Effects of Ammonia on Broiler Chicken Health and Mitigation Measures: Postprint

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Abstract

Ammonia is the most hazardous gas in poultry houses, and chronic ammonia stress is detrimental to the healthy growth of broiler chickens. Strengthening monitoring of ammonia concentration in broiler houses and investigating the effects of ammonia on broiler health and mitigation measures are of great significance for guiding rational regulation of ammonia levels in poultry facilities and the development of healthy farming practices. This paper primarily reviews the sources of ammonia in poultry houses, its effects on broiler growth performance, slaughter performance and meat quality, immune function, respiratory tract, reproductive performance, welfare, and other aspects, as well as monitoring and mitigation measures for ammonia in poultry houses, thereby providing a reference for in-depth research on the mechanisms of ammonia' s effects on broiler health and rational regulation of ammonia concentration in broiler houses.

Full Text

Effects of Ammonia on Broiler Health and Countermeasures

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Abstract

Ammonia is the most hazardous gas in poultry houses, and chronic ammonia stress adversely affects the healthy growth of broiler chickens. Strengthening monitoring of ammonia concentrations in broiler houses and investigating the impacts of ammonia on broiler health, along with developing effective mitigation measures, are crucial for guiding rational ammonia control and promoting healthy poultry production practices. This paper comprehensively reviews the sources of ammonia in poultry houses and its effects on broiler growth performance, slaughter performance and meat quality, immune function, respiratory health, reproductive performance, and welfare. Additionally, we examine monitoring and abatement strategies for ammonia, providing a reference for further research into the mechanisms underlying ammonia' s effects on broiler health and for establishing rational approaches to controlling ammonia levels in broiler houses.

Keywords: ammonia; broiler; hazard; emission reduction

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1. Sources of Ammonia in Poultry Houses

According to the European Environment Agency, 92% of ammonia emissions originate from agricultural activities, with 80% specifically from livestock production. Broiler chickens continuously produce ammonia, primarily through metabolic activities in organs and tissues, with a smaller portion generated by microbial decomposition in the gastrointestinal tract. Research indicates that approximately 67% of dietary nitrogen is excreted by poultry, while only 33% is incorporated into tissues or eggs. From 1 to 42 days of age, each broiler produces 0.37 g of total fecal nitrogen and volatile ammonia nitrogen daily, with maximum levels reaching 0.78 g per day. Zhang et al. found that White-feathered broilers emitted an average of 2,778 mg of ammonia per bird during the 1-42 day period, corresponding to an average emission rate of 66 mg per bird per day.

The primary sources of ammonia in poultry houses include: (1) nitrogen metabolism in poultry produces uric acid through amino acid degradation and purine nucleotide metabolism, which is excreted into the gastrointestinal tract and hydrolyzed into ammonia under the catalytic action of microbial urease; (2) the short digestive tract of poultry results in low nutrient digestibility, causing undigested proteins, amino acids, and other nitrogenous compounds to be excreted in feces and decomposed by various microorganisms to produce ammonia; and (3) the decomposition of nitrogen-containing organic matter from accumulated feed residues and litter through fermentation. Additionally, high stocking density, poor ventilation, and excessive humidity in poultry houses all contribute to elevated ammonia concentrations.

2.1 Effects on Growth Performance

High blood ammonia concentrations disrupt metabolism in brain nerve and muscle cells, leading to ammonia toxicity and suppression of feeding centers. Furthermore, high ammonia concentrations intensify detoxification processes in the liver and other organs, consuming substantial energy and consequently reducing broiler growth performance. Elevated ammonia levels decrease body weight gain, feed intake, and feed conversion ratio in broilers. Research has shown that 52 mg/kg ammonia significantly reduces feed conversion ratio in 21-day-old broilers, while 80 mg/kg ammonia significantly decreases average daily gain and average daily feed intake in 42-day-old broilers. Li et al. reported that as ammonia concentration in poultry houses increases, both average daily gain and daily feed intake of broilers decrease. Charles et al. found that exposure to high ammonia concentrations of 102 mg/kg for one week significantly reduced average daily feed intake and daily gain. Li et al. similarly reported that 80 mg/kg ammonia significantly decreased average daily gain and average daily feed intake. Miles et al. observed that broilers exposed to 50 and 75 mg/kg ammonia for 28 days had significantly lower body weights than the control group. Collectively, these findings demonstrate that ammonia stress impairs broiler growth performance and is detrimental to healthy broiler development.

2.2 Effects on Slaughter Performance and Meat Quality

Ammonia stress reduces broiler slaughter yield, semi-eviscerated yield, fully-eviscerated yield, breast muscle percentage, and leg muscle percentage to varying degrees. Ammonia stress significantly increases saturated fatty acid content in leg muscle while decreasing unsaturated fatty acid content and the ratio of polyunsaturated to saturated fatty acids. High ammonia concentrations in poultry houses affect meat quality, with research showing that the impact intensifies with increasing ammonia concentration and exhibits a cumulative time effect. High ammonia concentrations cause breast muscle blistering, reduce carcass grading scores, increase breast muscle drip loss and shear force, increase lightness (L*) and yellowness (b*)* values, and decrease redness (a*) values. High-throughput sequencing revealed that 25 mg/kg ammonia exposure resulted in 96 downregulated genes and 67 upregulated genes in breast muscle tissue. Li et al. reported that ammonia significantly increased drip loss in breast muscle, though its effects on breast muscle pH and meat color did not reach significant levels. Meanwhile, increased abdominal fat percentage with rising ammonia concentration suggests that high ammonia influences fat deposition in broilers. Zhou found that exposure to 50 mL/m^3 ammonia for two weeks significantly decreased breast muscle pH and increased meat lightness (L*). These studies collectively demonstrate that ammonia exposure impairs both slaughter performance and meat quality in broilers.

2.3 Effects on Immune Function and Blood Physiological Parameters

Under ammonia stress conditions, broilers produce large quantities of globulins for defense; however, immune function gradually declines with prolonged ammonia exposure. Both gastrointestinal ammonia and environmental ammonia in the house affect broiler immune function, with research indicating that ammonia concentrations reaching 15 mg/kg significantly reduce animal resistance. Ammonia entering the blood through pulmonary alveoli binds with hemoglobin, converting heme to methemoglobin and reducing the oxygen-carrying capacity of hemoglobin, thereby decreasing disease resistance. Ammonia stress affects blood cytokine levels and impairs immune function. High ammonia concentrations significantly reduce lysozyme activity and natural killer cell cytotoxicity in broiler blood. Li found that 50 mg/kg ammonia significantly decreased interleukin-1β (IL-1β) and interleukin-6 (IL-6) levels in 42-day-old broiler serum. Ammonia stress significantly reduced plasma glutathione peroxidase activity while increasing plasma malondialdehyde content and glutamate-pyruvate transaminase activity. Zhang et al. reported that 75 mg/kg ammonia exposure resulted in upregulation of 21 proteins related to lipid synthesis, amino acid degradation, oxidative stress, and liver injury, and downregulation of 17 proteins associated with energy metabolism, cytoskeletal structure, immune and inflammatory responses, and detoxification functions. Song et al. found that ammonia entering the blood through pulmonary alveoli can be partially converted to uric acid in the liver, but most remains in the blood, leading to elevated blood ammonia concentrations. Zhang reported that high ammonia concentrations (770 mg/kg) in poultry houses significantly increased blood ammonia levels, serum total protein, globulin, and urea nitrogen content, and significantly elevated activities of lactate dehydrogenase, creatine kinase, and alkaline phosphatase in broiler blood. Research has also shown that red blood cell count, hematocrit, and mean corpuscular volume increase with rising ammonia concentration. Ammonia significantly elevated serum levels of thyroid hormones triiodothyronine (T3) and thyroxine (T4), which are involved in lipid metabolism, thereby affecting broiler fat metabolism.

2.4 Effects on the Respiratory System

The respiratory system is particularly sensitive to ammonia stimulation. Ammonia reaches the lungs through the trachea, and prolonged exposure causes pathological changes and even necrosis in tracheal and lung tissues, potentially leading to obstruction and edema of bronchial epithelium, atelectasis, hemorrhage, and pulmonary alveolar emphysema, resulting in respiratory dysfunction. Li found that with increasing ammonia concentration, expression of tight junction protein-1 (claudin-1) and mucin-2 (muc2) in tracheal tissue decreased significantly, while caspase-3 expression increased significantly, indicating that ammonia stress damages the mucosal barrier function of tracheal tissue and induces apoptosis in tracheal cells. Studies have reported that ammonia stress causes necrosis, desquamation, and hemorrhage of tracheal epithelial cells, as well as obvious hemorrhage and congestion in lungs, with the degree of tracheal and lung injury increasing with ammonia concentration.

2.5 Effects on Reproductive Performance

High ammonia concentrations impair reproductive function and harm embryonic development. Ammonia stress reduces laying performance in hens, with more significant effects at higher concentrations. Research reported that when ammonia concentration reached 23.4 mg/m^3, each 1 mg/m^3 increase reduced laying rate by 0.81%. Housing in 50-80 mg/kg ammonia for eight weeks decreased egg production by 9%, while 100 mg/kg ammonia for ten weeks reduced laying rate from 81% to 68%. At 200 mg/kg ammonia, egg production was significantly reduced. These studies demonstrate that ammonia stress decreases egg production and impairs reproductive performance.

2.6 Effects on Welfare

The degree of damage from ammonia depends on both concentration and duration of exposure. Chronic ammonia exposure affects broiler welfare. When ammonia concentration reaches 25 mg/kg, the incidence of airsacculitis increases; at 50 mg/kg, the incidence of eye keratitis and conjunctivitis increases. Li et al. reported that 50 mg/kg ammonia significantly reduced lying duration in broilers, while 80 mg/kg ammonia extremely significantly reduced lying duration. Meng et al. found that ammonia significantly affected footpad scores, hock joint scores, and gait scores, with increasing ammonia concentration leading to higher incidence and severity of feather soiling, footpad infections, and lameness. Ammonia at 25 mg/kg significantly reduced feeding, resting, and feather-pecking behaviors in laying hens. Wathes reported that ammonia exceeding 50 mg/kg in poultry houses caused obvious lameness, exacerbated skin damage and inflammation at hock joints or footpads, and reduced welfare levels. Wang et al. found that ammonia concentrations below 40 mg/kg did not cause ascites syndrome, while 80 mg/kg ammonia induced ascites.

3.1 Enhanced Management and Environmental Monitoring

Research shows that ammonia concentration in livestock and poultry houses is closely related to temperature and humidity. Ferguson et al. found that high humidity increases ammonia release from litter. Wheeler et al. discovered that houses with reused litter had significantly higher ammonia emissions than those with fresh litter. Therefore, maintaining clean housing conditions, promptly removing manure, replacing litter regularly, controlling appropriate temperature and humidity, and ensuring adequate ventilation can effectively reduce ammonia concentration. Additionally, monitoring ammonia levels in broiler houses is essential for understanding temporal variations and enabling timely adjustments. Modern poultry house environmental monitoring systems integrated with multiple sensors enable continuous multi-point monitoring of temperature, humidity, and ammonia, with automatic data processing and threshold-based alarms, providing scientific management approaches and improving efficiency. Peng et al. designed a ZigBee-based wireless environmental monitoring system that tracks temperature, humidity, and ammonia parameters, allowing farmers to access real-time environmental data remotely via the internet.

3.2 Rational Dietary Regulation

Diet composition is a primary factor affecting ammonia concentration in broiler houses. Formulating low-protein diets using ideal protein technology reduces dietary protein levels, improves protein utilization efficiency, and decreases nitrogen excretion. Ammonia production is related to dietary protein content and digestibility. Research indicates that 99% of nitrogen in broiler excreta originates from feed. Studies show that reducing total dietary protein content while maintaining essential amino acid intake can decrease nitrogen losses: each 1% reduction in dietary protein level reduces urinary nitrogen and fecal nitrogen excretion by 8-9% and 2-3%, respectively, and decreases ammonia emissions by 8.0-12.5%.

3.3 Proper Use of Additives

Dietary supplementation with enzymes, probiotics, and plant extracts can reduce fecal ammonia emissions. Enzyme addition decreases intestinal content viscosity, enhances intestinal enzyme activity, and improves nutrient digestibility, thereby reducing fecal nitrogen content and ammonia production. Probiotics reduce ammonia and other harmful substances generation in the intestine, decreasing intestinal ammonia levels and emissions. Hossain et al. reported that dietary supplementation with 0.1% compound probiotics (Bacillus subtilis, Clostridium butyricum, and Lactobacillus acidophilus) significantly reduced ammonia emissions. Sun et al. found that adding 0.3% inulin and 0.1% Bacillus significantly decreased ammonia emission from broiler excreta. Yucca extracts and other plant-derived compounds have strong adsorption capacity, improve intestinal environment, reduce ammonia emissions, and improve air quality. Additionally, urease inhibitors suppress microbial urease activity in intestinal contents or excreta, inhibiting decomposition of nitrogenous compounds like uric acid and urea, thereby reducing ammonia emissions. Studies show that dietary urease inhibitors affect nitrogen metabolism, effectively slowing ammonia nitrogen decomposition in feces and urine, reducing total nitrogen excretion and ammonia concentration. Aluminum salts also control ammonia release by decreasing pH and altering urease activity and nitrogen loss in chicken manure.

3.4 Manure Management

Composting is one of the most common and effective methods for harmless treatment of poultry manure, but it generates substantial ammonia emissions. Many studies show that improving composting conditions can reduce ammonia emissions. Adding wheat straw, coconut fiber, or peat during composting increases the carbon-to-nitrogen ratio and effectively reduces ammonia volatilization and nitrogen loss. Ammonia from nitrogenous compounds in manure first dissolves as ammonium ions (NH_4^+); as NH_4^+ concentration increases, the equilibrium NH_4^+ $NH_3 + H^+$ shifts rightward, and when aqueous ammonia reaches a certain concentration, it is released as gas. Reducing manure pH drives the reaction toward NH_4^+ formation, decreasing ammonia production. Microbial deodorants applied to manure rapidly establish dominant microbial communities that, through nitrification, enable harmless treatment, inhibit ammonia-producing microorganisms, or enhance ammonia absorption by dominant flora, reducing emissions. Studies show that inoculating chicken manure with soil increases bacterial and fungal populations, accelerating ammonium nitrogen (NH_4^+-N) transformation and reducing ammonia emission. Gutarowska et al. reported that adding multiple bacterial strains to poultry manure effectively reduced ammonia production. Kim et al. added nitrifying bacteria to broiler manure, effectively decreasing NH_4^+-N concentration and ammonia emission. Liu et al. demonstrated that spreading Chinese herbal residue litter significantly reduced ammonia concentration, possibly through ammonia adsorption followed by nitrification conversion to nitrate nitrogen. Adsorbents like activated carbon and zeolite, with large surface areas, porous structures, and strong adsorption capacity, effectively reduce ammonia concentration. Studies show that adding bentonite, zeolite, and alum to poultry manure most effectively reduces ammonia emissions.

With the intensification of broiler production and continuous improvement in genetic breeding technology, broiler growth performance has increased while marketing age has decreased, but broilers have become increasingly susceptible to environmental influences. This paper summarized the sources, hazards, and mitigation measures of ammonia in broiler houses. However, the specific mechanisms underlying ammonia' s effects on broiler health remain unclear, and most current research evaluates the impact of ammonia as a single factor, with few studies investigating combined effects with temperature, humidity, and other environmental factors. Therefore, in-depth investigation of ammonia concentration dynamics, clarification of mechanisms using multi-omics technologies, and exploration of practical and effective ammonia reduction measures are crucial for the healthy development of China' s broiler industry.

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