Monitoring and Analysis of Antibody Levels and Immunization Efficacy for Five Major Diseases in Large-scale Pig Farms

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Abstract [**Objectives**] This study was conducted to evaluate the immunization efficacy and infection status of classical swine fever (CSF), foot-and-mouth disease (FMD), porcine reproductive and respiratory syndrome (PRRS), pseudorabies (PR), and porcine circovirus type 2 (PCV2) in large-scale pig farms. [**Methods**] Antibody and pathogen detection was performed on 56 serum samples collected in March 2025. [**Results**] The antibody qualification rates for CSF, FMD, and PRRS were 76.8%, 73.2%, and 76.8%, respectively, all meeting the national standards. However, nursery pigs exhibited an immunity gap, indicating a need for timely booster vaccinations. No PRV gE antibodies or PCV2 antibodies were detected, reflecting the absence of vaccination against these diseases and suggesting significant effectiveness of comprehensive biosecurity measures. The low antibody qualification rate for PRRS in the nursery stage highlights the need for improved immunization management. [**Conclusions**] This study provides data support and practical insights for integrated disease prevention and control in large-scale pig farms.

Key words Antibody detection; Pathogen detection; Immune analysis; Prevention and control research
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China is a major animal farming country, accounting for half of the global pig inventory. However, the level of disease control remains relatively low, with multiple epidemics prevalent, posing severe challenges to prevention and control efforts[1]. Intensive farming practices in large-scale operations can lead to declined animal constitution, increased cross-infection, and accelerated disease transmission, thereby complicating epidemic containment[2]. Currently, classical swine fever (CSF), foot-and-mouth disease (FMD), porcine reproductive and respiratory syndrome (PRRS), pseudorabies (PR), and porcine circovirus type 2 (PCV2) represent five critical infectious diseases threatening intensive pig farms in China, significantly impacting the swine industry. With rising farming density, the risk of disease spread intensifies, frequently resulting in mixed infections and complex clinical presentations, which limit the effectiveness of traditional single-intervention strategies. Therefore, implementing dynamic serological and pathogen surveillance to develop science-based prevention and control strategies is of paramount importance[3]. This study aims to evaluate immunization efficacy and infection status by conducting antibody and pathogen testing across different pig groups in a large-scale farm, thereby providing a scientific basis for disease prevention and control.

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Materials and Methods

Sample source and collection

In March 2025, samples were collected from a large-scale pig farm in Guizhou Province. Using a random sampling method, 56 blood samples were collected from clinically healthy pigs, covering key production stages including boars, pregnant sows (early, mid, and late gestation), non-pregnant sows, lactating sows, nursery piglets, post-nursery piglets, finishing pigs, and replacement gilts. All blood samples were collected from the jugular vein or anterior vena cava into sterile vacuum blood collection tubes. After standing at room temperature for 2 h, the samples were centrifuged at 3 000 r/min for 10 min at 4 ℃ to separate serum. The serum was aliquoted and stored at −20 ℃ for subsequent testing.

Main reagents and instruments

Main reagents Classical swine fever virus antibody test kit (Blocking ELISA, IDEXX Laboratories, USA); porcine reproductive and respiratory syndrome virus antibody test kit (ELISA, IDEXX Laboratories, USA); foot-and-mouth disease (type O) vaccine antibody and foot-and-mouth disease virus non-structural protein 3ABC antibody test kit (Blocking ELISA, IDEXX Laboratories, USA); pseudorabies virus gE antibody test kit (ELISA, SVANOVA, Switzerland); porcine circovirus type 2 antibody test kit (ELISA, GENETBIO, Korea).

Main instruments Multifunction microplate reader (Synergy

H1, BioTek, USA); fluorescence quantitative PCR system (CFX96 Touch, Bio-Rad, USA); benchtop high-speed refrigerated centrifuge (ST16R, Thermo Fisher, Germany); biological safety cabinet (BSC-1100IIA2, Anhui Aerospace Bion Technology Co., Ltd., China); nucleic acid electrophoresis system (JY-600E); horizontal electrophoresis tank (JY-SPCT, Beijing Junyi Dongfang); gel imaging system (G:BOX F3, Syngene, UK); vortex mixer (VM200, Beijing Tuomoqin); mini shaker (MH-1, Haimen Qilinbeier, China); ultrapure water system (Milli-Q Integral 3, Merck Millipore, France).

Testing methods

Diluted serum samples and controls were added to the pre-coated 96-well plate and incubated at 37 ℃ for 60 min in a constant temperature incubator. Using a plate washer, washing buffer was added to soak the wells for 30 s before aspiration. This washing step was repeated five times. The plate was then patted dry on absorbent paper. Enzyme-conjugated antibody was added to each well, and the plate was incubated at 37 ℃ for 30 min. After incubation, the washing procedure was repeated five times. Substrate solution (TMB) was then added to each well, and the plate was incubated at 37 ℃ in the dark for 15 min for color development. Stop solution was added to each well, and after gentle mixing, the optical density (OD) values of each well were immediately measured at the appropriate reference wavelength using a microplate reader. The S/P value, inhibition rate, or S/N value of each sample was calculated according to the kit's formula, and results were analyzed based on the established criteria. Through the aforementioned standardized procedures and evaluation criteria, the immune antibody levels and infection status of PRR, CSF, and PRV-gE could be be assessed.

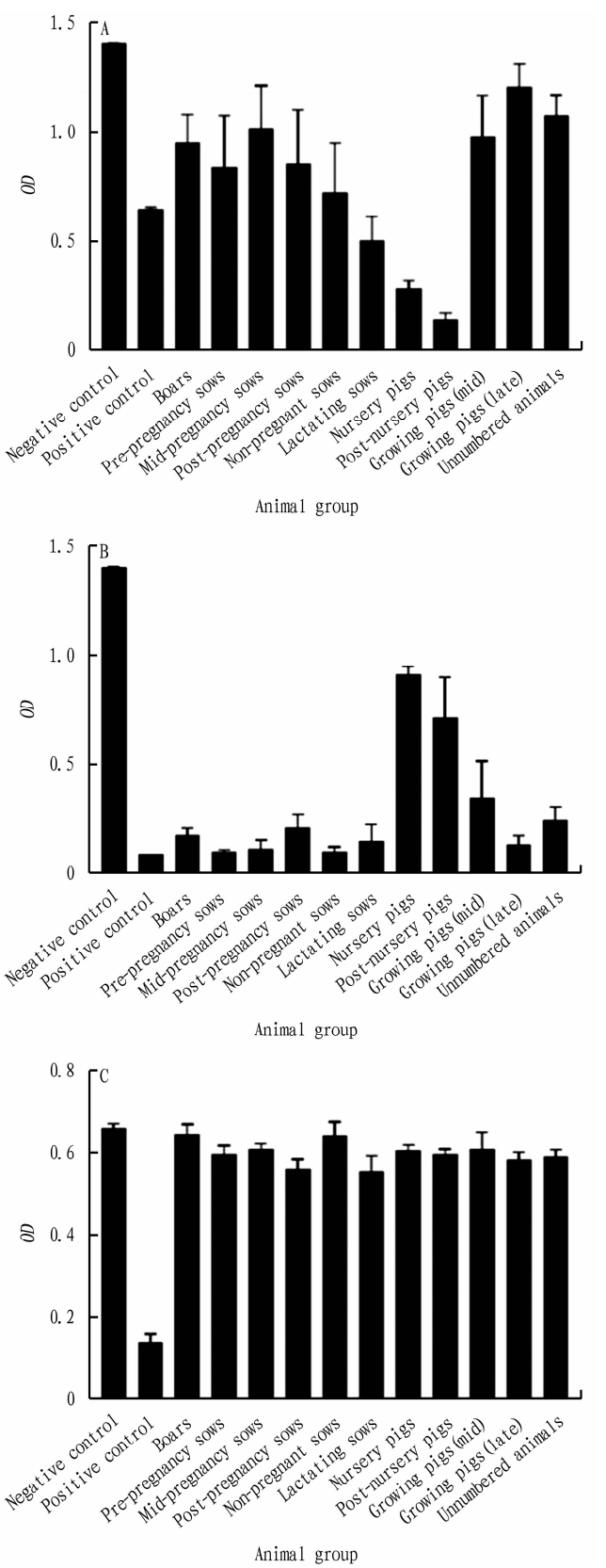
Results and Analysis

Antibody detection results

PRRS, CSF and PRV-gE antibody detection results ELISA testing revealed an overall PRRS antibody qualification rate of 76.8%. Boars, mid-to-late gestation sows, and finishing pigs achieved a 100% qualification rate, while early gestation and non-pregnant sows reached 75%. In contrast, nursery piglets showed a rate of only 41.7%, and post-nursery piglets dropped to 0%. The coefficient of variation (CV) ranged from 16.0% to 68.9%, indicating uneven antibody levels among nursery piglets and highlighting the need for timely booster immunization.

The overall CSF antibody qualification rate was 76.8%. Boars, sows at all stages, and replacement gilts achieved 100% qualification, while mid-finishing pigs reached 75%. However, nursery piglets showed a rate of only 16.67%, improving to 50% in the post-nursery stage. The high CV (25.3% –46.0%) suggested suboptimal immunization efficacy in nursery piglets.

No PRV-gE antibodies were detected (0%). Combined with farm records, this confirmed the farm's status as a PRV-free herd without gE vaccination. The CV ranged from 3% to 11.4% across boars, sows, finishing pigs, and replacement gilts, demonstrating effective PRV control in this large-scale farm (Fig. 1, Table 1).



A. PRRS antibody (ELISA); B. CSFV antibody (Blocking ELISA); C. PRV-gE antibody (gE-ELISA).

Fig. 1 Analysis of antibody detection for three diseases

Table 1 Detection results of PRRS, CSF and pseudorabies gE antibodies in large-scale pig farms

Animal group	PRRS antibody (ELISA)			CSF antibody (Blocking ELISA)			PRV-gE antibody (gE-ELISA)		
	OD value	S/P	Result	*OD* value	Blocking rate//%	Results	*OD* value	S/N	Result
Negative control	0.067	–	–	1.407	–	–	0.65	–	–
	0.065	–	–	1.404	–	–	0.67	–	–
Positive control	0.654	–	–	0.090	–	–	0.158	–	–
	0.636	–	–	0.091	–	–	0.119	–	–
Boars	0.683	1.066	Positive	0.214	85	Positive	0.678	1.027	Negative
	0.842	1.34	Positive	0.141	90	Positive	0.558	0.845	Negative
	0.711	1.114	Positive	0.215	85	Positive	0.683	1.035	Negative
	1.299	2.13	Positive	0.056	96	Positive	0.668	1.012	Negative
	1.216	1.986	Positive	0.264	81	Positive	0.639	0.968	Negative
Pre-pregnancy sows	1.34	2.2	Positive	0.087	94	Positive	0.592	0.897	Negative
	0.269	0.351	Negative	0.089	94	Positive	0.54	0.818	Negative
	1.091	1.77	Positive	0.11	92	Positive	0.616	0.933	Negative
	0.652	1.012	Positive	0.122	91	Positive	0.64	0.97	Negative
Mid-pregnancy sows	0.567	0.865	Positive	0.077	95	Positive	0.597	0.905	Negative
	0.814	1.292	Positive	0.237	83	Positive	0.65	0.985	Negative
	1.392	2.29	Positive	0.069	95	Positive	0.599	0.908	Negative
	1.288	2.111	Positive	0.079	94	Positive	0.597	0.905	Negative
Post-pregnancy sows	0.555	0.845	Positive	0.263	81	Positive	0.59	0.894	Negative
	1.453	2.396	Positive	0.129	91	Positive	0.528	0.8	Negative
	0.345	0.482	Positive	0.127	91	Positive	0.52	0.788	Negative
	1.051	1.701	Positive	0.354	75	Positive	0.608	0.921	Negative
Non-pregnant sows	0.225	0.275	Negative	0.117	92	Positive	0.577	0.874	Negative
	1.052	1.703	Positive	0.051	96	Positive	0.641	0.971	Negative
	0.466	0.691	Positive	0.125	91	Positive	0.727	1.102	Negative
	1.144	1.862	Positive	0.126	91	Positive	0.627	0.95	Negative
Lactating sows	0.609	0.938	Positive	0.075	95	Positive	0.594	0.9	Negative
	0.389	0.558	Positive	0.23	84	Positive	0.514	0.779	Negative
Nursery pigs	0.237	0.295	Negative	1.026	27	Negative	0.671	1.017	Negative
	0.098	0.055	Negative	0.971	31	Suspicious	0.635	0.962	Negative
	0.447	0.658	Positive	0.955	32	Suspicious	0.653	0.989	Negative
	0.1	0.059	Negative	0.972	31	Suspicious	0.628	0.952	Negative
	0.383	0.547	Positive	1.058	25	Negative	0.583	0.883	Negative
	0.333	0.461	Positive	0.872	38	Suspicious	0.565	0.856	Negative
	0.399	0.575	Positive	0.599	57	Positive	0.581	0.88	Negative
	0.218	0.263	Negative	0.913	35	Suspicious	0.604	0.915	Negative
	0.266	0.345	Negative	0.938	33	Suspicious	0.602	0.912	Negative
	0.419	0.61	Positive	1.031	27	Negative	0.594	0.9	Negative
	0.258	0.332	Negative	0.907	35	Suspicious	0.541	0.82	Negative
	0.236	0.294	Negative	0.729	48	Positive	0.643	0.974	Negative
Post-nursery pigs	0.145	0.136	Negative	0.399	72	Positive	0.624	0.945	Negative
	0.126	0.104	Negative	1.018	28	Negative	0.6	0.909	Negative
	0.212	0.252	Negative	0.406	71	Positive	0.573	0.868	Negative
	0.072	0.01	Negative	1.056	25	Negative	0.6	0.909	Negative
Growing pigs (mid)	0.809	1.283	Positive	0.156	89	Positive	0.665	1.008	Negative
	0.526	0.794	Positive	0.195	86	Positive	0.671	1.017	Negative
	1.367	2.247	Positive	0.179	87	Positive	0.605	0.917	Negative
	1.199	1.957	Positive	0.856	39	Suspicious	0.498	0.755	Negative
Growing pigs (late)	1.2	1.959	Positive	0.247	82	Positive	0.54	0.818	Negative
	1.013	1.636	Positive	0.121	91	Positive	0.57	0.864	Negative

(Continued)

(Table 1)

Animal group	PRRS antibody (ELISA)			CSF antibody (Blocking ELISA)			PRV-gE antibody (gE-ELISA)		
	OD value	S/P	Result	*OD* value	Blocking rate//%	Results	*OD* value	S/N	Result
Unnumbered animals	1.104	1.793	Positive	0.122	91	Positive	0.579	0.877	Negative
	1.497	2.472	Positive	0.047	97	Positive	0.64	0.97	Negative
	1.291	2.116	Positive	0.297	79	Positive	0.615	0.932	Negative
	1.091	1.77	Positive	0.179	87	Positive	0.619	0.938	Negative
	1.134	1.845	Positive	0.628	55	Positive	0.521	0.789	Negative
	1.35	2.218	Positive	0.182	87	Positive	0.569	0.862	Negative
	0.696	1.088	Positive	0.181	87	Positive	0.56	0.848	Negative
	1.204	1.965	Positive	0.206	85	Positive	0.654	0.991	Negative
	1.301	2.133	Positive	0.41	71	Positive	0.63	0.955	Negative
	1.048	1.696	Positive	0.064	95	Positive	0.529	0.802	Negative
	0.555	0.845	Positive	0.081	94	Positive	0.631	0.956	Negative
Total		Pass rate	76.8%		Pass rate	76.8%			

No PRV-gE antibodies were detected in the herd without gE vaccination.

ELISA-based diagnostic criteria were applied as follows: for PRRS antibody detection, samples with S/P <0.3 were considered negative, S/P $\geqslant 0.4$ positive, and $0.3 < S/P < 0.4$ suspicious. For CSF antibody blocking ELISA, a blocking rate $\geqslant$40% indicated positivity, $\leqslant$30% negativity, and 30% < blocking rate < 40% suspicion. For PRV-gE antibody ELISA, S/N $\leqslant 0.5$ defined positivity, S/N >0.6 negativity, and $0.5 < S/N < 0.6$ suspicion.

Table 2 Analysis of porcine reproductive and respiratory syndrome (PRRS) antibody positive rate

Category	Boars	Pre-pregnancy sows	Mid-pregnancy sows	Post-pregnancy sows	Non-pregnant sows	Lactating sows	Nursery pigs	Post-nursery pigs	Growing pigs (mid)	Growing pigs (late)	Unnumbered animals
Positive rate//%	100.00	75.00	100.00	100.00	75.00	100.00	41.70	0	100.00	100.00	100.00
CV//%	29.20	53.20	35.60	55.00	59.00	25.40	51.30	68.90	36.20	16.00	18.90
S/P value	1.527	1.333	1.64	1.356	1.133	0.748	0.375	0.126	1.57	1.965	1.876

Based on the farm's actual conditions and the table data, the PRRS antibody qualification rates reached 100% in boars, mid-late gestation sows, non-pregnant sows, suckling piglets, mid-finishing pigs, late-finishing pigs, and unmarked replacement gilts, indicating effective immunization and stable antibody levels. However, the qualification rate was only 75.0% in early-gestation sows and weaned sows (non-pregnant pens), suggesting moderate immunization efficacy though still within the protective range. Notably, the nursery stage showed a critically low qualification rate of 41.7%, while post-nursery pigs dropped to 0%, highlighting an urgent need for booster vaccination.

Table 3 Analysis of classical swine fever (CSF) antibody positive rate

Indicator	Boars	Pre-pregnancy sows	Mid-pregnancy sows	Post-pregnancy sows	Non-pregnant sows	Lactating sows	Nursery pigs	Post-nursery pigs	Growing pigs (mid)	Growing pigs (late)	Unnumbered animals
Positive rate//%	100.00	100.00	100.00	100.00	100.00	100.00	16.67	50.00	75.00	100.00	100.00
CV//%	5.90	1.40	5.50	8.10	2.20	6.10	25.30	46.00	27.80	5.90	14.10
Blocking rate//%	87.4	92.75	91.75	84.5	92.5	89.5	34.917	49	75.25	90.25	78.714

Based on the farm's actual conditions and the table data, the overall CSF immunization antibody qualification rate was 76.8% (43/56). Boars, sows in early/mid/late gestation, non-pregnant sows, suckling piglets, finishing pigs, and unmarked replacement gilts all achieved a 100% qualification rate, indicating excellent immunization efficacy and stable antibody levels. However, mid-finishing pigs showed a 75.0% qualification rate with one suspicious case, reflecting acceptable but suboptimal immunity. Critically, nursery-stage piglets had only a 16.67% qualification rate (with six suspicious cases), while post-nursery piglets reached 50.0%, both failing to meet the national standard of $\geqslant$70% qualification. The high discrete degree further confirmed poor immunization efficacy in nursery-stage piglets, highlighting the urgent need for booster vaccination[4].

Based on the farm's actual conditions, this large-scale pig farm has never implemented pseudorabies vaccination, and no clinical cases of pseudorabies virus infection have been observed. As shown in the table, serological antibody testing revealed zero PRV-gE antibodies across all pig groups, indicating effective control of pseudorabies disease risks through comprehensive biosecurity measures. This underscores the importance of consistently sourcing breeding stock from pseudorabies-free farms.

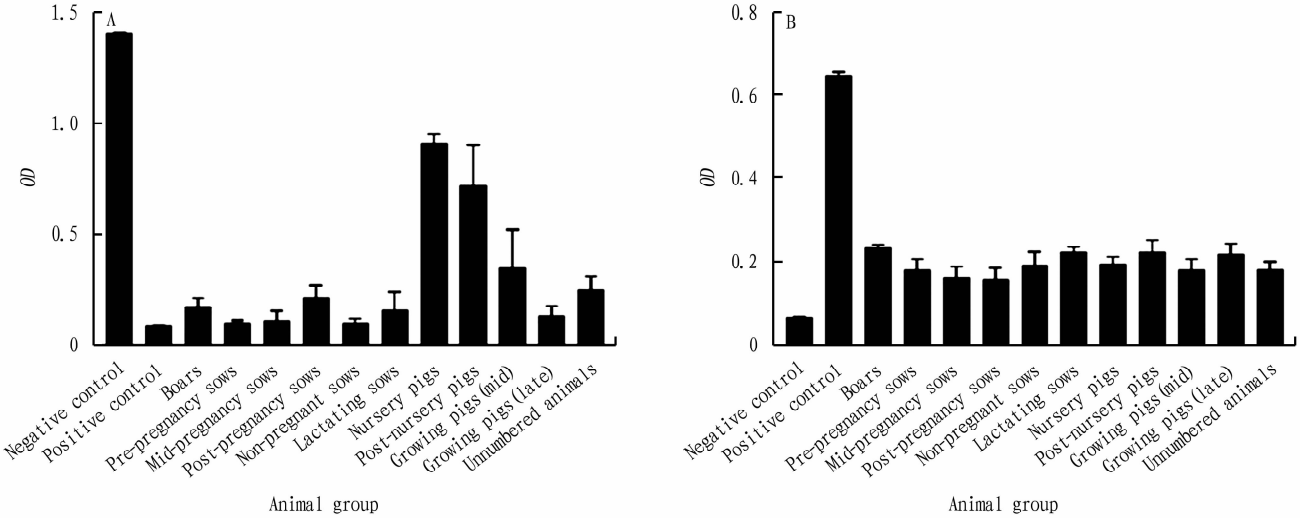
Table 4 Analysis of pseudorabies gE antibody positive rate

Indicator	Boars	Pre-pregnancy sows	Mid-pregnancy sows	Post-pregnancy sows	Non-pregnant sows	Lactating sows	Nursery pigs	Post-nursery pigs	Growing pigs (mid)	Growing pigs (late)	Unnumbered animals
Positive rate//%	0	0	0	0	0	0	0	0	0	0	0
CV//%	7.2	6.2	3.7	6.8	8.4	7.2	6.1	3	11.4	6.3	7.3
S/N value	0.977	0.905	0.926	0.851	0.974	0.84	0.922	0.908	0.924	0.882	0.902

FMD and PCV2 antibody detection results ELISA testing showed an overall qualification rate of 73.2% (41/56) for foot-and-mouth disease (type O) vaccine antibodies. Boars, sows in early/mid/late gestation, non-pregnant sows, finishing pigs, and unmarked pigs all achieved 100% qualification, while mid-finishing pigs reached 75%. However, post-nursery piglets dropped to 50%, and nursery piglets were as low as 16.67%, with a discrete degree ranging from 1.4% to 46.0%, reflecting uneven antibody levels. The farm did not administer PCV2 vaccination, and all test results were negative, with a low discrete degree (0% -41.5%).

Foot-and-mouth disease (type O) antibody results: The overall qualification rate for FMD (type O) antibodies was excellent, with all pig groups (boars, sows at all stages, finishing pigs, *etc.*) achieving 100% qualification except for the nursery and post-nursery stages. This indicates highly effective immunization against FMD across most populations. However, the qualification rate dropped sharply to 16.67% in the nursery stage and only reached 50% in the post-nursery stage, suggesting an urgent need for booster immunization in these groups (Fig. 2, Table 5).

PCV2 antibody results: As shown in Table 6, all 56 samples tested negative for PCV2 antibodies (*S/P* values <0.3). Consistent with the farm's practice of not vaccinating against PCV2, and the absence of clinical signs indicative of wild-type PCV2 infection, these results demonstrate effective biosecurity control measures within the farm.



A. FMD antibodies; B. PCV2 antibodies.

Fig. 2 Analysis of antibody detection for two diseases

Table 5 Detection of vaccine antibodies for foot-and-mouth disease (type O) and porcine circovirus type 2 (PCV2)

Group	FMD (O) (Blocking ELISA)			RV2 (ELISA)		
	OD value	Blocking rate	Result	*OD* value	*S/N*	Result
Negative control	1.408	-	-	0.067	-	-
	1.405	-	-	0.065	-	-
Positive control	0.092	-	-	0.654	-	-
	0.091	-	-	0.636	-	-
Boar	0.213	85	Positive	0.218	0.263	Negative
	0.142	90	Positive	0.217	0.265	Negative
	0.214	85	Positive	0.235	0.293	Negative
	0.055	96	Positive	0.258	0.332	Negative
	0.263	81	Positive	0.236	0.294	Negative
Pre-pregnancy sows	0.086	94	Positive	0.145	0.136	Negative

(Continued)

(Table 5)

Group	FMD (O) (Blocking ELISA)			RV2 (ELISA)		
	OD value	Blocking rate	Result	*OD* value	S/N	Result
	0.088	94	Positive	0.126	0.104	Negative
	0.121	92	Positive	0.212	0.252	Negative
	0.123	91	Positive	0.236	0.294	Negative
Mid-pregnancy sows	0.076	95	Positive	0.145	0.136	Negative
	0.236	83	Positive	0.126	0.104	Negative
	0.068	95	Positive	0.236	0.294	Negative
	0.078	94	Positive	0.145	0.136	Negative
Post-pregnancy sows	0.262	81	Positive	0.126	0.104	Negative
	0.128	91	Positive	0.236	0.294	Negative
	0.126	91	Positive	0.145	0.136	Negative
	0.355	75	Positive	0.126	0.104	Negative
Non-pregnant sows	0.116	92	Positive	0.258	0.258	Negative
	0.052	96	Positive	0.236	0.236	Negative
	0.123	91	Positive	0.145	0.145	Negative
	0.125	91	Positive	0.126	0.126	Negative
Lactating sows	0.075	95	Positive	0.212	0.212	Negative
	0.24	84	Positive	0.236	0.236	Negative
Nursery pigs	1.025	27	Negative	0.145	0.145	Negative
	1.472	31	Negative	0.258	0.258	Negative
	1.454	32	Negative	0.236	0.236	Negative
	1.474	31	Negative	0.145	0.145	Negative
	1.057	25	Negative	0.126	0.126	Negative
	1.473	38	Negative	0.258	0.258	Negative
	1.498	47	Negative	0.236	0.236	Negative
	1.414	35	Negative	0.145	0.145	Negative
	1.437	33	Negative	0.126	0.126	Negative
	1.032	27	Negative	0.212	0.212	Negative
	1.406	35	Negative	0.236	0.236	Negative
	1.428	48	Negative	0.145	0.145	Negative
Post-nursery pigs	0.039	72	Positive	0.258	0.258	Negative
	1.019	28	Negative	0.236	0.236	Negative
	0.040	71	Positive	0.145	0.145	Negative
	1.055	25	Negative	0.258	0.258	Negative
Growing pigs (mid)	0.157	89	Positive	0.236	0.236	Negative
	0.196	86	Positive	0.145	0.145	Negative
	0.178	87	Positive	0.126	0.126	Negative
	1.459	39	Negative	0.212	0.212	Negative
Growing pigs (late)	0.248	82	Positive	0.236	0.236	Negative
	0.123	91	Positive	0.145	0.145	Negative
	0.124	91	Positive	0.258	0.258	Negative
	0.046	97	Positive	0.236	0.236	Negative
Unnumbered animals	0.296	79	Positive	0.145	0.145	Negative
	0.178	87	Positive	0.126	0.126	Negative
	0.629	55	Positive	0.212	0.212	Negative
	0.185	87	Positive	0.236	0.236	Negative
	0.185	87	Positive	0.145	0.145	Negative
	0.206	85	Positive	0.258	0.258	Negative
	0.430	71	Positive	0.236	0.236	Negative
	0.063	95	Positive	0.145	0.145	Negative
	0.082	94	Positive	0.126	0.126	Negative
Total		Pass rate	73.2%			

As shown in Table 6, the diagnostic criteria for antibody detection were as follows: for foot-and-mouth disease (type O) blocking ELISA, a blocking rate ≥ 50% was considered positive, while < 50% was negative. For porcine circovirus type 2 antibody ELISA, $S/P < 0.3$ indicated negativity, $S/P \geq 0.4$ positivity, and $0.3 < S/P < 0.4$ was classified as suspicious.

Table 6 Analysis of foot-and-mouth disease (type O) antibody positive rate

Indicator	Boars	Pre-pregnancy sows	Mid-pregnancy sows	Post-pregnancy sows	Non-pregnant sows	Lactating sows	Nursery pigs	Post-nursery pigs	Growing pigs (mid)	Growing pigs (late)	Unnumbered animals
Positive rate//%	100.00	100.00	100.00	100.00	100.00	100.00	0.00	50.00	75.00	100.00	100.00
CV//%	5.90	1.40	5.50	8.10	2.20	6.10	25.30	46.00	27.80	5.90	14.10
Blocking rate//%	87.4	92.75	91.75	84.5	92.5	89.5	34.917	49	75.25	90.25	78.714

The positive rates for FMD antibodies reached 100% in boars, sows at all gestation stages, non-pregnant sows, lactating sows, late-finishing pigs, and replacement gilts, with low coefficients of variation ($CV < 7\%$ except for late-gestation sows at 8.1%), indicating stable and uniform immunity. However, the nursery group showed a critical drop to 0% positivity, while the post-nursery group had only a 50% qualification rate, revealing a complete lack of protective antibodies in nursery piglets and underscoring the urgent need for FMD vaccine boosters. The high *CV* values (25.3% and 46.0%) in these groups further reflected low average antibody levels and significant individual variability, suggesting both immunization gaps and elevated risks of viral infection (Table 7).

Table 7 Analysis of porcine circovirus type 2 (PCV2) antibody positive rate

Indicator	Boars	Pre-pregnancy sows	Mid-pregnancy sows	Post-pregnancy sows	Non-pregnant sows	Lactating sows	Nursery pigs	Post-nursery pigs	Growing pigs (mid)	Growing pigs (late)	Unnumbered animals
Positive rate//%	0	0	0	0	0	0	0	0	0	0	0
CV//%	12.5	37.9	40.5	41.5	35.3	7.1	28.9	0	31.9	7.9	37.3
S/P value	0.271	0.172	0.168	0.159	0.191	0.224	0.202	0.258	0.18	0.236	0.159

Although this pig farm does not vaccinate against PCV2, it has successfully blocked the transmission of the virus through effective biosecurity management practices. Currently, no clinical signs of PCV2 field virus infection are observed in the herd, demonstrating that the disease is preventable and controllable with significant effectiveness. Furthermore, testing of 56 serum samples for antibodies against FMDV non-structural proteins yielded negative results (details in Table 8), ruling out the threat of field strain FMD infection in the herd.

Table 8 Foot-and-mouth disease virus non-structural protein 3ABC antibodies

Detection method	Non-structural protein ELISA		
	S/P	Blocking rate	Result
Negative control	1.402	–	–
	1.404	–	–
Positive control	0.095	–	–
	0.096	–	–
Boars	0.111	15	Negative
	0.172	34	Negative
	0.163	32	Negative
	0.152	31	Negative
	0.171	34	Negative
Pre-pregnancy sows	0.112	19	Negative
	0.122	20	Negative
	0.133	23	Negative
	0.132	24	Negative

(Continued)

(Table 8)

Detection method	Non-structural protein ELISA		
	S/P	Blocking rate	Result
Mid-pregnancy sows	0.124	25	Negative
	0.122	23	Negative
	0.173	35	Negative
	0.152	33	Negative
Post-pregnancy sows	0.131	24	Negative
	0.122	20	Negative
	0.133	23	Negative
	0.130	25	Negative
Non-pregnant sows	0.150	92	Negative
	0.160	32	Negative
	0.190	27	Negative
	0.134	21	Negative
Lactating sows	0.144	25	Negative
	0.102	23	Negative
	0.161	30	Negative
	0.144	28	Negative
	0.151	29	Negative
	0.132	26	Negative
	0.142	32	Negative
	0.171	34	Negative
	0.181	35	Negative
	0.126	33	Negative
	0.157	27	Negative

(Continued)

(Table 8)

Detection method	Non-structural protein ELISA		
	S/P	Blocking rate	Result
	0.138	35	Negative
	0.177	34	Negative
Post-nursery pigs	0.166	31	Negative
	0.116	28	Negative
	0.166	32	Negative
	0.155	25	Negative
Growing pigs (mid)	0.133	24	Negative
	0.165	32	Negative
	0.172	34	Negative
	0.182	35	Negative
Growing pigs (late)	0.144	31	Negative
	0.126	22	Negative
	0.127	22	Negative
	0.148	31	Negative
Unnumbered	0.162	32	Negative
animals	0.173	37	Negative
	0.129	25	Negative
	0.175	27	Negative
	0.165	27	Negative
	0.166	35	Negative
	0.143	21	Negative
	0.123	25	Negative
	0.132	23	Negative

The diagnostic criteria were defined as follows: a sample with a blocking rate (*PI* value) $\geqslant 50\%$ was judged positive for FMDV non-structural protein 3ABC antibodies, while a blocking rate $< 50\%$ was considered negative. Quality control requirements specified that the average $OD_{450\ nm}$ value of the negative control must be >1.0, the blocking rate of the weak positive control serum should exceed 50%, and the positive control serum blocking rate should be $>70\%$.

Conclusions

This study systematically monitored the antibody levels and infection status of five major diseases on a large-scale pig farm in Guizhou Province, comprehensively evaluating the effectiveness of immunization and disease control measures. The results showed that the qualified antibody rates for classical swine fever (CSF), foot-and-mouth disease (FMD), and porcine reproductive and respiratory syndrome (PRRS) were 76.8%, 73.2%, and 76.8%, respectively, indicating effective immunization protection against these diseases. However, nursery piglets exhibited low and uneven antibody levels with high coefficients of variation, highlighting the need for timely booster vaccinations and potential adjustments to their immunization protocols. Failure to address this issue could lead to outbreak risks if susceptible viruses emerge in the surrounding environment.

For CSF, eight suspicious cases were detected, but PCR testing of whole blood samples confirmed no pathogen presence. All 56 serum samples tested negative for FMDV non-structural protein 3ABC antibodies, ruling out the risk of field strain FMD infection.

No PRV-gE or PCV2 antibodies were detected, demonstrating that despite the absence of vaccination, effective biosecurity management and comprehensive control measures successfully blocked viral infections. This reflects the farm's significant achievements in controlling non-vaccinated diseases.

Discussion

Statistical data indicate that annual economic losses due to swine diseases in China reach approximately ¥2 billion, accounting for over 20% of total losses in the livestock industry. Currently, mixed infections are the predominant form of disease occurrence in large-scale pig farms, with widespread co-infections of multiple pathogens and increasing harm from immunosuppressive diseases. However, risks can be effectively reduced by optimizing rearing environments, enhancing nutritional support, standardizing immunization protocols, implementing biosecurity measures, and supplementing with rational drug prophylaxis and treatment, thereby improving overall herd health.

Based on these epidemiological characteristics and control principles, and considering the uneven intensification of China's pig industry, it is crucial to implement differentiated, scale-matched precision control strategies. Accordingly, prevention and control systems are recommended to be stratified into three levels based on the farm's sow inventory:

Large-scale pig farms should prioritize disease eradication, establishing in-house laboratory capabilities for regular ELISA antibody and PCR pathogen testing monthly. Advanced biosecurity measures, such as air filtration systems, automated feeding systems, and enclosed corridor links between barns, should be deployed to block pathogen introduction. Eradication programs for PRV and PRRS should be strengthened through testing-and-culling strategies to establish negative breeding herds.

Medium-scale pig farms should aim for disease stability by establishing basic testing capacity or collaborating with third-party labs to conduct quarterly monitoring of antibody dynamics and pathogen status. Immunization protocols should be optimized based on antibody decay patterns.

Small-scale pig farms should focus on controlling key diseases by partnering with external labs or veterinary services for semi-annual serological and pathogen testing. Basic biosecurity measures, such as isolation zones, strict personnel/vehicle controls, and regular disinfection, should be enhanced to reduce transmission risks.

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Table 1 Results of the ablation comparison experiment

Model	Mean average precision (mAP)	Average precision (AP)							
		Standing	Lying	Eating	Drinking	Fighting	Mounting	Limping	Walking
YOLOv11n	0.895	0.773	0.876	0.908	0.780	0.961	0.990	0.967	0.907
YOLOv11n-RCM	0.905	0.781	0.909	0.912	0.740	0.977	0.994	0.978	0.946
YOLOv11n-CBM	0.909	0.795	0.927	0.918	0.751	0.980	0.995	0.970	0.932
YOLOv11n-DASI	0.916	0.751	0.913	0.928	0.806	0.985	0.994	0.981	0.967
YOLOv11n-DASI-MDCR	0.930	0.801	0.907	0.928	0.867	0.988	0.995	0.987	0.970

Analysis of model training results

To evaluate the performance optimization and improvement effects of the model, the basic YOLOv11n model and the improved YOLOv11n-DASI-MDCR model were selected for dual comparative experiments under different scenarios in this study. Both indoor and outdoor conditions were included in the comparison, while high-density gatherings of cow herds under real pasture working conditions and varying lighting intensity conditions were used as the primary simulation environments. From the quantitative comparison results in Fig. 5, it is evident that in multi-target scenarios characterized by overlapping objects and uneven lighting, the improved model better preserves feature information while simultaneously increasing the confidence levels for recognizing key cow behaviors. Notably, it demonstrates enhanced performance in localization accuracy under low-light conditions (such as dawn and dusk) and in dense cow areas.

Conclusions

To address the challenges of multi-target cow behavior recognition under complex environmental conditions, an intelligent detection method based on an improved YOLOv11n model was proposed. By integrating a DASI module into the backbone network and an MDCR module into the neck network, this method significantly enhances the model's adaptability to small targets and complex backgrounds. Notably, it achieves substantial breakthroughs in recognizing key cow behaviors such as drinking and walking. The DASI module effectively addresses feature information loss and background clutter in small target detection through adaptive feature selection and fusion, while the MDCR module enhances small target localization capability by capturing spatial features of different receptive fields through multiple depthwise separable convolutional layers. Experimental results indicate that the improved YOLOv11n-DASI-MDCR model increased the accuracy rate from the original 85.4% to 90.7%, and the mean average precision (mAP) rose from the original 89.5% to 93%. The recognition accuracy for drinking and walking behaviors was improved by 8.7% and 6.3%, respectively, effectively addressing issues related to occlusion caused by camera angles and interference from similar behaviors. Furthermore, the model demonstrated strong robustness in various scenarios, including indoor and outdoor environments, varying lighting conditions, and dense cattle gatherings.

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