Effects of Carbon Dioxide on Poultry and Control Measures (Postprint)

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Abstract

Environmental control is the most critical component of broiler production technology, as high concentrations of harmful gases can affect the healthy growth of broilers. Although carbon dioxide itself is not toxic, prolonged exposure to high concentrations of carbon dioxide in poultry houses may reduce broiler growth performance and compromise broiler health. Strengthening research on the hazards of indoor carbon dioxide to livestock and poultry health, and exploring effective measures to improve air quality in livestock and poultry houses, is of great significance for the healthy growth of livestock and poultry and environmental friendliness. This paper mainly provides a theoretical basis for in-depth research on the effects of carbon dioxide on broiler health and rational regulation of indoor carbon dioxide concentrations by reviewing the hazards of indoor carbon dioxide and measures to reduce carbon dioxide concentrations.

Full Text

Effects of Carbon Dioxide on Poultry and Control Measures

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Abstract: Environmental control is the most critical component of broiler production technology, as high concentrations of harmful gases can compromise healthy growth. Although carbon dioxide itself is not toxic, prolonged exposure to elevated CO_2 levels in poultry houses may reduce growth performance and jeopardize broiler health. Strengthening research on the hazards of CO_2 to livestock health and exploring effective measures to improve air quality in animal facilities are of great significance for both animal welfare and environmental sustainability. This paper reviews the hazards of CO_2 in poultry houses and measures for reducing its concentration, providing a theoretical basis for further

research on CO_2' s impact on broiler health and for rational regulation of CO_2 levels in poultry facilities.

Keywords: carbon dioxide; broilers; hazards; control measures

With the development of large-scale livestock production, environmental impacts on animal health have become increasingly prominent. Prevention is more important than treatment, and effective environmental control is essential for profitable poultry operations. Air quality within the house is a key factor for healthy broiler growth. Long-term exposure to poor air quality leads to frequent respiratory diseases such as tracheitis and broiler respiratory syndrome, indirectly reducing growth performance and immune function. Harmful gases in poultry houses mainly include ammonia, hydrogen sulfide, and carbon dioxide. While numerous studies have investigated the effects of ammonia and hydrogen sulfide on broilers [1-5], research on carbon dioxide remains limited.

In recent years, rising fuel prices have led farmers to reduce ventilation rates to maintain house temperature, particularly during winter, resulting in increased CO_2 concentrations. Atmospheric CO_2 levels are relatively stable at approximately 0.03%, but human activities have caused a gradual increase, with global average concentrations reaching 400 mg/kg for the first time in 2015—a new record. Outdoor CO_2 concentrations in urban areas range from 375–450 mg/kg and are projected to reach 700 mg/kg by the end of the 21st century [6]. Broilers have rapid growth rates, vigorous metabolism, high oxygen demand, and consequently high CO_2 emissions. Winter ventilation is minimal, and many houses use coal heating, further elevating CO_2 levels. Burns et al. [7] reported that CO_2 emissions from broilers increase linearly with age. Zhang et al. [8] found that CO_2 emissions from 1–42 day-old broilers initially increase gradually with age before stabilizing.

Although CO_2 itself is not toxic, excessively high concentrations reduce oxygen levels, and chronic hypoxia can lead to chronic poisoning, decreased immune function and feed intake, and reduced production efficiency [9]. Many producers remain uncertain about what constitutes a reasonable CO_2 concentration and whether it should be a management priority. Therefore, understanding CO_2' s effects on broiler growth and health is crucial for the sustainable development of the poultry industry. This review summarizes CO_2 sources, hazards, and control measures in poultry houses to provide early warning parameters for air quality and theoretical support for further research on CO_2' s mechanisms of action and rational control strategies.

1 Overview of Carbon Dioxide

Carbon dioxide is colorless, odorless, and non-toxic, but high concentrations can cause discomfort and even harm. CO_2 concentration indicates ventilation effectiveness and air cleanliness; when CO_2 levels rise, other harmful gas concentrations also increase, making CO_2 a reliable indicator for monitoring air pollution [10]. In broiler houses, CO_2 primarily originates from bird respiration

and aerobic decomposition of carbohydrates, influenced by bird body weight. Microbial decomposition of manure and litter also produces CO_2, accounting for 4–7% of total emissions [11]. As broilers grow, increased respiration raises house CO_2 concentrations [12].

China' s National Indoor Air Quality Standard (GB/T 18883–2002) specifies that indoor CO_2 concentrations should not exceed 0.10% (1,000 mg/kg). The American Conference of Government Industrial Hygienists (ACGIH) recommends a workplace exposure limit of 5,000 mg/kg. Wang et al. [13] suggested 5,000 mg/m^3 as a control standard for belt-cleaned layer houses. China' s livestock farm environmental quality standard (NY/T 388–1999) sets an upper limit of 1,500 mg/m^3 (approximately 765 mg/kg) for poultry houses. Current standards appear outdated, and CO_2 concentration parameters need revision.

2 Monitoring of CO_2 Concentration in Poultry Houses

Current research on CO_2 in broiler production focuses primarily on monitoring house CO_2 concentrations and emissions. Li et al. [14] developed a wireless sensor network-based real-time monitoring system for poultry house CO_2, enabling multi-point monitoring and timely air quality control. Shen et al. [15] reported no significant differences in CO_2 concentration among upper, middle, and lower tiers in stacked cage systems, with concentrations ranging from 4,000–6,000 mg/m^3 during weeks 3–6. Shen et al. [16] also found that winter CO_2 concentrations were significantly higher than in autumn (3,633–5,681 mg/m^3 vs. 2,725–3,477 mg/m^3).

Zhang et al. [17] studied a commercial broiler house with 32,400 birds and found CO_2 concentrations of 2,777–7,790 mg/m^3 after three weeks, exceeding recommended limits and requiring enhanced ventilation. Wang et al. [18] reported average CO_2 concentrations of 3,673 mg/m^3 (8.29 times outdoor levels) and peak concentrations of 4,680 mg/m^3 (10.56 times outdoor levels). Hu et al. [19] measured winter environmental parameters in three broiler house types, finding CO_2 concentrations of 3,700 mg/L in closed houses, 3,712 mg/L in closed-window houses, and 2,740 mg/L in semi-open houses—all severely exceeding standards. Zhou et al. [20] reported that caged broilers aged 36–42 days had average CO_2 emission factors of $(154.4\$\pm45.7)g/(d \cdot bird).Summerventilationrateswerehighest, yieldingthelowestCO\{2\}\$$ *concentrations (1,522$±97mg/m*$^{\{3\}), whilewinterventilationwasminimal, resultinginthehighestconcentrations}(3,818\pm329mg/m^{\{3\}})$ concentrations commonly exceed national standards, and the health impacts and threshold concentrations warrant further investigation.

3.1 Hazards of Carbon Dioxide

Although non-toxic, high CO_2 concentrations reduce atmospheric oxygen content, causing hypoxia that rapidly depletes brain ATP. This deprives the central nervous system of energy, impairs sodium pump function, and allows Na^+ and H^+ influx into cells, increasing intracellular osmotic pressure and causing cere-

bral edema [21]. Excessive CO_2 also damages the lungs and cardiovascular system [22]. Most toxicity research focuses on medical applications with extremely high concentrations (5–6% or lethal doses). Fang et al. [23] reported that hypoxia with high CO_2 increased blood-brain barrier permeability in mice. Wang et al. [24] found that high CO_2 concentrations caused significant toxic damage to rat right ventricles and lung tissue, reducing superoxide dismutase activity while increasing lipid peroxidation, indicating impaired antioxidant capacity and enhanced oxidative damage.

Hypoxia with high CO_2 induced neuronal apoptosis in mouse cortex and hippocampus, with effects becoming more pronounced over time [25]. Chronic hypoxia with high CO_2 caused mitochondrial dysfunction in mouse brains, reducing ATP and AMP concentrations, SOD activity, and glutathione content, leading to muscle fiber atrophy, mitochondrial damage, and inflammatory cell infiltration [26-27]. CO_2 poisoning patients showed creatine kinase activity approximately 20 times normal levels, with ALT and AST activity 2–4 times normal, indicating severe myocardial and hepatic damage [28]. Additionally, classroom CO_2 concentrations often exceed 1,000 mg/kg, sometimes surpassing 3,000 mg/kg. While not dangerous to health, these levels impair cognitive function and decision-making, with performance declining in 6 of 9 tests when CO_2 exceeded 1,000 mg/kg [29]. Vehviläinen et al. [30] reported that high indoor CO_2 concentrations elevated transcutaneous CO_2 levels, caused abnormal heart rate changes, and increased peripheral blood circulation. These studies demonstrate severe effects on brain, lung, and cardiovascular systems in mice, but whether similar effects occur in broilers requires further investigation.

Livestock research on CO_2 health effects is limited and often dated. Studies show that rising atmospheric CO_2 causes cellular oxidation, DNA damage, and increased mutation frequency [31]. Purswell et al. [32] found that 2,500–6,500 mg/kg CO_2 had no significant effect on 28–49 day-old broiler weight gain or feed conversion. Reece et al. [33] reported that 3,000–6,000 mg/kg CO_2 did not affect 1–28 day-old broiler performance, but 12,000 mg/kg reduced body weight without affecting feed conversion. Olanrewaju et al. [34] found that 3,000–9,000 mg/kg CO_2 did not affect growth performance or blood parameters (pCO_2, pO_2, pH, hemoglobin, Na^+, K^+, Ca^{2+}, Cl^-) in 1–14 day-old broilers but increased later mortality. Mcgovern et al. [35] reported that 5-week exposure to 6,000 mg/kg CO_2 did not increase ascites syndrome incidence.

Dai et al. [36] found that CO_2 concentrations below 12 g/L did not significantly affect broiler performance, but levels above this threshold caused chronic respiratory acidosis, pulmonary alveoli filled with proteinaceous fluid, inflammatory cells, and shed epithelial cells, severe venous congestion, and reduced weight gain and feed efficiency. Another study [37] reported that 0.03–0.15% CO_2 had no significant effect on broiler carcass traits. Chen et al. [38] found that 3,000–15,000 mg/m^3 CO_2 did not affect serum IgA, IgM, or IgG levels, but at 12,000 mg/m^3, red blood cell counts decreased significantly while hemoglobin and white blood cell counts increased, indicating stress responses detrimental to

health. Helbacka et al. [39] reported that 5% CO_2 significantly reduced blood pH and eggshell thickness in laying hens. Lu et al. [40] found that increased CO_2 slightly reduced egg production and weight, but effects disappeared after adaptation.

3.2 Applications of Carbon Dioxide

Gerritzen et al. [41] demonstrated that CO_2 is the most important physiological regulator of respiration, with arterial pCO_2 being essential for maintaining respiratory drive. Chicken embryos appear to require CO_2 during critical developmental periods to enhance growth, early hatching, and improve hatchability, as CO_2 promotes organ development and function [42]. While traditionally considered detrimental to incubation, recent research suggests hypercapnia may benefit embryonic development during certain stages. Smit et al. [43] observed accelerated embryonic growth in broiler eggs incubated at 0.7% CO_2. Buys et al. [44] reported that elevated CO_2 during late incubation increased embryo weight, reduced ascites incidence, and advanced hatching with increased chick weight.

Extremely high CO_2 concentrations are used for stunning broilers to improve welfare. Inhalation of large CO_2 quantities causes respiratory and metabolic acidosis, reduces cerebrospinal fluid and neuronal pH, and exerts inhibitory and anesthetic effects on neurons [45]. Xu et al. [46] reported that different CO_2 stunning concentrations affected meat quality, though plasma corticosterone, glucose, meat pH, and color were unaffected.

4.1 Strengthening CO_2 Monitoring and Daily Management

Modern poultry house environmental monitoring systems integrate multiple sensors for continuous multi-point monitoring, enabling real-time assessment of environmental parameters, automatic data analysis, and threshold-based alarms to support scientific management [47]. Wang et al. [48] developed a wireless remote monitoring system for poultry house environments that tracks CO_2 and ammonia levels, providing scientific management tools and improving efficiency. Zhu et al. [49] developed a harmful gas monitoring system based on ZigBee and GPRS technology that monitors CO_2, ammonia, and hydrogen sulfide with convenient, fast, and accurate operation. Real-time remote monitoring is essential for understanding CO_2 levels, but management improvements are required when air quality declines.

Ventilation is the most direct and effective method to reduce CO_2, though temperature must be considered simultaneously. Increasing litter depth can reduce CO_2 concentrations—Shao et al. [50] reported that 12 cm litter significantly reduced CO_2 at 70 days compared to 4 cm litter. Reducing stocking density also lowers CO_2 levels and improves air quality, as Tong et al. [51] found that high-density houses had significantly higher CO_2 at 42 days than medium- and low-density houses.

4.2 Feed Additives and Disinfectants

Research shows that feed additives and disinfectants can effectively reduce ammonia concentrations, though studies on CO_2 are limited. Hu et al. [52] reported that Chinese herbal microecological preparations in cattle diets reduced CO_2 and other harmful gases, with effects improving over time. Liu et al. [53] found that spraying biological deodorizers reduced poultry house CO_2 by 31.94%. Chen et al. [54] reported that povidone-iodine disinfectant spray reduced CO_2 concentrations. These findings suggest certain additives and disinfectants can effectively reduce CO_2. However, specific products for poultry houses are lacking and require further research and development. Additionally, minerals with large surface areas and pore volumes strongly adsorb ammonia, hydrogen sulfide, CO_2, and moisture, improving air quality. Gong et al. [55] reported that alkaline absorbent GY-4 effectively absorbed CO_2 in cattle barns.

4.3 Reducing Ammonia Concentration

Wang et al. [13] summarized numerous studies on ammonia and CO_2 concentrations in layer houses with different manure removal systems, finding significant correlations between CO_2 and ammonia levels. Kocaman et al. [56] conducted two-month trials in layer houses and reported significant positive correlations between CO_2 and ammonia concentrations. Ni et al. [57] also found that ammonia and CO_2 concentrations followed similar trends, both negatively correlated with ventilation rate. Therefore, reducing ammonia concentration concurrently lowers CO_2 levels. Methods to reduce ammonia include supplementing essential amino acids, reducing dietary crude protein [58], and adding enzymes, probiotics, and plant extracts to feed [59-61], which indirectly reduce CO_2 concentrations.

5 Summary

As broiler production becomes more intensive, environmental impacts on health grow increasingly important. Although non-toxic, high CO_2 concentrations cause hypoxia, leading to appetite loss, reduced productivity, and weakened immunity. This paper summarized CO_2 sources, hazards, and mitigation measures in broiler houses. However, research on CO_2' s health effects remains incomplete, particularly regarding respiratory system impacts. Therefore, in-depth studies on CO_2 concentration dynamics, combined with high-throughput sequencing and omics technologies to investigate CO_2' s effects on broiler health and develop effective reduction strategies, are crucial for China' s broiler industry.

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