The nutritional applications of garlic (*Allium sativum*) as natural feed additives in animals

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ABSTRACT

Garlic (*Allium sativum*) is an essential vegetable that has been widely utilized as seasoning, flavoring, culinary and in herbal remedies. Garlic contains several characteristic organosulfur compounds, such as diallyl sulfide, allicin (diallyl thiosulphate), γ-glutamylcysteine, and S-allyl cysteine (alliin) and ajoene, which garlic has beneficial effects on inflammation, oxidative stress markers, hypertension, hyperlipidaemia and endothelial function *in vitro* or in animal model. These bioactive molecules are also playing pivotal role in livestock and fisheries production apart from its application in humans. Supplementation of animal feed with garlic and its related products is consistent with the modern agricultural concept of organic animal husbandry. This review compiles the information describing the effects of feeding garlic and its extracts on selected performance parameters in animals (chicken, rabbits, ruminants, pigs and fish). This review may provide reference for scientists and entrepreneurs to investigate the applications of feeds added with garlic and allicin by-products for the improvement of animal husbandry and aquatic production.

INTRODUCTION

The use of antibiotic growth promoters (AGPs) in feeds is considered as the greatest biotechnology of animal husbandry production in the 20th century. The AGPs have many functions, including animal performance promotion, disease prevention and treatment, which have been used in animal husbandry and aquaculture for a long time. However, the overuse of AGPs results in drug residues and bacterial resistance, which seriously affect the animal husbandry, aquatic product quality, and thus threatening food safety and human health. However, with the long term use of antibiotics, concerns have been raised regarding bacterial resistance and drug residues, increasing passage of laws banning the use of antibiotics in pig production (*Bi et al., 2017*). Many studies have demonstrated that natural growth promoters such as essential oil (*Li et al., 2012*), probiotic (*Pan et al., 2017*), chito-oligosaccharide (*Liu et al., 2010*) and other additives, can be used to replace AGPs in animal feeds without impairing the animal performance (*Yang et al., 2007*).

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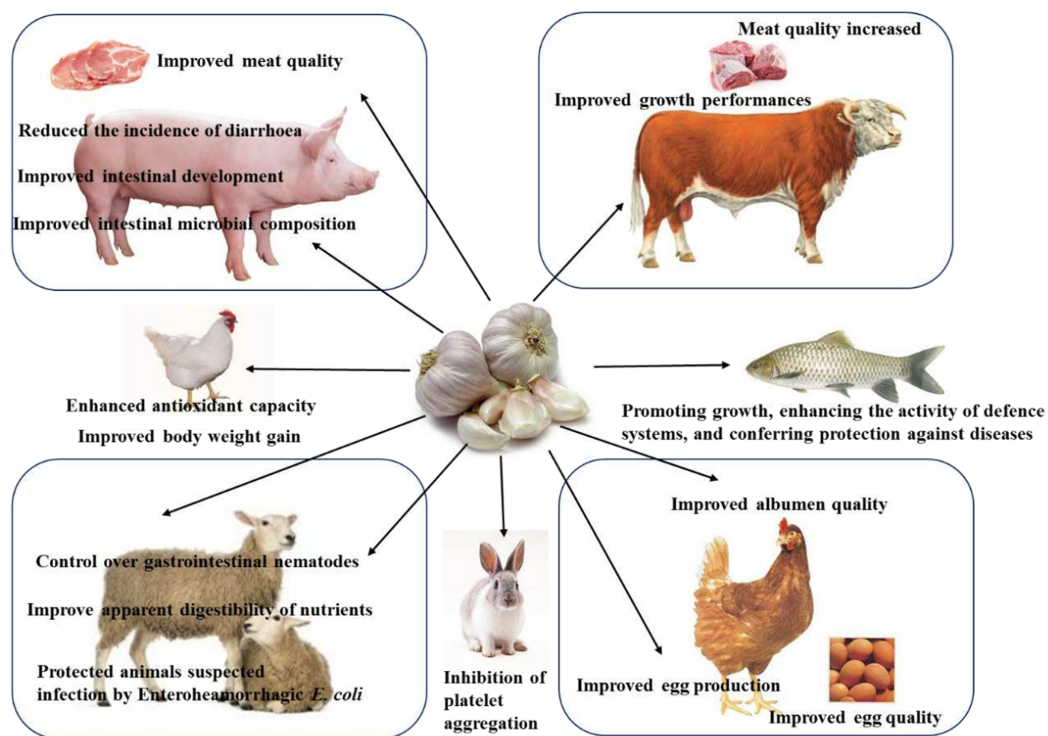
Figure 1 The remarkable beneficial effects of garlic in animals.

As an edible plant and one of the most well-known herbal medicines worldwide, garlic (*Allium sativum*) has generated a lot of interest throughout human history as a panacea in medicine. Phytochemical analysis showed that the main compound in garlic is allicin (diallyl thiosulphate), which is a non-protein amino acid. It is cleaved by alliinase (alliin lyase, EC 4.4.1.4, an α, β-eliminating endogenous lyase from Allium spp.) to allicin (*Marchese et al., 2016*), which can form many other sulfur compounds, , such as diallyl sulfide, γ-glutamyl-*S*-allyl-*L*-cysteines, and *S*-allyl-*L*-cysteine sulfoxides (alliin) and ajoene, altogether they are called allium compounds (*Lawson, 1996*; *Li et al., 2015*; *Suleria et al., 2015*). The main pharmacological effects of garlic are due to its featured organosulphur compounds (*Tapiero, Townsend & Tew, 2004*) and associated with its distinctive pungent smell and other curative properties (*Macpherson et al., 2005*). Moreover, researchers have found that garlic has a lot of biological functions, such as anti-microbial, anti-inflammatory, anti-atherosclerotic, anti-diabetic, anti-mutagentic, anti-carcinogenic, antioxidant and immune-modulation activities (*Cullen et al., 2005*; *Kim, 2016*; *Salehia et al., 2019*).

The aim of this paper, therefore, is to provide evidence for garlic and allicin to replace AGPs in animal production. This article reviews the available scientific literature on the application of garlic and its main extract allicin on livestock and aquatic animals including poultry, swine, fish, and others (Fig. 1).

METHODS

PubMed, Science Direct, CINAHL, MEDLINE, Alt Health Watch and Food Science Source electronic databases were searched online. After qualitatively evaluating the search for garlic and allicin on forums, social media, message boards, and Google, a search was made for the growth-promoting effects of garlic and allicin in livestock and aquatic animals. These keywords, "broiler", "Laying hen", "swine/pig/piglet", "rabbit", "ruminant", "fish" were searched together with garlic. Additionally, author names and reference lists were used for further search of the selected papers for related references. Thereafter, the tone of the narrative was used to objectively evaluate the impact of garlic or allicin on animal performance and meat or egg quality.

NUTRITIONAL APPLICATIONS IN ANIMALS

Effect of garlic supplementation on broiler chickens

Although dietary supplementation of garlic powder in chickens feed has been widely used, their application effects are different. Broiler fed the different levels of garlic (*Allium sativum*) powder (1.5%, 3%, and 4.5%) did not show improved body weight gain (BWG) or feed conversion ratio (FCR) (*Konjufca, Pesti & Bakalli, 1997*). Likewise, *Sklan, Berner & Rabinowitch (1992)* reported that BWG and FCR did not significantly change in chickens fed 2% garlic. Supplementation of garlic powder (1%, 3% or 5%) had no effect on growth performance (*e.g.*, weight gain, feed intake, and FCR) of chickens (*Choi, Park & Kim, 2010*). Addition of garlic did not influence average feed intake, weight gain and FCR of chickens, but reduced abdominal fat contents (*Onibi, Adebisi & Fajemisin, 2009*). A study by *Ao et al. (2010)* revealed that fermented garlic powder increased white blood cells and lymphocyte counts, decreased cholesterol and cortisol in blood, but had no significant effect on BWG and FCR in broilers. However, *Horton, Blethen & Prasad (1991)* added dried garlic (0.01%, 0.1% and 1%) to broiler diets and found that average daily gain increased at the two intermediary levels of garlic (0.01% and 0.1%) during the first 21 days. A previous study also found supplementation of 1% garlic significantly improved the BWG of broilers and could be a practical alternative to antibiotics in the feeding of broiler chicken (*Karangiya et al., 2016*). With the 0.1 and/or 0.2% dietary administration of Korean aged garlic extract by Leukonostoc citreum SK2556, increased BWG and decreased FCR, liver weight and cecal *E. coli* count in broilers were observed (*Hossain, Lee & Kim, 2014*). Although supplementation of garlic-in-water neither reduced the abdominal fat deposit nor serum cholesterol, the final live weight, breast and back weights of broilers fed soyabean diet were improved by soyabean oil and garlic supplementation (*Jegede, Onibi & Ogunwole, 2014*). In addition, dietary supplementation of allicin has been found to enhance antioxidative capacity and reduce blood lipid level in chickens (*Gong-chen et al., 2014*). *Elmowalid et al. (2019)* also suggested promising and useful insights into dietary garlic supplementation in broilers, which may protect consumers against antibiotic residues or toxic metabolites and lower the risk of infection with bacterial pathogens. Present investigations demonstrate that supplementation of diets fed to broilers with by-products of garlic can enhance growth performance and antioxidative capacity,

reduce the amount of cholesterol and cortisol in blood serum, besides the impact on FCR (*Jang et al., 2018*).

Effect of garlic supplementation on laying hens

Supplementation of garlic powder (0.5% or 1%) in diets improved egg weight and reduced cholesterol content in egg yolk as well as serum triglyceride of laying hens (*Yalcın et al., 2006*). *Olobatoke & Mulugeta (2011)* suggested that 3% addition of garlic powder to layer diets efficiently improved weight and albumen quality of eggs without showing negative effects on hen performance, consumer taste or preference. Mixing layer diets with 1–3% garlic powder could improve total immunoglobulin, but yolk height, egg weight, fertility, and hatchability were not affected in White Leghorns chickens (*Tesfaheywet et al., 2017*; *Meseret et al., 2018*). A recent study conducted by *Omer et al. (2019)* reported that the incorporation of garlic or onion powder or the mixture of them in laying hen diets could increase shell thickness and egg weight. In contrast, *Reddy, Lightsey & Maurice (1991)* and *Chowdhury, Chowdhury & Smith (2002)* did not find garlic paste or garlic oil affect egg weight. Similarly, *Hossain, Begum & Kim (2016)* also reported that no change was observed in the egg weight of laying hens fed diets supplemented with aged garlic extract by *Leuconostoc mesenteroides* KCCM35046. Whereas *Khan, Sardar & Anjum (2007)* found that laying hens fed on 2–8% dried garlic had increased egg-production intensity along with improved egg mass. Adding 1% garlic powder into laying hen diets increased egg mass from 52 to 60 weeks of age (*Abdulaziz, Khan & Rahi, 2016*). The results from different studies are inconsistent, which could be explained by the differences in sources, types and the preparation methods of garlic products or powder.

On the other hand, a study conducted by *Safaa (2007)* reported that 2% garlic addition to the diets increased yolk weight, yolk color and Haugh unit (HU). An increasing garlic powder level in diets linearly increased the HU after two weeks of storage (*Lee et al., 2014*). *Olobatoke & Mulugeta (2011)* stated that 3% garlic powder addition in the diet induced significant increases of 0.81 mm in albumen height and 2.71 HU of fresh eggs. *Mahmoud et al. (2010)* indicated that oral administration of garlic liquid showed higher albumen height and HU in the laying hens. *Ao et al. (2010)* found that the dietary supplementation of fermented garlic powder improved yolk color, yolk height and HU, but without remarkable influence on eggshell thickness of the laying hens after 5 weeks. However, these observations were different from the findings reported by *Yalcın et al. (2006)*, who observed that garlic did not significantly affect egg albumin, shell index, yolk index and HU values when the diets of laying hens were supplemented with garlic powder (0.5% or 1%) for 22 weeks. *Kaya & Macit (2012)* also found dried garlic powder did not positively influence eggshell thickness and HU in laying hens, furthermore, no change was found in the eggshell color, eggshell strength and yolk color (*Hossain, Begum & Kim, 2016*). The present studies cleared that inclusion of garlic powder in laying hens increased the egg weight, yolk weight, yolk color, and HU, but no effects on eggshell. Furthermore, the different garlic preparation and administration methods could be an explanation for the variations of the experimental results.

Effect of garlic supplementation on swine

Garlic and allicin have been used to improve health and performance in livestock production (*Cho, Liu & Kim, 2020*). The gut development and BWG of piglet were significantly improved with the supplementation of 10 ml/100 kg body weight aged garlic extract compared with the non-garlic treatment (*Tatara et al., 2005*). *Grela & Klebaniuk (2007)* found garlic increased the BWG of piglet and decreased the incidence of piglet losses, lowered plasma triglycerides and total cholesterol concentrations. *Janz et al. (2007)* showed that finishing pigs preferred the garlic-treated diet by presenting significantly increased feed intake and average daily gain (ADG). *Yan et al. (2011)* found that fermented garlic powder supplementation (0.2%) to the basal diet increased ADG and average daily feed intake in finishing pigs after a 6-week feeding. Moreover, supplemental fermented garlic powder (0.2% or 0.4 %) increased ADG and gain/feed ratio, apparent digestibility of dry matter (DM) and nitrogen (*Yan, Meng & Kim, 2012*). However, *Yan & Kim (2013)* demonstrated that with 0.05% fermented garlic powder administration, ADG but not DM digestibility increased in weaning piglets. *Huang et al. (2011)* showed that allicin supplementation may improve growth performance, decrease diarrhea incidence and fly attractiveness of the faces of weanling piglets, perhaps indicating reduced dissemination of pathogens. A recent study conducted by *Yun, Nyachoti & Kim (2018)* found that diets supplemented with fermented garlic by *Leuconostoc mesenteroides* KCCM35046 (0.1% and 0.2%) inhibited body weight losses of lactating sows and promoted the ADG of suckling piglets in lactation period. However, the outcomes of different animal studies were not always consistent. For example, *Horton, Blethen & Prasad (1991)* reported that no effect was shown in the growth performance when garlic (0.1% or 1%) was added into the pig diets. *Cullen et al. (2005)* also found that dietary garlic administration (0.1% or 1%) reduced feed intake but improved FCR, with no significant change in ADG grower-finisher pigs. These discrepancies could happen because of the differences in type, quality of the garlic products, and animal species and age (*Chen et al., 2008*).

Study which focuses on the effects of garlic on meat quality of livestock was limited. *Holden, Mckean & Franzenburg (1998)* found garlic supplementation in diets increased pH value and lowered cooking losses of meat products from finishing pigs. Pigs fed with garlic powder (1 g/kg) showed significant improvement in meat marbling, firmness scores, pH value and water holding capacity (*Chen et al., 2008*). *Kwon et al. (2005)* and *Omojola, Fagbuaro & Ayeni (2009)* also reported that flavor, color, tenderness and overall acceptability were improved with garlic supplementation. In a study by *Yan et al. (2011)*, meat marbling and the 2-thiobarbituric acid reactive substances parameters were positively influenced by fermented garlic powder (0.2% or 0.4%) supplementation.

On the other hand, the addition of garlic in swine could benefit from an improved dietary value of meat by reducing cholesterol content in muscle and the cholesterol and fat content of backfat. A previous experiment conducted by *Grela et al. (2013)* showed that inulin and garlic extract addition in drinking water resulted in improved carcass meatiness, including ham percentage and loin eye, reduced cholesterol content in the longissimus

muscle and lowest backfat thickness of pigs. *Omojola, Fagbuaro & Ayeni (2009)* found increasing dietary garlic levels (0.5%, 1% and 1.5%) in pigs reduced backfat thickness and total cholesterol content in muscles. Garlic supplementation results in reduction of cholesterol in hepatocytes and triglyceride levels in blood, limitation of the formation and secretion of very low density lipoproteins, and changes in the fatty acid profile of pigs' meat fat, which are beneficial for its dietary value (*Grela et al., 2013*).The combination of 0.5% garlic and 5% dandelion in diet was found most efficient in improving the growth performance, carcass quality traits, and many other parameters related with nutritional fat quality (*Samolińska et al., 2020*). The decline in the cholesterol content induced by garlic may be related to the reduced liver synthesis of the compound.

Moreover, *Wang et al. (2011)* detected that the *E. coli* count of growing pigs was largely declined by increasing amounts of fermented garlic. The effective mode of action by which allicin exhibit its antimicrobial benefits may be involved several physiological processes, which includes RNA synthesis and lipid biosynthesis (*Rahman, 2007*). Another potential use of allicin was investigated by *Liu et al. (2018)*, they found that dietary 1% α-ketoglutarate combined with 0.5% allicin improved cecal microbial composition and diversity, which might further promote total volatile fatty acids metabolism in growing pigs.

These studies suggested that pigs fed diets supplemented with garlic could improve performance, meat quality and intestinal microbiota.

Effect of garlic supplementation on rabbits

It is widely acknowledged that beneficial effects of garlic include the normalized plasma lipids, improved fibrinolytic activity, inhibited platelet aggregation, and reduced blood pressure and glucose. *El-Wafa, Sedki & Ismail (2002)* reported that feeding dried garlic for 8 weeks induced significant improvement in body weight, daily live weight gain of rabbit. Rabbits fed a 1% garlic powder diet exerted hypocholesterolemic and/or antiatherogenic effects and showed an inhibitory activity against cholesteryl ester transfer protein, which can delay the progression of atherosclerosis (*Kwon et al., 2003*). Furthermore, another study with a rabbit atherosclerosis model showed that garlic prevented the progression of the already existing atherosclerotic lesions, inhibited the occurrence of the new ones, thereby lowering the risk factor of atherosclerosis and its related cardiovascular diseases by influencing serum atherogenicity and intimal thickening (*Sobenin et al., 2016*). These studies demonstrated that dietary garlic could prevent the development of cholesterol-induced experimental atherosclerosis and possesses the direct anti-atherogenic activity.

Effect of garlic supplementation on ruminants

A previous study found that supplementing garlic at 200 mg/kg of DM in a barley diet had no effects on DM intake and ruminal fermentation characteristics of lambs, neither carcass characteristics nor meat quality was affected, the fatty acid composition of back fat and liver was decreased compared to lambs fed a no-garlic diet (*Chaves et al., 2008*). The periodic administration of five mL garlic extract in grazing lamb decreases serum

cholesterol level which can help in reducing the deposition of fat in mutton thereby improving meat quality (*Amin et al., 2015*). However, the use of milled garlic in commercially produced pelleted diets of sheep did not show potential effect on controlling (*Strickland et al., 2009*). *Strickland et al. (2011)* reported that the inclusion of garlic into the animal feed did not negatively affect the flavour of lamb, and the high level of garlic inclusion (3.6%) made the meat more acceptable to the panelists. *Khalesizadeh et al. (2011)* found that supplementation of garlic oil (0.4 g/d), monensin (0.2 g/d) and turmeric powder (20 g/d) in the lamb diets had minimal beneficial effects on total tract digestibility of lamb and did not alter feed digestion. Sheep fed with garlic stem and leaf silage diets (GS-diet, at ratio of 9:1) showed higher nitrogen and energy utilization without inhibiting ruminal fermentation (*Kamruzzaman et al., 2011*). Moreover, administration of commercial garlic juice product (1:1 dilution of 99.3% formula Garlic Barrier) did not alter blood packed cell volume and fecal egg counts in goats or lambs, therefore garlic is not recommended as an acute control for gastrointestinal nematodes (*Burke et al., 2009*).

In calf's diets, garlic extract supplementation at 250 mg/kg body weight per day showed significantly increased feed intake, FCR, and average body weight gain, but decreased the severity of scours with lower fecal score and fecal coliform count. *Ghosh et al. (2010)* indicated that supplementing dairy cows with garlic (5 g/d) and juniper berry (2 g/d) essential oils increased feed digestibility in the rumen, which probably was at the expense of the flow of bypass protein to the small intestine. According to reports of *Castillo-Lopez et al. (2021)*, dietary supplementation of garlic oil reduced the concentration of reticular total short-chain fatty acids (75.7, 71.3 and 60.1 mM) and tended to decrease ruminal acetate-to-propionate ratio (2.50, 1.78 and 1.87 ± 0.177) with no effect on ruminal pH in cattle. In addition, *in vitro* the addition of garlic juice at 0.5 mL/100 mL could enhance the production of propionate, and reduce the acetate to propionate ratio, implying that the supply of hydrogen for methanogens was limited (*Kekana, Luseba & Muyu, 2021*). These results suggest that garlic extract can be supplemented to the calves for better performance.

Effect of garlic supplementation on fish

Application of garlic in fish farming has become popular for promoting growth, improving the activity of defence systems, and protecting against diseases. The bioactive compound of garlic and allicin enhanced growth by stimulating the digestive enzyme and balancing the enteric microbial flora (*Talpur & Ikhwanuddin, 2012*). In some other studies, dietary garlic had a beneficial effect on body weight improvement and specific growth rate in *Oreochromis niloticus* and rainbow trout (*Oncorhynchus mykiss*) (*Diab, 2002*; *Nya & Austin, 2009*; *Farahi et al., 2010*). Addition of 3% garlic to Nile tilapia diets improved final weight, weight gain, and specific growth rate, reduced total bacteria, and improved fish health (*Shalaby, Khattab & Abdel Rahman, 2006*). Moreover, dietary garlic extracts improved growth performance and feed utilization, improved dietary glucose utilization by stimulating insulin secretion, consequently improving fish body quality and feed efficiency of juvenile and fingerling Sterlet Sturgeon, *Acipenser ruthenus* (*Hossain, Lee & Kim, 2014*; *Lee et al., 2012*). Oscar fish (*Astronotus ocellatus*) fed with 10 g/kg garlic powder showed increased final weight, weight gain rate, specific growth rate, FCR, and body

composition (*Saghaei, Ghotbeddin & Ghatrami, 2015*). In addition, the supplementation of garlic powder (1–1.5%) increased the feed utilization and the survival of red tilapia (*Hossain, Lee & Kim, 2014*). However, the addition of garlic and ginger (1.5%) to Nile tilapia (*O. Niloticus*) diets showed insignificant effect on growth performance, body composition, while significantly reduced lipid peroxidation and exhibited an antioxidant effect (*Mahmoud et al., 2019*). Therefore, addition of garlic in the diet of aquatic animal is a possible alternative rather than using synthetic or chemical supplements to improve the growth, feed utilization and survival of fish.

On the other hand, the garlic supplemented as a feed additive, increased resistance against infection of *Aeromonas hydrophila* in rainbow trout and in *Labeo rohita* (*Nya & Austin, 2009*; *Sahu et al., 2007*). Likewise, *Thanikachalam, Kasi & Rathinam (2010)* reported that dietary garlic peel enhanced the hematological parameters even at a low level (0.5%) supplementation and made African catfish *Clarias gariepinus* (Bloch) fingerlings highly immunopotent and more resistant to *A. hydrophila* infection. Dietary 1% garlic made Asian sea bass (*Lates calcarifer*) more resistant to the infection by *Vibrio harveyi* (*Talpur & Ikhwanuddin, 2012*). A recent study found that dietary 2% garlic powder increased resistance against *Yersinia ruckeri* infection in brown trout (*Salmo caspius*) through increasing the lysozyme activity (*Zaefarian, Yeganeh & Adhami, 2017*). In addition, *Abdel-Daim, Abdelkhalek & Hassan (2015)* suggested that dietary allicin attenuated deltamethrin-induced oxidative stress and might act as a therapeutic treatment to protect Nile tilapia (*Oreochromis niloticus*) on subacute deltamethrin toxicity. Administration of 0.15 mL of garlic extract per kg feed could be used to obtain optimal skin mucus immunity in female Guppy (*Poecilia reticulata*) (*Motlagh et al., 2020*). Thus, it has been considered that the use of dietary garlic has certainly led to protection in fish against a range of bacterial fish pathogens. There is a growing interest in studying the non-specific defence mechanism in fish, thus providing resistance to infections.

CONCLUSIONS AND FUTURE PROSPECTS

Researchers at home and abroad have conducted in-depth research on garlic and its extracts especially on their applications in animal production and human clinical studies. However, the mechanism of some of its pharmacological effects needs to be further explored. Allicin is a biologically active substance extracted from the bulb of garlic and can also be synthesized chemically. Currently, the synthetic rate of chemical allicin is 85% to 90%, whereas the extraction rate from fresh garlic is only 0.3% (*Nakamoto et al., 2020*). Therefore, chemically synthesized allicin has been widely used in animal production due to its low price, high purity of active ingredients and significant medicinal properties. Although it is not practical to replace antibiotics with allicin nowadays, with the development and advancement of modern science and technology, allicin and other additives will have profound potential to replace antibiotics and contribute to the production of pollution-free meat, improvement of animal welfare and sustainable

development of animal husbandry. As people's requirements for animal meat and egg quality increase, garlic and its extracts will have unique development and utilization value as green additives in improving the quality of commercial meat and eggs. Further research on garlic and its bioactive ingredients with different animal species, appropriate validation and clinical trials by exploiting the modern advances in biotechnology, nanotechnology and pharmacology will contribute to promote and propagate the nutritional and medicinal values of garlic, consequently enhance animal (chickens, laying hens, rabbits and fish) production and health.

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Competing Interests

The authors declare that they have no competing interests.

Author Contributions

- Jiashun Chen conceived and designed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Fang Wang performed the experiments, authored or reviewed drafts of the paper, and approved the final draft.
- Yexin Yin performed the experiments, prepared figures and/or tables, and approved the final draft.
- Xiaokang Ma analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.

Data Availability

This is a literature review, so data is not included.

REFERENCES

Abdel-Daim MM, Abdelkhalek NK, Hassan AM. 2015. Antagonistic activity of dietary allicin against deltamethrin-induced oxidative damage in freshwater Nile tilapia: *Oreochromis niloticus*. *Ecotoxicology and Environmental Safety* **111**:146–152.

Abdulaziz AA, Khan AA, Rahi MJ. 2016. Effects of adding different dietary levels of garlic (*Allium sativum*) powder on productive performance and egg quality of laying hens. *International Journal of Poultry Science* **15**:155.

Amin AB, Yousuf MB, Kolo UM, Ibrahim AA, Muhammad AI, Maigado AI. 2015. Influence of periodic administration of garlic extract on blood parameters of Grazing Lambs. *Biokemistri* **26(4)**:114–119.

Ao X, Yoo JS, Lee JH, Jang HD, Wang JP, Zhou TX, Kim IH. 2010. Effects of fermented garlic powder on production performance, egg quality, blood profiles and fatty acids composition of egg yolk in laying hens. *Asian-Australasian Journal of Animal Sciences* **23(6)**:786–791.

Bi Y, Yang C, Diao Q, Tu Y. 2017. Effects of dietary supplementation with two alternatives to antibiotics on intestinal microbiota of preweaned calves challenged with *Escherichia coli* K99. *Scientific Reports* **7**:5439.

Burke JM, Wells A, Casey P, Miller JE. 2009. Garlic and papaya lack control over gastrointestinal nematodes in goats and lambs. *Veterinary Parasitology* **159(2)**:171–174.

Castillo-Lopez E, Rivera-Chacon R, Ricci S, Petri RM, Zebeli Q. 2021. Short-term screening of multiple phytogenic compounds for their potential to modulate chewing behavior, ruminal fermentation profile, and pH in cattle fed grain-rich diets. *Journal of Dairy Science* **104(4)**:4271–4289.

Chaves AV, Stanford K, Dugan MER, Gibson LL, McAllister TA, Van Herk F, Benchaar C. 2008. Effects of cinnamaldehyde, garlic and juniper berry essential oils on rumen fermentation, blood metabolites, growth performance, and carcass characteristics of growing lambs. *Livestock Science* **117(2–3)**:215–224.

Chen YJ, Kim IH, Cho JH, Yoo JS, Wang Q, Wang Y, Huang Y. 2008. Evaluation of dietary l-carnitine or garlic powder on growth performance, dry matter and nitrogen digestibilities, blood profiles and meat quality in finishing pigs. *Animal Feed Science and Technology* **141(1–2)**:141–152.

Cho JH, Liu SD, Kim IH. 2020. Effects of dietary Korean garlic extract aged by *Leuconostoc mesenteroides* KCCM35046 on growth performance, digestibility, blood profiles, gas emissions, and microbiota in weanling pigs. *Canadian Journal of Animal Science* **100**:462–469.

Choi IH, Park WY, Kim YJ. 2010. Effects of dietary garlic powder and α-tocopherol supplementation on performance, serum cholesterol levels, and meat quality of chicken. *Poultry Science* **89(8)**:1724–1731.

Chowdhury SR, Chowdhury SD, Smith TK. 2002. Effects of dietary garlic on cholesterol metabolism in laying hens. *Poultry Science* **81(12)**:1856–1862.

Cullen SP, Monahan FJ, Callan JJ, O'Doherty JV. 2005. The effect of dietary garlic and rosemary on grower-finisher pig performance and sensory characteristics of pork. *Irish Journal of Agricultural and Food Research* **44(1)**:57–67.

Diab AS. 2002. Evaluation of Nigella sativa L (black seeds; baraka), Allium sativum (garlic) and BIOGEN as feed additives on growth performance and immunostimulants of O. niloticus fingerlings. *Suez Canal Veterinary Medicine Journal* **1**:745–750.

El-Wafa SA, Sedki AA, Ismail AM. 2002. Response of growing rabbits to diets containing black seed, garlic or onion as natural feed additives. *Egypt Journal of Rabbit Science* **12(1)**:69–83.

Elmowalid GA, Abd El-Hamid MI, Abd El-Wahab AM, Atta M, Abd El-Naser G, Attia AM. 2019. Garlic and ginger extracts modulated broiler chicks innate immune responses and enhanced multidrug resistant Escherichia coli O78 clearance. *Comparative Immunology Microbiology and Infectious Diseases* **66**:101334.

Farahi A, Kasiri M, Sudagar M, Iraei MS, Shahkolaei MD. 2010. Effect of garlic (Allium sativum) on growth factors, some hematological parameters and body compositions in rainbow trout (*Oncorhynchus mykiss*). *Aquaculture, Aquarium, Conservation Legislation* **3(4)**:317–323.

Ghosh S, Mehla RK, Sirohi SK, Roy B. 2010. The effect of dietary garlic supplementation on body weight gain, feed intake, feed conversion efficiency, faecal score, faecal coliform count and feeding cost in crossbred dairy calves. *Tropical Animal Health and Production* **42(5)**:961–968.

Gong-chen W, Lu-lu H, Jing W, Wan-nan L, Chuan-yi P, Yan-fei L. 2014. Effects of allicin on lipid metabolism and antioxidant activity in chickens. *Journal of Northeast Agricultural University* **21(3)**:46–49.

Grela ER, Klebaniuk R. 2007. Chemical composition of garlic preparation and its utilization in piglet diets. *Medycyna Weterynaryjna* **63(7)**:792–795.

Grela ER, Pietrzak K, Sobolewska S, Witkowski P. 2013. Effect of inulin and garlic supplementation in pig diets. *Annals of Animal Science* **13**:63–71.

Holden PJ, McKean J, Franzenburg E. 1998. Biotechnicals for pigs-garlic (ASLR1559). ISU Swine Research Report. Iowa State University, Ames, IA, 12.

Horton GMJ, Blethen DB, Prasad BM. 1991. The effect of garlic (*Allium sativum*) on feed palatability of horses and feed consumption, selected performance and blood parameters in sheep and swine. *Canadian Journal of Animal Science* **71(2)**:607–610.

Hossain MM, Begum M, Kim IH. 2016. Effect of *Leuconostoc mesenteroides* KCCM35046 fermented aged garlic extract on egg production, egg quality, odour gas emissions, targeted E. coli colony, haematological characteristics and fatty acids composition of egg yolk in laying hens. *Journal of Applied Animal Research* **44(1)**:458–465.

Hossain MM, Lee SI, Kim IH. 2014. Effect of dietary Korean aged garlic extract by Leukonostoc citreum SK2556 on production, hematological status, meat quality, relative organ weight, targeted Escherichia coli colony and excreta gas emission in broilers. *Animal Feed Science and Technology* **198**:333–340 DOI 10.1016/j.anifeedsci.2014.09.015.

Huang RH, Qiu XS, Shi FX, Hughes CL, Lu ZF, Zhu WY. 2011. Effects of dietary allicin on health and growth performance of weanling piglets and reduction in attractiveness of faeces to flies. *Animal* **5(2)**:304–311 DOI 10.1017/S1751731110001953.

Jang HJ, Lee HJ, Yoon DK, Ji DS, Kim JH, Lee CH. 2018. Antioxidant and antimicrobial activities of fresh garlic and aged garlic by-products extracted with different solvents. *Food Science and Biotechnology* **27(1)**:219–225 DOI 10.1007/s10068-017-0246-4.

Janz JAM, Morel PCH, Wilkinson BHP, Purchas RW. 2007. Preliminary investigation of the effects of low-level dietary inclusion of fragrant essential oils and oleoresins on pig performance and pork quality. *Meat Science* **75(2)**:350–355 DOI 10.1016/j.meatsci.2006.06.027.

Jegede OB, Onibi GE, Ogunwole OA. 2014. Effects of soyabean oil and garlic-in-water supplementation on performance, carcass trait, organs weight, haematology, and serum cholesterol content of finisher broiler chickens. *American Journal of Experimental Agriculture* **4(11)**:1410–1419 DOI 10.9734/AJEA/2014/10542.

Kamruzzaman M, Torita A, Sako Y, Al-Mamun M, Sano H. 2011. Effects of feeding garlic stem and leaf silage on rates of plasma leucine turnover, whole body protein synthesis and degradation in sheep. *Small Ruminant Research* **99(1)**:37–43.

Karangiya VK, Savsani HH, Patil SS, Garg DD, Murthy KS, Ribadiya NK, Vekariya SJ. 2016. Effect of dietary supplementation of garlic, ginger and their combination on feed intake, growth performance and economics in commercial broilers. *Veterinary World* **9(3)**:245–250.

Kaya H, Macit M. 2012. Effect of inclusion of garlic (*Allium sativum*) powder at different levels and copper into diets of hens on performance, egg quality traits and yolk cholesterol content. *International Journal of Poultry Science* **11(2)**:114–119.

Kekana MR, Luseba D, Muyu MC. 2021. Effects of garlic supplementation on in vitro nutrient digestibility, rumen fermentation and gas production. *South African Journal of Animal Science* **51(2)**:271–279.

Khalesizadeh A, Vakili A, Mesgaran MD, Valizadeh R. 2011. The effects of garlic oil (*Allium sativa*), turmeric powder (*Curcuma longa* Linn) and monensin on total apparent digestibility of nutrients in Baloochi lambs. *World Academy of Science, Engineering and Technology* **59**:2065.

Khan SH, Sardar R, Anjum MA. 2007. Effects of dietary garlic on performance and serum and egg yolk cholesterol concentration in laying hens. *Asian Journal of Poultry Science* **1(1)**:22–27 DOI 10.3923/ajpsaj.2007.22.27.

Kim HK. 2016. Garlic supplementation ameliorates UV-induced photoaging in hairless mice by regulating antioxidative activity and MMPs expression. *Molecules* **21(1)**:70 DOI 10.3390/molecules21010070.

Konjufca VH, Pesti GM, Bakalli RI. 1997. Modulation of cholesterol levels in broiler meat by dietary garlic and copper. *Poultry Science* **76(9)**:1264–1271 DOI 10.1093/ps/76.9.1264.

Kwon OS, Cho JH, Min BJ, Kim HJ, Chen YG, Yoo JS, Park HK. 2005. Effect of supplemental medicinal plants (Artemisia, Acanthopanax and Garlic) on growth performance, IGF-1 and meat quality characteristics in growing-finishing pigs. *Food Science of Animal Resources* **25(3)**:316–321.

Kwon MJ, Song YS, Choi MS, Park SJ, Jeong KS, Song YO. 2003. Cholesteryl ester transfer protein activity and atherogenic parameters in rabbits supplemented with cholesterol and garlic powder. *Life Sciences* **72(26)**:2953–2964 DOI 10.1016/S0024-3205(03)00234-0.

Lawson LD. 1996. The composition and chemistry of garlic cloves and processed garlic. In: Koch HP, Lawson LD, eds. *Garlic: The Science and Therapeutic Applications of Allium sativum L. and Related Species.* Baltimore: Williams & Wilkins, 37–109.

Lee DH, Lim SR, Han JJ, Lee SW, Ra CS, Kim JD. 2014. Effects of dietary garlic powder on growth, feed utilization and whole body composition changes in fingerling sterlet sturgeon, acipenser ruthenus. *Asian-Australasian Journal of Animal Sciences* **27(9)**:1303–1310.

Lee DH, Ra CS, Song YH, Sung KI, Kim JD. 2012. Effects of dietary garlic extract on growth, feed utilization and whole body composition of juvenile sterlet sturgeon (*Acipenser ruthenus*). *Asian-Australasian Journal of Animal Sciences* **25(4)**:577.

Li P, Piao X, Ru Y, Han X, Xue L, Zhang H. 2012. Effects of adding essential oil to the diet of weaned pigs on performance, nutrient utilization, immune response and intestinal health. *Asian-Australasian Journal of Animal Sciences* **25**:1617.

Li WQ, Zhou H, Zhou MY, Hu XP, Ou SY, Yan RA, Liao XJ, Huang XS, Fu L. 2015. Characterization of phenolic constituents inhibiting the formation of sulfur-containing volatiles produced during garlic processing. *Journal of agricultural and food chemistry* **63(3)**:787–794.

Liu S, He L, Jiang Q, Duraipandiyan V, Al-Dhabi NA, Liu G, Yao K, Yin Y. 2018. Effect of dietary α-ketoglutarate and allicin supplementation on the composition and diversity of the cecal microbial community in growing pigs. *Journal of the Science of Food and Agriculture* **98(15)**:5816–5821.

Liu P, Piao XS, Thacker PA, Zeng ZK, Li PF, Wang D, Kim SW. 2010. Chito-oligosaccharide reduces diarrhea incidence and attenuates the immune response of weaned pigs challenged with Escherichia coli K88. *Journal of Animal Sciences* **88**:1–3879.

Macpherson LJ, Geierstanger BH, Viswanath V, Bandell M, Eid SR, Hwang S, Patapoutian A. 2005. The pungency of garlic: activation of TRPA1 and TRPV1 in response to allicin. *Current Biology* **15(10)**:929–934.

Mahmoud R, Aziza A, Marghani B, Eltaysh R. 2019. Influence of ginger and garlic supplementation on growth performance, whole body composition and oxidative stress in the muscles of Nile tilapia (*O. niloticus*). *Advanced Animal Veterinary Science* **7(5)**:397–404.

Mahmoud KZ, Gharaibeh SM, Zakaria HA, Qatramiz AM. 2010. Garlic (*Allium sativum*) supplementation: influence on egg production, quality, and yolk cholesterol level in layer hens. *Asian-Australasian Journal of Animal Sciences* **23(11)**:1503–1509.

Marchese A, Barbieri R, Sanches-Silva A, Daglia M, Nabavi SF, Jafari NJ, Izadi M, Ajami M, Nabavi SM. 2016. Antifungal and antibacterial activities of allicin: a review. *Trends in Food Science & Technology* **52**:49–56.

Meseret A, Tesfaheywet Z, Negassi A, Mengistu U. 2018. Effects of supplementation of different levels of garlic (*Allium sativum*) on egg production, egg quality and hatchability of White Leghorn chicken. *Livestock Research for Rural Development* **30**:1203–1209.

Motlagh HA, Safari O, Selahvarzi Y, Baghalian A, Kia E. 2020. Non-specific immunity promotion in response to garlic extract supplemented diets in female Guppy (*Poecilia reticulata*). *Fish Shellfish Immunology* **97**:96–99.

Nakamoto M, Kunimura K, Suzuki JI, Kodera Y. 2020. Antimicrobial properties of hydrophobic compounds in garlic: Allicin, vinyldithiin, ajoene and diallyl polysulfides (review). *Experimental and Therapeutic Medicine* **19(2)**:1550–1553.

Nya EJ, Austin B. 2009. Use of garlic, Allium sativum, to control Aeromonas hydrophila infection in rainbow trout, Oncorhynchus mykiss (*Walbaum*). *Journal of Fish Diseases* **32(11)**:963–970.

Olobatoke RY, Mulugeta SD. 2011. Effect of dietary garlic powder on layer performance, fecal bacterial load, and egg quality. *Poultry Science* **90(3)**:665–670.

Omer HA, Ahmed SM, Abdel-Magid SS, El-Mallah GM, Bakr AA, Fattah MMA. 2019. Nutritional impact of inclusion of garlic (*Allium sativum*) and/or onion (*Allium cepa* L.) powder in laying hens' diets on their performance, egg quality, and some blood constituents. *Bulletin of the National Research Centre* **43(1)**:23.

Omojola AB, Fagbuaro SS, Ayeni AA. 2009. Cholesterol content, physical and sensory properties of pork from pigs fed varying levels of dietary garlic (Allium sativum). *World Applied Sciences Journal* **6(7)**:971–975.

Onibi GE, Adebisi OE, Fajemisin AN. 2009. Response of broiler chickens in terms of performance and meat quality to garlic (*Allium sativum*) supplementation. *African Journal of Agricultural Research* **4(5)**:511–517.

Pan L, Zhao PF, Ma XK, Shang QH, Xu YT, Long SF, Wu Y, Yuan FM, Piao XS. 2017. Probiotic supplementation protects weaned pigs against *enterotoxigenic Escherichia coli* K88 challenge and improves performance similar to antibiotics. *Journal of Animal Sciences* **95**:2627–2639.

Rahman MS. 2007. Allicin and other functional active components in garlic: health benefits and bioavailability. *International Journal of Food Properties* **10**:245–268.

Reddy RV, Lightsey SF, Maurice DV. 1991. Research note: Effect of feeding garlic oil on performance and egg yolk cholesterol concentration. *Poultry Science* **70(9)**:2006–2009.

Safaa HM. 2007. Effect of dietary garlic or fenugreek on cholesterol metabolism in laying hens. *Egypt Poultry Science* **27(4)**:1207–1221.

Saghaei A, Ghotbeddin N, Ghatrami ER. 2015. Evaluation of growth performance and body composition of Oscar fish (*Astronotus ocellatus*) in response to the consumption of dietary intake of garlic (*Allium sativum*). *Aquaculture, Aquarium, Conservation Legislation* **8(4)**:485–490.

Sahu S, Das BK, Mishra BK, Pradhan J, Sarangi N. 2007. Effect of Allium sativum on the immunity and survival of Labeo rohita infected with *Aeromonas hydrophila*. *Journal of Applied Ichthyology* **23(1)**:80–86.

Salehia B, Zuccab P, Orhanc IE, Azzinid E, Adetunjie CO, Mohammedf SA, Banerjeef SK, Sharopovg F, Riganoh D, Sharifi-Radi J, Armstrongj L, Martorellk M, Suredal A, Martinsm N, Selamoğluo Z, Ahmad Z. 2019. Allicin and health: a comprehensive review. *Trends in Food Science Technology* **86**:502–516.

Samolińska W, Grela ER, Kowalczuk-Vasilev E, Kiczorowska B, Klebaniuk R, Hanczakowska E. 2020. Evaluation of garlic and dandelion supplementation on the growth performance, carcass traits, and fatty acid composition of growing-finishing pigs. *Animal Feed Science and Technology* **259**:114316.

Shalaby AM, Khattab YA, Abdel Rahman AM. 2006. Effects of Garlic (*Allium sativum*) and chloramphenicol on growth performance, physiological parameters and survival of Nile tilapia (*Oreochromis niloticus*). *Journal of Venomous Animals and Toxins including Tropical Diseases* **12(2)**:172–201.

Sklan D, Berner YN, Rabinowitch HD. 1992. The effect of dietary onion and garlic on hepatic lipid concentrations and activity of antioxidative enzymes in chicks. *The Journal of Nutritional Biochemistry* **3(7)**:322–325.

Sobenin IA, Andrianova IV, Lakunin KY, Karagodin VP, Bobryshev YV, Orekhov AN. 2016. Anti-atherosclerotic effects of garlic preparation in freeze injury model of atherosclerosis in cholesterol-fed rabbits. *Phytomedicine* **23(11)**:1235–1239.

Strickland VJ, Fisher JS, Potts WT, Hepworth GW. 2009. Lack of response to garlic fed at different dose rates for the control of Haemonchus contortus in Merino wether lambs. *Animal Production Science* **49(12)**:1093–1099.

Strickland VJ, Fisher JS, Williams HG, Potts WT, Hepworth GW. 2011. Sensory quality of meat from lambs fed garlic. *Meat Science* **88(3)**:590–593.

Suleria HAR, Butt MS, Khalid N, Sultan S, Raza A, Aleem M, Abbas M. 2015. Garlic (*Allium sativum*): diet based therapy of 21st century-a review. *Asian Pacific journal of tropical disease* **5(4)**:271–278.

Talpur AD, Ikhwanuddin MHD. 2012. Dietary effects of garlic (*Allium sativum*) on haemato-immunological parameters, survival, growth, and disease resistance against Vibrio harveyi infection in Asian sea bass, Lates calcarifer (Bloch). *Aquaculture* **364**:6–12.

Tapiero H, Townsend DM, Tew KD. 2004. Organosulfur compounds from alliaceae in the prevention of human pathologies. *Biomedicine Pharmacotherapy* **58(3)**:183–193.

Tatara MR, Sliwa E, Dudek K, Mosiewicz J, Studzinski T. 2005. Effect of aged garlic extract and allicin administration to sows during pregnancy and lactation on body weight gain and gastrointestinal tract development of piglets: part I. *Bulletin-Veterinary Institute in Pulawy* **49(3)**:349.

Tesfaheywet Z, Meseret A, Negassi A, Mengistu U. 2017. Effects of supplementation of different levels of garlic (*Allium sativum*) on selected blood profile and immunity of white leghorn chicken. *Biotechnology in Animal Husbandry* **33(3)**:333–348.

Thanikachalam K, Kasi M, Rathinam X. 2010. Effect of garlic peel on growth, hematological parameters and disease resistance against Aeromonas hydrophila in African catfish Clarias gariepinus (Bloch) fingerlings. *Asian Pacific Journal of Tropical Medicine* **3(8)**:614–618.

Wang JP, Yoo JS, Jang HD, Lee JH, Cho JH, Kim IH. 2011. Effect of dietary fermented garlic by *Weissella koreensis* powder on growth performance, blood characteristics, and immune response of growing pigs challenged with Escherichia coli lipopolysaccharide. *Journal of Animal Science* **89(7)**:2123–2131.

Yalcın S, Onbaşılar EE, Reisli Z, Yalcın S. 2006. Effect of garlic powder on the performance, egg traits and blood parameters of laying hens. *Journal of the Science of Food and Agriculture* **86(9)**:1336–1339 DOI 10.1002/(ISSN)1097-0010.

Yan L, Kim IH. 2013. Effects of dietary supplementation of fermented garlic powder on growth performance, apparent total tract digestibility, blood characteristics and faecal microbial concentration in weanling pigs. *Journal of Animal Physiology and Animal Nutrition* **97(3)**:457–464 DOI 10.1111/j.1439-0396.2012.01286.x.

Yan L, Meng QW, Ao X, Zhou TX, Yoo JS, Kim HJ, Kim IH. 2011. Effects of fermented garlic powder supplementation on growth performance, blood characteristics and meat quality in finishing pigs fed low-nutrient-density diets. *Livestock Science* **137(1–3)**:255–259 DOI 10.1016/j.livsci.2010.09.024.

Yan L, Meng QW, Kim IH. 2012. Effects of fermented garlic powder supplementation on growth performance, nutrient digestibility, blood characteristics and meat quality in growing-finishing pigs. *Animal Science Journal* **83(5)**:411–417 DOI 10.1111/j.1740-0929.2011.00973.x.

Yang WZ, Benchaar C, Ametaj BN, Chaves AV, He ML, McAllister TA. 2007. Effects of garlic and juniper berry essential oils on ruminal fermentation and on the site and extent of digestion in Lactating Cows. *Journal of Dairy Science* **90(12)**:5671–5681 DOI 10.3168/jds.2007-0369.

Yun HM, Nyachoti CM, Kim IH. 2018. Effect of dietary supplementation of fermented garlic by *Leuconostoc mesenteroides* KCCM35046, on growth performance, blood constituents, nutrient digestibility, fecal microflora, and fecal scores in sows and their piglets. *Canadian Journal of Animal Science* **99(2)**:349–356.

Zaefarian A, Yeganeh S, Adhami B. 2017. Dietary effects of garlic powder (*Allium sativum*) on growth, blood indices, carcass composition, and lysozyme activity in brown trout (*Salmo caspius*) and resistance against Yersinia ruckeri infection. *Aquaculture International* **25(6)**:1987–1996.