

## Effects of Fumaric Acid on Growth Performance, Jejunal Development, and Serum Antioxidant and Immune Indices in Juvenile Rabbits During Summer

**Authors:** Qin Feng, Pan Xiaoqing, Shao Le, Yang Jie, Zhai Pin, Li Sheng, Li Jian

**Date:** 2018-12-24T00:00:00+00:00

### Abstract

The present experiment was conducted to investigate the effects of the organic acidifier fumaric acid on growth performance, jejunum development, and serum antioxidant and immune indices of young rabbits during summer. Ninety 56-day-old Rex rabbits with similar body weight [(919.00±8.92) g] were selected and randomly divided into 3 groups with 10 replicates per group and 3 rabbits per replicate. The control group was fed a basal diet, the fumaric acid group received the basal diet supplemented with 0.05% fumaric acid, and the compound acidifier group received the basal diet supplemented with 0.10% compound acidifier. A 7-day preliminary period was followed by a 35-day formal experimental period. The results showed: 1) Compared with the control group, dietary supplementation of fumaric acid increased the final body weight and average daily gain of young rabbits ( $P>0.05$ ) by 6.05% and 13.40%, respectively, and decreased the mortality rate ( $P>0.05$ ). 2) Compared with the control group, dietary supplementation of fumaric acid significantly increased the apparent crude protein digestibility ( $P<0.05$ ), significantly decreased the apparent phosphorus digestibility ( $P<0.05$ ), and showed a tendency to increase the apparent crude fiber digestibility ( $P>0.05$ ). 3) Compared with the control group, dietary supplementation of fumaric acid increased the jejunal wall thickness, villus height, and villus height to crypt depth ratio ( $P>0.05$ ) by 20.70%, 9.83%, and 18.60%, respectively, while also decreasing the crypt depth ( $P>0.05$ ). 4) Compared with the control group, dietary supplementation of fumaric acid increased serum total antioxidant capacity and superoxide dismutase activity ( $P>0.05$ ), decreased serum malondialdehyde content ( $P>0.05$ ), showed a tendency to increase serum lysozyme activity ( $P>0.05$ ), and had no significant effect on other serum indices ( $P>0.05$ ). Therefore, dietary supplementation of fumaric acid can improve je-

jejunum development, enhance intestinal absorption capacity, and increase protein utilization efficiency in young rabbits during summer, thereby improving growth performance, while also enhancing the body's antioxidant capacity and promoting overall health.

## Full Text

### Effects of Fumaric Acid on Growth Performance, Jejunum Development and Serum Antioxidant and Immunity Indicators of Young Rabbits in Summer

\*\*QIN Feng, PAN Xiaoqing, SHAO Le, YANG Jie\*, ZHAI Pin, LI Sheng, LI Jian\*\*

Institute of Animal Science, Jiangsu Academy of Agricultural Sciences, Nanjing 210014, China

#### Abstract

This study investigated the effects of dietary fumaric acid on growth performance, jejunum development, and serum antioxidant and immune indicators in young rabbits during summer. Ninety 56-day-old Rex rabbits with similar body weight [(919.00±8.92) g] were randomly assigned to three groups with 10 replicates per group and three rabbits per replicate. The control group received a basal diet, the fumaric acid group received the basal diet supplemented with 0.05% fumaric acid, and the compound acidifier group received the basal diet supplemented with 0.10% compound acidifier. The study consisted of a 7-day pre-trial period followed by a 35-day experimental period. The results showed: (1) Compared with the control group, dietary fumaric acid increased final body weight and average daily gain by 6.05% and 13.40%, respectively, and reduced mortality, though these differences were not statistically significant ( $P>0.05$ ). (2) Fumaric acid supplementation significantly increased crude protein apparent digestibility ( $P<0.05$ ) while significantly decreasing phosphorus apparent digestibility ( $P<0.05$ ); crude fiber apparent digestibility showed an increasing trend ( $P>0.05$ ). (3) Fumaric acid increased jejunal wall thickness, villus height, and the villus height/crypt depth ratio by 20.70%, 9.83%, and 18.60%, respectively, while decreasing crypt depth, though these changes were not significant ( $P>0.05$ ). (4) Dietary fumaric acid enhanced serum total antioxidant capacity and superoxide dismutase activity, reduced serum malondialdehyde content, and showed a tendency to increase serum lysozyme activity ( $P>0.05$ ), with no significant effects on other serum indicators. In conclusion, dietary fumaric acid supplementation improved jejunum development, enhanced intestinal absorption capacity, increased protein utilization, and improved growth performance in summer-raised young rabbits, while also enhancing antioxidant capacity and promoting overall health.

**Keywords:** young rabbits; fumaric acid; growth performance; digestibility; antioxidant

## Introduction

Young rabbit rearing is a critical component of rabbit production, with low post-weaning productivity representing a bottleneck for industry development. After weaning, young rabbits have underdeveloped intestinal function and insufficient gastric acid secretion, which is particularly problematic during summer when combined with nutritional and environmental stress. This leads to gastrointestinal damage, low nutrient digestibility, diarrhea, and impaired production. Traditional rabbit production has relied on antibiotics for prevention and treatment, which are effective but create problems of drug resistance and antibiotic residues. Research has shown that acidifiers can improve growth performance and health status in young livestock. Dietary acidifiers can compensate for physiological acid deficiency, regulate intestinal microbial balance by promoting beneficial bacteria and inhibiting harmful bacteria, enhance stress resistance and immunity, reduce intestinal pH, increase digestive enzyme activity, improve nutrient digestibility, and ultimately enhance growth performance [1-6]. While acidifiers have demonstrated positive effects on young animal health, results vary considerably due to differences in animal species, age, experimental conditions, and supplementation levels. Research on acidifier types and optimal dosages specifically for young rabbits remains limited. Our previous study investigated the effects of malic acid on Rex rabbit growth performance and determined appropriate supplementation levels [7]. The present study examines the effects of fumaric acid, an organic acidifier, on growth performance, jejunum development, and serum antioxidant and immune indicators in summer-raised young rabbits, providing a theoretical basis for acidifier application in rabbit production.

## 1. Materials and Methods

**1.1 Experimental Materials** Fumaric acid was purchased from Suzhou Youhe Technology Co., Ltd., and the compound acidifier (Acid Gift) was purchased from Guangdong Lvshengyuan Feed Technology Co., Ltd.

**1.2 Experimental Design** Ninety healthy 56-day-old Rex rabbits with similar body weight [(919.00±8.92) g] were selected as experimental animals after uniform immunization and randomly divided into three groups with 10 replicates per group and three rabbits per replicate. The control group received a basal diet, the fumaric acid group received the basal diet supplemented with 0.05% fumaric acid, and the compound acidifier group received the basal diet supplemented with 0.10% compound acidifier. The study consisted of a 7-day pre-trial period followed by a 35-day experimental period. The experiment was conducted at the Liuhe Experimental Rabbit Farm of Jiangsu Academy of Agricultural Sciences.

**1.3 Experimental Diet** The experimental diet was formulated according to NRC (1977) rabbit feeding standards [8] and the nutritional requirements for Rex rabbits recommended by Gu Zilin [9]. Digestible energy was supplied at

1.2 times the maintenance requirement. Fumaric acid and compound acidifier were premixed before addition to the diet, which was then processed into pellets. Supplementation levels were determined based on previous acidifier trials. The composition and nutrient levels of the basal diet are presented in Table 1.

**Table 1** Composition (air-dry basis) and nutrient levels (DM basis) of the basal diet

Ingredients	Content (%)	Nutrient levels	Content
Hay	40.0	Dry matter (DM)	90.2
Corn	20.0	Digestible energy (DE, MJ/kg)	10.5
Wheat bran	20.0	Crude protein (CP)	17.8
Soybean meal	18.5	Crude fiber (CF)	14.2
CaHPO	0.8	Total phosphorus (TP)	0.6
NaCl	0.5	Lysine (Lys)	0.82
Premix <sup>1</sup>	0.5	Methionine (Met)	0.42
Total	100.0		

<sup>1</sup> Per kg of premix contained: FeSO · H O 5,320 mg, CuSO · 5H O 1,080 mg, MnSO · H O 560 mg, ZnSO · H O 3,652 mg, CoCl · 6H O 1,000 mg, VA 180,000 IU, VD 18,000 IU, VE 900,000 IU.

<sup>2</sup> Measured values.

**1.4 Management** Before the trial, rabbit houses and cages were thoroughly cleaned and disinfected. Three rabbits were housed per cage and fed twice daily at 08:30 and 15:30. Young rabbits received pelleted feed (2-3 cm length) with free access to water. Cages were cleaned daily and all records were maintained. During the pre-trial period, rabbits were grouped and ear-tagged.

**1.5 Sample Collection and Measurement** Body weight was measured at the beginning and end of the trial to calculate average daily gain. Mortality was recorded to calculate death rate. Nutrient apparent digestibility was determined using the total fecal collection method. From day 21 of the trial, feces were collected continuously for 5 days while recording feed intake and fecal output. Dry matter (DM), crude protein (CP), crude fiber (CF), calcium (Ca), and phosphorus (P) contents in diets and feces were analyzed using AOAC methods [10].

Blood samples were collected on day 35, and serum was separated and stored at -20°C for antioxidant and immune indicator analysis according to kit instructions (Nanjing Jiancheng Bioengineering Institute). At the end of the trial, five rabbits with similar body weight were randomly selected from each group, fasted for 24 hours, and slaughtered. Middle jejunum tissue was collected, fixed in 4% paraformaldehyde, and processed into paraffin sections for hematoxylin-eosin (HE) staining. Using an inverted microscope with camera (10× eyepiece,

4× objective), 10 random fields were observed per slice. Tissue images were captured using Q-capture Pro 6.0 software and analyzed with Image-pro plus 6.0 to measure intestinal wall thickness, villus height, and crypt depth, and to calculate the villus height/crypt depth ratio.

**1.6 Data Analysis** Data were processed using Excel 2007 and analyzed using one-way ANOVA in SPSS 17.0. Duncan' s multiple comparison test was used to compare means, with  $P < 0.05$  considered statistically significant.

## 2. Results

**2.1 Effects of Fumaric Acid on Growth Performance and Nutrient Apparent Digestibility in Summer-Raised Young Rabbits** As shown in Table 2 , dietary supplementation with fumaric acid and compound acidifier increased final body weight and average daily gain while decreasing mortality in summer-raised young rabbits, though these differences were not statistically significant ( $P > 0.05$ ). Compared with the control group, the fumaric acid group showed 6.05% higher final body weight and 13.40% higher average daily gain. These results indicate that dietary fumaric acid can improve growth performance in summer-raised young rabbits.

**Table 2** Effects of fumaric acid on growth performance of young rabbits in summer

Items	Control group	Fumaric acid group	Compound acidifier group
Initial body weight (g)	917.5±15.4	923.8±16.5	915.7±15.0
Final body weight (g)	1,453.0±45.8	1,540.9±63.3	1,506.6±45.6
Average daily gain (g)	14.2±1.2	16.1±1.4	15.6±1.1
Mortality (%)	6.67	3.33	3.33

*In the same row, values with different small letter superscripts indicate significant difference ( $P < 0.05$ ), while values with the same or no letter superscripts indicate no significant difference ( $P > 0.05$ ). The same applies below.*

As shown in Table 3 , both fumaric acid and compound acidifier groups had significantly higher crude protein apparent digestibility ( $P < 0.05$ ) and significantly

lower phosphorus apparent digestibility ( $P < 0.05$ ) compared with the control group. Crude fiber apparent digestibility was higher in both treatment groups, though not significantly ( $P > 0.05$ ). These findings demonstrate that dietary acidifiers promote protein digestion.

**Table 3** Effects of fumaric acid on nutrient apparent digestibility of young rabbits in summer (%)

Items	Control group	Fumaric acid group	Compound acidifier group
CP ap- parent di- gestibil- ity	54.9±5.7	66.8±1.7	70.2±2.2
CF ap- parent di- gestibil- ity	32.6±7.9	35.8±1.9	39.0±5.8
Ca ap- parent di- gestibil- ity	59.1±5.8	64.3±2.4	56.7±4.6
P ap- parent di- gestibil- ity	88.3±0.3	86.6±0.4	87.1±0.3

**2.2 Effects of Fumaric Acid on Jejunum Development in Summer-Raised Young Rabbits** As shown in Table 4, dietary fumaric acid increased jejunal wall thickness, villus height, and villus height/crypt depth ratio by 20.7%, 9.83%, and 18.6%, respectively, while decreasing crypt depth, though these differences were not statistically significant ( $P > 0.05$ ).

**Table 4** Effects of fumaric acid on jejunum development of young rabbits in summer

Items	Control group	Fumaric acid group	Compound acidifier group
Intestinal wall thickness ( $\mu\text{m}$ )	201.4 $\pm$ 22.0	243.0 $\pm$ 15.8	225.1 $\pm$ 16.5
Villous height ( $\mu\text{m}$ )	629.0 $\pm$ 29.9	690.8 $\pm$ 106.8	619.0 $\pm$ 41.8
Crypt depth ( $\mu\text{m}$ )	97.1 $\pm$ 7.8	90.0 $\pm$ 7.4	86.2 $\pm$ 4.3
V/C ratio	6.56 $\pm$ 0.36	7.78 $\pm$ 1.25	7.31 $\pm$ 0.79

**2.3 Effects of Fumaric Acid on Serum Antioxidant and Immune Indicators in Young Rabbits** As shown in Table 5 , serum total antioxidant capacity (T-AOC) and superoxide dismutase (SOD) activity were higher in the fumaric acid group compared with the control group, while serum malondialdehyde (MDA) content was lower, though these differences were not significant ( $P>0.05$ ).

**Table 5** Effects of fumaric acid on serum antioxidant indicators of young rabbits in summer

Items	Control group	Fumaric acid group	Compound acidifier group
SOD (U/mL)	288.2 $\pm$ 15.0	307.7 $\pm$ 30.7	302.9 $\pm$ 21.9
MDA (nmol/mL)	4.15 $\pm$ 0.82	2.45 $\pm$ 0.33	3.32 $\pm$ 0.36
GSH-Px (U/mL)	455.2 $\pm$ 19.9	452.4 $\pm$ 29.9	390.5 $\pm$ 32.1
T-AOC (U/mL)	5.23 $\pm$ 1.54	6.41 $\pm$ 1.44	4.02 $\pm$ 0.23

As shown in Table 6 , dietary fumaric acid and compound acidifier had no significant effects on serum immunoglobulin G (IgG), immunoglobulin A (IgA), immunoglobulin M (IgM), complement 3 (C3), complement 4 (C4), alkaline phosphatase (AKP), or lysozyme (LZM) activities ( $P>0.05$ ), though serum LZM activity showed an increasing trend.

**Table 6** Effects of fumaric acid on serum immunity indicators of young rabbits in summer

Items	Control group	Fumaric acid group	Compound acidifier group
LZM (U/mL)	162.1±26.8	269.5±62.6	178.9±9.4
AKP (King's unit/dL)	13.4±0.9	12.9±2.0	14.7±0.5
IgG (µg/mL)	190.2±20.5	156.9±14.9	168.3±6.6
IgA (µg/mL)	51.5±5.4	49.9±3.4	53.9±2.1
IgM (µg/mL)	30.5±4.5	29.9±2.4	32.7±0.8
C3 (µg/mL)	8.52±0.61	7.87±0.52	7.96±0.23
C4 (µg/mL)	43.10±5.11	40.80±3.21	43.50±0.99

### 3. Discussion

**3.1 Effects of Fumaric Acid on Growth Performance and Nutrient Apparent Digestibility in Summer-Raised Young Rabbits** Fumaric acid, also known as fumaric acid, is widely used in food processing as an acidulant with antibacterial and preservative properties. For monogastric animals, fumaric acid serves as an acidifier and feed preservative that promotes animal health and growth performance by reducing gastrointestinal pH and preventing feed mold. Wang et al. [11] reported that dietary compound acidifier significantly increased average daily gain and reduced diarrhea rate in weaned piglets while improving protein and dry matter apparent digestibility. Palamidi et al. [12] found that dietary acidifier supplementation improved growth performance, nutrient apparent digestibility, and energy deposition in broilers. Zhu et al. [13] demonstrated that drinking water acidification with organic acids partially improved growth performance, compensated for gastric acidity, and affected cecal microbial community structure in growing rabbits, with an optimal pH of 4.3. In the present study, dietary fumaric acid improved crude protein and crude fiber apparent digestibility while increasing final body weight and average daily gain in summer-raised young rabbits. Li et al. [14] reported that dietary fumaric acid at various concentrations improved apparent digestibility of crude protein, neutral detergent fiber, and acid detergent fiber in dairy cows. Dietary fumaric acid also significantly increased average daily gain and reduced feed conversion ratio and diarrhea rate in weaned piglets [15]. Similar results have been reported for other acidifiers. Pan et al. [7] found that appropriate levels of malic acid improved growth performance and nutrient apparent digestibility in

Rex rabbits, consistent with our findings. Wang et al. [16] reported that dietary acidifier supplementation at 1.5% lactic acid optimized growth performance in mink by regulating feed and gastrointestinal pH. Recent studies on citric acid have shown similar benefits. Zhang et al. [17] found that dietary citric acid at 0.8%-1.6% improved growth performance in large yellow croaker fed high plant protein diets by enhancing mineral bioavailability, intestinal antioxidant capacity, and intestinal recovery. Liu et al. [18] reported that dietary citric acid at 10 and 15 mg/kg enhanced calcium, phosphorus, and protein absorption and improved humoral immune function in late gestation and lactating sows, benefiting piglets through colostrum and milk. Therefore, appropriate dietary acidifier supplementation can improve health and growth performance in young animals.

**3.2 Effects of Fumaric Acid on Jejunum Development in Summer-Raised Young Rabbits** Intestinal morphological development is a crucial factor affecting young rabbit health and growth. The transition from milk to solid feed after weaning can cause small intestinal villus atrophy and crypt deepening, impairing intestinal development and consequently affecting growth and health. Yan et al. [19] found that dietary slow-release compound acidifier significantly increased the villus height/crypt depth ratio in piglet jejunum, improving intestinal development, which was consistent with results from Lin et al. [20] on early-weaned piglets. Li et al. [21] reported that two types of compound acidifiers both significantly increased small intestinal villus height and decreased crypt depth in weaned piglets. In broiler production, dietary compound acidifier increased duodenal villus height at 21 days and reduced crypt depth while increasing jejunal villus height at both 21 and 42 days [22]. Similar results were obtained in the present study, where dietary fumaric acid increased jejunal wall thickness, villus height, and villus height/crypt depth ratio while decreasing crypt depth. These findings indicate that appropriate dietary fumaric acid can improve intestinal development and health, enhance intestinal digestion and absorption, and consequently increase growth performance in young rabbits.

**3.3 Effects of Fumaric Acid on Serum Antioxidant and Immune Indicators in Summer-Raised Young Rabbits** The present study found that dietary fumaric acid increased serum T-AOC and SOD activity while decreasing serum MDA content, but had no significant effects on serum IgG, IgA, and IgM levels, with only a tendency to increase serum LZM activity. Therefore, fumaric acid may improve antioxidant capacity but did not demonstrate significant immunomodulatory effects. Li et al. [21] reported that dietary compound acidifier significantly increased serum IgA and IgG levels in piglets, enhancing immune status. Guo [23] found that compound acidifier improved average daily gain in piglets and feed intake in lactating sows, and increased antioxidant capacity in sow milk without significantly affecting milk composition or immune function. Zhang et al. [24] reported that dietary citric acid improved cellular immune function in suckling piglets. However, Zhang et al. [15] showed that

dietary 1% fumaric acid did not significantly improve immune performance in weaned piglets, though no negative effects were observed, consistent with our findings. Li et al. [25] reported that dietary acidifiers did not significantly affect immune function in weaned piglets, though citric acid significantly improved antioxidant capacity and enhanced free radical scavenging capacity, helping to improve stress resistance. Zhou et al. [26] found that dietary compound acidifier significantly reduced dirty egg rate in laying hens, decreased MDA production in oviducts, alleviated lipid peroxidation, and inhibited Salmonella growth in oviducts. Shen et al. [27] reported that dietary compound acidifier improved immune performance and blood antioxidant indicators in growing layers. These findings suggest that dietary acidifiers can improve antioxidant capacity, though their effects on immune function require further investigation.

#### 4. Conclusion

Dietary fumaric acid supplementation improved growth performance, reduced mortality, enhanced intestinal development and absorption capacity, increased crude protein apparent digestibility, and improved antioxidant capacity and overall health in summer-raised young rabbits.

#### References

- [1] Qin ST, Zhang HF, Tang XF, et al. Main physiological functions of acidifiers and basis for compound acid selection [J]. Chinese Journal of Animal Nutrition, 2007, 19(1S): 515-520.
- [2] Ma X, Ma QG, Ji C, et al. Comparison of antibacterial effects of methionine hydroxy analog and organic acidifiers on major intestinal pathogens in vitro [J]. Chinese Journal of Animal Nutrition, 2008, 20(2): 238-241.
- [3] Mroz Z. Some developments on Dutch nutritional approaches to protect piglets against post-weaning gastrointestinal disorders in the absence of in-feed antibiotics [J]. Journal of Animal and Feed Sciences, 2001, 10(1S): 153-167.
- [4] Mroz Z. Organic acids as potential alternatives to antibiotic growth promoters for pig [J]. Advances in Pork Production, 2005, 16: 169-182.
- [5] Roth FX, Kirchgessner M. Organic acids as feed additives for young pigs: nutritional and gastrointestinal effects [J]. Journal of Animal and Feed Sciences, 1998, 7(1S): 25-33.
- [6] Kluge H, Broz J, Eder K. Effect of benzoic acid on growth performance, nutrient digestibility, nitrogen balance, gastrointestinal microflora and parameters of microbial metabolism in piglets [J]. Journal of Animal Physiology and Animal Nutrition, 2006, 90(7/8): 316-324.
- [7] Pan XQ, Yang J, Shao L, et al. Effects of malic acid on production performance, nutrient apparent digestibility and serum biochemical indicators in weaned Rex rabbits [J]. Jiangsu Journal of Agricultural Sciences, 2013, 29(1): 136-139.
- [8] NRC. Nutrition Requirements of rabbits [S]. Washington D.C.: National Academy Press, 1977.

- [9] Gu ZL. Study on the mechanism of diarrhea in weaned rabbit kits and regulation by bioactive substances [D]. PhD Dissertation. Harbin: Northeast Agricultural University, 2004.
- [10] AOAC. Official methods of analysis [M]. 15th ed. Arlington, Virginia: Association of official Analytical Chemists, 1990: 40-90.
- [11] Wang J, Chen YL. Effects of compound acidifier on production performance and feed apparent digestibility in weaned piglets [J]. Heilongjiang Animal Science and Veterinary Medicine, 2010(13): 77-79.
- [12] Palamidi I, Paraskeuas V, Theodorou G, et al. Effects of dietary acidifier supplementation broiler growth performance, digestive immune function indices [J]. Animal Production Science, 2016, 57(2): 271-281.
- [13] Zhu KH, Xu XR, Sun DF, et al. Effects of drinking water acidification by organic acidifier on growth performance, digestive enzyme activity and caecal bacteria in growing rabbits [J]. Animal Feed Science and Technology, 2014, 190: 87-94.
- [14] Li CH, Gao YX, Cao YF, et al. Effects of dietary fumaric acid at different concentrations on production performance and digestion-metabolism in dairy cows [J]. Heilongjiang Animal Science and Veterinary Medicine, 2011(5): 64-66.
- [15] Zhang XW, Qi ZL, Ren XH, et al. Effects of fumaric acid and bacillus on production performance and immune function of weaned piglets [J]. Feed Industry, 2008, 29(2): 12-14.
- [16] Wang KY, Bao K, Xu C, et al. Effects of feed acidifier on production performance and serum biochemical indicators in mink during winter fur period [J]. Journal of Northeast Agricultural University, 2012, 43(12): 78-85.
- [17] Zhang HL, Yi LN, Sun RJ, et al. Effects of dietary citric acid on growth performance, mineral status and intestinal digestive enzyme activities of large yellow croaker *Larimichthys crocea* (Richardson, 1846) plant protein diets [J]. Aquaculture, 2016, 453: 147-153.
- [18] Liu ST, Hou WX, Cheng SY, et al. Effects of dietary citric acid on performance, digestibility of calcium and phosphorus, milk composition and immunoglobulin in sows during late gestation and lactation [J]. Animal Feed Science and Technology, 2014, 191: 67-75.
- [19] Yan JY, Jia G, Wang KN, et al. Effects of slow-release compound acidifier on digestive tract acidity and intestinal function in weaned piglets [J]. Chinese Journal of Animal and Veterinary Sciences, 2009, 40(12): 1747-1754.
- [20] Lin YC, Chen JX, Jiang ZY, et al. Effects of compound acidifier on production performance, serum biochemical indicators, intestinal morphology and microflora in early-weaned piglets [J]. Swine Production, 2001(1): 13-16.
- [21] Li P, Wu SG, Zhang HJ, et al. Effects of compound acidifier on intestinal mucosal morphology, intestinal microflora and immune function in weaned piglets [J]. Chinese Journal of Animal Science, 2009, 45(9): 28-32.
- [22] Luo SW. Effects of compound acidifier on production performance and digestive tract environment in broilers [D]. Master's Thesis. Yangzhou: Yangzhou University, 2010.
- [23] Guo J. Effects of different pig house environments and dietary compound

acidifier on sow performance and antioxidant capacity [D]. Master' s Thesis. Guangzhou: South China Agricultural University, 2016.

[24] Zhang DC, Wu RP, Chen SY, et al. Effects of gastric acidity changes on red blood cell immune function in suckling piglets [J]. Feed Industry, 1994, 15(7): 28-29.

[25] Li JP, Shan AS, Xu QY. Effects of different types of acidifiers on gastric acid secretion, immune function and antioxidant function in early-weaned piglets [J]. Journal of Northeast Agricultural University, 2009, 40(4): 69-73.

[26] Zhou L, Ding XM, Luo YH, et al. Effects of compound acidifier and microecological preparation on production performance, blood biochemical indices, antioxidant indices and Salmonella infection in laying hens [J]. Chinese Journal of Animal Nutrition, 2016, 28(8): 2571-2580.

[27] Shen JK, Cao YF, Liang XW, et al. Effects of compound acidifier on growth, immune performance and serum antioxidant capacity of Hy-Line brown pullets [J]. China Poultry, 2017, 39(8): 48-51.

*Note: Figure translations are in progress. See original paper for figures.*

*Source: ChinaXiv –Machine translation. Verify with original.*