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Sero-epidemiology and Risk Factors Associated with Peste Des Petits Ruminants Virus Infection in Sheep and Goats in Some North-Eastern States of Nigeria

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ABSTRACT

Peste des Petits Ruminants (PPR) is a highly contagious viral disease of sheep and goats that causes substantial economic losses and threatens food security and rural livelihoods in endemic countries such as Nigeria. Reliable epidemiological data are essential for designing effective control strategies and supporting the global PPR eradication program. In this study, seroprevalence and associated risk factors of Peste des Petits Ruminants Virus (PPRV) were investigated in unvaccinated sheep and goats sampled from selected states in North-Eastern Nigeria. A total of 1,647 serum samples were collected from sheep (n=720) and goats (n=927) in Borno, Bauchi and Gombe states in May 2024 - February 2025. The sera were tested for the presence of antibodies against PPR using ID Screen competitive Enzyme-Linked Immunosorbent Assay. The overall seroprevalence to PPR was recorded as 55.3% (n=910/1,647), with state-specific seroprevalence of 63.0% in Borno, 57.7% in Bauchi, and 45.0% in Gombe. A total of 11 potential risk factors were evaluated using a structured questionnaire, of which 10 were found to be significantly associated with PPR seroprevalence ($p \leq 0.05$). Among the sampled LGAs, Jere, located in Borno Central Senatorial District, recorded the highest seroprevalence (66.9%) of PPR, followed by Maiduguri (65.0%) in the same agro-ecology. The lowest seroprevalence was observed in Gombe LGA (31.0%). PPR seroprevalence was higher in animals owned by pastoralists, animals not housed, females, and Yankasa breed of sheep, as well as the West African Dwarf breed of goats. Furthermore, PPR seroprevalence was significantly higher during the dry (Harmattan) season compared with the wet season. The 10 risk factors found to be associated with PPR seroprevalence were further analyzed multivariately by logistic regression, and finally 5 of them (states, localities, husbandry system, sex and age) were found to be associated with PPR seroprevalence ($p \leq 0.05$).

Keywords: North-Eastern Nigeria, PPR, Risk factor, Seroprevalence, Small ruminants

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Data Availability

Data supporting the findings are available from the corresponding author on reasonable request.

Introduction

Peste des Petits Ruminants (PPR) is a highly contagious viral disease of domestic and wild small ruminants caused by the Peste des Petits Ruminants virus (PPRV), a member of the genus *Morbillivirus* within the family *Paramyxoviridae* (Chukwudi et al., 2020). The disease,

which primarily affects sheep and goats, is characterized by fever, erosive stomatitis, ocular and nasal discharges, pneumonia, enteritis, and severe diarrhea (Luka et al., 2011a). Depending on the immune status of affected animals, the virulence of the circulating virus, and management practices, morbidity and mortality may

exceed 90%, making PPR one of the most economically devastating diseases of small ruminants worldwide (Balamurugan *et al.*, 2007; Abde *et al.*, 2017). Small ruminants play a vital role in the livelihoods of millions of households in Nigeria, particularly in rural and semi-arid regions where they provide income, food, employment, and financial security (Luka *et al.*, 2011a). Consequently, outbreaks of PPR result in substantial production losses through high mortality, reduced growth, decreased reproductive performance, lower milk production, increased treatment costs, and restrictions on livestock trade (Baah *et al.*, 2012; Dundon *et al.*, 2014). The disease therefore poses a significant threat to poverty reduction, food security, and sustainable livestock development (Banyard *et al.*, 2010; Lyons *et al.*, 2018). Because PPR poses a major threat to food security and rural livelihoods, the Food and Agriculture Organization of the United Nations (FAO) and the World Organization for Animal Health (WOAH; formerly OIE) launched a coordinated Global Control and Eradication Strategy (GCES) in 2015 with the ambitious objective of eradicating PPR worldwide by 2030 (OIE and FAO, 2015; FAO, 2021).

Nigeria is endemic for PPR and constitutes a key epidemiological focus in West Africa because of its large small-ruminant population, extensive livestock movements (including transhumance and cross-border trade), and the socio-ecological diversity across its regions (Woma *et al.*, 2016a; FAO, 2022). The north-eastern states of Nigeria present particular challenges and priorities for PPR control (Bello *et al.*, 2016). These states host diverse agro-pastoral systems, frequent seasonal movements, and complex market chains that facilitate viral spread. In addition, the Lake Chad Basin, which forms part of Borno state, has a transboundary socio-ecological system linking Nigeria, Niger, Chad and Cameroon and supporting tens of millions of people and large seasonal movements of livestock. Its geography and cross-border flows make it a persistent hotspot for animal disease spread and for any coordinated regional animal-health response (Bello *et al.*, 2016; FAO, 2021). Over the past decade, the Lake Chad region has been seriously affected by insurgency, with serious security challenges (FAO, 2022). The ongoing security challenges constitute a major constraint to the successful control and eradication of peste des petits ruminants (PPR). Inaccessible areas limit surveillance, sampling, and outbreak investigation by veterinary authorities. Routine vaccination campaigns are often disrupted or absent in high-risk LGAs due to safety concerns, creating immunity gaps that sustain viral circulation. Uncoordinated livestock movement, both internal displacement and cross-border transhumance, further facilitates the spread of PPRV across communities and international boundaries (FAO, 2021; Mantip *et al.*, 2021).

Due to these vulnerabilities, information on comprehensive, contemporary sero-epidemiological data and rigorous analysis of associated risk factors at the state and local government levels is insufficient, limiting the ability of national authorities to design cost-effective vaccination strategies and to meet the progressive stages set out in the PPR GCES. Improving the evidence base

in north-eastern Nigeria is therefore crucial both for national control planning and for contributing to the regional pathway towards the 2030 global eradication goal.

Achieving the 2030 global eradication target requires serological evidence to inform risk-based vaccination, evaluate program performance, and document progress along the PPR control pathway (OIE and FAO, 2015). This study therefore fills a gap by providing state-level and intra-state seroprevalence estimates that quantify the magnitude of population susceptibility and the degree of ongoing viral circulation, thereby playing a crucial role in contemporary immunity mapping. This study also fills a gap by revealing spatial variations in immunity between the three states, helping policymakers prioritize high-risk LGAs and production systems for intensified vaccination. Accordingly, this study aimed to determine the seroprevalence of PPR and to evaluate the risk factors associated with PPR infection in sheep and goats across three states in northeastern Nigeria.

Materials and Methods

Description of the Study Area

The study was conducted in Borno, Bauchi, and Gombe states, all geographically located in North Eastern Nigeria and between latitude $11^{\circ} 32'$ and $11^{\circ} 4'$ north and longitude $13^{\circ} 32'$ and $13^{\circ} 25'$ east, and located between the Sudan Savannah and Sahel Savannah vegetation zones. The North-East region of Nigeria, comprising Borno, Yobe, Adamawa, Bauchi, Gombe, and Taraba States, is characterized by vast semi-arid and savannah landscapes, a predominantly rural population, and a strong dependence on livestock production, especially sheep and goats (NSBS, 2011). The region hosts major transhumance routes linking Nigeria with Cameroon, Chad, and Niger, making it a critical hotspot for small ruminant trade and movement, with the Lake Chad serving as a major hub of livestock movement into Nigeria. Livestock rearing is central to household livelihoods, particularly among pastoralist and agro-pastoral communities, where small ruminants serve as a source of income, savings, and protein (DLS, 2017).

Ethical Clearance

Ethical approval for this study was obtained from the Ahmadu Bello University Committee on Animal Use and Care with certificate number: ABUCAU/2025/014

Study population

The study population comprised sheep and goats with no documented history of PPR vaccination, as determined from information provided by animal owners and available veterinary records. Animals were sampled from state veterinary clinics, livestock markets, households, and smallholder small-ruminant farms across Borno, Bauchi, and Gombe states in northeastern Nigeria. One LGA was randomly selected from each of the three senatorial districts in each state using a multistage random sampling approach. Serum samples were collected for serological analysis using the Enzyme-Linked-Immunosorbent-Assay (ELISA). In total, 1,647 serum samples were obtained from sheep and goats across the three study states.

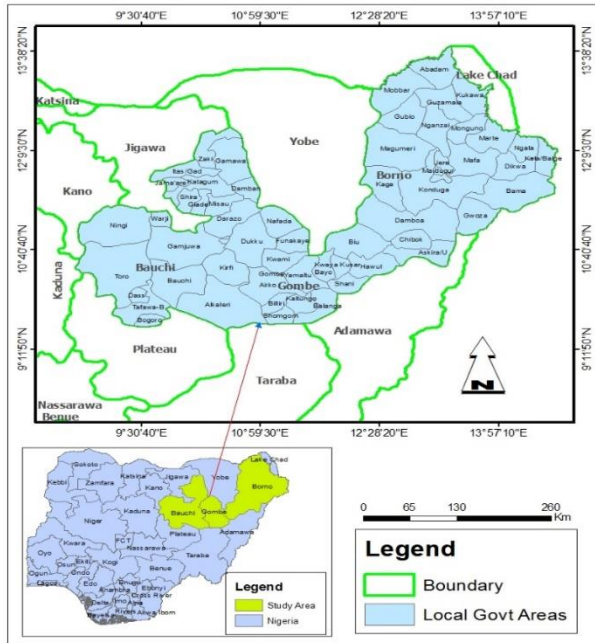


Figure 1: Map of study area showing the selected study locations in Borno, Bauchi and Gombe states, northeastern Nigeria

Source: Generated using ArcGIS 10.1, with geographic data obtained from Department of Geography, Ahmadu Bello University, Zaria.

Study Design

A cross-sectional study design was employed in the study.

Sample Size Estimation.

The sample size for sheep and goats was estimated using the formula described by Thrusfield (2005).

$$N = \frac{Z^2 P (1-p)}{e^2}$$

Where:

N= Sample size, P= prevalence, e = desired absolute precision (5%)

Z = 1.96 (constant)

Prevalence in sheep = 19.4% (Bello *et al.*, 2016)

$$= \frac{1.96^2 \times 0.194 (1-0.194)}{0.05^2} = 240$$

Prevalence for goats = 27.9% (Woma *et al.*, 2016b)

$$= \frac{1.96^2 \times 0.2797 (1-0.2797)}{0.05^2} = 309$$

- A total of **240 sheep** and **309 goat** serum samples were collected from each state.

Sampling Procedure

The study was conducted from the month of May, 2024 to February, 2025. Multistage sampling was carried out, and one LGA per senatorial district in each state was sampled. Sheep and goats presented to the state veterinary clinics, as well as those sourced from livestock markets, households, and smallholder farms from selected locations in Borno, Bauchi, and Gombe States, were sampled for blood and serum harvest, which was used for ELISA. For each sampled animal. Details of the age, sex, species, breed and location were also obtained and recorded appropriately. A questionnaire

was administered which consisted of open- and closed-ended questions to obtain information on risk factors for PPR.

Blood sample collection

Following adequate restraint of each animal by the owner, five (5) mL of whole blood was collected aseptically from the jugular vein of each sampled animal using a 10 mL syringe fitted with a 19G needle and transferred into 5mL sterile plain sample tubes. The tubes were kept away from direct sunlight in a slanting position at room temperature until the blood was clotted. Serum was harvested by centrifugation at 1008g (3000rpm) for 10 minutes using a Kaida KH19A centrifuge, and the serum was transferred into sterile 2mL cryovials, labeled with the animal's age, sex, breed and location. All serum samples were transported in ice boxes to the Biotechnology Laboratory of the National Veterinary Research Institute (NVRI), Vom, where they were stored at -20°C until analysis.

Competitive Enzyme-Linked Immunosorbent Assay(c-ELISA) for Detection of PPR antibodies.

Serum samples were screened for antibodies against peste des petits ruminants virus (PPRV) using a competitive enzyme-linked immunosorbent assay(c-ELISA) as described by Diallo *et al.* (2007), employing the ID screen® PPR Competition ELISA kit (ID vet innovative Diagnostics, France). All reagents were prepared, and the assay was performed according to the manufacturer's instructions.

Briefly, the microtitre plates were coated with diluted PPR antigen and incubated at 37°C for one hour. After washing, blocking buffer and serum samples, together with the appropriate positive and negative monoclonal antibody (MAB) and conjugate controls, were added to designated wells. Following incubation and washing, monoclonal antibody and anti-mouse conjugate were added sequentially, with each incubation step carried out at 37°C for one hour. The plates were washed between incubation steps. The chromagen/substrate solution was subsequently added, and the reaction was allowed to develop for 10 minutes at room temperature before being terminated with the stop solution. Optical density (OD) values were measured at 450nm using an ELISA micro-plate reader.

The percentage inhibition for each sample was calculated using the following formula:

$$PI (\%) = 100 - \frac{\text{Mean OD of the test sample}}{\text{Mean OD of MAb control}} \times 100\%$$

Mean OD of MAb control

Samples with a percentage inhibition (PI) $\geq 50\%$ were considered positive for antibodies against PPRV, whereas samples with $PI < 50\%$ were regarded as negative.

Data analysis

All data generated from field investigations and laboratory analyses were entered into Microsoft Excel and subsequently exported to Stata Statistical Software version 17.0 for statistical analysis. Descriptive statistics were used to summarize the data and estimate the seroprevalence of PPR virus antibodies in the study

population. Seroprevalence was calculated as the proportion of animals that tested positive for PPR antibodies relative to the total number of animals sampled and expressed as a percentage in accordance with the method described (Thrusfield, 2005). Univariate logistic regression was first performed to assess associations between each independent variable and PPRV seropositivity. Variables with $p \leq 0.20$ were entered into a multivariate logistic regression model to identify independent predictors. Odds ratios (OR) with 95% confidence intervals (CI) were reported. All values of $p < 0.05$ were considered significant.

Results

The seroprevalence of antibodies against Peste des Petits Ruminants Virus (PPRV) in sheep and goats from Borno, Bauchi and Gombe States, Nigeria, as determined using the competitive Enzyme-Linked Immunosorbent Assay (c-ELISA), is presented in Table 1. A total of 1,647 serum samples were analyzed, comprising 549 samples from each of the three states. Of these, 910 samples tested positive for PPRV antibodies, resulting in an overall seroprevalence of 55.3%. Among the three states, Borno State recorded the highest seroprevalence at 63.0% (346/549), followed by Bauchi State with 57.7% (317/549), while Gombe State had the lowest seroprevalence at 45.0% (247/549).

Statistical analysis demonstrated a significant variation in the seroprevalence of PPRV antibodies among the three states ($P = 0.0001$), suggesting that the level of PPRV exposure differed significantly across the study areas. The high proportion of seropositive animals detected across the three study states suggests extensive circulation of PPRV and widespread exposure of sheep and goats within the study area. The distribution of PPRV antibody seroprevalence according to sex is presented in Table 2. Female animals exhibited a significantly higher seroprevalence (58.5%) than males (50.2%) ($P=0.001$; $p<0.05$). This finding indicates that female sheep and goats were more frequently exposed to PPRV infection than their male counterparts. Table 3 presents the seroprevalence of Peste des Petits Ruminants Virus antibodies in sheep and goats sampled from Borno, Bauchi and Gombe States, stratified by species. The analysis showed that the seroprevalence was 35.3% in sheep and 70.2% in goats. Goats exhibited a significantly higher seroprevalence of PPRV antibodies than sheep, and the association between animal species and seropositivity was statistically significant ($P<0.05$). These findings suggest that goats were significantly more likely to be seropositive for PPRV antibodies than sheep.

Table 1: Seroprevalence of Peste des Petits Ruminants Virus Antibodies Among sheep and goats Using competitive Enzyme-Linked Immunosorbent Assay in Borno, Bauchi and Gombe states, Nigeria.

State	No. Sampled	No. Positive	Prevalence (%)	p-Value
Borno	549	346	63.0	0.0001*
Bauchi	549	317	57.7	
Gombe	549	247	45.0	
Overall	1,647	910	55.3	

*p-Value is significant at <0.0001 ; 0.05

Table 2: Seroprevalence of Peste des Petits Ruminants Virus in sheep and goats based on sex using competitive Enzyme-Linked Immunosorbent Assay in Borno, Bauchi and Gombe States.

Sex	No. Sampled (N)	No. Positive (n)	Prevalence (%)	p-Value
Male	649	326	50.2	0.001*
Female	998	584	58.5	
Total	1,647	910	55.3	

P-Value is significant at <0.05

Table 3: Seroprevalence of Peste des Petits Ruminants Virus in sheep and goats based on species using competitive Enzyme-Linked Immunosorbent Assay in Borno, Bauchi and Gombe States.

Species	No. Sampled (N)	No. Positive (n)	Prevalence (%)	p-Value
Sheep	720	259	35.3	0.0001*
Goats	927	651	70.2	
Total	1647	910	55.3	

p-Value is significant at <0.05

Assessment of Risk factors Associated with the occurrence of PPR in Borno, Bauchi and Gombe States, Nigeria.

A total of eleven risk factors were assessed using a structured questionnaire administered to small ruminant farmers during the seroprevalence sampling (Table 4). Univariate analysis was performed to evaluate the association between the eleven selected risk factors and the seropositivity of Peste des Petits Ruminants Virus (PPRV) among small ruminants in the study area. The analysis identified significant associations ($p < 0.05$) between PPRV seropositivity and several animal- and management-related factors, including state, locality, husbandry system, housing type, herd composition, species, breed, sex, age, source of animals, and season/climatic conditions.

Across the three states studied, significant variation in seroprevalence was observed ($\chi^2 = 38.17$; $p = 0.0051$). Borno State recorded the highest seroprevalence (63.0%), followed by Bauchi (57.7%), while Gombe had

the lowest prevalence (45.0%). Animals in Gombe were less likely to be seropositive compared with those in Borno (OR = 0.48; 95% CI: 0.38–0.61).

Within-state locality analysis demonstrated varying levels of seropositivity. In Borno State, locality had a significant association with PPRV seropositivity ($\chi^2 = 24.48$; $p = 0.0001$), with Jere and Maiduguri showing relatively higher odds of infection compared to Bayo. In Bauchi State, locality did not significantly influence seropositivity ($\chi^2 = 5.42$; $p = 0.066$), whereas in Gombe State, animals from Gombe locality exhibited lower odds compared with Akko.

Husbandry system significantly influenced seropositivity ($\chi^2 = 113.9$; $p < 0.0001$).

Animals reared under pastoral/nomadic production systems exhibited the highest seroprevalence (68.1%) and were 3 times more likely to be seropositive than those managed under intensive production systems (OR = 3.45; 95% CI: 2.58–4.61). In contrast, animals raised under semi-intensive management had a moderate seroprevalence (42.5%).

Housing conditions were significantly associated with PPRV seropositivity ($\chi^2 = 46.3$; $p < 0.0001$). Animals without housing facilities had significantly higher odds of infection (OR = 2.24; 95% CI: 1.71–2.94), while those housed in brick structures also exhibited an increased risk compared with animals kept in mud housing.

Herd composition was significantly associated with PPRV seropositivity ($\chi^2 = 14.9$; $p = 0.0006$). Mixed flocks comprising both sheep and goats had significantly greater odds of PPRV infection (OR = 1.64; 95% CI: 1.27–2.11) than flocks consisting exclusively of sheep.

Species was significantly associated with PPRV seropositivity ($\chi^2 = 174.9$; $p < 0.0001$). Goats exhibited a significantly higher seroprevalence (70.2%) than sheep (35.3%) and had approximately fourfold greater odds of being seropositive (OR = 4.32; 95% CI: 3.52–5.30).

Breed was also significantly associated with PPRV seropositivity. Among goat breeds, West African Dwarf (WAD) goats recorded the highest seroprevalence (85.4%) and were approximately three times more likely to be seropositive than Red Sokoto goats (OR = 3.01; 95% CI: 1.78–5.09). Among sheep breeds, Yankasa sheep had the highest seroprevalence (53.8%), whereas Balami and Uda breeds exhibited significantly lower odds of PPRV seropositivity. Sex significantly affected seropositivity ($\chi^2 = 98.77$; $p = 0.0001$), with females (58.5%) demonstrating higher odds of infection compared with males (OR = 1.39; 95% CI: 1.14–1.69). Age also showed a significant association ($\chi^2 = 10.53$; $p = 0.0052$), with animals aged 1–2 years showing increased odds of seropositivity (OR = 1.40; 95% CI: 1.12–1.74) compared with animals less than one year old.

Source of animals significantly affected seropositivity ($\chi^2 = 188.62$; $p = 0.0001$). Animals obtained from open markets exhibited the highest prevalence (68.4%) and were more than four times more likely to be seropositive (OR = 4.52; 95% CI: 3.35–6.10) compared with animals obtained as gifts.

Season/climate was significantly associated with PPRV seropositivity ($\chi^2 = 156.89$; $p = 0.0001$), with dry/harmattan season showing significantly higher prevalence (64.1%) than wet/rainfall season (33.3%). Animals sampled during the dry season were approximately 3.58 times more likely to be seropositive (OR = 3.58; 95% CI: 2.93–4.38).

The significant 10 factors found from univariate analysis were further subjected to multivariate analysis using a Logistic Regression model, and finally 5 risk factors were found to be associated with PPR seroprevalence (Table 5). Significant associations were observed for state, locality, husbandry system, sex, and age ($p < 0.05$).

Table 4: Univariate analysis for risk factors associated with PPR seropositivity (with OR and 95% CI)

	Risk factor	No. tested	No. positive	Sero prevalence %	χ^2	Df	p-value	OR	95% CI
State					38.17	2	0.0051*		
	Borno	549	346	63.0				1.00	-
	Bauchi	549	317	57.7				0.80	0.63-1.02
	Gombe	549	247	45.0				0.48	0.38-0.61
Locality					24.478	2	0.0001*		
	Bayo	183	105	57.4				1.00	-
Borno	Jere	166	111	66.9				1.50	0.97-2.32
	Maiduguri	200	130	65.0				1.38	0.91-2.09
					5.423	2	0.066		
	Bauchi	200	106	53.0				1.00	-
Bauchi	Katagum	194	110	56.7				1.16	0.78-1.73
	Ningi	155	101	65.2				1.66	1.07-2.58
	Akko	174	93	53.4				1.00	-
Gombe	Gombe	197	61	30.9				0.39	0.25-0.60
	Kaltungo	178	93	52.2				0.95	0.63-1.45
Husbandry system					113.9	2	<0.0001*		
Semi-intensive		400	170	42.5				1.19	0.86-1.64

Pastoral (Nomadic)	998	680	68.1				3.45	2.58–4.61
Intensive	249	95	38.2				1.00	-
Housing				46.3	4	<0.0001*		
No house	870	438	50.3				2.24	1.71–2.94
Building of bricks	350	166	47.4				2.00	1.46–2.73
Mud	300	93	31.0				1.00	-
Shrub fence	98	46	46.9				1.97	1.25–3.10
Wood & scrap	49	19	38.8				1.41	0.77–2.57
Herd Composition				14.9	2	0.0006*		
Sheep & goats	920	449	48.8				1.64	1.27–2.11
Sheep	327	120	36.7				1.00	-
Goats	400	181	45.3				1.43	1.06–1.92
Species				174.9	1	<0.0001*		
Sheep	720	259	35.3				1.00	-
Goats	927	651	70.2				4.32	3.52–5.30
Breed				19.7	2	<0.0001*		
Red Sokoto	480	317	66.0				1.00	-
WAD	137	117	85.4				3.01	1.78–5.09
Sahel	310	217	70.0				1.20	0.86–1.67
Breed				80.4	2	<0.0001*		
Yankasa	320	172	53.8				1.00	-
Balami	150	37	24.7				0.28	0.19–0.42
Uda	250	50	20.0				0.21	0.15–0.31
Sex				98.77	1	0.0001*		
Female	998	584	58.5				1.39	1.14–1.69
Male	649	326	50.2				1.00	-
Age (years)				10.53	2	0.0052*		
<1	512	227	44.3				1.00	-
1-2	825	435	52.7				1.40	1.12–1.74
Above 2	310	141	45.5				1.05	0.79–1.39
Source of animal				188.62	2	0.0001*		
Open market	850	581	68.4				4.52	3.35–6.10
Farm owners (breeding)	550	195	35.5				1.15	0.84–1.57
Gifts	247	80	32.4				1.00	-
Season/climate				156.89	1	0.0001*		
Dry/harmattan	847	543	64.1				3.58	2.93–4.38
Wet/rainfall	800	266	33.3				1.00	-

Table 5: Multivariate Logistic Regression analysis of associated risk factors and PPR seropositivity in sheep and goats in Borno, Bauchi and Gombe States.

Risk Factor	Seroprevalence (%)	OR	95% CI	p-value
States				
Borno	63.0	1.77	1.32-2.37	0.0001*
Bauchi	57.7	1.42	1.06-1.90	
Gombe	45.0		1	
Localities				
Bayo	57.4	2.07	1.32-3.25	0.0001*
Jere	66.9	3.82	2.32-6.28	
Maiduguri	65.0	3.52	2.19-5.65	
Bauchi	53.0	1.47	0.94-2.30	
Katagum	56.7	2.02	1.29-3.17	

Ningi	65.2	3.54	2.14-5.87	
Akko	53.4	1.49	0.95-2.34	
Gombe	30.9	1	1	
Kaltungo	52.2	1.39	0.88-2.18	
Husbandry system				
Semi intensive	42.5	1.02	0.75-1.39	0.0001*
Pastoral (Nomadic)	68.1	2.94	2.17-3.99	
Intensive	38.2	1	1	
Sex				
Female	54.5	2.42	1.95-3.01	0.0001*
Male	29.6	1		
Age(years)				
<1	44.3	1		
1-2	52.7	1.19	0.92-1.53	0.0052
>2	45.5	0.89	0.66-1.20	

* $p \leq 0.05$ was considered as significant; C.I.= confidence interval; OR = odds ratio

Discussion

Serological surveillance and evaluation of risk factors play a critical role in the effective control and eradication of PPR in endemic settings, particularly in developing countries like Nigeria, where the disease is endemic, and also to contribute towards the global eradication program by 2030. Several factors have been demonstrated to contribute to the transmission and spread of PPR (Huyam *et al.*, 2014), however, with an overall seroprevalence of 55.3%, our study showed that PPR is endemic in the security-challenged Northeastern region of Nigeria. Although our finding was lower compared to some other previous studies; for example, 61.6% by Bello *et al.* (2016), 61.8 % by Abdalla *et al.* (2012), 62.8% by Saeed *et al.* (2010), and 70.2% by Shuaib (2011). Nevertheless, this variation might be due to the wide coverage of vaccination against PPR in the previous years in the study area; however, this calls into question the validity and effectiveness of the exercise. It is possible that the animals vaccinated found their way to the market, leading to slaughter. The PPR prevalence was found to be significantly higher in Borno (63.0%), followed by Bauchi (57.7%). In contrast, Gombe State recorded the lowest PPRV seroprevalence (45.0%) among the three study states in Northeastern Nigeria.

The higher prevalence of PPR observed in Borno and Bauchi states may be attributed to the frequent movement of small ruminants between the two states, which serves as a livestock trade route; it may also be attributable to shared ecological and climatic characteristics between the two states, particularly the prolonged dry season and prevailing dusty winds. These environmental conditions may facilitate the transmission and persistence of PPRV. Previous studies have reported that harsh climatic conditions, including dry weather and strong winds, play a significant role in the epidemiology and spread of PPR (Bello *et al.*, 2018).

Borno State is strategically located in the northeast, bordering three different countries: Chad, Niger, and Cameroon, acting as a corridor for animal trade from these countries as well as the influx of nomadic small ruminants across international borders from the three

neighboring countries into the state through Lake Chad, which may contribute to the persistence and transmission of PPRV. The state has also experienced significant insecurity; as a result, conflict-related disruption may reduce veterinary outreach, vaccination campaigns, and disease control infrastructure, resulting in more uncontrolled PPR transmission. In such conflict zones, pastoralists may move animals more frequently, possibly mixing with other flocks and increasing transmission risk.

On the other hand, based on locality, the highest prevalence of PPR was found in Jere LGA (66.9%) in Borno State, followed by Ningi LGA in Bauchi State (65.2%). From these findings, it can be speculated that the prevalence of PPR varied significantly among the states as well as within a state in the northeast due to the geographical difference; these findings agreed with the results reported by Obidike *et al.* (2006) and Bello *et al.* (2016). However, the observation reported by Inusa *et al.* (2021) differed from our findings, in which they reported that geographical location is less significant in PPR seroprevalence, especially when the range is not extensive.

Consistent with the findings of Ozkul *et al.* (2011) and Bello *et al.* (2018), the present study demonstrated a significant association between age and the seroprevalence of PPR antibodies among sheep and goats ($P < 0.05$). Animals aged 1-2 years exhibited the highest seroprevalence (52.7%), followed by those younger than one year (44.3%), whereas the lowest seroprevalence was recorded among animals older than two years. This finding contrasts with the report of Abubakar *et al.* (2008) who observed that PPR seroprevalence increased with advancing age. The relatively lower seroprevalence observed in animals less than one year of age may be attributed to the passive transfer of maternal antibodies from previously infected dams to their offspring (Parida *et al.*, 2015; Albina *et al.*, 2013). Although maternally derived antibodies gradually decline over time, they generally remain above the protective threshold for approximately 3 to 4 months (Kihu *et al.*, 2015). Following the waning of maternal immunity, young animals become increasingly susceptible to PPR virus infection, which may explain the higher seroprevalence observed in animals aged 1-2

years.

Our findings demonstrated that female sheep and goats had a significantly higher seroprevalence of PPRV antibodies than males ($p < 0.005$). Logistic regression analysis further indicated that female animals were approximately 2.42 times more likely to be seropositive than their male counterparts ($OR = 2.42$). This finding is consistent with the report of Haan *et al.* (2015), who observed significantly higher PPRV antibody seroprevalence among female sheep and goats. Similar observations have also been reported in other countries (Singh *et al.*, 2010; Munir *et al.*, 2012 and Huyam *et al.*, 2014). The higher seroprevalence observed in females may be attributed to the prevailing livestock management practices in northern Nigeria, where breeding females are generally retained in flocks for longer periods, thereby increasing their cumulative exposure to PPRV. In contrast, male animals are more frequently sold for meat or slaughtered during festivals and religious ceremonies, resulting in shorter flock retention periods and reduced opportunities for exposure. Consequently, the prolonged retention of female animals may have contributed to the higher prevalence of PPRV antibodies observed in this study. However, this finding is inconsistent with the report of Inusa (2021), who stated that males are mostly affected by PPR and this might be due to genetic variation of the animals or their use as breeding stock.

In the present study, animals reared under the pastoralist system were mostly affected (68.1%). Low prevalence was found in the animals reared in the intensive system. This was similar to the findings of Maganga *et al.* (2013). Also, the interaction between sheep and goats in the pastoralist system, especially in states with high densities of wild animals like Borno and Bauchi, could affect the PPR prevalence, as the infectivity and role of PPR transmission through wild ruminants are mentioned by Gopilo (2005) and Bello *et al.* (2018).

PPR seroprevalence differed significantly among the various housing systems, with the highest prevalence recorded in animals that were not provided with housing compared to those maintained under other housing conditions. The lowest seroprevalence was observed in animals reared in mud houses. This finding contrasts with the report of Huyam *et al.* (2014), who observed the lowest PPR prevalence in animals housed in modern shelters with metal fencing.

The distribution of PPRV antibodies among the different goat breeds revealed that the West African Dwarf breed had the highest seroprevalence (85.4%), which was significantly greater than that observed in the Sahel and Red Sokoto breeds included in this study. This finding is consistent with the report of Bello *et al.* (2016), who also documented a higher prevalence of PPRV antibodies in West African Dwarf goats. However, it contrasts with the findings of Inusa (2021), who reported that the Red Sokoto breed exhibited a significantly higher seroprevalence of PPRV antibodies than other goat breeds. The observed variation in seroprevalence among the different breeds may be attributed to genetic differences, including breed-related susceptibility or resistance to PPRV infection, as previously suggested by Couacy-Hymann *et al.* (2002).

It is possible that the West African Dwarf breeds of goats are genetically more susceptible to PPR infection than the other breeds sampled in this study (Salami *et al.*, 2014; Woma *et al.*, 2016b). Among sheep, the Yankasa breed exhibited a significantly higher seroprevalence of PPRV antibodies than the Balami and Uda breeds. This observed variation may be attributable to breed-related genetic differences that influence susceptibility or immune response to PPRV infection (Roger *et al.*, 2001). The association between the positive cases against PPR and the potential risk factors found through univariate analysis was assessed with a multivariate analysis using logistic regression, with a 95% confidence interval and $p \leq 0.05$. The multivariate analysis revealed an association between PPR seropositivity and the geographical location at the state and locality levels, which was in line with Inusa (2021). Sheep and goats from three localities were at high risk for PPR infections: Jere in Borno state ($OR = 3.82$), Ningi in Bauchi state ($OR = 3.54$), and Maiduguri ($OR = 3.52$) in Borno state. Regarding the husbandry system, logistic regression revealed a significant association between the systems and PPR seropositivity. The animals owned by nomadic pastoralists were at high risk for PPR with $OR = 2.94$ and $p = 0.0001$ as compared to other systems. This could be due to vulnerability of small ruminant herds in pastoralists and open grazing systems to infected herds in pastures and watering points (Tounkara *et al.*, 2019). These herds might have arrived from other states, particularly from the states located at country borders like Borno state with high PPR prevalence. This finding is in agreement with the observations of Souley *et al.* (2015).

A limitation of this study is that the conventional live attenuated PPR vaccine (Nigeria 75/1), currently used in Nigeria, is not DIVA-compatible. Consequently, antibodies produced following vaccination cannot be distinguished serologically from those resulting from natural PPRV infection. This limitation may complicate the interpretation of serological surveillance, particularly during extensive vaccination campaigns. Nevertheless, this limitation was minimized in the present study by restricting sampling to sheep and goats with no reported history of PPR vaccination based on information obtained from animal owners and available veterinary records. However, reliance on vaccination history may still introduce some degree of misclassification where vaccination records are incomplete or inaccurate.

It is concluded from the study that the detection of PPRV antibodies in unvaccinated sheep and goats across Borno, Bauchi and Gombe States confirms the continued circulation of the virus in northeastern Nigeria. An overall seroprevalence of 55.3% indicates that PPR remains endemic in the region. Age, sex, species, breed, husbandry system and geographical location were identified as important factors associated with PPR occurrence, highlighting the need for enhanced surveillance, routine vaccination and effective control strategies.

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Authors' Contributions

All authors (ID, LPD, AUB, ABA, KCA) contributed equally in the study design, laboratory work, and manuscript preparation. All authors read and approved the final manuscript.

Conflict of interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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