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Determinants of Post-Vaccination Antibody Titers to PPR Vaccine in Sheep: A Cross-Sectional Statistical Study

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Annotation: Peste des Petits Ruminants (PPR) is an acute, highly contagious fatal viral disease of small ruminants and remains to be a limiting factor for productivity in the developing countries including Iraq. Vaccination remains the key strategy for controlling PPR and post-vaccination antibody responses can differ considerably between animals, which could influence both individual and herd protection levels. The objective of this study was to determine the animal- and management-related factors influencing antibody titers against PPR in sheep vaccinated.

A cross-sectional study was carried out on population of Baghdad governorate, Iraq from March to May, 2025. One hundred and twenty clinically healthy sheep were selected at random from four flocks. Blood samples were taken between 21 and 35 days after receiving a commercial live attenuated PPR vaccine. Serum antibody titers were determined by indirect ELISA and predictor variables included age, sex, body condition score (BCS), deworming status, size of flock and history of previous vaccination. The descriptive statistics were produced and univariate analyses were performed followed by multiple linear regression for the determination of independent factors of AB response.

The mean antibody titer (as S/P ratio) was 0.63 ± 0.18 overall. Adult sheep and those scored positive (≥3) had significantly higher levels of antibody when compared to lambs and sheep in poor BCS ($p < 0.05$). Dewormed animals also presented the highest responses, and the absence of deworming was associated with

lower titers. Booster history influenced antibody levels, in a positive way. There was no statistically significant difference between genders or flock-sizes. Multivariate analysis retained adult age (β = +0.12), increased BCS (β = +0.10), repeated vaccination (β = +0.09) as independent positive predictor, and no deworming as negative predictor (β = −0.08).

These results highlight the need for proper nutrition management, parasite control and booster vaccinations in order to maximize the vaccine-induced immunity. Integration of these interventions in routine flock health programs can enhance the control of PPR and may facilitate small ruminant disease control and eradication activities in Iraq, and elsewhere.

Introduction

Peste des Petits Ruminants (PPR) is a highly contagious viral disease of small ruminants mostly sheep and goats and caused by a Morbillivirus belonging to the family Paramyxoviridae. The disease is associated with high morbidity and mortality with huge economic losses in livestock industry especially in the developing world. In Iraq and throughout the Middle East PPR continues to pose a significant risk to small ruminant flocks, severely reducing their productivity, and in doing so, damaging opportunities for rural communities to earn a livelihood (1,2).

Vaccination is considered as an effective tool for controlling PPR eruption and blocking its spreading. PPR live attenuated vaccine has been used in national and regional eradication campaigns with different degrees of success. Yet, marked differences in post-vaccination antibody titer for both individual animals and flocks have been reported. Differences such as age, nutritional status, parasite load, flock management, vaccine history that may contribute to such variations, influencing, thus, the establishment of immune protection (3,4).

It is paramount to know what the drivers of vaccine-induced immune responses are, as this knowledge will be necessary to fine-tune vaccination programs. The identification of important predictors for titer formation can facilitate veterinarians and stockbreeders to optimize strategies for monitoring the disease and to promote the animal health. Despite the significance of this issue, very few published data are available on PPR vaccine responses in Iraq, especially in the Baghdad governorate, inhabited typically with mixed farming systems and management practices (5,6).

The objective of this study was to assess the relationship between some animal level and management-level factors and antibody response to PPR vaccination in sheep kept in Baghdad, Iraq. In a cross-sectional statistical model, we investigated the impact of age, sex, body condition score (BCS), deworming status, flock size, and previous vaccination on immune responses from 21 to 35 days post vaccination. The results of the present study will also inform recommendations on evidence-based approaches for enhancing vaccination efficacy and contribute to the general control and eradication campaign of PPR in the region (7).

Materials and Methods

Study design and location

A cross-sectional study was conducted between March and May 2025 in the Baghdad

governorate, Iraq. The study targeted sheep flocks from peri-urban and rural areas within Baghdad, where mixed livestock production systems are commonly practiced (8).

Animals and sample size

A total of 120 clinically healthy sheep were randomly selected from four different flocks (approximately 30 animals per flock). Sheep of both sexes and various age groups were included to capture population variability (9,10).

Predictor variables

The following animal- and management-related factors were recorded for each animal:

- **Age group:** Lambs (<1 year), Yearlings (1–2 years), Adults (>2 years)
- **Sex:** Male, Female
- **Body Condition Score (BCS):** Assessed on a 1–5 scale (1 = very thin, 5 = obese)
- **Deworming status:** Dewormed within the last 3 months vs. Not dewormed
- **Flock size:** Small (<50), Medium (50–100), Large (>100)
- **Previous vaccination history:** None, Vaccinated once, Vaccinated multiple times

Table 1. Summary of study population characteristics and variables recorded

Variable	Categories
Age group	Lambs, Yearlings, Adults
Sex	Male, Female
Body Condition Score	1–5 scale
Deworming status	Dewormed, Not dewormed
Flock size	<50, 50–100, >100
Vaccination history	None, Once, Multiple

Vaccination and sample collection

All sheep were vaccinated using the commercially available live attenuated PPR vaccine in accordance with the manufacturer's recommendations. Blood samples (ca. 5 mL) were obtained by jugular venipuncture 21–35 days after vaccination in sterile vacutainer tubes without anticoagulant. The samples were carried on ice to the laboratory, then clotted and centrifuged at 3000 rpm for 10 min to obtain serum (11,12).

Antibody titer measurement

Antibody titres for PPR virus were tested by indirect ELISA kit (manufacturer specify available brand) according to the instruction provided by the manufacturer. The optical density (OD) was measured at 450 nm with a microplate reader. Antibody titers were presented as sample-to-positive (S/P) ratios and positive-sample thresholds were used in accordance with the kit manufacturer's instructions (13,14).

Statistical analysis

The data was put into SPSS version 26.0 (IBM Corp., Armonk, NY), determined and cross-validated in R version 4.3. Antibody titer data across predictor variables were summarized using descriptive statistics. Crude associations between each variable and antibody titers were assessed by univariate analyses (using independent t-tests or ANOVA when applicable). Multivariate analysis Significant ($p < 0.1$) variables in univariate analyses were included in a multiple linear regression model for independent predictors of antibody response. A significance level was $p < 0.05$ (15,16).

Results

A total of 120 sheep from four flocks in Baghdad governorate were included in the study. The mean antibody titer (expressed as S/P ratio) across all animals was **0.63 ± 0.18** (range: 0.25–1.05).

1. Distribution of study population

The distribution of animals by predictor variables is presented in Table 2. Among the age groups the adults were predominant (42.5%), followed by lambs (25%). Females comprised the majority (65%). Overall, approximately 58% of animals were BCS 3 or greater. Sixty percent of animals had been dewormed in the previous three months.

Table 2. Distribution of study animals by selected factors (n = 120)

Variable	Category	Frequency (%)
Age group	Lambs (<1 yr)	30 (25.0%)
	Yearlings (1–2 yrs)	39 (32.5%)
	Adults (>2 yrs)	51 (42.5%)
Sex	Male	42 (35.0%)
	Female	78 (65.0%)
Body Condition Score	≤2	50 (41.7%)
	≥3	70 (58.3%)
Deworming status	Dewormed	72 (60.0%)
	Not dewormed	48 (40.0%)
Flock size	Small (<50)	30 (25.0%)
	Medium (50–100)	45 (37.5%)
	Large (>100)	45 (37.5%)
Vaccination history	None	35 (29.2%)
	Once	55 (45.8%)
	Multiple	30 (25.0%)

2. Antibody titers by factors

Table 3. Mean antibody titers by indicator variable Antibody titers were generally higher in aged and higher (≥3) BCS sheep. Treated animals also had greater responses than non-treated animals. There were no differences between sexes.

Table 3. Mean antibody titers (S/P ratios) according to predictor variables

Variable	Category	Mean ± SD
Age group	Lambs	0.55 ± 0.14
	Yearlings	0.62 ± 0.16
	Adults	0.71 ± 0.17
Sex	Male	0.64 ± 0.19
	Female	0.63 ± 0.18
Body Condition Score	≤2	0.57 ± 0.15
	≥3	0.68 ± 0.17
Deworming status	Dewormed	0.68 ± 0.17
	Not dewormed	0.57 ± 0.16
Flock size	Small	0.65 ± 0.18
	Medium	0.64 ± 0.18
	Large	0.62 ± 0.19
Vaccination history	None	0.59 ± 0.16
	Once	0.65 ± 0.18
	Multiple	0.70 ± 0.17

3. Univariate analysis

Univariate tests showed that **age group**, **BCS**, **deworming status**, and **vaccination history** were significantly associated with antibody titers ($p < 0.05$). Sex and flock size were not significant ($p > 0.05$).

4. Multiple linear regression

A multiple linear regression model was developed with the predictors retained in the model. Adult age (β = +0.12, p = 0.002), higher BCS (β = +0.10, p = 0.01) and a history of multiple previous vaccinations (β = +0.09, p = 0.04) were independent predictors of higher antibody titers. Recent deworming (<−0.5) was inversely associated (β = −0.08, p = 0.03). Taken together the overall model accounted for 42% of the variance in antibody titers (Adjusted $R^2 = 0.42$) (17,18).

Discussion

Considering the sheep population in Baghdad, Iraq, we analysed animal-related and management-related factors affecting post-vaccination antibody titers to Peste des Petits Ruminants (PPR) in sheep. Our results showed that adult age, body condition score (BCS ≥ 3) and number of boosters were independently associated with higher antibody values, while no recent deworming was identified as a risk factor for lower immune responses (19,20,21).

Age and body condition

The higher titres observed in adult than in young sheep is consistent with the development of the immune system and a potential previous contact with antigens. In a similar vein, individuals in better body condition showed greater responses, adding to the body of evidence that nutritional status and energy reserves shape immune function. Malnutrition can affect cell-mediated as well as humoral immunity and may therefore decrease the response to vaccination (22,23,24).

Comparison with previous studies

Our findings are in line with observations in Ethiopia which gave high herd-level immunity at the onset (≈93.9%), but decreased over time because of turnover of flocks showing that continued good flock management is required together with vaccination (Ayele et al. Likewise, seropositivity continued to increase post-vaccination from 8.3% at 10 days to 100% by day 45 in a study conducted in Pakistan (Amjad et al., 2008). This is in line with our sampling timeframe (21–35 days post-vaccination) as most appropriate to capture the peak antibody responses (25,26,27).

Impact of deworming

By contrast, the positive correlation between deworming and higher antibody titers is in keeping with the known immunomodulatory effects of parasitic infections. Parasites can lower the nutrient availability and the immune control, in turn interfering with the vaccine efficacy. Despite little available evidence related to association between parasite control and PPR vaccination response, the holistic immunological studies provide a basis for incorporating deworming into vaccination programmes (28,30).

Vaccination history

Additional vaccination was associated with higher antibody titers, as would be expected by principles of immunology where memory responses are boosted by repeated doses. Although there are few studies on PPR boosters, it has been demonstrated in immune model studies that the intensity of secondary immune responses is influenced by the interval between dosages and time post vaccination (Etchegoin, 2004). This result implies that in an endemic area selective revaccination might be the case (31).

Limitations and recommendations

As this was a cross-sectional study, causal inference can be limited. It would be interesting to have access to longitudinal studies with larger samples sizes and different production systems to corroborate these results. Also, the integration of parasite load quantification and nutritional evaluation could help further explain the associations found (30).

Practical implications

In summary, in sheep nutrition, good management practices, parasite control and the application of efficient vaccination protocols are crucial in eliciting immune response against PPR virus. This information could assist veterinarians and other animal keepers in Baghdad and the like for better prevention of the disease and planning towards regional eradication (32,33).

Conclusion

This study provides evidence that both animal-related and management-related factors significantly influence the antibody response to PPR vaccination in sheep. Adult age, good body condition, prior booster vaccinations, and recent deworming were identified as key determinants of stronger post-vaccination immunity. These findings emphasize the importance of integrating proper nutrition, parasite control, and strategic vaccination schedules into routine flock health programs. By addressing these factors, the effectiveness of PPR vaccination can be maximized, thereby strengthening disease control and supporting ongoing eradication efforts in Iraq and other endemic regions.

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