 (30)	1.4 (0.6-3.5)	0.476
	1-3 years	118	91 (77)	27 (23)	Ref	Ref
	>3 years	71	51 (71.8)	20 (28.2)	1.3 (0.7-2.6)	0.488
Gender	Male	67	56 (83.6)	11 (16.4)	Ref	Ref
	Female	152	109 (71.7)	43 (28.3)	2 (1-4.2)	**0.0637**
Body condition score	Good	148	114 (77)	34 (23)	Ref	Ref
	Thin	71	50 (70.4)	21 (29.6)	1.4 (0.7-2.7)	0.32
Physiological condition	Dry	64	36 (56.3)	28 (43.7)	6.5 (2.3-18.7)	**<0.0001**
	Pregnant	47	42 (89.4)	5 (10.6)	Ref	Ref
	Lactation	17	12 (70.6)	5 (29.4)	3.5 (0.9-14.1)	0.117
History of abortion	Exist	41	34 (82.9)	7 (17.1)	Ref	Ref
	None	178	129 (72.5)	49 (27.5)	1.8 (0.8-4.4)	0.233

*Odds ratio at 95% confidence interval as calculated by http://vassarstats.net/ (accessed on 5-10 November 2023).
#*p-value* was evaluated by Fisher exact test using online statistics software http://vassarstats.net/ (accessed on 5-10 November 2023) and GraphPad Prism version 5; Ref.; is the value that used as a reference.

Table 3: Farm and environmental factors-wise and the seropositivity of *C. burnetii* antibodies among small ruminants at Sohag governorate, southern Egypt.

Analyzed factor		No. of tested	Seropositivity		Odds ratio	*p-value*
			Negative No. (%)	Positive No. (%)		
Localities	Sohag	51	38 (74.5)	13 (25.5)	1.7 (0.6-5)	0.432
	Tahta	31	23 (74.2)	8 (25.8)	1.7 (0.5-5.7)	0.385
	Akhmim	34	23 (67.6)	11 (32.4)	2.4 (0.8-7.4)	0.166
	Al Balyana	30	16 (8)	6 (20)	1.9 (0.5-6.8)	0.505
	Al Minshah	37	27 (73)	10 (27)	1.8 (0.6-5.8)	0.397
	Al Maraghah	36	30 (83.3)	6 (16.7)	Ref*	Ref
Breeding system	Individual	40	26 (65)	14 (35)	3.2 (1.4-7.4)	0.010
	Smallholder	103	88 (85.5)	15 (14.5)	Ref	Ref
	Mass farming	76	51 (67.1)	25 (32.9)	2.8 (1.4-6)	0.006
Feeding	Concentred	71	54 (76.1)	17 (23.9)	Ref	Ref
	Mixed ration	148	109 (73.6)	39 (26.4)	0.9 (0.5-1.8)	0.866
Contact with pet animal	Exist	208	154 (74)	54 (26)	0.6 (0.1-3)	0.733
	None	11	9 (81.8)	2 (18.2)	Ref	Ref
Contact with other animal	Exist	139	103 (74.1)	36 (25.9)	Ref	0.513
	None	80	63 (78.8)	17 (21.2)	Ref	Ref
Veterinary care	Regular	84	62 (73.8)	22 (26.2)	1.1 (0.6-2)	0.875
	Accidental	135	101 (74.8)	34 (25.2)	Ref	Ref
Production type	Lactation	152	112 (73.7)	40 (26.3)	1.5 (0.7-3)	0.308
	Fattening	67	54 (80.6)	13 (19.4)	Ref	Ref
Season	Spring	27	22 (81.5)	5 (18.5)	Ref	Ref
	Summer	115	83 (72.2)	32 (27.8)	1.7 (0.6-4.9)	0.465
	Autumn	42	31 (73.8)	11 (26.2)	1.6 (0.5-5.1)	0.565
	Winter	35	27 (77.1)	8 (22.9)	1.3 (0.4-4.6)	0.760

*Ref.; is the value that used as a reference.

Statistical analysis

The significance of the differences in the prevalence rates was analyzed with the Fisher exact test, 95% confidence intervals (including continuity correction), and odds ratios using an online statistical website, www.vassarstats.net (accession dates; 5-10 November 2023), as described previously (Fereig et al., 2022). *p-values* and odds ratio were also confirmed with GraphPad Prism version 5 (GraphPad Software Inc., La Jolla, CA, USA). A comparison of seropositive and seronegative groups was analyzed using an unpaired t-test. The results were considered significant when the *p-value* was <0.05.

Results

Seroprevalence and associated risk factors

The overall seroprevalence was found against *C. burnetii* (25.6%; 56/219), subdivided to 22.8% (23/101) in sheep and 28% (33/118) in goats (Table 1). In the case of sheep, seropositive samples were subdivided into strong positive 2% (2/101) and moderate positive samples 20.8% (21/111). While in the case of goats, strong seropositive constituted 14.4% (17/118), and moderate positive was 13.6% (16/118). Also, several samples showed doubtful results, overall (6.4%), sheep (7.9%), and goats (5.1%) (Table 1).

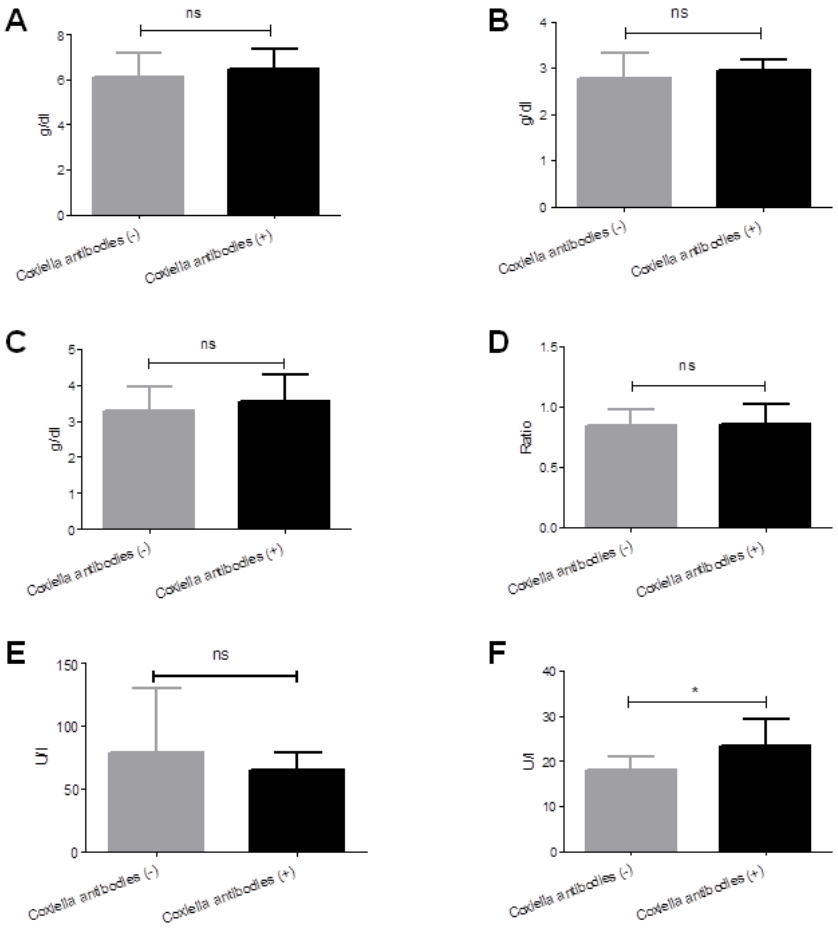

Figure 2: Biochemical analysis of serosurveyed animals for *C. burnetii* antibodies. Values of various serum biochemical variables in *C. burnetii* seronegative (n = 10) and seropositive (n = 10) groups. Each bar represents the mean±SD with a *p-value* comparing the two groups using an unpaired Student's t-test. Significance at $p \leq 0.05$. (A) Total protein, (B) Albumin, (C) Globulin, (D) Albumin / globulin ratio, (E) aspartate aminotransferase, (F) alanine transaminase. A significant difference was estimated only in the case of ALT ($p = 0.019$).

Possible associations between antibodies against *C. burnetii* and several factors confined to animals, farms, or the environment were analyzed to detect the predisposing factors for infection. Regarding animal-relevant factors, females were more likely to be seropositive, with a prevalence of 28.3% compared to 16.4% in males (odds ratio [OR] 2, $p = 0.0637$), although it was not statistically significant. The physiological condition was regarded as a predisposing factor in tested adult females for *C. burnetii* infection, with a higher prevalence in females in the dry period (43.7%; OR = 6.5; $p = <0.0001$), lactating females (29.4%; OR = 3.5; $p = 0.17$), compared to the seroprevalence in pregnant females (10.6%) set as a reference. Other factors relevant to animals were also tested but without recording marked differences, such as animal species (sheep versus goat), age (<1 year vs. 1-3 years vs. > 3 years old), body condition score (good vs. thin), and the presence or absence of abortion (Table 2).

Numerous management and environment-relevant factors were also analyzed as risks of infection for *C. burnetii* in sheep and goats. Only the breeding system was regarded as a predisposing factor in tested animals for *C. burnetii* infection, with a higher prevalence in animals bred in the individual system (35%; OR = 3.2; $p = 0.010$), mass farming (32.9%; OR = 2.8; $p = 0.006$), compared to the smallholders bred animals (14.5%) set as a reference. Other factors were also tested as predisposing factors for infections, such as different Sohag cities, feeding systems, production types, seasons, veterinary care, and contact with pets or other animals without detection marked variations (Table 3).

Clinical and biochemical findings in *C. burnetii* seropositive animals

To detect the impact of Q fever on animal health, we investigated the changes in some clinical parameters. Significant temperature and respiratory rate increases but insignificant changes in pulse rate ($p < 0.05$) between the seropositive and seronegative animals were reported. Moreover, alterations in appetite, mucous membranes, and skin and coats were more frequently observed in *C. burnetii*-seropositive animals than in the seronegative ones (Table 4).

Table 4: Clinical effects of *C. burnetii* seropositivity in tested animals.

Parameter	Seropositivity (mean±SD)	
	Seronegative animals (n = 111)	**Seropositive animals (n = 34)**
Temperature	39.4±0.5	39.7±0.5 ($p = 0.002$)*
Pulse rate	81.3±5.1	83.4±5.6 ($p = 0.061$)
Respiratory rate	29.6±3	31±4.2 ($p = 0.030$)*
Appetite	Good to slightly reduced	Reduced to anorexia
Mucous membranes	Rosy red	Rosy red to congested
Skin and coat	Shiny and healthy	Shiny to rough

*Indicates significant *p-value* calculated by unpaired t-test.

Table 5: Previous seroprevalence reports of *C. burnetii* in sheep and goats in Egypt.

Region	Sheep			Goats			Method*	Reference
	No. of tested	Positive		No. of tested	Positive			
		No.	%		No.	%		
North Sinai	89	20	22.5	71	12	16.8	IFA	Mazyad and Hafez (2007)
Ismailia	91	11	12.1	91	15	16.5	ELISA	El-Mahallawy et al. (2012)
Non-specified	55	18	32.7	30	7	23.3	ELISA	Nahed and Abdel-Moein (2012)
Giza	174	14	8	-	-	-	ELISA	Horton et al. (2014)
Qaluobia	100	23	23	100	27	27	IFAT	Khalifa et al. (2016)
El Minya	109	28	25.7	39	11	28.2	ELISA	Abushahba et al. (2017)
Various regions (western and eastern desert, Valley and Delta)	716	64	8.9	311	21	6.8	ELISA	Klemmer et al. (2018)
Various regions in northern Egypt	110	25	22.7	80	10	12.5	ELISA	Selim et al. (2018)
Giza	50	10	20	25	9	36	ELISA	Sobhy et al. (2019)
Fayoum	70	18	25.7	40	8	20		
Beni Suef	40	12	30	-	-	-		
El Minya	70	20	28.5	-	-	-		
Mansoura	40	12	30	-	-	-		
Sharkia	60	15	25	-	-	-		
Assuit	60	12	20	-	-	-		
Quena	30	8	26.7	-	-	-		
Assiut	50	28	56	35	16	45.7	IFAT	Abbass et al. (2020)
	50	30	60	35	18	51.4	ELISA	
Northern Egypt	54	27	50	9	0	0	ELISA	Hegazy et al. (2021)
Non-specified	308	38	12.3	192	23	12	ELISA	Saleh et al. (2021)
Assiut & Sohag	184	69	37.5	-	-	-	ELISA	Kamaly et al. (2022)

*Abbreviations: IFA; Indirect flourescent antibody assay, ELISA; Enzyme-linked immunosorbent assay, IFAT; Immunofluorescence antibody test.

The results in Figure 2 show the serum biochemical variables between the seronegative and seropositive *C. burnetii* selected group. These results revealed a significant increase ($p \leq 0.05$) in ALT (23.4±5.87 vs 18±3.16, U/l) for the seropositive vs. seronegative group, respectively. However, non-statistically significant variations ($p \geq 0.05$) were obtained for total protein (6.5±0.85 vs. 6.1±1.09, g/dl), albumin (2.95±0.24 vs. 2.8±0.55, g/dl), globulin (3.54±0.75 vs. 3.3±0.64, g/dl), A/G ratio (0.86±0.16 vs. 0.85±0.13), and AST (65.4±13.23 vs. 79.4±50.66, U/l) for seropositive vs. seronegative group, respectively. These results indicate the suffering of *C. burnetii* seropositive animals from liver insufficiency.

Discussion

Q fever, caused by *C. burnetii* bacteria, is a significant disease in both veterinary and public health sectors. Q fever in humans can range from asymptomatic to flu-like illness; in severe cases, it can have serious consequences. Ruminants are typically infected with the disease but do not show any symptoms. However, they may experience reproductive disorders like abortions. Sheep and goats, in particular, play a critical role in transmitting *C. burnetii* infection to other susceptible animals and humans (Georgiev et al., 2013).

Under the lack of available data on the seroprevalence of *C. burnetii* antibodies in Sohag governorates, southern Egypt, we conducted this study using sheep and goat samples. Sohag is a governorate with one of the highest animal population densities in Egypt, particularly in southern Egypt. The seroprevalence of *C. burnetii* antibodies was 25.6%, 22.8%, and 28% in all tested animals, sheep, and goats, respectively. In the case of sheep in local regions of Egypt, these results were similar to the results obtained by Mazyad and Hafez (2007) in North Sinai (22.5%), Khalifa et al. (2016) in Qaluobia (23%), Abushahba et al. (2017) in El-Minya (25.6%), Selim et al. (2018) in northern Egypt (22.7%), and Sobhy et al. (2019) in various regions (25.5%), and much higher than El-Mahallawy et al. (2012) in Ismailia (12.1%), Horton et al. (2014) in Giza (8%), Klemmer et al. (2018) in various regions (8.9%), and Saleh et al. (2021) in a non-specified region (12.3%). While this percentage was much lower than those obtained by Nahed and Abdel-Moein (2012) in non-specified regions (32.7%), Abbass et al. (2020) in Assiut (60%), Hegazy et al. (2021) in northern regions (50%), and Kamaly et al. (2022) in Assiut and Sohag (32.7%).

Regarding goats, our recorded seroprevalence of 28% was similar to the results reported by Khalifa et al. (2016) in Qaluobia (27%) and Abushahba et al. (2017) in El-Minya (28.2%). Consistently, our seropositive rate was higher than those reported by Mazyad and Hafez (2007) in North Sinai (16.8%), El-Mahallawy et al. (2012) in Ismailia (16.5%), Nahed and Abdel-Moein (2012) in non-specified regions (23.3%), Klemmer et al. (2018) in various regions (6.8%), Selim et al. (2018) in northern Egypt (12.5%), and Saleh et al. (2021) in non-specified regions (12%). Oppositely, our rate was much lower than those obtained by Sobhy et al. (2019) in Giza (36%) and Abbass et al. (2020) in Assiut (51.4%). More results, including the number of samples and used methods, were illustrated in Table 5. Also, these results suggested the importance of precise specification of tested locations because some studies neglected this point, adversely affecting the results comparisons with other studies and the data accuracy. Also, we compared our results with different reports representing different regions of the globe (Table 5).

In the case of sheep and at the level of Arabic, Middle East, and African countries, our result was similar to a study from Algeria (24.9%) (Belhouari et al., 2022), Iraq (20.6%) (Al-Farwachi and Al-Robaiee, 2021) and Iran (22%) (Asadi et al., 2014). At the same time, such a rate was higher than those reported by Guesmi et al. (2023) in Tunisia (17.2%), Hireche et al. (2020) in Algeria (12.4%), Aljafar et al. (2020) in Saudi Arabia (5.8%), Adamu (2019) in Nigeria (11.7%), Wainaina et al. (2022) in Kenya (9.1%). On the contrary, our seroprevalence in sheep was lower than those obtained by Karim et al. (2017) in Algeria (27.8%), Lafi et al. (2020) in Jordan (27%), Johnson et al. (2019) in Ghana (28%). Also, we compared our data from other countries from different continents and found that our was higher than those obtained in India by Leahy et al. (2020) (5%) and Stephen et al. (2014) (1.85%), in Pakistan (15.6%) by Ullah et al. (2018), in China (14.4%) by Yin et al. (2015), in Brazil (2.2%) by de Souza et al. (2018) and Hatchette et al. (2002) in Canada (5.2%) and lower than those reported by Laidoudi et al. (2023) in France (47.6%), and Barlozzari et al. (2020) in Italy (29.9%).

A similar comparison was conducted also for goat seroprevalence in our current and other studies from different world regions. Our result was similar to Hussien et al. (2012) in Sudan (24.2%), Asadi et al. (2014) in Iran (28.1%), Wainaina et al. (2022) in Kenya (25.4%), Muleme et al. (2017) in Australia (25%). While our recorded seropositive rate in goats was higher than those reported by Aljafar et al. (2020) in Saudi

Table 6: Previous seroprevalence reports of *C. burnetii* in sheep and goats in different countries.

Region	Sheep			Goats			Method*	Reference
	No. of tested	Positive		No. of tested	Positive			
		No.	%		No.	%		
Sudan (Various states)	-	-	-	460	111	24.2	ELISA	Hussien et al. (2012)
Tunisia (seven governorates)	793	136	17.2	-	-	-	ELISA	Guesmi et al. (2023)
Algeria (Sidi Belabbe)	180	50	27.8	-	-	-	ELISA	Karim et al. (2017)
Algeria (Constantine)	226	28	12.4	-	-	-	ELISA	Hireche et al. (2020)
Algeria (Ain Delfa)	184	46	24.9	-	-	-	ELISA	Belhouari et al. (2022)
Jordan (Northern regions)	480	129	27	250	108	43.3	ELISA	Lafi et al. (2020)
Saudi Arabia (Eastern provinces)	571	33	5.8	307	48	15.6	ELISA	Aljafar et al. (2020)
Iraq (Mosul city)	330	68	20.6	-	-	-	ELISA	Al-Farwachi and Al-Robaiee (2021)
Iran (Various regions)	803	177	22	167	47	28.1	ELISA	Asadi et al. (2014)
Ghana (Volta region)	158	45	28	100	10	10	ELISA	Johnson et al. (2019)
Nigeria (Kaduna State)	-	-	-	400	35	8.8	ELISA	Adamu et al. (2020)
Nigeria (Yobe State)	420	49	11.7	-	-	-	ELISA	Adamu (2019)
Kenya (Tana River County)	88	8	9.1	228	58	25.4	ELISA	Wainaina et al. (2022)
South Africa (North West province)	-	-	-	216	32	14.8	ELISA	Magadu and Thompson (2023)
India (Assam, Odisha states)	21	1	5	411	21	5	ELISA	Leahy et al. (2020)
India (Puducherry, Tamil Nadu)	216	4	1.85	195	11	5.64	ELISA	Stephen et al. (2014)
Pakistan (Punjab)	500	78	15.6	500	75	15	ELISA	Ullah et al. (2018)
China (Maqu, Tianzhu County, Nyingchi Prefecture)	2112	304	14.4	-	-	-	ELISA	Yin et al. (2015)
China (Hubei province)	-	-	-	1157	55	4.75	ELISA	Li et al. (2018)
France (Hérault, Montpellier city)	21	10	47.6	7	0	0	ELISA	Laidoudi et al. (2023)
Italy (Rome province)	2873	857	29.9	-	-	-	ELISA	Barlozzari et al. (2020)
Australia (Victoria)	-	-	-	164	41	25	ELISA	Muleme et al. (2017)
Brazil (Northeastern region)	-	-	-	312	172	55.1	ELISA	dde Oliveira et al. (2018)
Brazil (Northeastern region)	403	3	2.2	412	9	2.1	IFAT	de Souza et al. (2018)
Canada (Newfoundland)	327	17	5.2	64	12	18.7	IFAT	Hatchette et al. (2002)

*Abbreviations: IFA; Indirect flourescent antibody assay, ELISA; Enzyme-linked immunosorbent assay, IFAT; Immunofluorescence antibody test.

Arabia (15.6%), Johnson et al. (2019) in Ghana (10%), Adamu et al. (2020) in Nigeria (8.8%), Magadu and Thompson (2023) in South Africa (14.8%), Stephen et al. (2014) in India (5.64%), Leahy et al. (2020) in India (5%), Ullah et al. (2018) in Pakistan (15%), Li et al. (2018) in China (4.75%), de Souza et al. (2018) in Brazil (2.1%), Hatchette et al. (2002) in Canada (18.7%). At the same time, our seroprevalence in goats was lower than those obtained by Lafi et al. (2020) in Jordan (43.3%) and de Oliveira et al. (2018) in Brazil (55.1%). The variations in seroprevalence rates between our study and another study might be attributable to the differences in sampling animals, location, timing, and method and approach of testing. More details on the seroprevalence of *C. burnetii* antibodies in sheep and goats, including numbers and used methods from different countries, are described in Table 5.

Furthermore, we investigated numerous animal, farm, and environmental factors to recognize the potential risks of *C. burnetii* infection. On the animal factor level, sex and physiological condition were regarded as predisposing factors for *C. burnetii* infection. Females were more likely to be seropositive compared to males. At the farm and environmental level, although investigations of many factors (location, feeding, biosecurity, and season), only the breeding system was confined to the increased risk of infection where high rates of seropositivity were recorded in individual and mass farming rather than animals bred in smallholders. This result conflicted with Abushahba et al. (2017), where no significant difference was observed among tested female and male small ruminants in El-Minya, Egypt. However, other studies (Asadi et al., 2014; Abushahba et al., 2017) exhibited a consistent result concerning the non-significant effect of different ages, locations, and abortion history. Oppositely, our finding conflicted with other reports correlating coxiellosis and abortion in sheep and goats (de Oliveira et al., 2018; Elsohaby et al., 2021; Belhouari et al., 2022).

Also, Selim et al. (2018) reported that the differences in locations did not affect markedly the seroprevalence of Q fever, which is consistent with our result. Our data regarding the identification of flock size/breeding system risk for infection conflicted with some reports that reported no effect for such variables (Asadi et al., 2014; Barlozzari et al., 2020). Also, females in the dry period were more susceptible to infection than pregnant females. No previous literature has investigated such an effect. However, this might be related to the low level of feeding and caring directed to animals in this stage, as opposed to pregnant or lactating animals. Non-significant differences among tested locations might be attributable to the proximity of tested areas and the free transportation of animals among the same governorate. High seropositivity in all seasons suggested the endemicity of *C. burnetii* infection among tested animals and regions. Although seasonal variations were recorded, no significant differences were reported. Variations in the results of analyzed risk factors with other reports are expected because of differences in sampling animal, location, timing, and testing method.

To confirm the health hazards of Q fever on infected ani-

mals, we tested such effect by comparing some clinical and biochemical parameters in seropositive and seronegative animals to *C. burnetii* antibodies. Our investigations demonstrated altered clinical parameters, including temperature, pulse rate, respiratory rate, appetite, mucous membranes, and skin, among the two groups. Additionally, a significant increase in ALT was observed in the seropositive rather than the seronegative group. These results indicate the adverse effect of *C. burnetii* infection in infected sheep and goats which subsequently will affect animal production and reproduction. Recent reports have linked *C. burnetii* infection and liver diseases in many hosts, including humans (Moore et al., 1991; Jang et al., 2017; El-Mokhtar et al., 2022). Further studies are required to investigate higher numbers and diverse animal species in different regions in Egypt. Also, molecular investigations and genotyping will be valuable to serological studies.

Conclusion

Owing to its potential public health and veterinary concerns, this study provides useful information on *C. burnetii* infection in sheep and goats in Sohag governorate, southern Egypt. We provided a comprehensive report on the existence, associated risk factors, and health hazards of *C. burnetii* seropositivity. High seroprevalence was recorded in both sheep and goats. We identified physiological conditions and breeding system/flock size as predisposing factors for seroreactivity. The pathological impact of *C. burnetii* infection in sheep and goats was reported as indicated in significant changes in some clinical and biochemical variables. This study suggests Q fever's high existence and endemicity in our tested areas and selected animal species. Consequently, Q fever should be taken into account by veterinarians and physicians when dealing with feverish and abortion cases in tested areas.

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