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Review article

A systematic scoping review of microbial pathogens in ruminants with or without a history of abortions in Nigeria

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Abstract

Abortifacient pathogens such as bacterial [*Brucella* spp., *Listeria* spp., *Leptospira interrogans ser.*, *Coxiella burnetii*, *Campylobacter* spp., *Anaplasma* spp., *Chlamydia* spp.], mycotic [*Aspergillus* spp. and *Candida* spp.], protozoan [*Toxoplasma gondii*, *Neospora* spp.], and viral [Bluetongue virus (BTV), Schmallenberg virus (SBV), Bovine viral diarrhea virus (BVDV), and Peste des petits ruminants virus (PPRV)] pathogens are challenges for the productive and reproductive performance of ruminants (cattle, sheep, and goats) globally. No comprehensive report on epidemiology, associated risk factors, or economic burden of these infectious pathogens is available for Nigeria. This review estimated the distribution and burden of abortive pathogens in ruminants in Nigeria for the last twenty-two years (2000-2022). Research articles reporting the detection of any of the above-mentioned abortive pathogens in ready-to-slaughter ruminants (RTSR), sick ruminants (SR), and ruminants with abortive history (RWAH) in Nigeria were accessed using different repositories, including Google Scholar, Proquest, PubMed, ResearchGate and Scopus to determine the prevalence, spatial distribution, and associated risk factors. From a total of 140 articles selected for this review, eight bacterial, four viral, two parasitic, and two mycotic infectious agents were reported for Nigeria. This study reveals a prevalence of 28.2% viral agents, 14.43% bacterial pathogens, 14.24% protozoans, and 28.1% fungal agents in the reported tested samples. Brucellosis was the most often reported among bacterial diseases, followed by leptospirosis and listeriosis. PPRV infection was the most common viral disease, followed by BTV. Additionally, two parasitic diseases, neosporosis and toxoplasmosis, and two mycotic diseases, aspergillosis and candidiasis, were reported. In this study, stillbirth and abortion were recorded in 49.2% of sheep with PPRV, 58.95% in goats with *Chlamydophila abortus* and PPRV, and 6.4% in cattle with *Brucella abortus* and *Histophilus somni* infections. Lack of vaccines, open markets, and extensive husbandry systems were among the risk factors associated with different abortive pathogens. This study is a useful tool for researchers and government officers in risk assessment and management of livestock to improve livestock production in Nigeria.

Keywords: Abortive diseases, Brucellosis, Morbidity, Ruminants, Stillbirth

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Introduction

The term "abortion" refers to the termination of pregnancy between the 42nd and 28th day of gestation for cattle, the 20th and 150th for goats, and the 21st and 152nd for sheep (Peter, 2000). Farmers and veterinarians often face difficulties in diagnosing the cause of abortions. Herds have experienced a precipitous and severe increase in abortions over a prolonged period, with huge and inevitable financial losses in the livestock sector (De Vries, 2006; Hossein-Zadeh, 2013). Infectious and non-infectious causes contribute to ruminant abortion. In a few studies, non-infectious variables like hereditary and non-genetic illnesses have been reported (Peter, 2000; Hansen, 2002; Okoli, 2003; Sani and Amanloo, 2007; Sen et al., 2010; Dereje et al., 2018).

Heat stress, production stress, seasonal effects, and seasonal fluctuations are the most significant non-genetic risks for abortion (Hansen, 2002; Sani and Amanloo, 2007). Genetic disorders, such as chromosomal abnormalities and single genes, can lead to abortion in cows, sheep, goats, and calves' sterility (Okoli, 2003). However, infectious reproductive diseases, including bacterial, viral, fungal, and parasitic agents, are responsible for massive fetal deaths in ruminants (Okoli, 2003; Sen et al., 2010). Depending on the stage of pregnancy, different syndromes are noticed. In cases where the placenta experiences a rapid bacterial infection from the early stages of gestation through the other stages, foetal death can occur due to sepsis (Dereje et al., 2018). The deceased foetus is often ejected within five days, and autolytic alterations cover the small gross lesions induced by the pathogens (Quinn et al., 2011).

The retention of the foetal membranes is a typical side effect of metritis. The foetus may be born normally if the infection happens at a late stage of gestation, but it may not survive (Quinn et al., 2001). From an economic point of view, more than ten diseases are responsible for stillbirth and abortion in both large and small ruminants (Quinn et al., 2001), with brucellosis and peste des petits ruminant (PPR) infections being the most important of these diseases due to the large economic loss caused particularly in endemic areas (El-Yuguda et al., 2013; Akinyemi et al., 2022). Other significant infectious abortive diseases in ruminants include anaplasmosis, leptospirosis, listeriosis, bovine viral diarrhea (BVD), campylobacteriosis, chlamydophilosis, my-

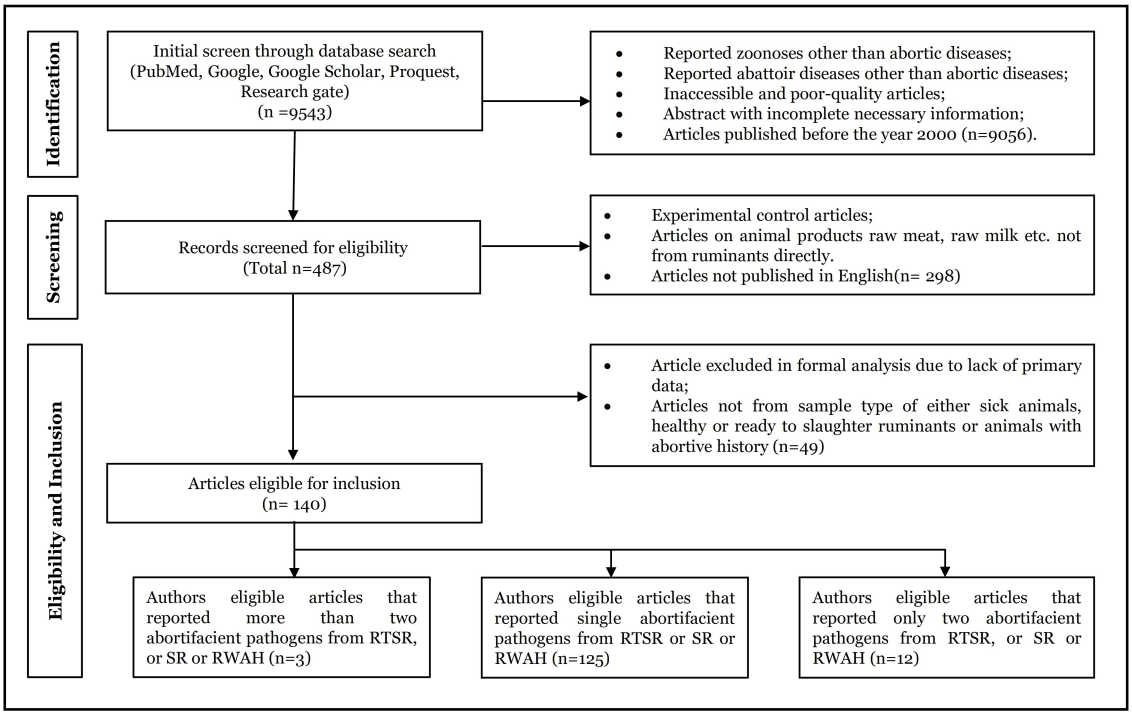

Figure 1: Flowchart of a systematic review of abortion diseases in ruminants for selection of eligible articles. Ready-to-slaughter ruminants (RTSR), sick ruminants (SR), or ruminants with a history of abortion (RWHA).

cotic abortion, neosporosis, *Arcanobacterium* pyogenic disease, Q-fever, bluetongue viral disease (BTV), Schmallenberg virus (SBV) infection, *Tritrichomonas foetus* disease, epizootic bovine abortion, and toxoplasmosis (Dereje et al., 2018). Although the precise percentage of cases caused by infectious agents is unknown, 90% of cases in which an aetiological diagnosis is made have an infectious origin (Parthiban et al., 2015). In Nigeria, ruminants constitute a substantial proportion of the livestock sub-sector, and about 80% of the estimated ruminant population lives in the Northern part of Nigeria (Lawal et al., 2012; El-Yuguda et al., 2013). The estimated cattle population is 34.5 million, with 22.1 million sheep and 13.9 million goats. In the recent past, livestock contributed an estimated 23.3% to the Nigerian National Gross Domestic Product (GDP) and 9% to the agro-economy (Neils et al., 2011). To meet the food needs of a growing population (red meat and dairy products), farmers and the government paid attention to improving the breed, pasture, and animal health to boost livestock productivity and address the high rate of urbanization. Several factors have hampered these efforts, of which infectious reproductive health complications are the main impact. In ruminants, abortive diseases have been of paramount interest since these diseases are connected with significant financial losses to the livestock industry (Neils et al., 2011). However, there is no comprehensive review of microbial pathogens in ruminants with or without a history of abortions and their associated risk factors. Thus, this study addresses these gaps based on the review of published articles in the last two decades in Nigeria.

Materials and methods

Area of study

This study was conducted in six geopolitical zones of Nigeria including 36 States: North-East (NE), 6 States: North-West (NW), 7 States: North-Central (NC), 6 States: South-East (SE), 5 States: South-West (SW), 6 States and South-South (SS), 6 States including a federal capital territory (Abuja). The North-West zone comprises 242,425 km^2, or 25.75%, of the nation's total land area. There are around 272,451 km^2 in the North-East zone. The North-Central zone spans over 193,088 km^2 of the state. In the Southern zone of Nigeria, however, 79,665 km^2 of land is occupied by the South-West zone, 79,525 km^2 by the South-South zone and roughly 84,587 km^2 by the South-East zone.

Search strategy and data acquisition

The systematic review protocols (PRISMA-P) 2015 (Moher et al., 2015) checklist was followed for the review of meta-analysis of original research studies that reported twenty microbial pathogens in cattle and small ruminants with or without a history of abortion using public scientific databases such as Google Scholar, Scopus, PubMed, Proquest, Academia, and ResearchGate, from January 1, 2000, to December 1, 2022. The objective was to identify original articles that reported on prevalence, serotypes, and antibiotic resistance in all six geopolitical zones of Nigeria, with a specific focus on culture, serology, and molecular approaches.

Additionally, the following search strings/terms were used: Peste des petits ruminants virus, *Brucella*, *Ureaplasma*, *Anaplasma* spp., *Anaplasma marginale*, *Leptospira interrogans ser*, *Listeria monocytogenes*, viral diarrhea virus, *Campylobacter* spp., *Campylobacter fetus*, *Chlamydophila* spp., *Archnobacterium pyogen*, *Aspergillus* spp., *Candida* spp., *Mortelella wolfii*, *Neospora caninum*, *Coxiella burnetii*, BTV, SBV, *Tritrichomonas foetus*, *Histophilus somni*, *Toxoplasma* spp., *Toxoplasmas gondii*; or brucellosis, undulant fever, Mediterranean fever, gastric remittent fever, Malta fever, ureaplasmosis, anaplasmosis, leptospirosis, listeriosis, bovine viral diarrhoea (BVD), campylobacteriosis, chlamydophilosis mycotic abortion, neosporosis, *Archnobacterium pyogen* disease, Q-fever, bluetongue viral disease, schmallemberg viral infection, *Tritrichomonas foetus* disease, *Histophilus somni* infection, epizootic bovine abortion, toxoplasmosis, bovine herpes virus Pestis des petits, animals, cattle, small ruminants, febrile, abortion, abortive, incidence, prevalence, sensitivity testing, antibiotic susceptibility, antimicrobial activity, or treatment.

Selection criteria and inclusion criteria

Online publications (full text/abstracts) were individually evaluated. Following this study's inclusion criteria, relevant papers were retrieved and examined, including their reference sections. Publications including full-text articles, abstracts, dissertations, thesis, short communication, and conference proceedings in the English language on cohort, case, and cross-sectional studies were included if samples were taken from a named farm, herd, community, slaughterhouse/abattoir, state, or geopolitical zone, or if the study recruited animals (cattle, sheep, and goats) originated from Nigeria.

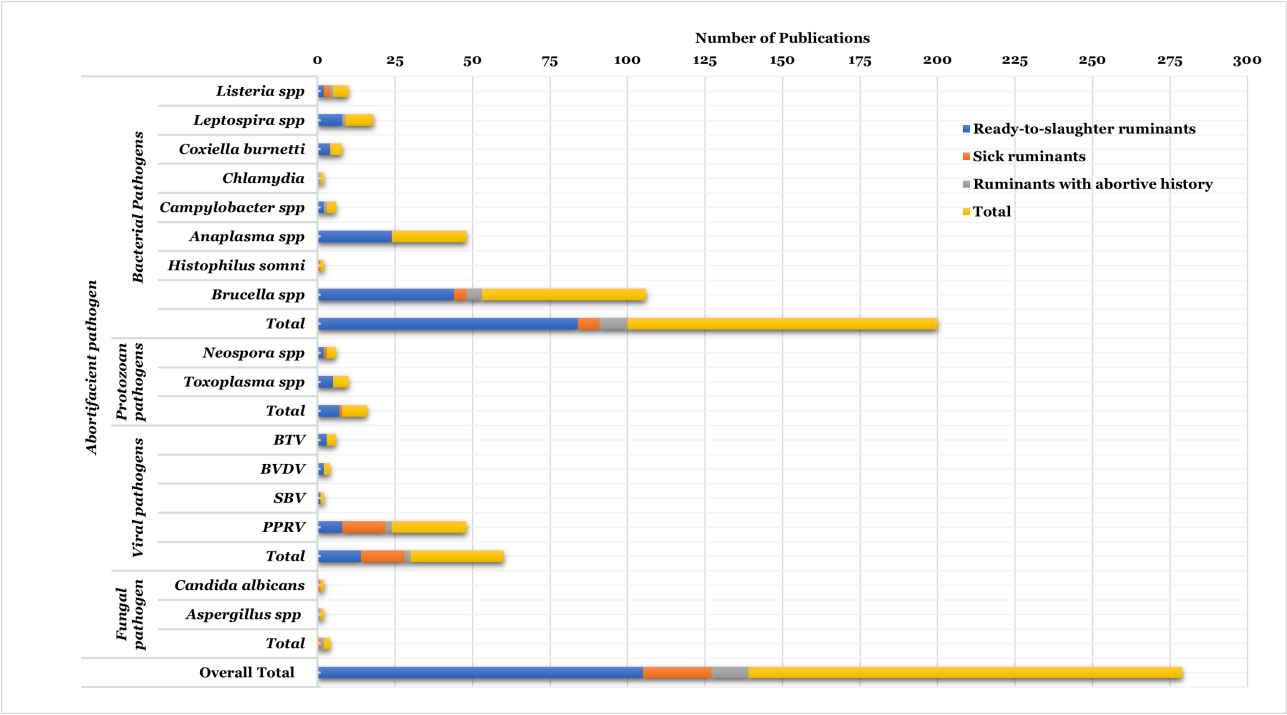

Figure 2: Categories of abortive diseases and numbers of publications in these statuses from 2000-2022. Abbreviations: ready-to-slaughter ruminants (RTSR), sick ruminants (SR), or ruminants with a history of abortion (RWHA), bovine viral diarrhea (BVD), bluetongue viral disease (BTV), Schmallenberg virus (SBV), and peste des petits ruminant virus (PPRV).

The following abortive pathogens were of concern: *Brucella*, PPRV, *Ureaplasma* spp., *Anaplasma* spp., *Anaplasma marginale*, *Leptospira interrogans*., *Listeria monocytogenes*, BVD, *Campylobacter* spp., *Campylobacter fetus*, *Chlamydophila* spp., *Archnobacterium pyogene*s, *Aspergillus* spp. *Candida* spp., *Mucor* spp., *Mortelella wolfii*, *Neospora caninum*, *C. burnetii*, BTV, SBV, *Tritrichomonas foetus*, *H. somni*, agents of epizootic bovine abortion, *Toxoplasma* spp., and *Toxoplasmas gondii*. Ready-to-slaughter ruminants (RTSR), sick ruminants (SR), or ruminants with a history of abortion (RWHA) were included.

Exclusion criteria

Studies were disregarded if the reported abortive pathogens were not supported by serology, culture, or molecular approach results and if the abortive pathogens in the inclusion criteria were not isolated or detected from RTSR, SR, or RWHA samples. This study did not include reports based on books, book chapters, systematic reviews, experimental studies, ecological associations, or clinical diagnoses. Two de-duplication tools, including the Mendeley citation management and Ovid multi-file search, were used to identify and eliminate duplicate articles.

Data extraction

From each of the chosen articles, descriptive and quantitative data on the inclusion criteria established were evaluated and a standard template was made using a Microsoft Excel 2013 file. Double data extraction and entry were done to assure accuracy. State, geopolitical zone, year of sampling/study, first author's name, publication date, date of sample collection, source/type of sample (blood, body fluid, secretion), sample size, number of ruminants, types of animals, testing method, number of positive samples from serology, culture, and molecular methods, the number of isolates, and species of the abortive pathogen with biotypes were among the data extracted from the articles.

Results

Data analysis

A descriptive analysis of the data obtained was carried out. Between 1st January 2000 and 1st December 2022, 9543 papers were retrieved from the searched online databases. A total of 189 articles were determined to be qualified, and 140 articles were retained after duplicated papers had been removed. Specifically, 125 articles reported a single abortive pathogen, and 12 articles reported two abortive pathogens, while three reported more than two abortive pathogens in RTSR, SR, and RWAH (Figure 1). Sixteen possible abortifacient pathogens were identified in this investigation, and the prevalence was estimated as the proportion of any abortifacient pathogen isolated/detected from positive samples in the total samples recorded.

Methods of detection of abortifacient pathogens from reviewed publications

The publications that were reviewed reported sixteen different detection techniques. Seven included in Table 1-Table 3 were the most popular or widely used. Among them are polymerase chain reaction (PCR), culture (CTL), serum agglutination test (SAT), and the serum agglutination test with EDTA, Rose Bengal plate test (RBPT), competitive enzyme-linked immunosorbent assay (c-ELISA), indirect enzyme-linked immunosorbent assay (i-ELISA), and immunoglobulin G/immunoglobulin M-enzyme-linked immunosorbent assay (IgG/IgM-ELISA). Other detection techniques include the use of Warthin Starry Silver (WSS), immunohistochemistry and impregnation (IH), microscopic agglutination test (MAT), and microhaematocrit test (MICRO/HCT). Out of the seven extensively reported methods of detection, the RBPT test is most frequently used to identify antibodies to *Brucella* species in 42 articles, followed by c-ELISA (n=33), CTL (n=29), SAT/SAT-EDTA (n=18), PCR (n=10), IgG/IgM-ELISA (n=9), while the least frequent test used was the i-ELISA (n=7). Intriguingly, it should be noted that of the 140 publications examined, 105 (75%) conducted screening on RTSR (Table 1), 23 (16.4%) on SR (Table 2), and 12 (8.6%) on RWAH (Table 3).

Categories of abortive diseases in Nigeria

A total of 140 research articles covering 31 states (Benue, Plateau, Kwara, Niger, Nasarawa, Borno, Yobe, Bauchi, Adamawa, Taraba, Gombe, Kano, Kaduna, Katsina, Sokoto, Jigawa, Zamfara, Enugu, Ebonyi, Imo, Anambra, Abia, Cross River, Akwa-Ibom, Rivers, Bayelsa, Oyo, Osun, Ondo, Lagos, and Ogun) and the federal capital territory (Abuja) were identified. Suspected abortive diseases were reported in six

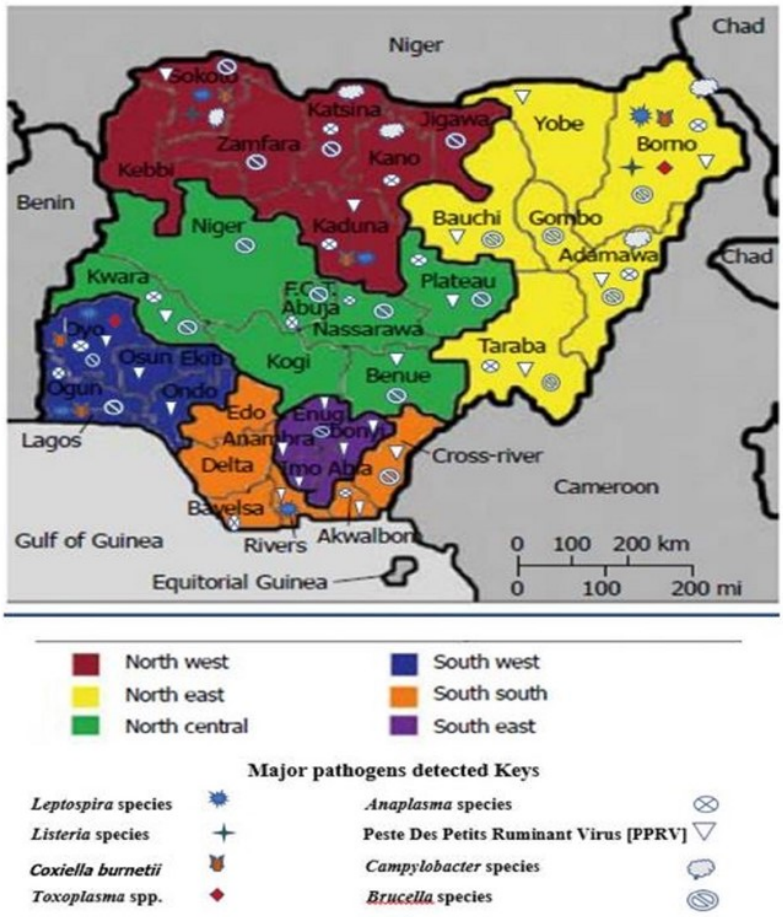

Figure 3: Geo-political distribution of pathogens suspected to likely cause abortion in ruminants.

geo-political zones in Nigeria. Four categories of these diseases were found, including bacterial, viral, parasitic, and fungal abortive. Eight bacterial genera (*Brucella*, *Leptospira*, *Listeria*, *Anaplasma*, *Chlamydia*, *Campylobacter*, *Histophilus*, and *Coxiella*), four viral agents (BVDV, PPRV, BTV, and SBV), two protozoans (*Neospora* and *Toxoplasma*) and two fungi (*Aspergillus* and *Candida*) were reported from three animal statuses (RTSR, SR, and RWAH). One hundred and one articles on bacterial diseases, i.e., brucellosis (n=53), leptospirosis (n=9), listeriosis (n=5), Q-fever (n=4), campylobacteriosis (n=3), anaplasmosis (n=25), chlamydiosis (n=1) and *H. somni* associated pneumonia (n=1). Also, eight articles on parasitic abortive diseases were reviewed, including neosporosis (n=3) and toxoplasmosis (n=5). Furthermore, 30 articles on viral abortive diseases were reviewed, with PPRV having the highest number of publications (n=24), followed by BTV (n=3), BVDV (n=2), and SBV (n=1), as well as two articles on mycotic infections. Detailed data can be found in Figure 2.

Geographical distribution of suspected pathogens likely to cause abortion in ruminants

According to the literature reviews for this study, the suspected abortive pathogens have been reported in several geopolitical regions of Nigeria. Eight agents were reported in less than four publications and only in a few geopolitical areas. They are *H. somni*, *Chlamydia* spp., *Neospora* spp., BVDV, BTV, SBV, and fungal pathogens (*Aspergillus* spp. and *Candida albicans*). Eight groups of important pathogens were documented in two or more geopolitical zones and published in at least four articles. These include *Leptospira interrogans ser.*, *Anaplasma* spp., *Campylobacter* spp., PPRV, *C. burnetii*, *Listeria* spp., *Toxoplasma* spp., and *Brucella* spp. (Figure 3). Notably, *Brucella* spp. and PPRV were reported in all six geopolitical regions of Nigeria (NE, NC, NW, SS, SE, and SW), followed by *Anaplasma* spp. in five regions (SW, SS, NC, NW, and NE), *Leptospira interrogans ser.* in four regions (NE, NW, SW, and SS), *C. burnetii* in three regions (SW, NW, and NE), and *Listeria* spp. in two regions (NW and NE). Within the six geopolitical zones, there are 36 states, and of these, 31 states had at least one case of one of the sixteen infections known to induce abortion in small ruminants. Only five states (Kebbi-NW, Kogi-NC, Ekiti-SW, Edo-SS, and Delta-SS) had no cases of suspected infections likely to cause abortion.

Prevalence of suspected pathogens likely to cause abortion in ruminants

In this study, the estimated cumulative prevalence of suspected pathogens likely to result in abortion among the pathogens considered is 19.36% (21835/112804). The pooled prevalence s from cattle, sheep, and goats of different statuses of the abortive bacterial pathogen is shown in Table 4, while the pooled prevalence of viral, protozoal, and fungal pathogens is shown in Table 5. A prevalence of 28.2% (11534/40883) for viruses, 28.1% (47/167) for fungi, 14.24% (403/2831) for protozoans, and 14.43% (9851/68252) for bacterial pathogens was noted. The four viral agents that make up 28.2% prevalence are BVDV (57%), BTV (39%), SBV (29%), and PPRV (27.0%). Of the 14.43% bacterial pathogens documented, *H. somni* has the highest (100%) prevalence of the eight bacterial pathogens reported from reviewed literature on RTSR, SR, and RWAH of cattle, goats, and sheep. *Leptospira interrogans ser* prevalence was 27.2%, followed by *Brucella* species at 14%, *Campylobacter* species at 13%, *Anaplasma* species at 23%, *C. burnetii* at 9%, *Chlamydia* spp. at 4%, and *Listeria* spp. at 3.2%. Additionally, the prevalence for the *Neospora* and *Toxoplasma* spp. were 10% and 15.0%, respectively. Interestingly, 28.1% of mycotic infections are caused by two fungal genera (*Aspergillus* spp. and *Candida albicans*) were reported from only two publications in this study.

Table 1: Methods of detecting pathogens likely to cause abortion in RTSR based on sample sources and the number of articles.

No. of articles	Sample type (n)	Pathogen type (n)	Detection methods*								References
			PCR	CTL	SAT/SAT -EDTA	BPT	c-ELISA	i-ELISA	IgG/IgM-ELISA	Other	
24	Blood (24)	*Anaplasma marginale* (20); *A. centrale* (1); *A. bigemina* (1); *A. ovis* (5)	18	2	-	-	-	-	2	3	Akande et al. (2010); Kamani et al. (2010a); Pukuma et al. (2011); Ademola and Onyiche (2013); Pam et al. (2013); Abdullahi et al. (2014); Olatunde et al. (2014); Anyanwu et al. (2016); Elelu et al. (2016); Lorusso et al. (2016); Adua and Idahor (2017); Deme et al. (2017); David et al. (2018); Adejoh et al. (2019); Atsuwe et al. (2019); Happi et al. (2020a,b); Olorunshola et al. (2020); Gboeloh and Araka (2022); Kamani et al. (2022b) Kamani et al. (2022a); Onyiche et al. (2022)
8	Blood (8); kidney samples (1)	*Leptospira interrogans* serovar *hardjo* (4); *L. interrogans* (2); *Leptospira* spp. (1); *L. pomona* (1); *L. icterohaemorrhagiae* (1)	-	2	-	-	-	-	3	3	Agunloye et al. (2000); Junaidu et al. (2011); Ngbede et al. (2012); Bashiru et al. (2013); Ngbede et al. (2013); Oruene and Bekwele (2020) Ajayi et al. (2021); Stephen et al. (2022)
2	Raw milk (2)	*Listeria monocytogenes* (2); *L. innocua* (1), *L. seeligeh* (1), *L. welshine* (1)	-	2	-	-	-	-	-	-	Yakubu et al. (2012); Uwanibe et al. (2014)
4	Blood (4)	*Coxiella burnetii* (4)	-	-	-	-	-	4	-	-	Adamu et al. (2018); Cadmus et al. (2020); Adamu et al. (2022)
44	Sera (40); milk (5)	*Brucella abortus* (39); *Brucella* spp. (20); *Brucella melitensis* (3)	1	-	15	35	19	-	-	2	Bale et al. (2003); Junaidu and Garba (2006); Junaidu et al. (2006); Cadmus et al. (2008); Bertu et al. (2010); Cadmus et al. (2010); Junaidu et al. (2011); Mbuk et al. (2011); Mohammed et al. (2011); Wungak et al. (2011); Lawal et al. (2012); Mai et al. (2012); Alhaji and Wungak (2013); Cadmus et al. (2013) Cadmus et al. (2021); Kaltungo et al. (2013); Maurice (2013); Ogugua et al. (2014); Zubairu et al. (2014); Dauda et al. (2015); Kaltungo et al. (2015); Adamu et al. (2016); Akinseye et al. (2016) Alhaji et al. (2016); Buhari et al. (2016); Dawang et al. (2016); Jajere et al. (2016); Agada et al. (2017); Aworh et al. (2017); Ayinmode et al. (2017); Farouk et al. (2017); Adamu et al. (2018); Agada et al. (2018); Ekere et al. (2018); Ogugua et al. (2018); Olufemi et al. (2018); Shu'aibu et al. (2018); Kaltungo et al. (2019); Yusuf and Abdulrasheed (2019); Buhari et al. (2020); Cadmus et al. (2020); Ibrahim et al. (2020); Mohammed et al. (2020); Ukwueze et al. (2020)
2	Rectal swab (1); Preputial washing 1)	*Campylobacter jejuni* (1), *C. coli* (1), *C. lari* (1), *C. laridis* (1), *C. fetus* (3)	-	2	-	-	-	-	-	-	Salihu et al. (2009); Mai et al. (2013)
5	Blood; serum	*Toxoplasma gondii* (5)	-	-	-	-	-	3	1	1	Joshua and Akinwumi (2003); Kamani et al. (2010b); Onyiche and Ademola (2015); Ayinmode and Abiola (2016); Ayinmode et al. (2017)
2	Blood (2)	*Neospora caninum* (2)	-	-	-	-	-	-	2	-	Ayinmode (2013); Ayinmode et al. (2017)
3	Blood (4)	Blue tongue virus(1)	2	-	-	-	2	-	-	-	Oluwayelu et al. (2011); Oladimeji and Kelechi (2019); Zanna et al. (2021)
1	Blood/serum (1)	Schmallenberg virus (1)	-	-	-	-	1	-	-	-	Oluwayelu et al. (2015)
2	Sera (2)	Bovine viral diarrhea virus (2)	-	-	-	-	-	-	2	-	Peter et al. (2016); Sanusi et al. (2016)
8	Sera (47); lymph nodes (1); nasal swab (1)	Peste des petits ruminants virus (8)	1	5	-	-	-	-	-	3	El-Yuguda et al. (2009a); Lawal et al. (2011); El-Yuguda et al. (2013); Nwobodo et al. (2013); Victor et al. (2017); Bello et al. (2018); Chukwudi et al. (2020); Bukar et al. (2020)
	Total number of articles= 105		**22**	**11**	**15**	**35**	**22**	**7**	**10**	**12**	

*Keys. Other: (LA: Latex agglutination; LM: Light Microscopy; MAT: Microscopic Agglutination Test; IH: Impregnation and Immunohistochemistry; Micro/HCT: Microhaematocrit); PCR: Polymerase Chain Reaction; SAT: Serum Agglutination Test/SAT-EDTA; c-ELISA: Competitive ELISA; i-ELISA: Indirect-ELISA; CTL: Culture.

Table 2: Methods of detecting pathogens likely to cause abortion in diseased Animals based on sample sources and the number of articles.

No. of articles	Sample type (n)	Pathogen type (n)	Detection Methods*								References
			PCR	CTL	SAT/SAT-EDTA	BPT	c-ELISA	i-ELISA	IgG/IgM-ELISA	Other	
2	Blood (2)	*Listeria* species (1); *L. monocytogen* (1)	-	2	-	-	-	-	-	-	Peter (2015); Idris Ibrahim (2021)
4	Blood/serum (4)	*Brucella* spp. (4)	-	-	1	4	-	-	-	-	Dauda et al. (2015); Bamidele et al. (2020); Cadmus et al. (2020); Ukwueze et al. (2020)
1	Lungs (1); spleen (1); liver (1)	*H. somni* (1)	-	1	-	-	-	-	-	-	Odugbo et al. (2009)
1	Blood (1)	*Anaplasma marginale* (1); *A. centrale* (1)	-	-	-	-	-	-	-	1	Osue et al. (2022)
1	Milk (1)	*Aspergillus niger* (1); *A. filmigatus* (1); *Fusarium chlamydosporium* (1); *A. nidule* (1); *A. terreus* (1); *Candida albicans* (1)	-	1	-	-	-	-	-	-	Adelowo (2020)
14	Sera (10); nasal swab (2); lungs (1); lymph (1); ocular swab (1); liver (1); intestine (1)	Peste des petits ruminants virus (14)	6	1	-	-	6	-	-	4	Okoli (2003); Luther et al. (2005); Owai (2007); El-Yuguda et al. (2009b); Lawal et al. (2011); Luka et al. (2011); Ularamu et al. (2012); Woma et al. (2015); Jarikre and Emikpe (2017); Adedeji et al. (2019); Chukwudi et al. (2020, 2021); Idris Ibrahim (2021); Mantip et al. (2022)
Total number of articles= 23			**6**	**5**	**1**	**4**	**6**	**0**	**0**	**5**	

*Keys. Other: (LA: Latex agglutination; LM: Light Microscopy; MAT: Microscopic Agglutination Test; IH: Impregnation and Immunohistochemistry; Micro/HCT: Microhaematocrit); PCR: Polymerase Chain Reaction; SAT: Serum Agglutination Test/SAT-EDTA; c-ELISA: Competitive ELISA; i-ELISA: Indirect-ELISA; CTL: Culture.

Table 3: Methods of detecting pathogens likely to cause abortion in RWAH based on sample sources and the number of articles.

No. of articles	Sample type (n)	Pathogen type (n)	Detection methods*								References
			PCR	CTL	SAT/SAT-EDTA	BPT	c-ELISA	i-ELISA	IgG/IgM-ELISA	Other	
1	Preputial washing (1); cervical-vagina mucus swab (1)	*Campylobacter fetus* (1)	-	1	-	-	-	-	-	-	Mshelia et al. (2012)
1	Blood (1)	*Listeria monocytogenes* (1)	-	1	-	-	-	-	-	-	Peter (2015)
1	Blood	*Chlamydia abortus* (1)	-	1	-	-	-	-	-	-	Abubakar (2015)
1	Blood (1)	*Leptospira interrogans* ser *hardjo* (1)	-	-	-	-	-	-	1	1	Stephen et al. (2022)
5	Blood/sera (5); milk (6); Vagina Swab (6); hygroma fluid (8)	*Brucella abortus* (9); *Brucella* spp. (1)	-	9	2	3	-	-	-	-	Ocholi et al. (2004, 2005); Onoja et al. (2008); Mbuk et al. (2011); Bertu et al. (2020)
2	Serum (6)	Peste des petits ruminants virus (6)	-	1	-	-	5	-	-	1	Lawal et al. (2011); Wachida et al. (2018)
1	Blood (1)	*Aspergillus* spp. (1) *Candida* spp. (1)	-	1	-	-	-	-	-	-	Biobaku et al. (2016)
Total number of articles= 12			**0**	**14**	**2**	**3**	**5**	**0**	**1**	**2**	

*Keys. Other: (LA: Latex agglutination; LM: Light Microscopy; MAT: Microscopic Agglutination Test; IH: Impregnation and Immunohistochemistry; Micro/HCT: Microhaematocrit); PCR: Polymerase Chain Reaction; SAT: Serum Agglutination Test/SAT-EDTA; c-ELISA: Competitive ELISA; i-ELISA: Indirect-ELISA; CTL: Culture.

Risk factors associated with suspected abortive pathogens

Eight key risk factors related to infections likely to induce abortion in ruminants were documented. Age, season, and breed were the most often mentioned risk factors (Eniolorunda et al., 2008; Kamani et al., 2010a; Pukuma et al., 2011; Salihu et al., 2009; Ngbede et al., 2013; Sanusi et al., 2016; Victor et al., 2017; Ibrahim et al., 2020; Cadmus et al., 2020; Ajayi et al., 2021; Stephen et al., 2022). Seasonally, ruminants are more susceptible to Leptospira, Toxoplasma, and *Anaplasma* spp. transmission. (Eniolorunda et al., 2008; Kamani et al., 2010a; Pukuma et al., 2011). Additionally, due to the high wind speeds associated with the dry season, ruminants are reportedly more susceptible to PPRV and *Brucella* spp. during that time (Salihu et al., 2009; Victor et al., 2017).

Open grazing, pastoral systems, and semi-intensive husbandry are also among the most frequently mentioned risk factors for *Brucella* spp., *Toxoplasma* spp., PPRV, and BVDV (Kamani et al., 2010a; Sanusi et al., 2016; Victor et al., 2017; Ibrahim et al., 2020). Interestingly, ruminants without a history of immunization are more susceptible to PPRV than animals with a history of vaccination (Victor et al., 2017).

It should be highlighted that the source of the animals, such as the open market for purchase, is another significant risk factor for infection with *Brucella* spp. (Ibrahim et al., 2020), *C. burnetii* (Cadmus et al., 2020) and *Leptospira interrogans ser* (Pukuma et al., 2011). It was discovered that certain animal breeds, such as West Africa Dwarf (WAD) breeds of goats, Yankasa varieties of sheep, and Sokoto Gudali (SG) breeds of cattle, were more susceptible to contracting PPRV, *C. burnetii*, and *Brucella* spp. (Salihu et al., 2009; Victor et al., 2017; Cadmus et al., 2020). Sex (Pukuma et al., 2011; Sanusi et al., 2016; Victor et al., 2017; Stephen et al., 2022), history of abortion, and other reproductive diseases (Ibrahim et al., 2020) are additional reported risk factors as shown in Table 6.

Records of stillbirth and abortion in ruminants infected with microbial pathogens

This study recorded alarming stillbirth and abortion of 49.2% (369/782) in sick sheep with PPRV, 58.95% (619/1050) in sick goats with *Chlamydophila abortus* and PPRV, and 6.4% (166/2606) in sick cattle with *Brucella abortus* and *H. somni* infections. Interestingly, 79.1% (291/368) of stillbirth and abortion were recorded in sick goats due to *Chlamydia* infection, 50% (95/184) in sick cattle due to histophillosis, 49.7% (319/642) in sick goats due to PPRV infection, and 22.5% (9/40) in sick goat due to aspergillosis and candidiasis. Furthermore, 13.0% (36/270) of abortions in bovine due to campylobacteriosis and 2.0% (35/2152) due to brucellosis were recorded.

Discussion

Infections in ruminants pose a significant danger to veterinary public health and food security due to financial implications (Herrero et al., 2013). Therefore, this study systematically reviews the literature reporting possible abortifacient pathogens in Nigerian ruminants. To our knowledge, this is the first comprehensive analysis of the diversity of possible abortifacient pathogens in ruminants in Nigeria. It was observed that 31 out of the 36 states reported abortive pathogens in ruminants documented by 140 eligible published articles. The lack of information from the remaining five states (Edo, Kebbi, Kogi, Ekiti, and Delta) is an indication of gaps in the published articles, which may be due to a lack of definitive diagnostic tools, inadequate infrastructure for assays for definitive detection of abortive pathogens, and a lack of researchers' interest in studying and publishing reports on these pathogens. In this study, the overall prevalence of the sixteen documented abortive pathogens is proven. The sixteen possible abortifacient pathogens are grouped into four categories according to etiology, i.e., bacterial, viral, protozoan, and fungal disease. A prevalence of 28.2% for viruses, 14.43% for bacterial pathogens, 14.24% for protozoans, and 28.1% for fungi were recorded.

Viral abortifacient diseases in Nigeria

An overall seroprevalence of 28.2% for viral abortive pathogens was documented, such as BVDV (57%), BTV (39%), SBV (29%), and PPRV (27%) prevalence was recorded. Notably, a 57% prevalence of BVDV was reported only in RTSR with BTV and SBV. Although they are not yet confirmed zoonotic, the potential to cause zoonoses may not be ruled out in the future. Similar studies around the world had reported different prevalent rates, such as 46.3% in western China (Gao et al., 2013), 70% in South Africa (Njiro et al., 2011), between 50-90% recorded in Iran (Sani and Amanloo, 2007), Canada (Ahmad et al., 2011) and South Vietnam (Duong et al., 2008). However, a lower prevalence of BVDV was reported in Yucatan cattle in Mexico (Solis-Calderon et al., 2005).

The variation of the prevalent rate recorded at different locations across the globe has been attributed to different factors such as the management method, animal populations, husbandry system, diagnostic techniques, and biosecurity measures (Stand Alenius, 2012). In Nigeria, the first case of BVDV was reported in 1977 in Northern Nigeria (Taylor et al., 1977). After that, in 1994, the pathogen was detected in sick sheep and goats in Maiduguri (Baba et al., 1994) and in 2016 in Sokoto state (Sanusi et al., 2016).

The seroprevalence of BTV in this study was 39%. This result was higher than the 12.2% recorded in China (Gong et al., 2021) and 25.7% in Saudi Arabia (Yousef et al., 2012). The disparity could be attributed to differences in animal populations, study scope, and circulating strains. Interestingly, all Nigerian BTV strains number NIG 1982/10 found from the reviewed articles in this study were similar to the Australian BTV-16 strain through phylogenetic analysis, representing a distinct virus lineage within the major eastern topotype (Mertens et al., 2013). Although SBV has been reported in other countries such as Ethiopia (Sibhat et al., 2018), the Netherlands (Elbers et al., 2012), Iraq (Al-Baroodi, 2021), and Germany (Wernike et al., 2014) but only one article reported a seroprevalence of 29% for SBV in Nigerian cattle from the year 2000 till date (Oluwayelu et al., 2015). An indication that this virus is not common in Nigerian ruminants.

PPRV was the most frequently reported possible abortifacient viral agent with or without a history of abortion, with a pooled seroprevalence of 27.0% from 21 of the 36 states across the six geopolitical zones. This result indicates that this virus is endemic and continually circulating in Nigeria despite the availability of PPRV vaccine intervention (Zhao et al., 2021). The high prevalence rates of PPVR recorded in this study were in consonant with studies documented in other countries like Sudan (42.0%) (Ali et al., 2019), Saudi Arabia (24.1%) (Hemida et al., 2020), Rwanda (18.8%) (Shyaka et al., 2021), and the northeastern region of India (14.5%) (Balamurugan et al., 2020). In Nigeria, the coverage of the PPRV vaccine is poor (Fadiga et al., 2013; Zhao et al., 2021). It is important to note that among the four abortive viral agents identified in this study, only PPRV was reported in RTSR cattle, sheep, goats, diseased sheep and goats, and RWAH cattle and goats.

Several African countries, Middle Eastern states, the Arabian Peninsula, and south India have been affected by PPRV, causing significant economic hardships (Balamurugan et al., 2010; Muse et al., 2012; Balamurugan et al., 2020). PPRV is considered a major obstacle to the successful rearing of small ruminants and has a profound impact on the financial situation of rural farmers. However, there is a lack of sufficient epidemiological data on PPRV in Nigeria, which is crucial for developing effective preventative and control strategies (Banyard et al., 2010; Zahur et al., 2014). Serological assays such as c-ELISA, agar diffusion, and PCR have been widely used for the detection of other viruses, including BTV, BVDV, and SBV. However, unlike PPRV, detailed information regarding the origin, transmission dynamics, vaccination history, mortality, and origin of BVDV, BTV, and SBV is currently unavailable.

Bacterial abortifacient diseases in Nigeria

Notably, a total of 14.43% bacterial abortive pathogens pooled prevalence was found. Of this, 100% prevalence for *H. somni*, 27% for *Leptospira interrogans ser*, 14% for *Brucella* spp., 13.0%

Table 4: The pooled prevalence of abortive bacterial pathogens from cattle, sheep, and goats of different statuses.

Pathogens detected	Samples	No. of samples	Positive samples no.	Prevalence (%)	Animal status (no.)*								
					RTSR (no.)			Sick/diseased animal (no.)			RWAH (no.)		
					Goat	Sheep	Cattle	Goat	Sheep	Cattle	Goat	Sheep	Cattle
Leptospira interrogans ser	Blood, kidney samples	1963	534	27	113	20	392	0	0	0	6	0	3
Listeria spp.	Milk, Blood	4989	174	3	0	0	99	10	58	0	5	2	0
Chlamydia spp.	Sera	368	14	4	0	0	0	0	0	0	12	2	0
Campylobacter spp.	Preputial washing, cervical-vagina mucus swab	3284	429	13	0	39	380	0	0	0	0	0	10
Coxiella burnetii	Blood, sera	1683	157	9	46	42	69	0	0	0	0	0	0
Histophilus spp.	Lungs, spleen, and liver samples	184	184	100	0	0	184	0	0	0	0	0	0
Brucella spp.	Blood, milk, aborted foetus, vs., hygroma fluid, Sera	47228	6397	14	640	524	4104	29	17	57	10	376	640
Anaplasma spp.	Blood	8553	1962	23	34	105	1810	0	0	13	0	0	0
Total		68252	9851	13.20	833	730	7038	39	75	70	33	380	653

*RTSR: Ready to slaughter ruminants; RWAH: Ruminants with abortive history; HF: hygroma fluid; no: number..

Table 5: The pooled prevalence of viral, protozoal, and fungal pathogens from cattle, sheep, and goats of different statuses.

Pathogens detected	Samples	No. of samples	Positive samples no.	Prevalence (%)	Animal status (no.)*								
					RTSR (no.)			Sick/diseased animal (no.)			RWAH (no.)		
					Goat	Sheep	Cattle	Goat	Sheep	Cattle	Goat	Sheep	Cattle
Peste des petits ruminants virus	Lungs, lymph, ocular, sera, large intestine, liver	38796	10602	27	1236	982	32	7180	1172	0	0	0	0
Blue tongue virus	Blood, sera	1262	492	39	26	265	201	0	0	0	0	0	0
Schmallenberg virus	Serum	120	35	29	0	0	35	0	0	0	0	0	0
Bovine viral diarrhea virus	Sera	705	405	57	40	44	321	0	0	0	0	0	0
Total viral agents		**40883**	**11534**	**28.2**	**1302**	**1291**	**589**	**7180**	**1172**	**0**	**0**	**0**	**0**
Toxoplasma spp.	Blood, serum	2597	379	15	22	30	327	0	0	0	0	0	0
Neospora spp.	Blood, sera	234	24	10	0	0	24	0	0	0	0	0	0
Total Hemoprotozoan		**2831**	**403**	**14.24**	**22**	**30**	**348**	**0**	**0**	**0**	**0**	**0**	**0**
Aspergillus spp.	Blood, sera	167	46	27.54	0	0	0	38	0	0	9	0	0
Candida albicans	Blood, sera	167	1	0.59	0	0	0	38	0	0	9	0	0
Total fungi		**167**	**47**	**28.1**	**0**	**0**	**0**	**38**	**0**	**0**	**9**	**0**	**0**

*RTSR: Ready to slaughter ruminants; RWAH: Ruminants with abortive history; HF: Hygroma fluid; no: number.

for *Campylobacter* spp., 23.3% for *Anaplasma*, 9% for *C. burnetii*, 3.8% for *Chlamydia* spp. and 3.2% for *Listeria* spp. was recorded. Notably, *C. burnetii* and *Neospora* spp. were only reported in RTSR by four and two publications, respectively. These findings imply the risk of zoonotic transmission, posing a significant threat to public health. Of the total prevalence of *Anaplasma* (23.3%) recorded, 23.08% prevalence was found in RTSR cattle, 13.3% in RTSR goats, 7.68% in RTSR sheep, and 18.57% in SR cattle with no record on RWAH.

Six *Anaplasma* spp. were reported, i.e., *A. marginale*, mostly (85%) reported, *A. centrale*, *A. ovis*, *A. platys*, and *A. bigemina*. It should be noted that only *A. marginale* and *A. centrale* were reported in the SR cattle (Osue et al., 2022). The most common detection methods reported include the microscopic hematocrits method used by 22/30 articles, followed by PCR in 7/30 articles, and the cultural method considered by 2/30 articles (Pam et al., 2013; Okwelum et al., 2021). *A. marginale* is widely distributed in Nigeria, covering 14/36 states within 5/6 geo-political zones (Figure 3).

The protozoan *A. marginale* is the cause of anaplasmosis, a contagious, hemolytic, and transmissible disease of cattle, sheep, and goats (Underwood et al., 2015). The genus *Anaplasma* belongs to the family *Anaplasmatacae* within the phylum *Rickettsiales* (Underwood et al., 2015). *A. ovis* and *A. centrale* were equally implicated in anaplasmosis in Nigeria. Anaplasmosis has been reported to be endemic in North African and Middle Eastern countries and represents a threat not only to the economies of these countries but also to public health (Parvizi et al., 2020). Studies conducted in other countries with a high prevalence of anaplasmosis have reported similar findings. For example, in Northern Pakistan, *Anaplasma* spp. was found in 21.7% of ruminants (Niaz et al., 2021), and a prevalence of 27.27% of *A. marginale*, *A. ovis*, and *A. centrale* was reported in Khartoum State, Sudan (Eisawi et al., 2020).

The prevalence of *C. burnetii*, another abortifacient bacterial pathogen investigated, was found to be 9%, which is higher than the 6.1% prevalence recorded in Bangladesh (Chakrabartty et al., 2016) and the 4.0% prevalence reported in Senegal (Magadu and Thompson, 2023). This study demonstrates unequivocally that ruminants are a substantial source of *C. burnetii* and present a serious threat to public health by spreading the disease to people in places where they are raised. Interestingly, histophillosis was reported in diseased ruminants with a 100% prevalence rate. Anorexia, coughing, nasal discharge, dyspnea, diarrhea, neck distension, lethargy, lameness of the limbs, recumbency, ocular discharge, and death (50% case-fatality) were

Table 6: Risk factors associated with abortive pathogens.

Pathogens	Animal	Climate	Gender	Age	Breed	HS	Source	Abortion/ other rep. dis.	VH	Vector	Risk factors *p-value*	Reference
Anaplasma spp.	Cattle	M-S (rainy)	M	Adult	NIB	-	-	-	-	Tick	<0.05	Pukuma et al. (2011)
Leptospira interrogans	Cattle	-	F	Adult	NIB	-	-	-	-	-	<0.05	Stephen et al. (2022)
L. interrogans	Goat	-	-	< 2	-	-	-	-	-	-	<0.05	Junaidu et al. (2011)
L. interrogans	Cattle	-	-	-	Exotic	-	-	-	-	-	<0.05	Ngbede et al. (2013)
L. interrogans	Cattle, sheep, and goat	M-S (rainy)	-	-	-	-	-	-	-	-	<0.05	Eniolorunda et al. (2008)
BVDV	Cattle	M-S (rainy)	M-F	-	-	-	-	-	-	-	<0.05	Sanusi et al. (2016)
PPRV	Goat	HWS (Dry)	F	Adult	WAD	OG, PS	-	-	WTVH	-	<0.05	Victor et al. (2017)
PPRV	Sheep	HWS (Dry)	F	Adult	Yankasa	OG, PS	-	-	WTVH	-	<0.05	Victor et al. (2017)
Coxiella burnetii	Cattle	-	-	-	SG, CB	-	OM	-	-	-	<0.05	Cadmus et al. (2020)
Toxoplasma gondii	Sheep	Rainy	-	Adult	-	Semi-intensive	-	-	-	-	<0.05	Kamani et al. (2010a)
Toxoplasma gondii	Goat	Rainy	-	Adult	-	Semi-intensive	-	-	-	-	<0.05	Kamani et al. (2010a)
Brucella spp.	Cattle	-	-	-	-	PS	OM	Yes	-	-	<0.05	Ibrahim et al. (2020)
Brucella spp.	Cattle	Dry	F	Adult	SG	-	-	-	-	-	<0.05	Salihu et al. (2009)

*Key. M: male, F: female, M-S (Rainy): May-September (Rainy), HWS: high wind speed in dry season, NIB: non-indigenous breeds, BVDV: bovine viral diarrhea virus, PPRV: peste des petits ruminants virus, SG: Sokoto Gudani, CB: crossbreed, WAD: West African Dwarf, OM: open market, OG: open grazing, PS: pastoral system, WTVH: without vaccination history. The *p-value* was estimated from the combination of two or more risk factors, Seasons: in tropical regions have only two seasons; rainy and dry, based on rainfall. This differs from temperate regions, where all four seasons are determined by temperature differences.

among the clinical symptoms reported on histophillosis (Odugbo et al., 2009). Similar studies have also been reported from the USA, Canada, Japan, New Zealand, Argentina, Scandinavia, Australia, and Eastern and Western Europe (Siddaramppa and Inzana, 2004).

H. somni is still an emerging disease in Nigeria and Africa. The detection of *H. somni* in Nigerian cattle herds is problematic because, except for *H. influenzae*, this organism is unmatched in the family *Pasteurellaceae* for its versatility as a commensal organism and for the wide range of clinical manifestations that can result from septicemia. Without mentioning the digestive system, *H. somni* infections of numerous bovine organ systems have been documented in all sexes, ages, and feedlots or dairy products in other countries of the world (Siddaramppa and Inzana, 2004).

Notably, both *Listeria* and *Brucella* were the only bacterial abortifacient pathogens reported in the three groups of ruminant animal status. For instance, five publications reported listeriosis, with two from RTSR, two from SR, and one from RWAH. However, of the 53 articles that reported *Brucella* spp., 44 were on RTSR, four on SR, and five on RWAH. Of the 3.2% *Listeria* spp. prevalence recorded, 44.6% was found in RTSR cattle, 0.5% in SR goats, 3.3% in SR sheep, 1.4% in RWAH goats, and 4.2% in RWAH sheep. *Listeria* spp. such as *L. innocua*, *L. ivanovii*, *L. monocytogenes*, *L. welshimeri*, and *L. seeligeri* were identified mainly by cultural methods. The overall *Listeria* spp. prevalence (3.2%) is lower than that of 9.5% (19/200) reported in Zambia (Mpundu et al., 2022).

Based on the findings of Dereje et al. (2018), listeriosis can present in three primary clinical forms: meningoencephalitis, abortion, and septicemia. Most clinical cases are associated with infection caused by *L. monocytogenes* and *L. ivanovii* (Radostits and Done, 2007). Experimental studies have demonstrated that within 24 hours of the onset of bacteremia, *L. monocytogenes* invades the reproductive organs and fetus following ingestion or injection into the bloodstream (Dereje et al., 2018). Abortion results within 5–10 days (Radostits and Done, 2007). Abortions and *Listeria* infections typically appear in tropical countries in the late winter, early spring, or rainy season (Radostits and Done, 2007). The last trimester of pregnancy is when abortions are most frequently noticed, and when all animals of the herd consume the same batch of tainted silage at the same time, abortion storms might happen (Yaeger, 2007). However, the prevalence of listeriosis in Nigeria in ruminant animals is sparsely reported. Thus, surveillance is necessary for making informed decisions and policies for diagnostics, therapeutics, prevention, and control.

In this study, 14% *Brucella* spp. prevalence was recorded, 11.3% prevalence was found in RTSR cattle, 7.2% in RTSR goats, 8.6% in RTSR sheep, 4.6% in SR cattle, 6.13% in SR goats, 4.4% in SR sheep, 16.7% in RWAH sheep, and 7.7% in RWAH. Notably, a 2.0% (35/2152) mortality/stillbirth rate was estimated. Interestingly, of the 53 articles on *Brucella* spp., 44, 4, and 5 articles were published on RTSR, SR, and RWAH, respectively. The species of *Brucella* identified include *B. abortus*, most often reported, and *B. melitensis*. These species were mostly detected by five methods: RBPT, PCR, culture, c-ELISA, and SAT/SAT-EDTA tests. Specifically, 80% of the literature reviewed on brucellosis used the RBPT method, 45% c-ELISA, 40% SAT/SAT-ELISA, 1% PCR (Yusuf and Abdulrasheed, 2019), and 3% isolation through the conventional method (Bale et al., 2003; Ocholi et al., 2004, 2005; Onoja et al., 2008).

Various studies on animal brucellosis with different prevalence rates have been published worldwide. For example, in Jordan, a prevalence of 6.5% was reported in cattle (Al-Majali et al., 2009), while in Southwestern Ethiopia, the prevalence was found to be 3.1% in cattle (Ibrahim et al., 2010). In Punjab, India, a prevalence of 18.6% was observed in cattle (Aulakh et al., 2008). In Bangladesh, the prevalence rates were 2.66% in cattle, 3.15% in goats, and 2.31% in sheep (Rahman et al., 2011). The high prevalence and coverage in 19/36 states within the six geopolitical zones indicate the high endemicity of animal brucellosis that may be associated with the lack of vaccination in Nigeria and other associated risk factors (Akinyemi et al., 2022).

Animal brucellosis is a major threat to food security. In Nigeria, neither the Federal nor State Ministries of Health pay

brucellosis the attention needed, even though the World Health Organization (WHO) now lists it as one of the top neglected zoonoses (Akinyemi et al., 2022). Infertility, late abortion, retained foetal membranes, and decreased productivity are the main reproductive symptoms of brucellosis in livestock (El-Diasty et al., 2021). Numerous species of animals are susceptible to brucellosis, but particularly susceptible are cattle, sheep, goats, and pigs due to the preferential infection of *Brucella* strains of certain animal species (El-Diasty et al., 2021). The disease is still widely spread in Africa, especially in regions with significant animal populations (McDermott and Arimi, 2002). Usually, brucellosis screenings are not conducted on livestock slaughtered for human consumption at Nigeria's several abattoirs, resulting in underreporting of brucellosis incidence in Nigeria (Akinyemi et al., 2022).

Leptospira interrogans serovar and *Campylobacter* spp. are significant bacterial abortive pathogens reported only in RTSR and RWAH animal statuses. An overall 27% prevalence of *Leptospira* was recorded in this study. Of this, 1.6% prevalence was recorded in RWAH goats, 0.8% in RWAH cattle, 15.5% in RTSR goats, 7.1% in RTSR sheep, and 30.3% in RTSR cattle. *L. interrogans* serovars detected included the following serovars: *hardjo*, *interrogans*, *pomona*, and *icterohaemorrhagiae*. They were diagnosed by IgG/IgM-ELISA, culture, and MAT. Most of the time, a diagnosis depends on identifying antibodies from the diseased animal. Globally, sheep, goats, and cow herds are infected with *Leptospira* serovar *hardjo*.

Like in Nigeria, significant seroprevalence has been reported in cattle (37%) and goats (29%) in India (Vijayachari P et al., 2014). Another study conducted in India using ELISA revealed a lower seroprevalence of 9.11% *Leptospira* serovar *hardjo* in cattle (Pandian et al., 2015). In Iran, a microscopic agglutination test revealed a prevalence of 4.3% in cattle (Haji Hajikolaei et al., 2007). Despite being native to Africa, leptospirosis epidemiology is poorly understood in sub-Saharan Africa (de Vries et al., 2014). In this study, *Leptospira interrogans* serovar was reported by nine reviewed articles in 16.67% (6/36) states of Nigeria, including Sokoto (NW), Kaduna (NW), Rivers state (SS), Borno (NE), Oyo (SW) and Ogun state (SW), on eight animals of RTSR and one of RWAH status (Stephen et al., 2022). This indicates that leptospirosis is an emerging and rapidly spreading disease in Nigeria. Leptospirosis has become recognized as an emerging zoonosis due to the rising incidence of cases worldwide (Vijayachari et al., 2008).

The prevalence of leptospirosis has been reported to significantly reduce reproductive effectiveness, decrease milk production, cause miscarriage, early neonatal death and stillbirth, and retention of feotal membranes in cattle and other ruminants, which result in significant financial losses for the livestock industry (Faine et al., 1999; Walker, 2005; Abiayi et al., 2015). Due to the African free trade policy, numerous animals are currently imported from diverse sources without being tested for leptospirosis. As a result, several pathogenic *Leptospira* serovars are frequently introduced to supplement existing ones (Stephen et al., 2022). Herd abortion and other symptoms of leptospirosis are poorly understood in Nigeria but are typically linked to illnesses such as brucellosis, campylobacteriosis, and listeriosis (Ajayi et al., 2021). In cases where the reason is not immediately apparent, viral agents are frequently blamed. Clinical indications of leptospirosis in ruminants are commonly missed because leptospirosis-causing bacteria are frequently challenging to isolate from diseased animals (Jubril et al., 2011).

The overall prevalence of *Campylobacter* spp. was 13.0% in this study; of this, 19.9% was estimated in RTSR cattle, 3.5% in RTSR sheep (Salihu et al., 2009; Mai et al., 2013), and 13.0% in RWAH cattle (Mshelia et al., 2012), covering only five of the 36 states in Nigeria, all within the northern Nigeria region including Lake Chad basin (NE), Sokoto (NW), Kano (NW), Kaduna (NW) and Adamawa (NE). Interestingly, a high prevalence of *Campylobacter* spp. was reported in both RTSR and RWAH cattle. The detection of campylobacteriosis within two of the northern regions only connotes the endemic nature of this pathogen in the region with the tendency to spread across other regions of the country due to the trans-regional mobility of the nomadic pastoralists in Nigeria.

Various *Campylobacter* species, namely *C. fetus*, *C. coli*, *C. jejuni*, *C. laridis*, and *C. lari*, were identified through cultural methods by the studies investigated in this review (Salihu et al., 2009; Mshelia et al., 2012; Mai et al., 2013). This highlighted the significant burden of campylobacteriosis in the country and the subsequent economic losses associated with it. Similarly, 31.1% of *Campylobacter* spp. prevalence was reported from RTSR bovine in Finland (Hakkinen et al., 2007), 51.2% in the US (Englen et al., 2007), and 16.5% in France (Chatre et al., 2010). The detection of *Leptospira interrogans* serovar and *Campylobacter* species in RTSR and RWAH poses a public health threat and is connected with significant economic loss to livestock production (Ezeh et al., 1987; El-Yuguda et al., 2013).

Interestingly, Chlamydia species with an overall prevalence of 3.8% were reported only from one state (Taraba state) (Abubakar, 2015) in North-Eastern Nigeria. It should be noted that it was the only eligible article that conducted a study on RWAH doe and ewe aborted fetuses. Of the overall prevalence, 2.6% were reported in RWAH ewes, and 4.1% in RWAH does. Abubakar (2015) was the first in-depth investigation into *Chlamydophila abortus* infection in small ruminants on a larger scale in Nigeria. *Chlamydia* was first discovered when an outbreak of sheep abortions at a research farm in Vom, Plateau State, was reported by Okoh (Okoh, 1986). Later, lambs and goats in the city of Maiduguri were shown to have antibodies against *Chlamydophila abortus*, with seroprevalences of 3.3% in sheep and 3.6% in goats (Amin and Silsmore, 1993). Several studies conducted in different countries have reported varying prevalence rates of *Chlamydophila abortus*.

For example, in Turkey, a seroprevalence of 5.38% was documented in sheep (Otlu et al., 2007), while in Saudi Arabia, the rates were 7.52% in sheep and 34.50% in goats (Aljumaah, 2012). In Brazil, the prevalence in goats was reported as 50.0% (Santos et al., 2012), and in Lithuania, it was 54.5% in sheep (Bagdonas et al., 2007). In Jordan, prevalence rates of 21.8% in sheep and 11.4% in goats were recorded (Al-Qudah et al., 2004), while in Mexico, the prevalence was 31.1% in healthy sheep and 21.3% in sheep with a history of clinical abortion (Jiménez-Estrada et al., 2008). Comparatively, the prevalence in Nigeria was somewhat similar to the rate of 2.88% reported by Zhao (2012) in China.

The low prevalence of *Chlamydophila abortus* in Nigeria might be due to the extensive husbandry system of small ruminant production, which is also the most popular practice in northern parts of Nigeria. Furthermore, the lack of data from other regions in Nigeria might be connected to missing research interest. It is known that intensively maintained flocks experience more chlamydial abortions than flocks managed via extensive management systems (Longbottom and Coulter, 2003; Maley et al., 2009; Stuen and Longbottom, 2011). Due to frequent usage of the same lambing/kidding field or pen, whether outdoors or inside, intensive management increases the likelihood of severe environmental contamination by infectious chlamydial elementary bodies. A key factor in the disease's spread is subjecting vulnerable females to such intense illness (Longbottom and Coulter, 2003; Maley et al., 2009; Stuen and Longbottom, 2011). It should be noted that none of the bacterial abortive pathogens have been studied using known molecular epidemiological surveillance tools for possible diagnostic, therapeutic, and prophylactic interventions in this reviewed study.

Hemoprotozoal abortifacient diseases in Nigeria

19.8% of protozoans' abortive prevalence was calculated from data from 8 articles. Of this, 10% of *Neospora* spp. and 14.59% of *T. gondii* prevalence was estimated from 3 and 5 publications, respectively. The prevalence of 10% *Neospora* spp. found in this study is generally lower than that recorded for Iran (32%) (Youssefi et al., 2009), Western Romania (27.7%) (Imre et al., 2012), and Senegal (17.9%) (Kamga-Waladjo et al., 2010). Notably, the prevalence of *N. caninum* in 10% of the herds indicates that neosporosis is endemic in Nigeria and that farmers must be educated. A key strategy for controlling neosporosis is to stop dogs (the definitive host) from contaminating pastures and feeding with waste (Hernandez et al., 2001; Dubey and Schares, 2011).

Interestingly, the 14.59% *T. gondii* prevalence was only recorded from RTSR by five articles (Joshua and Akinwumi,

2003; Kamani et al., 2010a; Onyiche and Ademola, 2015; Ayinmode and Abiola, 2016; Ayinmode et al., 2017). Of this, 14.21% prevalence was estimated in RTSR cattle and 2.55% in RTSR sheep. It threatens the consumer of undercooked, fresh meat and abattoirs (Dubey et al., 2020). Although toxoplasmosis was only recorded in 2/36 states in Nigeria [Oyo state (SW) and Borno state (NE)], there is a possibility of the widespread to other states (Dubey et al., 2020). A lower prevalence of 11.8% (64/541) was recorded in Spain (Mainar et al., 1996). However, a high prevalence of 41.7% in goats and 59.3% in sheep of *T. gondii* were detected in Northern Italy (Giannouli et al., 2010).

Other European countries, including the Netherlands, Portugal, France, Switzerland, Romania, Greece, and Spain, also reported high seroprevalence rates with large differences in *T. gondii* prevalence ranging from 18.5% to 52.8% in goats and from 27.8% to 89% observed in sheep. This disparity in prevalence may be connected to study locations, animal race, husbandry system, and detection methods (Gazzonis et al., 2015).

Mycotic abortifacient diseases in Nigeria

In this study, an overall 28.74% prevalence of abortive mycotic disease was found in SR goats and RWAH goats in Ogun state (SW) and Sokoto state (NW) (Biobaku et al., 2016). However, a lower prevalence of 11.7% was reported in Tanzania (Karimuribo et al., 2006). For clinical mastitis of goats in Nigeria prevalence ranging from 5.7% to 10.7% was recorded (Ameh et al., 1993; Ameh and Tari, 1999; Danmallam et al., 2018; Danmallam and Pimenov, 2019). It should be noted that aspergillosis is one of the most (27.54%) reported abortive diseases in ruminants, particularly in pregnant animals, resulting in significant economic and public health complications (Pal, 2015). Aspergillosis in the tropics might be connected to the indiscriminate feeding habits of ruminants. Therefore, it is suggested that animals raised in the tropics, particularly those in Sub-Saharan Africa, should be closely tended to or managed intensively to prevent mycotoxicosis. The best diet for ruminants is dry, high-quality feed that is not contaminated with moisture, thereby reducing the prevalence of mold development and feed contamination (Pal, 2015).

Risk factors contributing to abortion in Nigeria

Eight significant risk factors were reported to be connected to abortive pathogens in ruminants in this study (Table 6). The most often cited risk factors were age, season, and breed. Ruminants are more prone to contracting *Leptospira*, *Toxoplasma*, and *Anaplasma* species during the rainy season between April and October in Nigeria (Eniolorunda et al., 2008; Kamani et al., 2010a; Pukuma et al., 2011). Ruminants are allegedly more vulnerable to PPRV and *Brucella* species during the dry season between November and March in Nigeria as a result of the high wind speeds associated with this period (Salihu et al., 2009; Victor et al., 2017). The most often cited risk factors for *Brucella*, *Toxoplasma*, PPRV, and BVDV are open grazing, pastoral systems, and semi-intensive husbandry (Kamani et al., 2010a; Sanusi et al., 2016; Victor et al., 2017; Ibrahim et al., 2020).

Non-vaccinated ruminants are more vulnerable to PPRV than vaccinated animals (Victor et al., 2017). It should be noted that the source of the animals for purchase, such as the open markets, is another significant risk factor for *Brucella* (Ibrahim et al., 2020), *C. burnetii* (Cadmus et al., 2020), and *Leptospira interrogans* serovars infection (Pukuma et al., 2011). Certain animal breeds, such as West Africa Dwarf (WAD) breeds of goats, Yankasa varieties of sheep, and Sokoto Gudali (SG) breeds of cattle, were more susceptible to contracting PPRV, *C. burnetii*, and *Brucella* species (Salihu et al., 2009; Victor et al., 2017; Cadmus et al., 2020). Sex (Pukuma et al., 2011; Salihu et al., 2009; Sanusi et al., 2016; Victor et al., 2017; Stephen et al., 2022), history of abortion, and other reproductive diseases (Ibrahim et al., 2020) are additional reported risk factors.

Stillbirth, economic and public health implications of abortive pathogens among ruminants

This study, therefore, confirmed the increasing prevalence of pathogens likely to cause abortion in RTSR and RWAH animals that had no vaccination except PPRV. Furthermore, alarming fetal loss is recorded for diseased goats, sheep, and cattle. An overall 58.95% (619/1050) stillbirth and abortion in sick goats, 49.2% (369/782) in sick sheep, and 6.4% (166/2606) in sick cattle are connected to six abortive diseases, i.e., chlamydiosis, aspergillosis, PPRV infection, brucellosis, campylobacteriosis, and histophillosis.

Notably, 79.1% (291/368) stillbirth and abortion in sick goats was reported due to *Chlamydia* infection, 49.7% (319/642) stillbirth and abortion in sick goats due to PPRV infection, 55.63% (95/184) in sick cattle due to histophillosis, 22.5% (9/40) stillbirth and abortion in sick goat due to aspergillosis and candidiasis. A 13.0% (36/270) abortions and stillbirths were recorded in bovine due to *Campylobacter* infection and 2.0% (35/2152) in cattle due to *Brucella* infection. These diseases are associated with significant economic loss. For instance, around 80% of Nigeria's population relies on 34.5 million cattle, 22.1 million sheep, and 13.9 million goats that produce meat, milk, and other products (Lawal-Adebowale, 2012).

The annual value of cattle production in Nigeria exceeds USD 300 million. A beef farmer in the country spends approximately USD 200 for a typical beef cow (Bourn et al., 1994). Hence, over 1 million cattle in Nigeria may be affected by different abortive pathogens with direct costs of over USD 10 million due to abortion and other reproductive complications caused by the seven pathogens implicated in RWAH (Mshelia et al., 2012), as observed in this current study. Also, 12 of the 16 abortive pathogens recorded are zoonotic agents, while the remaining four viral agents are epizootic. Hence, conducting continuous surveillance of these pathogens to ascertain the true burden of these pathogens in veterinary and human medicine and their economic impacts is important.

Conclusion

This study confirmed the high prevalence of 16 abortive pathogens in ruminants in Nigeria, with brucellosis, PPRV, and anaplasmosis being widely distributed in over 18 of the 36 states of Nigeria. Notably, 12 abortive pathogens (Anaplasma, *Leptospira interrogans ser*, *Toxoplasma*, *Listeria*, *C. burnetii*, *Neospora*, *Brucella*, *Campylobacter*, BTV, SBV, BVDV, and PPRV) were recorded from RTSR, 7 (*Listeria*, *Brucella*, *H. somni*, *Aspergillus*, *Candida*, *Anaplasma*, and PPRV) from SR and 7 (*Campylobacter*, *Listeria*, *Chlamydia*, *Leptospira interrogans ser*, *Brucella*, *Aspergillus*, and PPRV) from RWAH.

Specifically, 105, 23, and 12 publications reported abortive pathogens from RTSR, SR, and RWAH, respectively. Several risk factors were identified, such as lack of vaccine for all the abortive pathogens except PPRV, open market systems of procuring animals, husbandry systems, and non-indigenous breeds. All the pathogens except viral abortive agents reported are considered zoonotic public health threats. However, the high prevalence of these pathogens is of great economic significance as they are linked to mortality, stillbirth, infertility, and low productivity of ruminants in Nigeria. Therefore, there is a need for molecular epidemiology, constant surveillance of abortive pathogens, improved husbandry systems, vaccine production, massive administration, and intensive education of pastoralists to improve livestock production in Nigeria.

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