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Review Article

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Mitigating Ammonia Emissions in Poultry Production: Impacts, Influencing Factors, and Effective Strategies for Health and Environmental Protection

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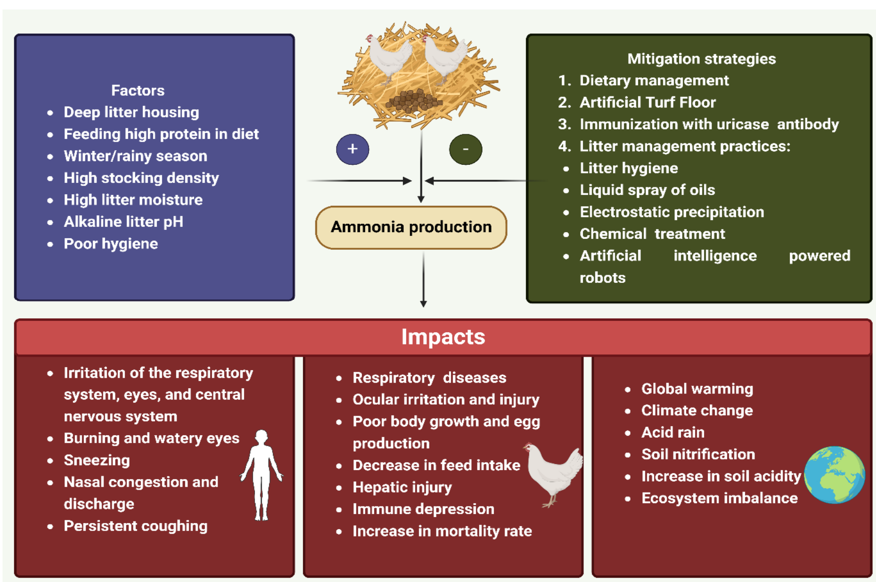

Graphical Abstract: Factors affecting, implications and mitigation strategy of ammonia emission in poultry production.

Abstract

Chicken is the most widely produced type of meat worldwide, playing a vital role in providing a substantial amount of protein for human consumption. The poultry industry in India has experienced rapid growth, with an approximately sixteen percent increase in the poultry population in recent years. Despite the importance of poultry production in meeting the global demand for meat and eggs, it is crucial to address the issue of ammonia emissions associated with this industry. Ammonia emissions pose significant environmental and health risks to both birds and humans. By analyzing the impact of various factors on ammonia release and exploring potential solutions, this review will provide valuable insights into the sources, impacts, and mitigation strategies for ammonia emissions in the poultry industry, thereby safeguarding bird welfare, human health, environment, and ecosystems.

Keywords: Ammonia, Poultry, Health, Mitigation, Emission

1. Introduction

Poultry production plays a crucial role in the global food system, providing a significant source of protein for human consumption. The Food and Agriculture Organization reports that chicken accounts for approximately 85-88% of total poultry meat production worldwide, making it the most widely produced type of poultry [1]. The poultry industry in India has experienced rapid growth in recent decades, with a 16.8% increase in the poultry population, largely driven by advancements in scientific and technological innovations, the introduction of high-yielding breeding stock, and increased consumer demand due to rising disposable incomes and changing dietary preferences [2-4].

While the expansion of the poultry industry has been beneficial in meeting the global demand for meat and eggs, it has also resulted in environmental impacts. Ammonia is a major environmental concern associated with poultry operations, contributing approximately 4% of total global ammonia emissions [1,5]. The extensive use of fertilizers in agriculture, as well as emissions from livestock and their waste, are significant contributors to NH3 release. High levels of ammonia in the surrounding atmosphere can lead to various environmental problems, such as the formation of secondary inorganic aerosols and the conversion of ammonia into the potent greenhouse gas, nitrous oxide. Additionally, the increased excretion of nitrogen and phosphorus from poultry production is considered a significant pollutant [6,7].

Ammonia emissions not only impact the environment but also pose serious health risks to both poultry and farm workers. High levels of ammonia in poultry houses can lead to respiratory issues, decreased immunity, and reduced growth and production in birds. Exposure to ammonia can also cause eye and respiratory irritation, headaches, and other health problems in farm workers [8,9]. Agriculture, including livestock and animal production, manure management and storage, livestock housing, and the application of manure/slurry and synthetic fertilizers to land, accounts for 80-90% of global ammonia emissions [10,11]. Among livestock, the major contributors to ammonia emissions are cattle, chickens, and pigs, with other animals such as sheep, goats, buffaloes, horses, and ducks also playing a role [12,13]. Addressing the issue of ammonia emissions from poultry production is crucial, and a sustainable management approach is needed to mitigate the environmental and public health impacts.

1.1 Ammonia Formation in Poultry House

A variety of factors influence ammonia emissions in poultry production. For instance, excess dietary protein consumed by the birds is initially stored as glucose or fat, and when these amino acids are converted to glucose or fat, the nitrogen is first transported to the liver and converted into urea [14,15]. In chickens, this urea is then transported to the kidneys and excreted as uric acid. After the excretion of this nitrogen-containing waste, the nitrogen in the excreta, uric acid, and any remaining feed protein nitrogen is rapidly hydrolyzed to form ammonia through microbial degradation facilitated by various enzymes produced by the microbes present in the manure [16]. Ammonia, a colorless, water-soluble gas, is a by-product of this microbiological decomposition of organic nitrogen compounds in the poultry manure. The microbial breakdown of uric acid in the litter is considered the primary source of NH3 formation, with the bacterium Bacillus pasteurii being a key player in this process [17].

1.2 Impact of Ammonia Emissions

a. Environmental Effects:

Once emitted, NH3 can quickly react with acidic atmospheric compounds like nitric acid and sulfuric acid, forming aerosolized ammonium particles, typically ammonium sulfate and ammonium nitrate. These ammonium salts eventually fall to the ground or are washed out of the atmosphere by rain, leading to deposition in the soil and subsequent nitrification. Nitrification is the process in which ammonium ions in the soil are oxidized to nitrate ions [18]. This process increases soil acidity due to the presence of H+ ions. Nitrate, a crucial nutrient for plant growth, is a by-product of nitrification. The excess nitrate from ammonia nitrification benefits nitrophilous (nitrogen-loving) plants, while disadvantaging other types of plants that prefer less acidic soil conditions [19]. This can lead to a shift in the plant community composition, favoring nitrophilous species over more sensitive or slower-growing plants, potentially disrupting the natural ecosystem balance.

b. Human Health:

Ammonia is a precursor to secondary particulate matter and plays a significant role in the formation of fine particulate matter (PM2.5). These tiny airborne particles can negatively impact human health through their effects on the lungs, eyes, nose, and throat. Exposure to ammonia can lead to various symptoms, including irritation of the respiratory system, eyes, and central nervous system [20,21]. Epidemiological studies have revealed that poultry workers are more adversely affected by ammonia exposure compared to those not working in poultry environments. Poultry workers exposed to elevated ammonia levels often experience symptoms such as burning and watery eyes, sneezing, nasal congestion and discharge, and persistent coughing [22,23]. These health issues can have significant implications for the well-being and productivity of poultry industry workers.

c. Poultry Health:

The general recommendation for the maximum acceptable ammonia concentration in poultry houses is 25 parts per million (ppm), with an ideal exposure limit of less than 10 ppm; however, transient increases up to 25 ppm are considered not directly harmful to the birds [24]. Almuhanna et al. (2011) identified NH3 as the most prevalent toxic gas in poultry houses [25]. When ammonia gas comes into contact with moisture, it forms a basic, corrosive solution known as ammonium, which can be detrimental to the health and welfare of the birds. This ammonium solution can damage the respiratory tract lining of chickens and impair or destroy the cilia of epithelial cells, which are essential for clearing the airways [26]. Research by Zhou et al. (2020) found that exposure to NH3 at concentrations as low as 25 ppm and 35 ppm negatively affects the growth performance of broiler chickens [27]. Additionally, even brief exposure to 15 ppm for just three days was shown to increase IL-6 (interleukin-6) levels in the trachea and ileum of the birds, triggering an inflammatory response. High concentrations of NH3 not only hinder the growth and production performance of poultry but can also diminish the overall meat quality of broilers [28,29].

1.3 Ammonia Emission Influential Factors

Ammonia emissions in poultry houses are influenced by a range of factors, including climatic conditions, geographical location, and various management practices. The specific factors affecting emissions can vary significantly between different poultry operations, owing to differences in diet, housing systems, and management techniques [30]. Key factors that influence indoor ammonia levels include the type of housing, bird stocking density, litter conditions, handling methods, and ventilation rates. Moreover, indoor environmental parameters such as temperature, relative humidity, manure/litter pH, and air velocity can also directly or indirectly impact NH3 emissions [31].

a. Housing System and Type: The choice of poultry housing system significantly impacts ammonia emissions. Various studies have demonstrated the influence of different housing conditions on ammonia levels and the associated health risks for the birds. Ammonia concentrations tend to be higher in housing systems where manure composting occurs within the structure. Research has revealed that caged systems, including traditional and furnished cages, generally exhibit lower ammonia emissions compared to floor systems and aviaries. Additionally, houses equipped with bell drinkers have been found to emit more ammonia than those with nipple drinkers [32].

b. Litter Moisture Content and pH: There is a direct relationship between pH and ammonia production, as alkaline pH conditions favor the growth of ammonia-producing bacteria. An alkaline pH range of 7.5 to 8.5 is optimal for ammonia-producing bacteria in poultry manure and litter. Some studies have also shown that reducing the pH of poultry litter from 7 to 3 can lead to a significant 60-80% decrease in ammonia emissions [33].

C. Feed Nutrition Contents: Commercial poultry are typically fed high-protein diets to meet their nutritional requirements for growth and production. However, these higher-protein feeds can lead to increased nitrogen in the manure and higher ammonia emissions, as undigested proteins and uric acid are major sources of ammonia. Power and Angel found that reducing the crude protein content in broiler diets by 22% resulted in a corresponding decrease in ammonia emissions. Similarly, a 1% reduction in the crude protein content of layer diets led to a 10% decrease in ammonia emissions compared to a standard diet [34].

D. Diurnal and Seasonal Variations in Ammonia Emissions: Ammonia levels within poultry houses exhibit diurnal fluctuations, with higher concentrations observed during periods when hens in aviary systems are active on the litter floor. This suggests that the birds' activities on the litter, which often contains substantial amounts of manure, may contribute to increased ammonia production. Furthermore, colder weather conditions, characterized by reduced ventilation rates and elevated humidity, lead to increased moisture content in the litter [35]. This, in turn, creates more favorable conditions for the bacterial decomposition of uric acid into ammonia. Studies conducted in Scandinavia have shown a significant rise in ammonia concentrations during the winter months, likely due to decreased ventilation to minimize heating costs and the concomitant increase in humidity from condensation [36].

Seasonal variations in temperature and house ventilation also influence NH3 emissions. Outdoor and indoor temperatures can significantly impact ammonia levels in poultry houses. An inverse relationship between outside temperatures and NH3 concentrations inside the house has been observed, where higher temperatures and reduced ventilation rates enhance ammonia volatilization. During the winter, decreased ventilation to lower heating costs can lead to higher humidity from condensation, further contributing to increased ammonia production [37].

e. Poultry Age and Stocking Density Impacts: The correlation between the age of poultry and ammonia production in poultry houses is significant. As chickens mature, their metabolic processes change, leading to variations in ammonia generation. Younger birds tend to produce less ammonia compared to older birds, likely due to differences in dietary requirements, growth rates, and metabolic processes. Additionally, higher stocking densities in poultry houses result in increased moisture content in the litter and elevated NH3 emissions. Studies have shown that increasing the stocking density of broilers from 10 to 20 birds per square meter can significantly increase ammonia emissions [9].

While the factors discussed above can significantly impact ammonia levels in poultry facilities, it is important to note that the interplay between these factors can be complex and dynamic. Comprehensive, site-specific assessments are often necessary to accurately characterize and mitigate ammonia emissions from poultry operations.

1.4 Ammonia Mitigation Strategies

Numerous studies have reported that effective litter management can significantly reduce NH3 emissions in poultry houses. Roumeliotis and Van Heyst (2008) observed notable reductions in NH3 levels through improved litter management practices [38]. Choosing high-quality litter materials is crucial for lowering ammonia concentrations in poultry environments.

a. Litter Management Practices: Increasing the frequency of litter removal can reduce gaseous emissions, particularly NH3, as the volatilization of NH3 increases with the amount of time the litter remains in the poultry shed. Liang et al. (2005) found that daily removal of litter resulted in a 47% decrease in NH3 emissions compared to removal twice a week [39].

Liquid spray: Ammonia emissions can be reduced by using oil sprays, which work through the scrubbing action of the droplets that capture NH3 due to its high water solubility. The absorption of NH3 into water droplets increases as the droplet radius and velocity decrease. Liquid sprays, whether applied manually with handheld sprayers or mechanically with installed systems, can effectively reduce NH3 emissions. Zhang et al. (1998) demonstrated a 30% reduction in NH3 in broiler houses using a spray mixture of a small amount of plant oil and water [40]. Similarly, Ikeguchi (2002) achieved comparable results with a 2% solution of emulsified canola oil using an ultrasonic sprayer that generated particles ranging from 7 to 150 µm in diameter for layer hens [41]. It was observed that spraying of water alone at different level decreased dust level and PM but increased ammonia concentration. Hence, it was suggested that oil and acidic water would be better choice for reduction of NH3 emissions.

Electrostatic Precipitation: This technology employs an electric charge to attract and capture particulate matter and associated NH3 molecules, leading to the formation of larger particles or molecules in the air. Electrostatic particle charging systems have been observed to reduce airborne dust by 43% and NH3 by 13%. This method can be a valuable complement to other ammonia mitigation strategies, as it targets both particulate matter and gaseous NH3 emissions, providing a more comprehensive solution [42].

1.5 Chemical Management:

Alum Amendment: Alum is an inorganic chemical compound consisting of a hydrated double sulfate salt of aluminum. It helps to decrease litter pH by absorbing moisture from the litter, which in turn helps to reduce the ammonia volatilization from the litter. Madrid et al. (2012) observed a reduction in ammonia levels in poultry houses when alum was applied at a rate of 0.25 kg/m2 with wood shavings as the litter material [43].

Clinoptilolite Zeolite: Clinoptilolite zeolite is another material that can adsorb ammonia ions from animal urine and feces, which can help reduce the overall ammonia levels in a livestock or poultry house. The porous structure and high cation exchange capacity of clinoptilolite allow it to effectively capture and hold ammonia, preventing it from being released into the air [44].

Other Chemicals: Chemicals like copper sulfate, aluminum sulfate, and phosphates can also help in the absorption of ammonia, thereby inhibiting volatilization. Queiroz (2015) reported the effectiveness of these chemical amendments in reducing ammonia emissions from poultry facilities.

Dietary Manipulation: Protein Level Management: Dietary formulation is a key approach to reducing ammonia emissions in poultry houses. The principle behind this approach is that ammonia is primarily produced from the breakdown of undigested proteins and uric acid in manure. Reducing the crude protein content in poultry diets by just 1% can lead to a 10-22% decrease in NH3 emissions. Preventing ammonia formation can be achieved by formulating diets based on the specific amino acid requirements of the birds, rather than solely on crude protein requirements [46]. This approach reduces nitrogen excretion by lowering the total dietary nitrogen intake, which in turn decreases the available substrate for ammonia production.

Additionally, supplementing feed with various additives can help decrease ammonia emissions in poultry operations. Probiotics, which contain beneficial bacteria, can enhance digestibility and nutrient utilization, leading to reduced nitrogen excretion and lower ammonia production [47]. Prebiotics, such as inulin or fructooligosaccharides, promote the growth of these beneficial gut microbes, further improving nutrient absorption and reducing waste products [48]. Enzymes, when added to the diet, can improve the breakdown and utilization of feed components, again minimizing the amount of undigested material available for ammonia formation [49]. Herbal products, like those derived from the yucca plant, are also effective in mitigating ammonia emissions. Yucca, rich in saponins and phenolic compounds, can modify the gut microbiome, enhance digestion, and improve nutrient absorption, all of which contribute to better growth and production performance in poultry while reducing ammonia levels [49].

Yucca Plant Extract – Yucca, a commercially used plant known for its rich content of saponins and phenolic compounds with antioxidant properties, is effective in mitigating ammonia emissions. Extracts from the yucca plant help reduce ammonia levels by modifying gut microbiota, enhancing digestion, and improving nutrient absorption, which leads to better growth and production performance in poultry [50].

In addition to feed additives, the use of litter amendments and other litter management practices can also contribute to reducing ammonia emissions in poultry facilities. Litter additives, such as alum, clinoptilolite zeolite, and certain chemical compounds, can help absorb and bind ammonia, preventing its volatilization into the air. Proper litter management, including frequent removal and replacement, can also help lower ammonia levels in the poultry house environment.

Recent Techniques: Uricase-specific antibody treatment: Researchers have explored the potential of using uricase-specific antibodies to mitigate ammonia emissions in poultry operations. The approach involves immunizing hens with the uricase enzyme through a series of three injections. The resulting uricase-specific antibodies were found to inhibit the activity of microbial uricase, an enzyme that plays a crucial role in the breakdown of uric acid and the subsequent formation of ammonia. While further studies are necessary to fully understand the impact of this uricase-specific IgY on microbial uricase, this targeted approach holds promise for reducing ammonia volatilization from poultry manure [51]. By interfering with the uricase enzyme, which is central to the production of ammonia, this treatment strategy aims to address the source of the problem and potentially contribute to more sustainable and environmentally friendly poultry production.

Artificial Turf Floor and Electronic Nose System: In a recent study, Jones et al. investigated the potential of using artificial turf as a floor substrate to replace traditional wood shavings in a cage-free aviary system. The researchers aimed to determine the effects of this floor substrate change on hen behaviour and ammonia emission. Their findings revealed that the replacement of wood shavings with artificial turf significantly reduced the concentrations and emissions of both ammonia and carbon dioxide in the poultry house [52]. This suggests that artificial turf can serve as an effective alternative to traditional litter materials, potentially offering a more sustainable and environmentally friendly solution for improving air quality in poultry facilities. The use of artificial turf as a floor substrate could help to mitigate the negative impacts of ammonia on the health and well-being of both the chickens and the farm workers, while also contributing to more efficient and productive poultry operations.

Ai-Powered Robots for Litter Management: Robotics have emerged as a promising solution for various tasks in poultry houses, including early disease detection, litter management, and ammonia concentration monitoring. These autonomous, small vehicles can improve barn sanitation by automating tasks like regular litter turning, removal, and replacement [28,29]. This can help maintain optimal litter conditions and reduce ammonia emissions, as well as boost chicken activity and overall productivity. The use of AI-powered robots to enhance litter management is a particularly exciting development, as it can streamline these critical tasks and contribute to more sustainable and efficient poultry production.

2. Conclusion

Ammonia is a highly noxious gas that poses significant challenges in poultry operations, requiring effective control strategies to mitigate its emissions. Several key factors, including pH, moisture content, litter conditions, bird age, manure age, relative humidity, ventilation rate, and temperature, all play crucial roles in the production of ammonia within poultry houses. To address this issue, a range of mitigation strategies have been employed, including improved litter management, dietary adjustments to optimize nutrient utilization, the use of chemical treatments and additives, as well as the adoption of emerging technologies such as uricase-specific antibodies, artificial turf flooring, and AI-powered robotic litter management systems. However, these emission control strategies can be costly, underscoring the need for government assistance programs to support the transition towards more sustainable and environmentally friendly poultry production practices.

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Data availability statement

This study does not involve in synthesis of data.

NH3 level (ppm)	Effects on birds health	Source
25	Respiratory system damage, ocular abnormalities, Negative effect on productive performance and immune response.	Yi et al. 2016
30	Immune depression, inflammatory reaction	Chen et al. 2017
50	Body weight loss, depression on body weight	Aziz and Barnes, 2010
75-78	Reduction in growth performance, antioxidative capacities meat quality and increase in mortality.	Miles et al. 2004
100	Reduction in egg production, egg weight, egg mass, feed intake, and body weight gain	Amer et al. 2004
200	Severe chronic hepatic injury, lesions in respiratory tract, and keratoconjunctivitis	Yi et al. 2016
More than 200	Irritation to mucous membrane in the eyes and respiratory system, increase susceptibility to respiratory diseases and mortality	Olanrewaju et al. 2008

Table 1: Effect of ammonia on birds health

Litter pH level	Results	Reference
9	Uric acid decomposition/ NH_3 productions reach maximum	Li *et al*. 2013
7.5 – 8.5	Highest NH_3 productions	EPA, 2004
=7	Start to increase NH_3 productions	Carr *et al*. 1990
<7	NH3 production is negligible or the lowest. Reduces the uricolytic bacterial population	Ferguson *et al*. 1998
3	Lowest NH_3 emissions and PM reduction by 60 % to 70 %	Chai *et al*. 2017
2	NH3 concentrations decreased by 84.3 %	Ashtari *et al*. 2016

Table 2: Volatilization of NH_3 from manure at various litter pH levels.

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