

Effects of dietary *Carica papaya* leaf meal, *Allium sativum* powder and their combination on immune function and antioxidant status of broiler chickens

Ifeoluwa Adebawale, Sodiq Adeola Ismail* and Babatunde Richard Oluwasegun Omidwura

Department of Animal Science, Faculty of Agriculture, University of Ibadan, Nigeria.

*Corresponding author Email: ismailsodiadeola@gmail.com; Co-authors: adebomore223@gmail.com, rb.omidiwura@ui.edu.ng

Copyright © 2026 Adebawale et al. This article remains permanently open access under the terms of the [Creative Commons Attribution License 4.0](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Received Date: 16 August 2026 | Accepted Date: 28 September 2026 | Published Date: 30 October 2026

ABSTRACT: Intensive broiler production and rapid growth impose substantial physiological stress on birds, which can predispose them to oxidative stress and immune dysfunction. Vaccine failure and concerns about antimicrobial resistance and residues have increased the need for safer alternative dietary approaches to enhance antioxidant defence and immune function in broiler chickens. This study evaluated the effects of dietary supplementation with Pawpaw Leaf Meal (PLM) and Garlic Powder (GP) on immune response and antioxidant status in broiler chickens during the starter phase. A total of 250 one-day-old unsexed Arbor Acres broiler chicks were randomly allotted to five dietary treatments in a completely randomised design, with five replicates of ten birds each. Birds in Treatments 1 and 2 (positive control and negative control, respectively) received the basal diet without phytogenic inclusion. Other treatments contained 3%PLM, 1%GP and 3% PLM+1%GP, respectively. Birds in Treatment 1 served as the positive control and received routine vaccination against Newcastle and Gumboro diseases, together with coccidiostat medication. Birds in Treatments 2-5 did not receive vaccination or medication throughout the experimental period. At day 21, blood was sampled for the determination of serum cytokines, immunoglobulin A (IgA), antioxidant biomarkers, and total serum protein. Data were analysed using ANOVA at $\alpha 0.05$. Birds fed 3%PLM+1%GP had the highest concentrations of interferon- γ (51.83 pg/mL), interleukin-1 β (415.09 pg/mL), interleukin-6 (43.04 pg/mL), total antioxidant capacity (16.94 mM TE) and IgA (338.32 mg/dL), while those fed 3%PLM had the highest serum total protein (45.82 g/L). Birds in the negative control group had the least interferon- γ (23.49 pg/mL), interleukin-1 β (177.96 pg/mL), and IgA (167.05 mg/dL), while birds fed 3%PLM had the least interleukin-6 (26.19 pg/mL). Birds in the positive control group had the lowest total antioxidant capacity (7.74 mM TE) and serum total protein (34.44 g/L). In conclusion, dietary inclusion of 3% pawpaw leaf meal and 1% garlic powder enhanced immune response and antioxidant status in broiler chickens during the starter phase, highlighting their potential as natural immunomodulatory feed additives.

Keywords: Antioxidant status, Broiler chickens, Cytokines, Garlic powder, immunoglobulin A, Pawpaw leaf meal, Phytogenic feed additives.

INTRODUCTION

Intensification of poultry production has led to the development of fast-growing broiler strains that are highly susceptible to oxidative stress and infectious diseases. Although vaccination has been widely adopted to control disease outbreaks, cases of vaccine failure continue to occur, leading to substantial economic losses. Likewise, the prolonged and indiscriminate use of synthetic antibiotics has contributed to the emergence of antimicrobial-

resistant pathogens and drug residues in broiler meat pose public health concerns. Consequently, there is increasing interest in the use of natural feed additives as safe, cost-effective and sustainable alternatives for enhancing immune competence and improving physiological resilience. Phytogenic feed additives have been reported to modulate the gut microbiota, enhance digestive enzyme activity, improve immune function, and strengthen antioxi-

dant defence, thereby promoting better health and productivity in poultry (Wang *et al.*, 2024). Owing to the presence of diverse bioactive compounds, phytogetic feed additives exhibit antimicrobial, antifungal, anti-inflammatory, antiviral, and antioxidant properties that contribute to improved animal performance and disease resistance (Abd El-Hack *et al.*, 2022).

Among the promising phytogetic plants, pawpaw (*Carica papaya*) has attracted considerable attention because of its medicinal and nutritional properties. Pawpaw leaves contain several bioactive compounds, including papain, chymopapain, phenolics, and flavonoids, which possess antimicrobial, antioxidant, and anti-inflammatory activities that support gut integrity and immune function in broiler chickens (Oloruntola *et al.*, 2018). Dharmarathna *et al.* (2013) reported that *Carica papaya* leaf extract improved platelet counts and haematological functions, while Aravind *et al.* (2013) demonstrated its ability to stimulate the production of Th1-type cytokines involved in immune regulation. Furthermore, Omidwura *et al.* (2020) reported improved gut function and digestive efficiency in broiler chickens fed diets supplemented with *Carica papaya* leaf meal, suggesting its potential as a natural feed additive for enhancing nutrient utilisation and health. Garlic (*Allium sativum*) is another well-established phytogetic additive with potent immunostimulatory, antimicrobial, and antioxidant properties. Its biological activities are largely attributed to sulphur-containing compounds, particularly allicin, which exhibits broad-spectrum antimicrobial, antiviral, and antifungal effects (Rahman *et al.*, 2020; Omidwura *et al.*, 2026). Garlic has also been shown to improve digestive function and immune responses through its interaction with immune cell receptors (Sharma *et al.*, 2022; Kim, 2023). In poultry, dietary garlic supplementation has been associated with improved growth performance, reduced disease risk (Toghyani *et al.*, 2011) and enhanced carcass yield and survivability under heat stress conditions (Elbaz *et al.*, 2022).

Although the individual health benefits of pawpaw and garlic have been widely reported, information on their combined effects on immune response and antioxidant status in broiler chickens remains limited, particularly during the starter phase when birds are more vulnerable to environmental and disease-related stress. Therefore, this study investigated the effects of dietary supplementation with pawpaw (*Carica papaya*) leaf meal and garlic (*Allium sativum*) powder, administered individually and in combination, on serum cytokine profile, immunoglobulin A concentration, antioxidant status, and total serum protein in broiler chickens.

MATERIALS AND METHODS

Experimental site

The experiment was conducted at the Poultry Unit of the

Teaching and Research Farm, University of Ibadan, Oyo State, Nigeria, located within the tropical rainforest zone.

Preparation of pawpaw leaf meal and garlic powder

Fresh, mature pawpaw (*Carica papaya*) leaves were harvested from within and around the University of Ibadan, while fresh indigenous garlic (*Allium sativum*) bulbs were purchased from Bodija Market, Ibadan. The pawpaw leaves were sorted, washed with clean water, chopped into smaller pieces, and air-dried to a constant weight before being milled into a fine powder. The garlic bulbs were peeled, sliced, air-dried, and similarly milled into powder. Both phytogetic materials were stored separately in airtight containers until incorporation into the experimental diets.

Experimental birds and management

A total of 250 one-day-old unsexed Arbor Acres broiler chicks were obtained from a commercial hatchery in Ibadan, Nigeria. Upon arrival, the birds were individually weighed and randomly allotted to five dietary treatments in a completely randomised design. Each treatment consisted of five replicates of 10 birds, giving a total of 50 birds per treatment. The experiment lasted for 21 days, during which the birds were fed the experimental starter diets and provided with feed and clean drinking water *ad libitum*. Standard management and biosecurity practices were maintained throughout the experimental period.

Experimental diets

The starter diets were formulated to meet the nutrient requirements of broiler chickens according to NRC (1994). Treatment 1 served as the positive control and received the basal diet with routine vaccination and coccidiostat medication, whereas Treatment 2 served as the negative control and received only the basal diet without vaccination and medication. 1 and 2 received the basal diet without phytogetic supplementation. Treatment 3 was supplemented with 3% pawpaw leaf meal (PLM), Treatment 4 with 1% garlic powder (GP), while Treatment 5 received a combination of 3% PLM and 1% GP. Birds in Treatments 2- 5 did not receive vaccination or medication throughout the experimental period.

Blood collection and laboratory analysis

On day 21, two birds were randomly selected from each replicate for blood collection via jugular venipuncture. Blood samples were allowed to clot at room temperature and centrifuged at $3,000 \times g$ for 15 min to obtain serum. The serum samples were transferred into sterile tubes and

stored at -20°C until analysis. Serum concentrations of interferon-gamma (IFN- γ), interleukin-1 beta (IL-1 β), interleukin-6 (IL-6), interleukin-10 (IL-10), interleukin-4 (IL-4), tumour necrosis factor-alpha (TNF- α), and immunoglobulin A (IgA) were determined using commercial enzyme-linked immunosorbent assay (ELISA) kits according to the manufacturers' instructions. Antioxidant indices, including Superoxide Dismutase (SOD), catalase (CAT), Glutathione Peroxidase (GPx), Total Antioxidant Capacity (TAC), and Malondialdehyde (MDA), were also determined using commercial assay kits. Total serum protein was determined using the Biuret method.

Ethical approval

All experimental procedures involving animals were conducted in accordance with the guidelines of the Animal Care and Use Research Ethics Committee of the University of Ibadan. Ethical approval for this study was obtained prior to the commencement of the experiment (Approval No.: ACUREC/145-0626/18).

Statistical analysis

Data were subjected to one-way analysis of variance (ANOVA) using SAS software (Version 9.4; SAS Institute Inc., Cary, NC, USA). Treatment means were separated using Duncan's Multiple Range Test, and differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Serum cytokine profile of broiler chickens fed pawpaw leaf meal and garlic powder supplemented diet on (Day 0–21)

The serum cytokine profile of broiler chickens fed dietary pawpaw leaf meal and garlic powder is presented in Table 1. Dietary supplementation significantly ($p < 0.05$) influenced serum concentrations of interferon- γ (IFN- γ), interleukin-1 β (IL-1 β), interleukin-6 (IL-6), interleukin-10 (IL-10) and interleukin-4 (IL-4), whereas tumour necrosis factor-alpha (TNF- α) remained unaffected. The combined supplementation of 3% pawpaw leaf meal and 1% garlic powder produced the highest concentrations of IFN- γ , IL-1 β , and IL-6, while birds fed 1% garlic powder recorded the highest IL-10 concentration. Similarly, dietary pawpaw leaf meal resulted in the highest IL-4 concentration, indicating that both phytochemical additives positively influenced immune regulation through different immunological pathways. The immunomodulatory effects observed may be attributed to the bioactive compounds present in pawpaw leaves and garlic, including flavonoids, phenolics,

papain, and allicin, which have been reported to stimulate immune cell activity and cytokine production. The higher concentrations observed in the combined treatment suggest an enhanced immunomodulatory response compared with the individual supplementation treatments; however, this should not be interpreted as evidence of synergy. These findings agree with Hanieh *et al.* (2010), who reported enhanced cytokine production following dietary garlic supplementation. Similarly, Singh *et al.* (2020) reported that *Carica papaya* leaf preparations exhibit potent anti-inflammatory and immunomodulatory activities.

Antioxidant status of broiler chickens fed pawpaw leaf meal and garlic powder supplemented diet on (Day 0–21)

The effects of dietary pawpaw leaf meal and garlic powder on serum antioxidant status are presented in Table 2. Significant ($P < 0.05$) differences were observed in catalase (CAT), superoxide dismutase (SOD), glutathione peroxidase (GPx), and total antioxidant capacity (TAC), whereas malondialdehyde (MDA) was not significantly affected by the dietary treatments. Birds receiving the combined supplementation exhibited the highest total antioxidant capacity, while individual supplementation with garlic or pawpaw leaf meal showed slight numerical variation in the activities of CAT, SOD and GPx enzymes across treatments. The highest total antioxidant capacity observed in birds receiving the combined supplementation indicates an improved overall antioxidant status owing to the influence of the bioactive compounds present in pawpaw leaves and garlic. The absence of significant differences in serum malondialdehyde concentrations further suggests that dietary supplementation effectively maintained lipid peroxidation at a low level despite increased metabolic activity associated with rapid growth. This finding indicates that the enhanced antioxidant defence system was sufficient to preserve oxidative homeostasis throughout the experimental period. These findings are consistent with Zhang *et al.* (2022), who reported that garlic supplementation reduced oxidative stress by enhancing antioxidant enzyme activities, particularly SOD and CAT in broiler chickens.

Serum immunoglobulin and total serum protein of broiler chickens fed pawpaw leaf meal and garlic powder

The effects of dietary pawpaw leaf meal and garlic powder on serum immunoglobulin A (IgA) and total serum protein are presented in Table 3. Dietary treatments significantly ($p < 0.05$) influenced both parameters. Birds fed the combined supplementation recorded the highest serum IgA concentration, whereas those receiving pawpaw leaf

Table 1. Effect of garlic powder and pawpaw leaf meal supplementation on serum cytokine profile of broiler chickens

Parameters	Treatments					SEM	P-value
	PC+0%LM	NC+0%LM	3%PLM	1%GP	3%PLM +1%GP		
IFN- γ (pg/ml)	46.53 ^{ab}	23.49 ^c	30.10 ^{bc}	44.10 ^{ab}	51.83 ^a	3.38	0.018
IL-1 β (pg/ml)	227.07 ^b	177.96 ^b	180.97 ^b	340.30 ^a	415.09 ^a	23.40	0.000
IL-6 (pg/ml)	26.89 ^b	26.54 ^b	26.19 ^b	31.93 ^b	43.04 ^a	1.74	0.002
IL-10 (pg/ml)	4.31 ^c	4.24 ^c	3.50 ^c	25.67 ^a	17.32 ^b	2.00	0.000
TNF- α (pg/ml)	61.38	45.86	39.42	56.40	51.03	4.45	0.548
IL-4 (pg/ml)	142.63 ^c	134.15 ^c	279.50 ^a	208.08 ^b	205.01 ^b	13.79	0.000

^{a,b,c} Means on the same row with different superscripts are significantly ($p < 0.05$) different, SEM- Standard Error of Mean, IFN-G: Interferon-gamma, IL: Interleukins, TNF-A: Tumour Necrosis Factor-Alpha, PC: Positive Control, NC: Negative Control, LM: Leaf Meal, PLM: Pawpaw Leaf Meal, GP: Garlic Powder.

Table 2. Effects of garlic powder and pawpaw leaf meal supplementation on serum antioxidative parameters of broiler chickens.

Parameters	Treatments					SEM	P-value
	PC+0%LM	NC+0%LM	3%PLM	1%GP	3%PLM+1%GP		
MDA (μ M)	0.84	0.83	0.85	0.82	0.86	0.01	0.940
CAT (U/mg prot.)	3.19 ^a	2.52 ^{ab}	1.33 ^c	2.30 ^b	1.95 ^{bc}	0.16	0.000
SOD (U/mg prot.)	0.017 ^{ab}	0.023 ^a	0.014 ^b	0.023 ^a	0.017 ^{ab}	0.001	0.043
GPX (U/L)	44.94 ^b	119.64 ^a	123.75 ^a	34.18 ^b	58.80 ^b	10.68	0.001
TAC (mM TE)	7.74 ^c	9.77 ^{bc}	11.49 ^b	11.53 ^b	16.94 ^a	0.72	0.000

^{a,b,c} Means in the same row with different superscripts differ ($p < 0.05$), MDA: Malondialdehyde, CAT: Catalase, SOD: Superoxide Dismutase, Total Serum Protein, GPx: Glutathione Peroxidase, PC: Positive Control, NC: Negative Control, SEM: Standard Error of Mean, LM: Leaf Meal, GP: Garlic Powder, PLM: Pawpaw Leaf Meal.

Table 3. Effects of garlic powder and pawpaw leaf meal supplementation on total serum protein and immunoglobulin A (IgA) of broiler chickens.

Parameters	Treatments					SEM	P-value
	PC+0%LM	NC+0%LM	3%PLM	1%GP	3%PLM+1%GP		
TSP (g/L)	34.44 ^c	38.49 ^{bc}	45.82 ^a	38.27 ^{bc}	40.00 ^b	0.99	0.001
IgA (mg/dl)	228.65 ^b	167.05 ^b	200.53 ^b	184.20 ^b	338.32 ^a	16.84	0.000

^{a,b,c} Means in the same row with different superscripts differ ($p < 0.05$). TSP: Total Serum Protein, IgA: Immunoglobulin A, PC: Positive Control, NC: Negative Control, SEM: Standard Error of the Mean, LM: Leaf Meal, GP: Garlic Powder, PLM: Pawpaw Leaf Meal.

meal alone exhibited the highest total serum protein concentration. The elevated serum IgA concentration observed in birds fed the combined supplementation indicates enhanced humoral immune function. Immunoglobulin A is the principal antibody responsible for protecting mucosal surfaces against pathogenic microorganisms and plays a critical role in maintaining intestinal immune homeostasis. Increased IgA production therefore suggests improved mucosal immunity and greater resistance to enteric pathogens during the early stages of growth. The variation in total serum protein showed a relatively higher concentration in birds receiving pawpaw leaf meal, followed by the combined supplementation, with comparatively lower values in the other groups. This pattern indicates a relatively higher

circulating serum protein profile in pawpaw leaf meal-supplemented birds, suggesting a possible contribution of the supplementation to maintaining serum protein levels. The superior IgA response observed in birds receiving both pawpaw leaf meal and garlic powder may be attributed to synergistic stimulation of gut-associated lymphoid tissue (GALT), resulting in increased differentiation of plasma cells responsible for IgA secretion. Improved antioxidant status observed in the same treatment may also have contributed to maintaining immune cell integrity and supporting efficient antibody synthesis. Together, these responses indicate that the combined phytogenic supplementation strengthened both systemic and mucosal immune functions. These findings are consistent with Omidwura *et al.* (2020), who reported

improved gut integrity and physiological performance in broiler chickens supplemented with *Carica papaya* leaf meal. Similarly, Oloruntola *et al.* (2018) demonstrated that pawpaw-derived phytochemicals enhance digestive efficiency and antioxidant status.

Conclusion

This study demonstrated that dietary supplementation with pawpaw (*Carica papaya*) leaf meal and garlic (*Allium sativum*) powder positively influenced the immune response and antioxidant status of broiler chickens during the starter phase. Birds fed the combined supplementation (3% pawpaw leaf meal + 1% garlic powder) exhibited a superior serum cytokine profile, immunoglobulin A concentration, total antioxidant capacity compared with the control groups. While total serum protein showed only a slight variation across treatments, birds fed pawpaw leaf meal recorded a significantly different total serum protein concentration from the others. These findings affirmed that the use of pawpaw leaf meal and garlic powder, either individually or combined, can serve as an effective natural phytogenic feed additive for improving immune competence and antioxidant defence in broiler chickens at the early stage of production.

Recommendations

Based on the findings of this study, dietary supplementation with combined 3% pawpaw (*Carica papaya*) leaf meal and 1% garlic (*Allium sativum*) powder is recommended for improving immune response and antioxidant status in broiler chickens during the starter phase. Further studies should investigate the effects of this dietary combination throughout the entire production cycle, evaluate its influence on growth performance, gut microbiota, meat quality, and economic returns under commercial production conditions.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

The authors sincerely appreciate the Department of Animal Science, University of Ibadan, for providing the facilities used in conducting this research. We also acknowledge the technical staff of the Teaching and Research Farm and the laboratory personnel for their assistance during sample collection and laboratory analyses.

REFERENCES

Abd El-Hack, M. E., El-Saadony, M. T., Salem, H. M., El-Tahan,

- A. M., Soliman, M. M., Youssef, G. B. A., Taha, A. E., Soliman, S. M., Ahmed, A. E., El-kott, A. F., Syaad, K. M., & Swelum, A. A. (2022). Alternatives to antibiotics for organic poultry production: types, modes of action and impacts on bird's health and production. *Poultry Science*, 101(4), 101696. <https://doi.org/10.1016/j.psj.2022.101696>.
- Aravind, G., Debjit, B., Duraivel S., & Harish, G. (2013). Traditional and medicinal uses of *Carica papaya*. *Journal of Medicinal Plant Studies*, 1(1), 7-15.
- Dharmarathna, S. L. C. A., Wickramasinghe, S., Waduge, R. N., Rajapakse, R. P. V. J. & Kularatne, S. A. M. (2013). Does *Carica papaya* leaf-extract increase the platelet count? An experimental study in a murine model. *Asian Pacific Journal of Tropical Biomedicine*. 3(9), 720-724. [https://doi.org/10.1016/S2221-1691\(13\)60145-8](https://doi.org/10.1016/S2221-1691(13)60145-8)
- Elbaz, A. M., Ashmawy, E.S., Salama, A. A., Abdel-Moneim, A. E., Badri, F. B., & Thabet, H. A. (2022). Effects of garlic and lemon essential oils on performance, digestibility, plasma metabolite, and intestinal health in broilers under environmental heat stress. *BMC Veterinary Research*, 18, Article 430. <https://doi.org/10.1186/s12917-022-03530-y>
- Hanieh, H., Narabara, K., Piao, M., Gerile, C., Abe, A., & Kondo, Y. (2010). Modulatory effects of two levels of dietary Alliums on immune response and certain immunological variables, following immunization, in White Leghorn chickens. *Animal Science Journal*, 81(6), 673-680. <https://doi.org/10.1111/j.1740-0929.2010.00798.x>
- Kim, J. H. (2023). Determination of safe levels and toxic levels for feed hazardous materials in broiler chickens: A review. *Journal of Animal Science and Technology*. 65, 490–510. <https://doi.org/10.5187/jast.2023.e26>
- National Research Council (NRC). (1994). Nutrient Requirement of Poultry. National Academy of Science.
- Oloruntola, O. D., Ayodele, S. O., Adeyeye, S. A., Ogunsipe, M. H., Daramola, O. T., Ayedun, E. S. (2018). Effect of pawpaw leaf meal and multi-enzyme supplementation in the diet on performance, digestibility, and oxidative enzyme status of rabbits. *Journal of Basic and Applied Zoology*. 79, 26-35. <https://doi.org/10.1186/s41936-018-0039-1>
- Omidwura, B. R. O., Adekunle, A. O., & Badamosi, R. B. (2026). Influence of phytogenics (clove, garlic and pawpaw) on growth, gut health and immune status of broiler chickens. *Asian Journal of Research in Animal and Veterinary Sciences*, 9(2), 260-269. <https://doi.org/10.9734/ajravs/2026/v9i2411>
- Omidwura, B. R. O., Agboola, A. F., Omotosho, O. Y., & Mustapha-Olosho, J. A. (2020). Influence of diets supplemented with *Carica papaya* and *Cromolaena odorata* leaf meals on performance, blood profile and gut integrity of broiler chickens. *Journal of Animal Science and Veterinary Medicine*, 5(5), 173-183. <https://doi.org/10.31248/JASVM.2020.220>
- Rahman, M. M., Islam, M. R., & Khan, M. J. (2020). Effects of garlic on growth performance, hematological parameters, and immune response in broilers. *Journal of Animal Science*, 98(10), 5439-5446.
- SAS, Statistical Analysis Systems Institutes Inc., 2012. Users Guide: Statistics, Version 9.4. Statistical Analysis Systems Institutes Inc. Cary, NC, U.S.A.
- Sharma, A., Sharma, R., Sharma, M., Kumar, M., Barbhai, M. D., Lorenzo, J. M., Sharma S, Samota, M. K., Atanassova, M, Caruso, G, Naushad, M., Radha, Chandran, D, Prakash, P., Hasan, M., Rais, N., Dey, A., Mahato, D. K., Dhumal, S, Singh, S., Senapathy, M., Rajalingam, S., Visvanathan, M., Saleena. L. A. K., & Mekhemar, M. (2022). *Carica papaya* L. leaves:

- Deciphering its antioxidant bioactives, biological activities, innovative products, and safety aspects. *Oxidative Medicine and Cellular Longevity*, Volume 2022, Article ID 2451733, 20 pages. <https://doi.org/10.1155/2022/2451733>.
- Singh, S. P., Kumar, S., Mathan, S. V., Tomar, M. S., Singh, R. K., Verma, P. K., Kumar, A., Kumar, S., Singh R. P., & Acharya, A. (2020). Therapeutic application of *Carica papaya* leaf extract in the management of human diseases. *DARU Journal of Pharmaceutical Sciences*, 28(2), 735-744. <https://doi.org/10.1007/s40199-020-00348-7>.
- Toghyani, M., Toghyani, M., Gheisari, A., Ghalamkari, G., & Eghbalsaid, S. (2011). Evaluation of cinnamon and garlic as antibiotic growth promoter substitutions on performance, immune responses, serum biochemical and haematological parameters in broiler chicks. *Livestock science*, 138(1-3), 167-173. <https://doi.org/10.1016/j.livsci.2010.12.018>
- Wang, J., Deng, L., Chen, M., Che, Y., Li, L., Zhu, L., Chen, G., & Feng, T. (2024). Phytogenic feed additives as natural antibiotic alternatives in animal health and production: A review of the literature of the last decade. *Animal Nutrition*, 17, 244-264.
- Zhang, R., Liu, J., Liu, Y., Wu, Y., Xu, Y., & Feng, J. (2022). Dietary garlic powder alleviates lipopolysaccharide-induced inflammatory response and oxidative stress through regulating the immunity and intestinal barrier function in broilers. *Animals*, 12(17), 2281. <https://doi.org/10.3390/ani12151970>.