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Phytochemical analysis and inhibition of multidrug-resistant *Salmonella* by garlic extract in broiler chicken meat

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Abstract
The emergence of multidrug-resistant (MDR) *Salmonella* strains in poultry farming has posed a significant challenge to food safety and public health. Conventional antibiotics, which have traditionally been used to control *Salmonella* infections, are becoming less effective due to the growing problem of antibiotic resistance. In this context, garlic (*Allium sativum*) has emerged as a promising natural antimicrobial agent due to its bioactive compounds, including allicin, diallyl disulfide, and sulfur-containing compounds, which have demonstrated potent antibacterial activity. This review explores the phytochemical composition of garlic and its inhibitory effects on MDR *Salmonella* strains isolated from broiler chicken meat. The antibacterial properties of garlic extract are discussed, highlighting its ability to disrupt bacterial cell membranes and inhibit protein synthesis. Additionally, the review examines the synergistic effects of garlic extract in combination with conventional antibiotics, which has been shown to enhance antibiotic efficacy against resistant strains. Furthermore, the potential application of garlic extract in poultry farming is considered, focusing on its role as a natural alternative to antibiotics for controlling *Salmonella* contamination in poultry products. Garlic extract offers a viable and sustainable solution to combat MDR *Salmonella*, reduce reliance on antibiotics, and promote food safety in the poultry industry. Further research is needed to determine the optimal dosage, safety, and regulatory approval for its widespread use in poultry production.

Keywords: Multidrug-resistant (MDR) *Salmonella*, poultry farming, food safety, antibiotic resistance

1. Introductions
To enhance the reliability and applicability of the findings, it is recommended that the review includes studies from a broader range of sources. This includes studies involving **Salmonella** strains isolated from various poultry farms across different geographical regions. This would allow the conclusions to be more generalized and would reflect the diverse farming practices and environmental conditions that might influence the efficacy of garlic extract as an antimicrobial agent in poultry farming. The poultry industry, a major contributor to global food production, is also a significant source of foodborne pathogens, with *Salmonella* being one of the leading causes of gastrointestinal diseases. *Salmonella* infections in humans are commonly linked to the consumption of contaminated poultry products, and the emergence of multidrug-resistant (MDR) *Salmonella* strains presents a serious challenge to public health. These resistant strains are less susceptible to common antibiotics, leading to treatment failures and prolonged infections. This growing resistance has prompted the need for alternative strategies, particularly in the context of poultry farming, to control and prevent *Salmonella* infections.

In recent years, the use of plant-derived antimicrobial agents, particularly those from herbs with well-known medicinal properties, has garnered significant attention. Garlic (*Allium sativum*), a plant traditionally used for its culinary and medicinal benefits, has emerged as a potent antimicrobial agent. The active compounds in garlic, such as allicin, diallyl disulfide, and other sulfur-containing compounds, have shown considerable antibacterial properties, including activity against MDR *Salmonella*. This review explores the phytochemical composition of garlic and its antibacterial effects, focusing on its potential to inhibit MDR *Salmonella* strains isolated from broiler chicken meat. Additionally, it evaluates the synergistic effects of garlic extract in combination with conventional antibiotics and its prospective use in poultry farming to combat antibiotic resistance.

2. Phytochemical Composition of Garlic

Garlic contains a variety of bioactive compounds that contribute to its medicinal properties. The most notable and well-studied bioactive compound in garlic is allicin. Allicin is a sulfur-containing compound formed when garlic is crushed or chopped, activating the enzyme alliinase, which converts alliin to allicin. Allicin has been shown to possess broad-spectrum antimicrobial activity, including antibacterial, antifungal, and antiviral effects. It is believed to exert its antibacterial action by disrupting bacterial cell membranes, interfering with bacterial enzymes, and preventing the synthesis of proteins essential for bacterial growth [1].

In addition to allicin, garlic contains other sulfur-containing compounds, such as diallyl disulfide, diallyl trisulfide, and S-allyl cysteine. These compounds have demonstrated antimicrobial properties, working synergistically to enhance garlic's overall antibacterial effect. Diallyl disulfide, for example, has been shown to inhibit bacterial growth by interacting with bacterial enzymes and disrupting their function. Diallyl trisulfide further amplifies garlic's antimicrobial properties by enhancing the integrity of the bacterial membrane [2].

Moreover, garlic is rich in flavonoids, phenolic acids, and saponins, all of which contribute to its antioxidant, anti-inflammatory, and antimicrobial effects. Flavonoids, for instance, are known to modulate bacterial cell signaling and prevent the attachment of pathogens to epithelial surfaces, thus reducing bacterial colonization^3. Garlic's ability to inhibit the growth of pathogenic bacteria, including *Salmonella*, is largely due to the synergistic actions of these bioactive compounds, making it a promising alternative to antibiotics in combating infections caused by drug-resistant pathogens.

3. Antibacterial Activity of Garlic Extract against *Salmonella*

Garlic extract's primary bioactive compound, allicin, is known to exert its antimicrobial effects by interacting with bacterial cell wall synthesis enzymes, such as transglycosylases and penicillin-binding proteins, which are critical for the formation of the bacterial cell wall. Allicin also reacts with thiol groups in bacterial enzymes and proteins, leading to the inhibition of key enzymatic processes. Additionally, allicin has been shown to disrupt bacterial cell membranes by integrating with membrane lipids, leading to increased membrane permeability and leakage of cellular contents, which causes cell death. Furthermore, allicin has been reported to interfere with bacterial DNA replication by inhibiting DNA polymerase activity, impairing bacterial replication and survival.

Garlic extract has been widely studied for its antimicrobial properties, especially its effectiveness against *Salmonella*. Numerous studies have demonstrated that garlic extract can inhibit the growth of both Gram-positive and Gram-negative bacteria, including *Salmonella*, by targeting multiple bacterial pathways. The antibacterial action of garlic is attributed to its ability to disrupt bacterial cell membranes, inhibit protein synthesis, and prevent the replication of bacterial DNA. Allicin, the primary active compound in garlic, is known to interact with bacterial cell wall synthesis enzymes, interfering with the formation of cell walls and rendering bacteria more susceptible to environmental stress [4].

Research has shown that garlic extract can inhibit the growth of *Salmonella* strains isolated from poultry meat, with inhibition zones ranging from 15 mm to 20 mm, depending on the concentration of garlic extract and the strain of *Salmonella*. Studies have reported that garlic extract is effective at concentrations as low as 50 µg/mL, suggesting its potential as a cost-effective antimicrobial agent for use in poultry farming^5. Additionally, garlic extract has demonstrated efficacy against MDR *Salmonella* strains, including those resistant to antibiotics such as amoxicillin, tetracycline, and ciprofloxacin, further underscoring its potential as a natural alternative to conventional antibiotics [6].

The ability of garlic extract to target both Gram-positive and Gram-negative bacteria, including antibiotic-resistant strains, makes it a versatile antimicrobial agent. Moreover, its broad-spectrum activity and low toxicity to animals and humans make it an attractive option for controlling *Salmonella* contamination in poultry products without contributing to the global issue of antimicrobial resistance.

4. Synergistic Effects of Garlic Extract and Antibiotics

The combination of garlic extract with conventional antibiotics has shown promising synergistic effects in overcoming antibiotic resistance. Synergy occurs when the combined effect of two antimicrobial agents is greater than the sum of their individual effects. Several studies have explored the synergistic potential of garlic extract when combined with antibiotics such as amoxicillin, ciprofloxacin, and tetracycline. The results indicate that garlic extract enhances the efficacy of these antibiotics against MDR *Salmonella* strains by reducing the minimal inhibitory concentration (MIC) of the antibiotics [7].

For example, one study demonstrated that combining garlic extract with amoxicillin resulted in a significant reduction in bacterial growth compared to either treatment alone. The fractional inhibitory concentration index (FICI) for this combination was found to be less than 0.5, indicating a strong synergistic effect. Similarly, the combination of garlic extract with ciprofloxacin has been shown to increase the antibiotic's ability to penetrate bacterial cells, improving its efficacy against MDR *Salmonella* [8].

The synergistic effects of garlic extract and antibiotics can be attributed to several mechanisms. Garlic compounds may increase the permeability of bacterial cell membranes, allowing greater antibiotic uptake. Additionally, garlic has been shown to inhibit bacterial efflux pumps, which are responsible for pumping out antibiotics from bacterial cells, thus enhancing the intracellular concentration of antibiotics [9]. This combination approach not only enhances the efficacy of antibiotics but also provides a promising strategy for combating MDR *Salmonella* and other drug-resistant pathogens.

5. Garlic Extract in Poultry Production: A Natural Alternative to Antibiotics

The incorporation of garlic extract in poultry farming requires careful consideration of its optimal dosage, safety, and long-term effects. Research is needed to determine the most effective concentration of garlic extract that can reduce **Salmonella** contamination without causing adverse health effects in poultry. Additionally, the safety of garlic extract in terms of its toxicity, if any, when administered in high doses needs to be assessed. Furthermore, the regulatory

approval process for using garlic extract as a feed additive must be addressed, including its inclusion in feed formulations and compliance with food safety standards. These aspects must be carefully explored to ensure the safe and sustainable use of garlic extract in poultry production.

In addition to garlic, other natural antimicrobial agents such as ginger, turmeric, and oregano have shown promise in combating **Salmonella** and other pathogens in poultry farming. A comparative analysis of garlic extract with these other natural agents could provide valuable insights into their relative effectiveness. Such comparisons would help identify the best candidates for integrated antimicrobial strategies, potentially combining garlic with other agents to enhance efficacy against **Salmonella** and other antimicrobial-resistant pathogens.

Although garlic extract is generally regarded as safe, it is important to address potential side effects, toxicity, or adverse reactions from prolonged use, especially in large doses. Excessive garlic consumption could lead to gastrointestinal upset, particularly in poultry. Therefore, the manuscript should include a discussion of acceptable dosages and possible side effects. Studies on the safety of garlic extract in long-term poultry feed supplementation are essential to ensure that it does not affect poultry health or meat quality negatively. Furthermore, regulatory bodies such as the FDA and EFSA must assess the safety of garlic extract before its widespread adoption in commercial poultry farming.

The use of garlic extract as a natural antimicrobial agent in poultry production is gaining attention due to concerns about the overuse of antibiotics in agriculture and its contribution to antimicrobial resistance. Garlic extract, with its antimicrobial, antioxidant, and immune-boosting properties, could serve as a sustainable alternative to antibiotics for preventing *Salmonella* infections in poultry. Incorporating garlic extract into poultry feed or water supplementation has the potential to reduce *Salmonella* contamination in poultry meat, thereby improving food safety and reducing the need for antibiotics in animal farming [10].

In addition to its antimicrobial properties, garlic extract has been shown to improve the overall health and productivity of poultry. Garlic's immune-boosting effects may help poultry resist infections, enhancing their overall well-being and reducing the reliance on veterinary treatments. Furthermore, garlic extract is inexpensive and has a low risk of toxicity when used in appropriate doses, making it an attractive option for sustainable and organic poultry farming.

Despite these promising benefits, further research is required to determine the optimal dosage, safety, and long-term efficacy of garlic extract in poultry production. The development of guidelines for its use in animal feed, as well as regulatory approval from food safety authorities, will be necessary for its widespread adoption in commercial poultry farming. As more studies are conducted on garlic's practical applications in poultry farming, it is likely that garlic extract will play an important role in reducing *Salmonella* contamination and promoting food safety.

6. Conclusion

This review highlights the antimicrobial properties of garlic extract, particularly its ability to inhibit MDR *Salmonella* strains isolated from broiler chicken meat. The phytochemicals in garlic, especially allicin, contribute significantly to its antibacterial effects. Garlic extract not only exhibits potent antimicrobial activity on *Salmonella* but also enhances the efficacy of conventional antibiotics through synergistic interactions. This combination offers a promising strategy to combat antibiotic-resistant pathogens in poultry production.

Garlic extract represents a viable natural alternative to antibiotics in poultry farming, potentially reducing *Salmonella* contamination and improving food safety. However, further research is needed to optimize its dosage, establish safety protocols, and gain regulatory approval for its use in commercial poultry production. Garlic extract has the potential to contribute to sustainable farming practices by offering a natural solution to the global issue of antimicrobial resistance.

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