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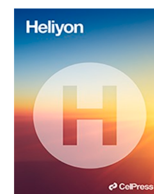

Research article

Seroprevalence and associated risk factors of Peste des petits ruminants in selected districts of Awi zone, Northwest Ethiopia

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A R T I C L E I N F O

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A B S T R A C T

A cross-sectional study to estimate the antibody seroprevalence of the PPR virus and determine the associated risk factors was conducted from February 2021 to May 2022 in the Guangua and Jawi districts of the Awi zone. Of the total 380 sera samples tested using cELISA, 231 (60.8 %) were found positive for the PPRV antibody. A significantly higher prevalence of 76.2 % (OR = 4.5, P = 0.000) was observed in the Jawi district than in the Guangua district (45.5 %). Seroprevalence of 61.9 % (109/176) in sheep and 59.8 % (122/204) in goats was also detected in the present study (P > 0.05). Significantly higher prevalence was revealed in old (69.7 %, OR = 3.4) and adult (65.7 %, OR = 2.3) age groups compared to young (48.9 %) age groups. A prevalence of 63.4 % and 55.6 % were reported in female and male animals respectively (P > 0.05, $\chi^2 = 1.85$). As evidenced by the serological test result, PPR is highly circulated in the Guangua and Jawi districts of the Awi zone. The higher circulation of the PPR virus, the uncontrolled movement of animals, and the regular practice of communal grazing systems in the area indicate the chance of continued dissemination within and to other places. Hence, proper implementation of prevention and control measures and further study on sequencing and characterization of the circulating virus are advised.

1. Introduction

In developing countries like Ethiopia, the livestock production system is the fast-growing sub-sector of agriculture that contributes nearly thirty percent of agricultural gross domestic product [75] and about eighty percent of the livelihood of the rural population [38]. Small ruminants play a crucial role in rural economies and are an important asset for poor farmers to generate income [37]. Ethiopia possesses a large number of sheep and goats with an estimated population of 30.7 million sheep and 30.2 million goats [18, 38]. However, the benefit gained is meager because of multiple factors including diseases. One of the most important diseases that lead to the lowest benefit, highly reducing production and productivity of the animals in the country is Peste des Petits Ruminants (PPR) [6, 67].

Peste des Petits Ruminants is an economically important transboundary disease of small ruminants that was reported for the first time in Cote d'Ivoire [61]. It is an acute contagious disease caused by *Morbillivirus* specifically, *Peste des petits ruminants virus* (PPRV). The disease is known to cause high morbidity and mortality rates in infected animals [12,42,44]. The virus has a single serotype

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consisting of four distinct lineages (I-IV) classified depending on sequence comparison of nucleo-protein and fusion gene C-terminus of the virus [20].

Peste des Petits Ruminants is manifested by pyrexia, watery profuse diarrhea conjunctivitis, oculo-nasal discharges, stomatitis, and bronchopneumonia. A tentative diagnosis of the disease depends on the characteristic clinical signs and post-mortem lesions it causes. Considering its differential diagnoses such as rinderpest, pneumonic pasteurellosis, foot and mouth disease, orf, bluetongue, contagious caprine pleuropneumonia, and gastro-intestinal helminth infestations is also very important. It can be confirmed by isolating the virus and performing different serological and molecular tests [12,25,60].

Peste des Petits Ruminants potentially spread through discharges and loose feces, all of which contain high levels of the virus titers. Usually, it can also occur via aerosol over short distances [53]. Direct transmission through contact with newly introduced infected animals is also possible. Asymptomatically infected and recovered animals can shed the virus for more than 3 months. Thus, quarantining and testing new animals before introducing them to a herd is necessary to minimize the probability of infection [19].

Peste des Petits Ruminants is the most economically important small ruminant disease [40] that causes economic losses from reduced body weight gains, impaired growth of the animals, reduced production yield, death of the animals, high costs of treatment, and trade ban [67,69]. A morbidity rate of fifty to one hundred percent and mortality rate varying from twenty to hundred percent had been documented in PPR-infected small ruminants [40]. Control and eradication of PPR can be achieved by cleaning and disinfecting infected premises, quarantining new animals, controlling the animal's movement, euthanizing infected and exposed animals, and vaccinating the animals in high-risk areas [19].

Initially, PPR occurrence was suspected in Ethiopia in 1977 and its actual presence was confirmed late in 1991 with a cDNA probe from an outbreak that happened in a holding area near Addis Ababa. The outbreak was implicated in causing the mortality of more than 60 % of the goats [25]. Serological evidence of the disease was also reported in 1991 and it was isolated from an outbreak in 1996. The virus's full genome was eventually sequenced in 2014 [46].

A serosurveillance study conducted in 1997 at abattoirs in Bishoftu town, Ethiopia, revealed a high seroprevalence of PPR antibodies. Since its confirmation in Ethiopia, the PPR has had a long-term impact on sheep and goat production and productivity. It exacerbated food shortages, having a significant economic impact on the production and export of animals particularly in vulnerable parts of the country [4,25].

In the previous five years, from 2016 to 2021, 632 PPR outbreaks with a total of 255794 cases and 116341 deaths have been documented from various agroecological zones of Ethiopia. The highest number of outbreaks was reported from the Amhara region (258 outbreaks) followed by Oromia (146), Somali (136), Afar (64), SNNP (27), Tigrai (13), and Benishangul Gumuz (3) regions. The highest mean morbidity rate (43.62 %), mean case fatality rate (42.71 %), and mean mortality rate (9.11 %) were reported from Benishangul Gumuz regional state. A low or high number of outbreak reports in a specific region does not necessarily indicate a low or

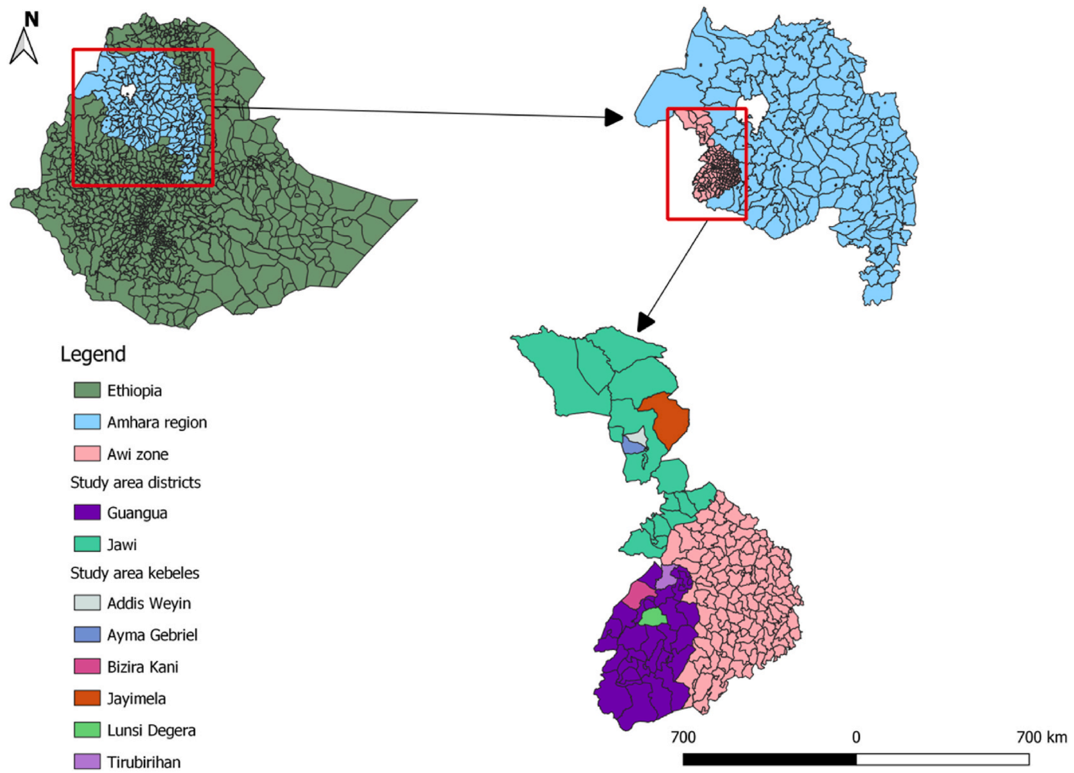

Fig. 1. Map of the study area.

high occurrence level of disease there. The more a region reports an outbreak, the higher the number reported and vice versa. Only 11 PPR outbreaks were reported from the Awi zone of the Amhara region with 2161 total cases and 216 total deaths. Six outbreaks were from the Jawi district and no outbreak was reported from the Guangua district.

Several PPR seroprevalence studies [6,7,24,26,34,35,37,70,74] have been conducted in various areas of Ethiopia. The epidemiological information on the disease in Awi Zone is scarce and only one seroprevalence study finding has been reported from the Awi Zone [32] and no study has been done in the Jawi and Guangua districts of the zone yet. Currently, Ethiopia has launched a progressive control and eradication strategy for PPR in collaboration with the Food and Agricultural Organization (FAO) and the World Organization for Animal Health (OIE). Understanding the seroepidemiology of the PPR is very important to implement the strategy because repeated vaccination of all susceptible small ruminants is unaffordable in developing countries like Ethiopia. Nevertheless, the epidemiology of the disease is not clearly understood and its seroepidemiological information is not revealed in the present study area. Therefore, additional information on the seroepidemiology of the disease that assists in understanding the status of the disease in the area is important to support the current initiative towards control and eradication of the disease that targets high-risk areas of endemic regions. Hence, the study aimed to estimate the seroprevalence of small ruminant PPRV antibodies and assess the associated risk factors in specific districts within the Awi zone.

2. Materials and methods

2.1. Study area description

The study was conducted in the Guangua and Jawi districts of Awi zone, Amhara Regional State (Fig. 1). The zone administrative town is called Enjibara, located around 430 km northwest of Addis Ababa. The Awi zone is bounded by the Benishangul Gumuz region, North Gondar, Oromia region, and West Gojam in the West, North, South, and East directions respectively. It has an average annual rainfall of 1750 mm with monthly average temperature fluctuating between seventeen to 27 °C [50].

Jawi district is located at a latitude of 10° 38′ to 11° 30′N and a longitude of 36° to 37° E [72]. It experiences fluctuating rainfall, with lengthy summer rains having an average annual rainfall of 1569.4 mm. The district's altitude spans from 648 to 1300 m above sea level, with average temperature ranging between 16.68 and 37.6 °C. The district is covered with a variety of vegetation types and it is well-known for its crop-livestock mixed production system. The main crops produced in the district include maize, sesame, sorghum, and cotton. According to a 2020 unpublished report of the district agricultural office, the district has an estimated total population of 27521 sheep and 87683 goats.

Guangua district is located 513 km northwest of Addis Ababa, the capital city of Ethiopia, and 52 km far from Enjibara. It is located at a latitude of 10.950°N and a longitude of 36.500°E with an altitude ranging from 1583 to 1710 m above sea level. The district receives annual rainfall ranging from 1300 to 1800 mm with a temperature ranging from twenty-two to 31 °C. The district covers around 106,914 ha of which twenty-nine percent of the land is cultivated during the main cultivation season, using rainfall, and about twelve percent is cultivated by irrigation. The population of the district is estimated to be about 223, 066 with 11,936 households [22, 50]. Guangua has an estimated population of 29828 sheep and 24,714 goats according to a 2020 unpublished report of the district gricultural office.

2.2. Study animals

The study population of this study was sheep and goats found in the Guangua and Jawi districts of the Awi zone where there was no PPR vaccination practice. Sheep and goats above six months were considered for the study to eliminate the likelihood of seropositivity outcomes attributable to maternal antibodies. Accordingly, the animals to be sampled were selected irrespective of sex and body condition from herds with no vaccination history against PPR disease. The size of the herd from which the animals were selected was classified into three categories small (herd with less than ten animals), medium (herd with ten to twenty animals), and large (herd with more than twenty animals) based on classification of the previous study [34]. The animals' ages were estimated by dentition [29] and classified into three groups less than one year (young), from one to three years (adult), and greater than three years (old). The recorded body condition of the sheep and goats was also grouped into three categories poor, medium, and good according to the Ethiopian Sheep and Goat Productivity Improvement Program classification [30].

2.3. Study design

This study was a cross-sectional study conducted from February 2021 to May 2022 to determine the seroprevalence of PPRV antibodies and associated risk factors in the Guangua and Jawi districts of Awi zones, North West Ethiopia.

2.4. Sample size determination

The sample size required for the present study was determined according to the Thrusfield [68] formula indicated below using a 5 % level of precision, 95 % level of confidence interval, and 55.34 % previous seroprevalence in the Awi zone [32].

$$n = \frac{1.96^2 \, P(1-P)}{d^2}$$

Whereas n is the total sample size, P = prevalence from the previous study, and d = precision level. Based on the formula, the total

number of animals required was determined to be 380. Accordingly, 176 sheep and 204 goats were included in the study.

2.5. Sampling techniques

The study area districts, namely Guangua and Jawi were selected by purposive sampling method depending on previous occurrence of PPR and the presence of a large population of sheep and goats. The disease occurrence information used to select the districts was obtained from epidemiology units of the area. The Kebeles were also purposively selected based on the production potential of sheep and goats. Accordingly, Kebeles having high sheep and goat populations were selected from each district. Subsequently, peasant associations (PAs) were randomly selected from the Kebeles. A list of farmers having sheep and goats was obtained from each selected PA and the farmers were selected using a systematic random sampling method. Finally, the study animals to be sampled were selected using a simple random sampling method. The number of animals to be selected was proportionally allocated to each district on small ruminant population within the districts.

2.6. Sample collection and processing

A whole blood sample was collected from the jugular veins of each animal using clot activator plain vacutainer tubes and 21G vacutainer needles. The samples were labeled on the tubes with information on the place of sample collection, date, and species of the animals and shipped to the laboratory in chilled ice boxes. Information regarding age, sex, body condition, size of each herd, housing system, origin, grazing system, physiological status, contact between herds, new animal introduction, and isolation of infected animals was also collected. The blood samples were kept in a tilted position for about 24 h to allow separation of the serum. The samples with no clear separated serum were centrifuged for 3 min at 5000 rotations per minute to allow clear serum collection by removing remnants of red blood cells. Accordingly, clear sera samples were collected into cryovial tubes in aliquots and kept at negative 20 °C until tested against serum antibodies (see Fig. 2).

2.7. Serological study

The collected sera samples were tested using a competitive ELISA kit based on instructions from the manufacturer (IDvet Innovative Diagnostics, France) (Fig. 3). Briefly, all chemicals stored in the refrigerator were brought to room temperature (15–21°C) and every microplate well was filled with 25 μL of dilution buffer 13 solution. Then, positive control, negative control, and dispensed sera samples, 25 μL of each were added to corresponding plate wells according to plate layout. Subsequently, the plate wells were sealed with an adhesive plate sealer and incubated at 37 °C for 45 min. After incubation, the plates were washed using a three hundred microliter wash solution and dried by tapping with a towel. One hundred microliters of the conjugate solution were added to each plate well and the plates were incubated at 21 °C and re-washed after 30-min incubation. Substrate solution (one hundred microliters) was added to the wells and incubated at room temperature for 50 min. Eventually, the enzymatic reaction was stopped by adding a stop solution to the wells. The optical density (OD) of the samples was read with ELx800 Absorbance Microplate Reader

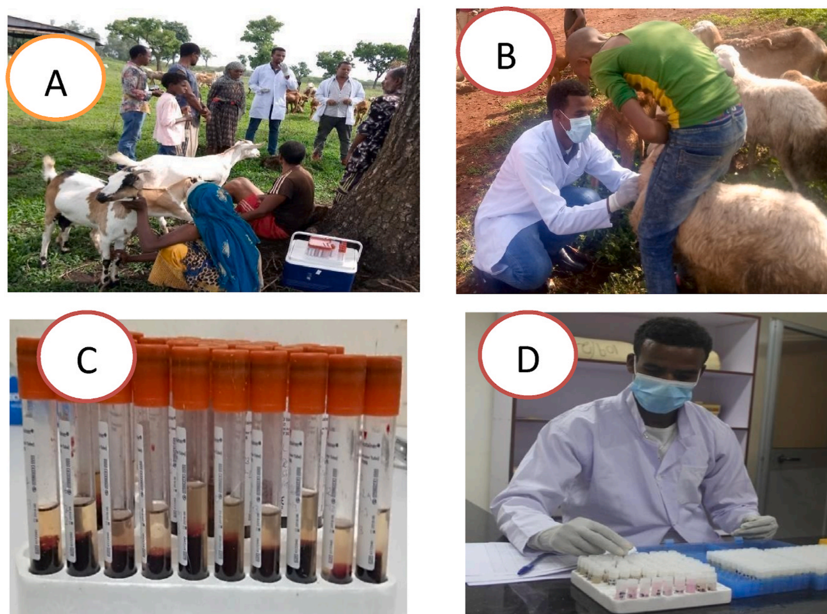

Fig. 2. The study sample collection and sera sample harvesting approach. Introducing the objectives of the study (A), blood sample collection (B), samples with separated serum (C), and arranging the sera samples (D).

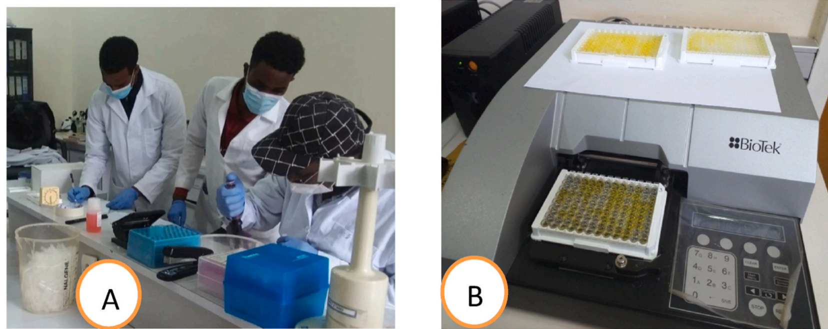

Fig. 3. Performing the serological test. Dispensing the sera samples (A) and loading the plates to the ELISA reader (B).

(BioTek®Instruments, Inc.USA) at 450 nm. The competition percentage (S/N%) of the samples was automatically calculated using Gen 5™ 3.04 software. In this way, samples with S/N% ≤ 50 % were considered positive and those with S/N % > 60 % were considered negative whereas S/N% > 50 and < 60 were considered doubtful.

2.8. Management and statistical analysis of the data

The raw data was fed into a Microsoft Excel spreadsheet, and R software of version 4.0.2 was used for analysis. Accordingly, it was summarized using descriptive statistics and the seroprevalence was computed by dividing the number of seropositive samples by the total number of samples multiplied by one hundred. The presence of the antibody seroprevalence variations among the levels of the variables was tested using Pearson's chi-square method ($\chi 2$). The strength of association that the variables had with PPR seroprevalence was assessed using binary logistic regression and odds ratio (OR) was used to quantify the association. All variables hypothesized as a risk factor were included in the multivariable logistic regression model and the model was simplified with the backward step-wise method. Variables having an OR equal to one were assumed to have no association with the antibody seroprevalence and the factors with OR less or greater than one were assumed to have an association with seropositivity to the disease and stronger the association. A statistically significant association between the variables was believed to exist if the computed P-value was less than 0.05 [24].

Ethical approval

This research work was ethically approved by the ethical review board of the University of Addis Ababa, College of Veterinary Medicine and Agriculture. All possible efforts were made to minimize the suffering of the animals during sample collection. The aim of the study was introduced and oral informed consent was obtained from the farmers before sample collection.

3. Results

Out of a total of 380 sera samples tested for PPRV serum antibodies, 60.8 % (231/380) were positive. A significantly higher prevalence of 76.2 % (144/189) was observed in the Jawi compared to the Guangua district (P-value <0.005, $\chi^2 = 36.1$). Higher Kebele-wise seroprevalence was observed in Jayimela (82.7 %) and Ayma Gebriel (81.5 %) while the lowest prevalence was from Bizra Kani Kebele (38.65) (P-value = 0.000, $\chi^2 = 47.2$) (Table 1).

Out of the total samples tested, 61.9 % (109/176) sheep and 59.8 % (122/204)) were detected positive for PPRV antibodies (P-value = 0.75). Statistically higher prevalence of PPR virus antibodies was observed in older small ruminants (69.7 %) followed by adult

Table 1
Prevalence of PPR virus antibodies in the Awi zone and the study area districts.

Variables		Categories	Number tested	Number positive	% seroprevalence (95 % CI)	χ^2	P-value
Districts		Guangua	191	87	45.5 (38.4–52.9)	36.1	0.000
		Jawi	189	144	76.2 (69.4–81.9)		
		Total	**380**	**231**	**60.8 (55.7–65.7)**		
Kebeles	Guangua	Bizira Kani	70	27	38.6 (27.4–51)	47.2	0.000
		Lunsi Degera	66	28	42.4 (30.6–55.2)		
		Tirubirhan	55	32	58.2 (44.1–71)		
	Jawi	AddisWeyn	72	48	66.7 (54.5–77.1)		
		Ayma Gebriel	65	53	81.5 (69.6–89.7)		
		Jayimela	52	43	82.7 (69.2–91.3)		
		Total	**380**	**231**	**60.8 (55.7–65.7)**		

χ^2 = Chi-square test, CI= Confidence interval, % = percentage.

ones (48.9 %) (P-value <0.05, $\chi^2 = 13.9$). Seroprevalence of 63.4 % in female and (55.6 %) in male animals was observed (P-value >0.05). Significantly higher prevalence was also found in animals having poor body condition (68.6 %, $\chi^2 = 8.04$, P-value = 0.02). The seroprevalence was significant in differences among categories of flock size, origin, housing system, and isolation practice of infected animals (P-value< 0.05) (Table 2).

The antibody seroprevalence was higher in sheep and goats from medium flock size (67.4 %, P-value = 0.04, CI = 58.8–78.8) and lower in those living alone in a bed housing system (50.9 %). The prevalence was also higher when the isolation of infected animals from a flock was absent (62.6 %, P-value = 0.02, CI = 57.3–67.6) (Table 2). Univariable logistic regression analysis for seropositivity of individual variables to PPR virus antibodies, showed district, Kebele, age, body condition, origin, housing method, the animal's physiological status, and infected animals isolation to be potential risk factors (Table 3).

The multivariable logistic regression of the variables showed the study area districts, body condition of the animals, age of the animals, flock size, grazing management, introduction of new animals, and isolation status of infected sheep and goats to be variables potentially associated with seropositivity to PPR virus (P-value <0.05). The animals from the Jawi district were also at higher risk of being infected with the virus (OR = 4.5, SE = 0.26, P-value = 0.00).

The probability of old and adult sheep and goats to be positive to PPR virus antibody was about 3.4 and 2.3 times higher compared to young animals. The odds of being seropositive to PPR virus antibody are also 4.5 times higher in animals from medium flock size. The animals with poor body condition were also found to be more positive for serum PPR virus antibodies (OR = 2.1). The absence of isolating sick animals from healthy flocks increases the probability of being seropositive to PPR antibodies (OR = 2.6, P-value <0.05) (Table 4).

4. Discussion

The overall PPR virus antibody seroprevalence observed in the present study area (60.8 %) was lower than the one previously reported by Yalew et al. [74] in the Benishangul Gumuz region (75.7 %) and Woldemichael et al. [71] in Amhara region (73.45 %) of Ethiopia. Seroprevalence of 74.9 % in Pakistan [76] and 80.9 % in Sudan[39] which is higher than the current finding was also reported. In contrast, the present finding is much higher than the reports of 26.3 % [54], 29.2 % [37], 32.5 % [65], and 2.1 % [34] in Ethiopia. However, it is in agreement with findings by Fentie et al. [32] in Ethiopia (55.34 %), Saeed et al. [63] in Sudan (62.8 %), Saritha et al. [16] in India (67.87 %), Abd El- Rahim et al. [1] in Egypt (63.4 %), Luka et al. [47] in Uganda (57.62 %), and Abdalla et al. [2] in Sudan (61.8 %). A slightly lower prevalence was also reported in Tigray (47.5 %) [6] and Oromia (48.43 %) [33] region.

Table 2
Prevalence of PPR virus serum antibodies depending on different variables.

Factors	Categories	Number tested	Number positive	% seroprevalence (95 % CI)	χ^2	P-value
Species	Ovine	176	109	61.9(54.3–69)	0.1	0.75
	Caprine	204	122	59.8(52.7–66.5)		
Age	Young	143	70	48.9(40.6–57.4)	13.9	0.001
	Adult	108	71	65.7(55.9–74.4)		
	Old	129	90	69.7 (61–77.4)		
Sex	Female	254	161	63.4(57.1–69.3)	1.85	0.17
	Male	126	70	55.6(46.5–64.3)		
Physiological status	Lactating	87	57	65.5(54.5–75.2)	10.7	0.057
	Pregnant	100	66	66(55.8–75)		
	Dry	67	38	56.7(44.1–68.7)		
	Young Male	92	45	48.9 (38.4–59.5)		
	Adult Male	26	20	76.9 (55.9–90.2)		
	Old Male	8	5	62.5 (25.9–89.7)		
Body condition	Good	126	64	50.8 (41.8–59.8)	8.04	0.02
	Medium	219	143	65.3(58.5–71.5)		
	Poor	35	24	68.6(50.6–82.7)		
Origin	Born in herd	267	148	55.4(49.2–61.5)	10.1	0.001
	Brought in	113	83	73.4 (64.2–81.1)		
Flock size	Small	262	159	60.7(54.5–66.6)	6.2	0.04
	Medium	89	60	67.4(58.8–78.9)		
	Large	29	12	41.4(24.1–60.8)		
Inter herd contact	Absent	16	9	56.3(30.6–79.2)	0.01	0.9
	Present	364	222	61(55.7–66)		
Introduction of new animal	Absent	200	113	56.5(49.3–63.4)	2.89	0.09
	Present	180	118	65.6(58.1–72.4)		
Housing	Alone and bed	108	55	50.9 (41.2–60.6)	6.16	0.04
	Alone and floor	139	90	64.7(38.2–52.4)		
	Floor and mixed	133	86	64.7(55.8–72.6)		
Grazing management	Private	19	8	42.1 (21.1–66)	2.16	0.14
	Communal	361	225	61.8(56.5–66.8)		
Isolate sick	No	353	221	62.6(57.3–67.6)	5.8	0.02
	Yes	27	10	37.04(20.1–57.5)		

χ^2 = Chi-square test, CI= Confidence interval, % = percentage.

Table 3
Univariate regression analysis of risk factors for PPRV seropositivity.

Variables	Categories	% Prevalence (Number+/Number tested)	OR (95 % CI)	SE	Coefficients	P-value
District	Guangua (ref)	45.4(87/191)				
	Jawi	76.2(144/189)	3.8(2.5–6)	0.22	1.34	2.18e-09
Kebele	Bizra Kani(ref)	38.6(27/70)				
	AdisWeyni	66.7(48/72)	3.2(1.6–6.4)	0.35	1.16	9.46e-04
	Ayma Gebriel	81.5(53/65)	7(3.27–16)	0.4	1.95	1.30e-06
	Jayimela	82.7(43/52)	7.6(3.3–18.9)	0.44	2.03	4.23e-06
	Lunsi Degera	42.4(28/66)	1.2(0.6–2.3)	0.35	0.16	0.65
	Tirubirhan	58.2(32/55)	2.2(1.1–4.6)	0.37	0.8	0.03
Species	Ovine (ref)	61.9(109/176)				
	Caprine	59.8(122/204)	0.9(0.6–1.38)	0.21	−0.09	0.67
Age	Young (ref)	48.9(70/143)				
	Adult	65.7(71/108)	2(1.2–3.4)	0.26	0.69	0.008
	Old	69.7(90/129)	2.4(1.5–4)	0.25	0.88	0.0005
Sex	Male (ref)	55.6(70/126)				
	Female	63.4(161/254)	1.4(0.9–2.1)	0.2	0.3	0.14
Body condition	Good (ref)	50.8(64/126)				
	Medium	65.3(143/219)	1.8(1.2–2.9)	0.23	0.6	0.008
	Poor	68.6(24/35)	2(0.97–4.8)	0.41	0.75	0.06
Physiological Status	Young Male (ref)	48.9(45/92)				
	Dry	56.7(38/67)	1.4(0.7–2.6)	0.32	0.31	0.33
	Pregnant	66(66/100)	2(1.14–3.6)	0.3	0.71	0.01
	Lactating	65.5(57/87)	1.98(1.1–3.6)	0.31	0.69	0.02
	Adult Male	76.9(20/26)	3.5(1.3–10.2)	0.51	1.23	0.01
	Old Male	62.5(5/8)	1.7(0.4–8.9)	0.76	0.55	0.47
Flock size	Large (ref)	41.4(12/29)				
	Medium	67.4(60/89)	2.9(1.2–7.1)	0.44	1.08	0.01
	Small	60.7(159/262)	2.2(1.01–4.9)	0.4	0.78	0.04
Origin	Born in a herd (ref)	55.4(148/267)				
	Brought in	73.4(83/113)	2.2(1.4–3.6)	0.25	0.8	0.001
Inter-herd contact	Absent (ref)	56.3(9/16)				
	Present	61(222/364)	1.2(0.4–3.3)	0.5	0.2	0.7
Grazing management	Private (ref)	42.1(8/19)				
	Communal	61.8(225/361)	2.2(0.9–5.7)	0.8	0.48	0.09
Housing	Alone and bed (ref)	50.9(55/108)				
	Alone and floor	64.7(90/139)	1.77(1.06–3)	0.26	0.57	0.02
	Floor and mixed	64.7(86/133)	1.76(1.05–3)	0.26	0.58	0.03
Introduction of new animal	Absent (ref)	56.5(113/200)				
	Present	65.6(118/180)	1.5(0.97–2.2)	0.21	0.38	0.07
Isolate sick animals	Yes (ref)	37(10/27)				
	No	62.6(221/353)	2.8(1.3–6.6)	1.05	0.4	0.01

CI= Confidence interval, + = positive, % = percentage, SE = standard error, ref = reference.
OR= Odds ratio.

Table 4
Multivariate logistic regression analysis of the risk factors.

Variables	Categories	%Prevalence (Number+/Number tested)	OR (95 % CI)	SE	Coefficients	P-value
District	Guangua (ref)	45.4(87/191)				
	Jawi	76.2(144/189)	4.5 (2.8–7.5)	0.26	1.5	0.000
Species	Ovine (ref)	61.9(109/176)				
	Caprine	59.8(122/204)	0.5 (0.3–0.8)	0.27	−0.7	0.01
Age	Young (ref)	48.9(70/143)				
	Adult	65.7(71/108)	2.3 (1.3–4.1)	0.3	0.8	0.006
	Old	69.7(90/129)	3.4 (1.9–6.1)	0.3	1.2	0.000
Body condition	Good (ref)	50.8(64/126)				
	Medium	65.3(143/219)	1.8 (1.1–3.1)	0.26	0.6	0.02
	Poor	68.6(24/35)	2.1 (0.8–5.4)	0.5	0.7	0.13
Flock size	Large (ref)	41.4(12/29)				
	Medium	67.4(60/89)	4.5 (1.7–12.6)	0.5	1,5	0.002
	Small	60.7(159/262)	3.1 (1.2–6.7)	0.47	1,1	0.02
Grazing management	Private (ref)	42.1(8/19)				
	Communal	61.8(225/361)	2.5	0.55	0.9	0.1
Introduction of new animal	Absent (ref)	56.5(113/200)				
	Present	65.6(118/180)	1.6	0.25	0.47	0.059
Isolate sick animals	Yes (ref)	37(10/27)				
	No	62.6(221/353)	2.6	0.46	0.96	0.03

CI= Confidence interval, + = positive, % = percentage, SE = standard error, ref = reference, OR= Odds ratio.

The present seroprevalence was also slightly higher than the earlier findings in Sudan (45.6 %) [64] and Uganda (55.2 %) [17]. This difference might be attributed to variations in the number of samples tested, sampling techniques, geography, and production system.

Species-wise antibody seroprevalence was non-significantly higher in sheep (61.9 %) as indicated by the present study (P-value = 0.75). The absence of significant variation in the prevalence could be attributed to the equal likelihood of exposure to the disease stemming from the unrestricted movement of the animals and the usual sharing of watering and grazing points. In agreement with this finding, previous studies [7,33,35,36,74] also found higher antibody seroprevalence of the PPR virus in sheep. Indeed, research in Sudan [2,28], Nigeria [27,73], Uganda [8], Pakistan [5,41], and India [13,49] also showed sheep to be more seropositive. The lower mortality rate of PPR in infected sheep and the higher mortality rate of infected goats could be the reason for the higher prevalence in sheep [3,21].

In the present study, the antibody seroprevalence was higher in old (69.7 %, OR = 3.4) and adult (65.7 %, OR = 2.3) animals compared to young animals (P-value<0.001). In line with this finding, earlier studies [24,33,48,70,76] detected a higher prevalence in older sheep and goats. Previous studies in Ethiopia [32,35,37], Nigeria [27], Pakistan [43,55], and India [23] also revealed higher seroprevalence of PPR virus antibodies in old and adult animals. This could result from a higher exposure chance of older animals to the PPR virus challenge [13,15,34]. The fact that the animals infected at an earlier age remain seropositive for a longer time also contributes to the higher seroprevalence in older sheep and goats [74].

The sex-wise antibody prevalence in this study was higher in females (63.4 %, P-value >0.05). This report agrees with previous study findings [6,31,33–35,45] that showed nonsignificantly higher seroprevalence in female sheep and goats. Even though the difference in the seroprevalence was significant, studies in Tanzania [11,67], Ethiopia [32,51,70], Sudan [64], Nigeria [14], Uganda [8], and Pakistan [43] also reported higher prevalence in female animals. The higher prevalence in females could be a result of the habit of keeping females for a longer time for breeding purposes and selling males at an early age for income generation. Keeping females for a long time might indirectly account for the detection of high seroprevalence. Stress from pregnancy, kidding, or lambing in females might also contributed to the higher prevalence as a consequence of increased risk of infection.

The prevalence of PPR virus antibodies detected in the present study was significantly higher in poor body-conditioned sheep and goats (68.6 %, OR = 2.1) than in medium (65.3 %) and good body-conditioned (50.8 %) animals (P-value = 0.02). It concurs with the previous study in the Asosa zone of Benishangul Gumuz region [74] and in India [59] which reported a higher seroprevalence in poor body-conditioned sheep and goats. The higher prevalence of PPR virus serum level antibodies in the small ruminants with poor body conditions manifests how importantly the disease causes body gain loss.

Concerning flock size, higher antibody prevalence was detected in sheep and goats from medium flock size (P-value <0.05). This finding is supported by a study conducted in the Horo Guduru zone of the Oromia region [35]. The odds of positivity to antibodies of the PPR virus were much higher in animals from medium flock size (P-value = 0.002, OD = 4.5) in agreement with the finding of Ozkul et al. [58]. The previous studies [9,10,24] also reported non-significantly higher antibody seroprevalence in medium flock size. However, another work done in Ethiopia [34] and Nigeria [56] revealed a higher prevalence of PPR virus antibodies in large and small flock sizes respectively. The lower seroprevalence in the large category of flock size could be attributed to the limited sample size of the group studied. It could also be because of the regular presence of the disease in the study area.

Sheep and goats brought into a flock were observed to be more seropositive to PPR virus antibodies (73.4 %) than the ones born within the flock (55.4) (P-value = 0.01). In agreement with this finding, previous studies in the Eastern Amhara region by Alemu [9] and in the Horo Guduru Zone of Western Ethiopia by Gelana et al. [35] also revealed significantly higher antibody seroprevalence in small ruminants brought into a flock. Earlier studies [52,62] also support the current study finding. Moreover, it is supported by the findings of Saeed et al. [62] in Sudan and Mbyuzi et al. [52] in Tanzania. The higher prevalence could be due to the higher infection rates of the disease in the animals from stress factors such as long-distance movement, environmental change, and change in management.

This study has shown nonsignificantly different prevalence of PPR virus antibodies among animals sampled from a flock to which there was a recent introduction of new animals (65.6 %) and no recent introduction of new animals (56.5 %). The current finding is supported by the findings of Saeed et al. [62] and Shuaib et al. [66] who documented insignificantly different new animal introduction-based seroprevalence in Sudan. In contrast to this finding, earlier investigations in Ethiopia [9,34,35] reported statistically significant variation in the PPR virus antibody seroprevalence the higher prevalence being observed in the presence of new animal introduction. The difference in the number of sampled animals in each category and the geographical source of the newly introduced animals could be the reason for variation in the prevalence between the present and the previous findings.

Housing system-based seroprevalence was reported to be significantly lower in the goats and sheep living separately in bed houses (P-value = 0.04) with prevalence of 50.9 % (CI = 41.2–60.6, χ^2 = 6.16). This finding indicates the importance of rearing the animals together as a potential factor to PPR virus antibody distribution which agrees with the findings of Akwongo et al. [8]. Previous works in Ethiopia [9,35] and Sudan [66] also found a result that agrees with the current finding. A higher prevalence of PPR virus antibodies was also detected in goats and sheep living separately in floor houses compared to the ones living in bed houses. The ease of bed houses for cleaning and other management practices that can reduce contamination could be the reason for the lower prevalence in the animals living on bed houses.

In terms of grazing systems, our study found non significantly different seroprevalence among animals from private and communal grazing systems. This finding aligns with Gelana et al.'s [35] observation of the absence of a significant association between the grazing system and PPR virus antibody seroprevalence. Non-significant differences in the prevalence could result from the endemic occurrence of PPR in the current study area. However, contrary to our findings, studies by Alemu [9], Dejene [24], and Mbyuzi et al. [52] indicated statistically higher seroprevalence in sheep and goats with communal grazing systems. This discrepancy could be attributed to the increased infection risk from the increased interred contact and contact with infected wild animals at shared grazing fields.

The prevalence of PPR virus antibody was found to be significantly higher in small ruminants of farmers not practice isolation of sick animals (62.6 %) in relation to the farmers who practiced isolation of sick animals from the flock (37.04 %) (P = 0.02, $\chi^2 = 5.8$. The odds of sheep and goats being seropositive to PPR virus antibodies were found to be high when the infected animals were not isolated from the flock (OD = 0.3, P = 0.007) (Table 3). Hence, isolating PPR-infected sheep and goats from the flock can minimize the likelihood of transmission of the disease to non-infected [57].

5. Conclusion and recommendations

This investigation confirmed higher PPRV antibody seroprevalence in the study area. The study area districts, age of the animals, size of the flock, body condition of the animals, the animal's housing system, and sick animal, isolation status were found to be potential risk factors associated with seroprevalence of the PPR. The higher antibody distribution of the virus in the study area with the usual free animal movement to the area from other parts of the country along with that of Sudan borders and the communal field grazing within the extensive production system of the area may cause further spread of the virus within and to other disease-free places. Therefore, properly implementing the disease control and prevention techniques such as vaccinating target groups of animals, surveillance, and monitoring of the disease in the area is crucial. Indeed, further study on molecular detection, the virus gene sequence analysis, and characterization is recommended.

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Data availability statement

The data used for this article will be available upon request from the corresponding author.

CRediT authorship contribution statement

Yalew Abiyu Senbeto: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Demeke Sibhatu:** Writing – review & editing, Validation, Supervision, Resources, Investigation. **Yasmin Jibril:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] I.H.A. Abd El-Rahim, S.S.A. Sharawi, M.R. Barakat, E.M. El-Nahas, An outbreak of peste des petits ruminants in migratory flocks of sheep and goats in Egypt in 2006, Rev Sci Tech 29 (3) (2010) 655–662.
[2] A.S. Abdalla, A.A. Majok, K.H. El Malik, A.S. Ali, Sero-prevalence of Peste des petits ruminants virus (PPRV) in small ruminants in Blue Nile, Gadaref, and North Kordofan States of Sudan, J. Public Health Epidemiol 4 (3) (2012) 59–64.
[3] M. Abdellatif, A.Z. Mahmoud, L. Shazali, Prevalence of PPR virus antibodies in sheep, goats, and camels in Hail, Saudi Arabia, Br. J. Virol. 3 (3) (2016) 86–89.
[4] G. Abraham, Epidemiology of peste des petits ruminants virus in Ethiopia and molecular studies on virulence, Institut National Polytechnique de Toulouse, France, 2005. PhD Thesis.
[5] M. Abubakar, S.M. Jamal, M.J. Arshed, M. Hussain, Q. Ali, Peste des petits ruminants virus (PPRV) infection ; Its association with species, seasonal variations, and geography, Trop. Anim. Health Prod. 41 (2009) 1197–1202, https://doi.org/10.1007/s11250-008-9300-9.
[6] B. Afera, D. Hussien, K. Amsalu, Seroprevalence of peste des petits ruminants in goats of southern parts of Tigray Region, Glob. Vet 12 (2014) 512–516, https://doi.org/10.5829/idosi.gv.2014.12.04.8323.
[7] G.E. Agga, D. Raboisson, L. Walch, F. Alemayehu, Epidemiological Survey of Peste des Petits Ruminants in Ethiopia : Cattle as Potential Sentinel for Surveillance, Front. Vet. Sci. 6 (2019) 302, https://doi.org/10.3389/fvets.2019.00302.
[8] C.J. Akwongo, M. Quan, C. Byaruhanga, Prevalence, risk factors for exposure, and socio-economic impact of Peste des Petits Ruminants in Karenga District, Karamoja Region, Uganda, Pathogens 11 (2022) 54, https://doi.org/10.3390/pathogens11010054.
[9] B. Alemu, Epidemiology and identification of peste des petits ruminants (PPR) virus circulating in small ruminants of Eastern Amhara region bordering Afar, Ethiopia, Addis Ababa University, College of Veterinary Medicine and Agriculture, Department of Veterinary Clinical Studies, Bishoftu, Ethiopia, 2014. MSc Thesis.
[10] A.M. Al-Majali, N.O. Hussain, N.M. Amarin, A.A. Majok, Seroprevalence of and risk factors for peste des petits ruminants in sheep and goats in Northern Jordan, Prev. Vet. Med. 85 (2008) 1–8.

[11] E. Torsson, M. Berg, G. Misinzo, I. Herbe, T. Kgotlele, M. Päärni, N. Roos, A.L. Blomström, K. Ståhl, J. Johansson Wensman, Seroprevalence and risk factors for peste des petits ruminants and selected differential diagnosis in sheep and goats in Tanzania, Infect. Ecol. Epidemiol. 7 (1) (2017) 1368336, https://doi.org/10.1080/20008686.2017.1368336.

[12] V. Balamurugan, D. Hemadri, M.R. Gajendragad, R.K. Singh, H. Rahman, Diagnosis and control of peste des petits ruminants : a comprehensive review, Virus Disease 25 (1) (2014) 39–56, https://doi.org/10.1007/s13337-013-0188-2.

[13] V. Balamurugan, B. Varghese, D. Muthuchelvan, K.V. Kumar, G. Govindaraj, K.P. Suresh, P. Kumar, D. Hemadri, P. Roy, Seroprevalence of peste des petits ruminants in sheep and goats in Eastern India, VirusDisease 31 (3) (2020) 383–387.

[14] A.M. Bello, J.R. Lawal, J. Dauda, Y. Wakil, Y.M. Lekko, E.S. Mshellia, K.U. Ezema, S.Y. Balami, I. Wazari, A.U. Mani, Research for Peste des Petits Ruminants (PPR) Virus Antibodies in Goats, Sheep and Gazelle from Bauchi and Gombe States, North Eastern Nigeria, Direct Res. J. Agric. Food Sci. 4 (8) (2016) 193–198.

[15] M.B. Bello, Serological studies on peste des petits ruminants (PPR) in sheep, goats, and camels in Sokoto state, Nigeria, Ahmadu Bello University, Faculty of Veterinary Medicine, Zaria, Nigeria, 2013. MSc Thesis.

[16] G. Saritha, B. Shobhamani, B. Sreedevi, Seroprevalence of peste des petits ruminants in pastoral small ruminants with special reference on sensitivity to age and agro-climatic zones (India), Biol. 8 (3) (2014) 103–107.

[17] M. Bonny, P.R. Simon, A. Chrisostom, N.M. Frank, M. Dennis, O. William, Peste des petits ruminants serological survey in Karamoja sub-region of Uganda by competitive-elisa, Vet. World 4 (4) (2011) 149–152.

[18] Central Statistical Agency (CSA), Agricultural Sample Survey, Report on Livestock and Livestock Characteristics, Statistical Bulletin 585, Ethiopia, Addis Ababa, 2017, pp. 1–188.

[19] CFSPH, Peste des Petits Ruminants. The Center for Food Security and Public Health, Institute for International Corporation Animal Biologics, Ames, Iowa, 2008.

[20] B.D. Clarke, M.R. Islam, M.A. Yusuf, M. Mahapatra, S. Parida, Molecular detection, isolation, and characterization of Peste des petits ruminants virus from goat milk from outbreaks in Bangladesh and its implication for eradication strategy, Transbound. Emerg. Dis. 65 (2018) 1597–1604.

[21] E. Couacy-Hymann, Y.M. Koffi, P. Godji, L.A. Kouassi, K.C. Kouakou, A.H. Krou, P. Nana, Peste des petits ruminants: a permanent burden on the development of small ruminants in ivory coast, Austin Virol. Retrovirol 2 (1) (2015) 1–5.

[22] A. Dawud, A. Aki, Prevalence of Bovine Trypanosomosis in selected kebeles of Guangua, woreda, Amhara region, northwest part of Ethiopia, Researcher 10 (8) (2018) 53–59, https://doi.org/10.7537/marsrsj100818.07.

[23] A. De, B. Debnath, T.K. Dutta, S. Shil, S. Bhadouriya, D. Chaudhary, K.K. Rajak, R. Pachauri, M.A. Ramakrishnan, D. Muthuchelvan, Seroepidemiology of peste des petits ruminants in goats of Tripura state of North East India, Adv. Anim. Vet. Sci. 4 (5) (2016) 215–217.

[24] W. Dejene, Sero-epidemiology and spatial distribution of peste des petits ruminants virus antibodies in some selected pastoral areas of Somali regional state, Ethiopia, Addis Ababa University, College of Veterinary Medicine and Agriculture, Bishoftu, Ethiopia, 2016. MSc Thesis.

[25] F. Delil, Assessment of the epidemiology of peste des petits ruminants (PPR) and post vaccinal seroconversion rate of ppr-virus in small ruminants of Awash Fentale woreda, Afar national regional state, Ethiopia, Addis Ababa University, Faculty of Veterinary Medicine, Bishoftu, Ethiopia, 2007. MSc Thesis.

[26] F. Delil, Y. Asfaw, B. Gebreegziabher, Prevalence of antibodies to peste des petits ruminants virus before and during outbreaks of the disease in Awash Fentale district, Afar, Ethiopia, Trop. Anim. Health Prod. 44 (2012) 1329–1330, https://doi.org/10.1007/s11250-012-0110-8.

[27] A.D. El-Yuguda, S.S. Baba, A.G. Ambali, G.O. Egwu, Seroprevalence of peste des petits ruminants among domestic small and large ruminants in the semi-arid region of North Eastern Nigeria, Vet. World 6 (10) (2013) 807–811.

[28] K. Enan, K. Intisar, M. Haj, M. Hussien, K. Taha, A. Elfahal, Seroprevalence of two important viral diseases in small ruminants in Marawi Province Northern State, Sudan, Int. J. Livest. Prod. 4 (2) (2013) 18–21, https://doi.org/10.5897/IJLP11.048.

[29] ESGPIP, Estimation of Weight and Age of Sheep and Goats, vol. 23, Technical Bulletin, Ethiopia, 2009.

[30] ESGPIP, Body condition scoring of sheep and goats. *Technical Bulletin*8, Ethiopia, 2009.

[31] S. Farougou, M. Gagara, G.A. Mensah, Prevalence of peste des petits ruminants in the arid zone in the Republic of Niger, Onderstepoort J. Vet. Res. 80 (1) (2013) 544, https://doi.org/10.4102/ojvr.v80i1.544.

[32] T. Fentie, Y. Teshome, B. Ayele, W. Molla, N. Fenta, S. Nigatu, A. Assefa, S. Leta, A sero-epidemiological study of peste des petits ruminants in small ruminants in Amahara region, Ethiopia, Comp. Clin. Pathol. 27 (2018) 1029–1036, https://doi.org/10.1007/s00580-018-2697-2.

[33] G. Gari, B. Serda, D. Negesa, F. Lemma, H. Asgedom, Serological investigation of peste des petits ruminants in East shewa and arsi zones, Oromia region, Ethiopia, Vet. Med. Int. 2017 (2017) 9769071, https://doi.org/10.1155/2017/9769071.

[34] T. Gebre, Y. Deneke, F. Begna, Seroprevalence and associated risk factors of peste des petits ruminants (PPR) in sheep and goats in four districts of bench maji and kafa zones, South west Ethiopia, Glob.Vet 20 (6) (2018) 260–270, https://doi.org/10.5829/idosi.gv.2018.260.270.

[35] M. Gelana, E.Z. Gebremedhin, D. Gizaw, Seroepidemiology of Peste des Petits Ruminants in Sheep and Goats in the selected District of Horu Guduru Zone, Western Ethiopia, Res. Vet. Sci. 132 (2020) 527–534, https://doi.org/10.1016/j.rvsc.2020.07.019.

[36] F. Gizaw, O. Merera, F. Zeru, H. Bedada, M. Gebru, R.D. Abdi, Sero-prevalence and socioeconomic impacts of peste des petits ruminants in small ruminants of selected districts of Afar, Ethiopia, J. Vet. Sci. Technol. 9 (1) (2018) 513, https://doi.org/10.4172/2157-7579.1000513.

[37] G. Hailegebreal, Seroprevalence of peste des petits ruminants in selected districts of siltie and gurage zones, South region, Ethiopia, J. Vet. Sci. Technol. 9 (2) (2018) 529, https://doi.org/10.4172/2157-7579.1000529.

[38] M. Husen, F. Aliyi, S. Damtew, T. Negassa, H. Abebe, Prevalence of small ruminant helminthiases in and around tullo district in western harerghe zone, eastern Ethiopia, Austin J.Vet. Sci. Anim. Husb. 5 (1) (2018) 1–5.

[39] H.M.Z.A. Ibrahim, Sero-prevalence of Pestedes Petits Ruminants Virus (PPRV) Antibodies in Sheep and Goats from North and Central Sudan, Sudan University of Science & Technology, Sudan, 2018. MSc Thesis.

[40] O.M. Ishag, I.K. Saeed, Y.H. Ali, Peste des petits ruminants outbreaks in White Nile, Onderstepoort J. Vet. Res. 82 (1) (2015) 897–900, https://doi.org/10.4102/ojvr.v82i1.897.

[41] M.M. Jalees, I. Hussain, M. Arshad, G. Muhammad, Q.M. Khan, M.S. Mahmood, Occurrence of peste des petits in five districts of Punjab, Pakistan, Pak. Vet. J. 33 (2) (2013) 165–169.

[42] M. Kardjadj, B. Kouidri, D. Metref, P.D. Luka, M.H. Ben-Mahdi, Seroprevalence, distribution and risk factor for peste des petits ruminants (PPR) in Algeria, Prev. Vet. Med. 122 (1–3) (2015) 205–210, https://doi.org/10.1016/j.prevetmed.2015.09.002.

[43] H.A. Khan, M. Siddique, M. Abubakar, M.J. Arshad, M. Hussain, Prevalence and distribution of PPRV infection in small ruminants, Small Rumin. Res. 79 (2008) 152–157.

[44] S.M. Kihu, Risk factors and socioeconomic effects associated with the spread of peste des petits ruminants (PPR) in Turkana County, Kenya, University of Nairobi, Department of Veterinary Pathology, Microbiology and Parasitology, Nairobi, Kenya, 2014. PhD Thesis.

[45] S.M. Kihu, J.M. Gachohi, E.K. Ndungu, G.C. Gitao, L.C. Bebora, N.M. John, Seroepidemiology of Peste des petits ruminants virus infection in Turkana County, Kenya, BMC Vet. Res. 11 (1) (2015) 87, https://doi.org/10.1186/s12917-015-0401-1.

[46] W.G. Dundon, A. Diallo, G. Cattoli, Peste des petits ruminants in Africa : a review of currently available molecular epidemiological data, 2020, Arch. Virol. 165 (10) (2020) 2147–2163, https://doi.org/10.1007/s00705-020-04732-1.

[47] P.D. Luka, J. Erume, F.N. Mwiine, C. Ayebazibwe, Seroprevalence of Peste des petits ruminants Antibodies in Sheep and Goats after Vaccination in Karamoja, Uganda: Implication on Control, Int. J. Anim. Vet. Adv. 3 (1) (2011) 18–22.

[48] S. Lysholm, J.F. Lindahl, M. Munyeme, G. Misinzo, C. Mathew, K. Alvåsen, G. Dautu, S. Linde, L. Mitternacht, E. Olovsson, E. Wilén, M. Berg, J.J. Wensman, Crossing the line: seroprevalence and risk factors for transboundary animal diseases along the Tanzania-Zambia border, Front. Vet. Sci. 9 (2022) 809128, https://doi.org/10.3389/fvets.2022.80912.

[49] S. Mahajan, R. Agrawal, M. Kumar, A. Mohan, N. Pande, Risk of seroconversion to peste des petits ruminants (PPR) and its association with species, sex, age, and migration, Small Rumin. Res. 104 (2012) (2012) 195–200, https://doi.org/10.1016/j.smallrumres.2011.10.009.

[50] Y. Mazengia, Smallholder commercialization of maize production in Guangua district, North Western Ethiopia, World Scientific News 58 (2016) 65–83.

[51] B. Megersa, D. Biffa, T. Belina, E. Debela, A. Regassa, F. Abunna, T. Rufael, S.M. Stubsjøen, E. Skjerve, Serological investigation of Peste des Petits Ruminants (PPR) in small ruminants managed under pastoral and agro-pastoral systems in Ethiopia, Small Rumin. Res. 97 (2011) 134–138.
[52] A.O. Mbyuzi, E.V.G. Komba, S.I. Kimera, D.M. Kambarage, Sero-prevalence and associated risk factors of peste des petits ruminants and contagious caprine pleuro-pneumonia in goats and sheep in the Southern Zone of Tanzania, Prev. Vet. Med. 116 (2014) 138–144.
[53] M. Munir, Role of wild small ruminants in the epidemiology of peste des petits ruminants, Transbound.Emerg. Dis. 61 (5) (2014) 411–424, https://doi.org/10.1111/tbed.12052.
[54] K. Nigusu, T. Fentie, Prevalence and causes of selected respiratory infections in indigenous Gumuz sheep in metema district, northwest Ethiopia, Int. J. Sci. Basic Appl. Res. 5 (1) (2012) 14–20.
[55] A.R. Nizamani, Z.A. Nizamani, A.P. Umrani, P. Dewani, M.A. Vandiar, J.A. Gandahi, N.M. Soomro, Prevalence of peste des petits ruminants virus antibodies in small ruminants in Prevalence of PPR-virus antibodies in Sindh, Pakistan, J. Anim.Plant Sci. 25 (6) (2015) 1515–1519.
[56] J.J. Nkangaga, Disease status and risk factors for Peste des Petits Ruminants along the Tanzania-Burundi and the democratic republic of Congo border, The Sokoine University of Agriculture, Morogoro, Tanzania, 2014. MSc Thesis.
[57] OIE, Peste Des Petits Ruminants: aetiology, epidemiology, diagnosis, prevention and control references. OIE Technical Disease Cards, World Organisation for Animal Health, 2020, pp. 1–16.
[58] A. Ozkul, Y. Akca, F. Alkan, T. Barrett, T. Karaoglu, S.B. Dagalp, J. Anderson, K. Yesilbag, C. Cokcaliskan, A. Gencay, I. Burgu, Prevalence, distribution, and host range of Peste des Petits ruminants virus in Turkey, Emerg. Infect. Dis. 8 (7) (2002) 708–712.
[59] P.K. Rath, S.K. Panda, B.P. Mishra, D.K. Karna, G. Sahoo, U.K. Mishra, R.C. Patra, Epidemiological risk factor analysis in goats and sheep naturally infected with Peste des petits ruminants virus, J. Entomol. Zool. Stud. 8 (3) (2020) 546–549.
[60] P.G. Rudra, Prevalence and Molecular Characterization of Peste Des Petits Ruminants (PPR) in Goat Pran Gopal Rudra, Chattogram Veterinary and Animal Sciences University, Department of Medicine and Surgery, Chittagong, Bangladesh, 2019. MSc Thesis.
[61] V.N. Rume, S.C. Bodjo, B. Gurja, J.D.D. Baziki, D. Adama, P. Ankeli, N.D. Nwankpa, D. Yebchaye, T.S. Tessema, Sero-epidemiology of peste des petits ruminants in Oromia and Afar regional states of Ethiopia, Rev. Sci. Tech.-Off. Int.Epizoot. 39 (3) (2020) 863–870.
[62] F.A. Saeed, S.A. Abdel-Aziz, M.M. Gumaa, Seroprevalence and Associated Risk Factors of Peste des Petits Ruminants among Sheep and Goats in Kassala State, Sudan, Open J. Anim. Sci. 8 (2018) 381–395, https://doi.org/10.4236/ojas.2018.84029.
[63] K.I. Saeed, Y.H. Ali, A.I. Khalafalla, E.A. Rahman-Mahasin, Current situation of Peste des petits ruminants (PPR) in the Sudan, Trop. Anim. Health Prod. 42 (2010) 89–93.
[64] H.A.M.E. Salih, A.A.M. Elfadil, I.K. Saeed, Y.H. Ali, Sero-prevalence and risk factors of Peste des Petits Ruminants in sheep and goats in Sudan, J.Adv.Vet. Anim. Res. 1 (2) (2014) 42–49.
[65] H. Abesha, Y. Teshome, Y.A. Ferede, H. Dejene, Z.T. Seyoum, A. Assefa, Seroepidemiology of peste des petits ruminants virus in small ruminants in selected districts in Northwest Ethiopia, Vet. Med. Sci. 9 (2022) 884–890, https://doi.org/10.1002/vms3.994.
[66] Y.A. Shuaib, A.A.M. El-Fadil, M.E. Abdel-Rahman, H. Negussie, K.H. Zessin, Seroprevalence and risk factors of Peste des petits ruminants in sheep in the Kassala and North Kordofan States of the Sudan, Int. J. Vet. Sci. 3 (1) (2014) 18–28.
[67] E.S. Swai, A. Kapaga, F. Kivaria, D. Tinuga, G. Joshua, P. Sanka, Prevalence and distribution of Peste des petits ruminants virus antibodies in various districts of Tanzania, Vet. Res. Commun. 33 (2009) 927–936.
[68] M. Thrusfield, Veterinary Epidemiology, second ed., Blackwell Science, Oxford, 2005, pp. 117–198.
[69] A.E. Fine, M. Pruvot, C.T.O. Benfield, A. Caron, G. Cattoli, P. Chardonnet, M. Dioli, T. Dulu, M. Gilbert, R. Kock, J. Lubroth, J.C. Mariner, S. Ostrowski, S. Parida, S. Fereidouni, E. Shiilegdamba, J.M. Sleeman, C. Schulz, J.J. Soula, Y. Van der Stede, B.G. Tekola, C. Walzer, S. Zuther, F. Njeumi, meeting Participants, Eradication of Peste des Petits Ruminants Virus and the Wildlife-Livestock Interface, Front. Vet. Sci. 7 (2020) 50, https://doi.org/10.3389/fvets.2020.00050.
[70] A. Waret-szkuta, F. Roger, D. Chavernac, L. Yigezu, G. Libeau, D.U. Pfeiffer, J. Guitián, Peste des Petits Ruminants (PPR) in Ethiopia : Analysis of a national serological survey, BMC Vet. Res. 4 (2008) 34, https://doi.org/10.1186/1746-6148-4-34.
[71] G. Woldemichael, A. Aki, K. Gurmessa, Study on Seroprevalence and risk factor of Peste des Petitis ruminant disease in Small Ruminant at Metekel zone of selected District in Benishangul Gumuz Regional State, Western Ethiopia, Rep. Opinion 10 (8) (2018) 56–65.
[72] A. Wondim, Outbreak Investigation and Molecular Detections of Pox Virus Circulating in Sheep and Goats in Selected Districts of West Gojjam and Awie Zones Northwest, Ethiopia, Bahardar University, College of Agriculture and Environmental Science, Bahardar, Ethiopia, 2019. MSc Thesis.
[73] T.Y. Woma, P.S. Ekong, D.G. Bwala, J.O. Ibu, L. Ta'ama, D.Y. Dyek, Sero-survey of peste des petits ruminants virus in small ruminants from different agroecological zones of Nigeria, Onderstepoort J. Vet. Res. 83 (1) (2016) 1035, https://doi.org/10.4102/ojvr.v83i1.1035.
[74] S. Yalew, G. Woldemichal, M. Mamo, Seroprevalence of peste des petits ruminants virus antibody in assosa zone, benishangulgumuz region, Ethiopia, ARC J. Anim. Vet. Sci. 5 (3) (2019) 29–33.
[75] U. Yasin, B. Wodajnew, D. Tsehaineh, Study on the prevalence of GIT nematode infection of small ruminants in kurmuk woreda, assosa zone of Benishangul Gumuz region, western Ethiopia, Rep. Opinion 9 (10) (2017) 48–59.
[76] A.B. Zahur, H. Irshad, M. Hussain, A. Ullah, M. Jahangir, M. Qasim Khan, M. Sabir Farooq, The epidemiology of peste des petits ruminants in Pakistan, Rev.Sci. Techn. 27 (3) (2008) 877–884, https://doi.org/10.20506/rst.27.3.1848.