Effects of High Ambient Temperature on Production Performance in Laying Hens and Nutritional Intervention Strategies: Postprint

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Abstract

High ambient temperature during summer constitutes a critical factor affecting the production performance of laying hens. In recent years, with the widespread adoption of fan and pad cooling systems, temperatures in commercial laying hen houses during summer can generally be controlled below 30 °C, consequently leading to frequent neglect of the detrimental effects of high temperature in practical production. This review summarizes the impacts of environmental high temperature, particularly cyclic heat stress, on laying hen production performance, aiming to raise awareness among production personnel and researchers regarding summer thermal stress, and consolidates nutritional regulation strategies to mitigate heat stress from the perspectives of dietary energy and crude protein levels, thereby providing a scientific basis for rational diet formulation and feeding management of laying hens during high-temperature seasons.

Full Text

Abstract

High ambient temperature during summer is a critical factor affecting the performance of laying hens. In recent years, with the widespread adoption of cooling systems combining fans and wet curtains, temperatures in large-scale layer houses can generally be maintained below 30°C during summer. Consequently, the detrimental effects of summer heat are often overlooked in practical production. This paper systematically reviews the impacts of high ambient temperature, particularly cyclic high temperature, on laying hen performance, aiming to draw attention from producers and researchers to summer heat stress. Additionally, it summarizes nutritional mitigation techniques to alleviate heat stress effects by adjusting dietary energy and crude protein levels, providing a scientific basis for rational diet formulation and management of laying hens during

hot seasons.

Keywords: high temperature; laying hens; performance; nutritional regulation

Introduction

High ambient temperature is a significant factor affecting poultry production [1-2]. Heat stress can cause declines in laying performance and eggshell quality, resulting in substantial economic losses [3-4]. It is estimated that heat stress costs the U.S. livestock industry approximately $1.69–2.36 billion annually [5]. China produces a tremendous volume of poultry eggs [6-7]; according to the China Statistical Yearbook (2015), national egg production reached 28.939 million tons in 2014. However, major egg-producing regions are concentrated in central and eastern China, where summer daily average temperatures typically exceed 25°C. Currently, wet curtain and fan cooling systems are widely implemented in large-scale layer farms in China. Through evaporative cooling, these systems can reduce house temperatures by 10–12°C, generally maintaining them below 30°C [8]. As a result, the impact of summer heat is often neglected in actual production. Nevertheless, the effectiveness of wet curtain ventilation is influenced by ambient humidity [9], and significant temperature variations exist along the longitudinal and vertical dimensions of the house [8]. During certain summer periods, temperatures in some areas of layer houses can still exceed 32°C [10-12].

This paper comprehensively reviews research on how high ambient temperature, particularly cyclic high temperature, affects laying hen performance, aiming to raise awareness among producers and researchers regarding summer heat stress. It also summarizes nutritional regulation techniques for mitigating heat stress effects through dietary energy and crude protein adjustments, providing a scientific foundation for rational diet formulation and management of laying hens during hot seasons.

1. Effects of High Temperature on Production Performance

1.1 Feed Intake

When ambient temperature becomes excessively high, poultry reduce feed intake to decrease heat production and maintain body temperature homeostasis [13]. High temperature may directly inhibit the feeding center in the hypothalamus, causing appetite suppression [14]. Additionally, reduced gastrointestinal motility [15] and increased water consumption [16-17] can lead to digestive tract distension, which negatively feeds back to inhibit the feeding center and reduce feed intake [18].

Numerous studies have reported that high ambient temperature decreases feed intake in laying hens, with most research focusing on constant high temperature models. Compared to the thermoneutral temperature of 21–22°C, constant high temperature of 25–28°C has minimal impact on feed intake [19-21]. However, constant high temperature of 30–32°C reduces feed intake by 19.7–26.3% [14,20-25], while 33–35°C decreases feed intake by 22–52% [21,26-29]. In practical production, prolonged constant high temperature rarely occurs, yet research on cyclic high temperature—which reflects actual summer conditions—is limited. Emery et al. [30] reported that cyclic high temperature of 21.1–37.7°C reduced feed intake by an average of 15.6%. Miller et al. [31] found that cyclic high temperature of 27–38°C significantly decreased feed intake by 34.8%. Mashaly et al. [29] observed that during the first week of cyclic high temperature (23.9–35.0°C), feed intake decreased by 33.3%, but by the fifth week, the reduction was only 14.9%, indicating that laying hens gradually adapt to cyclic high temperature over time.

De Andrade et al. [22] compared cyclic and constant high temperature effects, finding that cyclic high temperature of 26.7–35.6°C reduced feed intake by 22.1%, whereas constant high temperature of 31°C decreased feed intake by 26.3%, with constant high temperature having a significantly greater impact. Similar findings were reported by Mashaly et al. [29]. These results demonstrate that even when house temperatures briefly reach 35.6–37.7°C, the reduction in feed intake is similar to or less than that observed under constant high temperature of 30–32°C. Since prolonged constant high temperature does not occur in summer production, research findings from constant temperature models cannot effectively guide practical production. Furthermore, with the widespread adoption of wet curtain and fan cooling systems, house temperatures are generally maintained below 30°C, necessitating further research on the effects of lower cyclic temperatures on feed intake.

1.2 Laying Performance

High ambient temperature reduces feed intake and affects digestion and metabolism in poultry [32-33], leading to insufficient nutrient intake and declining laying performance. Additionally, high temperature may directly affect follicle development in laying hens [34-35], potentially contributing to reduced laying performance.

Most research on high temperature effects has employed constant high temperature models. Compared to the thermoneutral temperature of 21–23°C, constant high temperature of 25–28°C has minimal effects on laying rate, egg weight, and body weight [19-20]. Constant high temperature of 30–32°C reduces laying rate by 3.4–19.6% [22-25] or has no significant effect [19-21,23], decreases egg weight by 0.6–5.9% [19,20,24-25], and reduces body weight by 9.2% [19]. At 33–35°C, constant high temperature reduces laying rate by 16.6–28.82%, decreases egg weight by 3.7–9.9% [21,26-28,36], and lowers body weight by 11.9% [21].

Research on cyclic high temperature is relatively scarce. Emery et al. [30] found that cyclic high temperature of 21.1–37.7°C did not significantly affect laying rate but significantly reduced egg weight by 7.4% and decreased body weight. De

Andrade et al. [22] similarly reported that cyclic high temperature of 26.7-35.6°C did not significantly reduce laying rate but significantly decreased egg weight and body weight, with consistent findings in other studies [29,31]. These results indicate that under cyclic high temperature, even when house temperatures briefly reach 35.6–37.7°C, laying rate is not significantly affected, with only egg weight and body weight being reduced. This may occur because the reduction in feed intake is relatively small under cyclic high temperature, and hens prioritize reproductive function. Under conditions of reduced feed intake and nutrient deficiency, hens maintain laying rate by mobilizing body energy and protein reserves, resulting in decreased egg weight and body weight.

1.3 Eggshell Quality

High ambient temperature adversely affects eggshell quality, increasing egg breakage rates, which may be a key factor reducing economic efficiency during summer heat. Studies have shown that exposure to constant high temperature of 30–32°C reduces eggshell thickness by 2.9–5.5% [29,37], decreases eggshell weight by 7.2% [38], and significantly increases breakage rates to 5.3% [22]. At 33–35°C, constant high temperature reduces eggshell thickness by 7.8–8.5% [28,39], decreases eggshell weight by 13.5–20.0% [28,38], and increases breakage rates to as high as 13% [39]. High temperature impairs calcium and phosphorus absorption and utilization [40-41] and may directly affect shell gland contractility [42], leading to deteriorated eggshell quality.

Research on cyclic high temperature effects is limited. Emery et al. [30] found that cyclic high temperature of 21.1–37.7°C reduced eggshell thickness by 15.4%. De Andrade et al. [22] reported that cyclic temperature variation of 26.7–35.6°C decreased eggshell thickness by 8.5%, with similar findings in other studies [29]. These results indicate that higher cyclic temperatures (21–37°C) significantly affect eggshell quality, while the effects of lower cyclic temperatures (below 30°C) require further investigation.

2. Nutritional Mitigation Measures for High Temperature

High temperature reduces feed intake and nutrient digestibility in laying hens, resulting in insufficient nutrient and energy intake, which may be the primary cause of decreased performance. Jackson [43] found that compared to ad libitum feeding, restricting daily energy intake of caged layers significantly reduced laying performance, but restricting the same amount of a high-nutrient diet did not affect performance. This suggests that increasing dietary nutrient levels may mitigate the adverse effects of high temperature, prompting researchers to conduct a series of studies.

2.1 Increasing Dietary Energy Level

Increasing dietary metabolizable energy (ME) from 13.35 MJ/kg to 14.78 MJ/kg under high temperature significantly improved daily weight gain and reduced feed conversion ratio in broilers [44]. However, increasing ME by 627.9 kJ/kg had no significant effect on broiler weight gain [45], suggesting that small increases in dietary ME may not significantly improve energy intake and thus cannot mitigate the negative effects of high temperature on broiler performance. Some studies indicate that fat supplementation under high temperature significantly improved broiler weight gain [44], likely because fat has low heat increment, and replacing some carbohydrates with fat in the diet can significantly increase ME intake in broilers.

Research on increasing dietary ME for laying hens under high temperature is limited. Marsden et al. [20] fed laying hens three energy levels (10.88, 11.92, and 12.97 MJ/kg) at different ambient temperatures (15–30°C) and found that increasing dietary energy level improved laying rate and egg weight. Peguri et al. [19] reported that increasing dietary energy level significantly increased egg weight, but this effect disappeared when ambient temperature exceeded 26.7°C, possibly because increased dietary energy level did not significantly improve energy intake due to reduced feed intake under high temperature. Usayran et al. [46] studied the effects of fat supplementation (maintaining constant dietary energy and crude protein levels) on laying hens under thermoneutral and high temperature conditions, finding that fat supplementation significantly improved weight gain, egg weight, and egg production in pre-peak hens, presumably by increasing energy intake.

2.2 Adjusting Dietary Crude Protein and Amino Acid Levels

Two opposing viewpoints exist regarding dietary crude protein levels for poultry under high temperature. One advocates feeding high-protein diets to compensate for reduced crude protein intake due to decreased feed intake, while the other recommends low-protein diets supplemented with essential amino acids. In broilers, studies have shown that high-protein diets under high temperature significantly improved weight gain and feed efficiency [47-48], but other research found no significant effect [49-50] or even negative effects [51]. Protein has high heat increment [52], which may be a disadvantage of high-protein diets under high temperature. Preference tests also indicate that broilers under heat stress do not prefer high-protein diets [53]. Therefore, high-protein diets may be beneficial only under extreme high temperature [54] or concurrent disease conditions [55], but high-quality protein sources must be selected, as low-digestibility proteins may exacerbate heat stress responses [33]. Cheng et al. [51] found that under high temperature, feeding broilers diets with 16% or 18% crude protein supplemented with five essential amino acids resulted in similar weight gain compared to a 20% crude protein diet. Alleman et al. [56] found that under 32°C high temperature, even with five essential amino acids supplemented, the 16% crude protein group had lower weight gain and feed efficiency than the 20% crude protein group, indicating that low-protein amino acid-supplemented diets cannot improve broiler growth under high temperature.

Research on optimal dietary crude protein levels for laying hens under high temperature is limited. Studies have shown that low-protein amino acid-supplemented diets under high temperature decrease egg weight [57]. Torki et al. [58] investigated the effects of different dietary crude protein levels (10.5%, 12.0%, 13.5%, 15.0%, and 16.5%) on laying hens during summer high temperature, with identical levels of essential amino acids including lysine and methionine. Quadratic model analysis indicated that the crude protein requirement to maintain egg production without significant reduction was 14.62%, suggesting that dietary crude protein level can be appropriately reduced under high temperature when essential amino acid requirements are met. Reid et al. [59] fed different crude protein levels at 21°C and 35°C to achieve identical crude protein intake (12.7–20.5 g/d) between temperatures, with average ME intake of 937.6 kJ/d (high temperature) and 1,460.9 kJ/d (thermoneutral). At 21°C, increasing crude protein intake significantly improved laying rate, but at 35°C, it had no effect on laying rate or egg weight. Multiple regression analysis indicated that reduced energy intake may be the key factor causing decreased laying rate and egg weight under high temperature. Based on these studies and broiler research findings, it can be speculated that feeding high-protein diets may not significantly affect laying hen performance under high temperature, while low-protein amino acid-supplemented diets may reduce egg weight, and increasing energy intake may effectively mitigate the adverse effects of high temperature.

Conclusion

Higher cyclic temperatures (briefly reaching 35.6–37.7°C) significantly reduce feed intake, egg weight, and body weight in laying hens, and affect eggshell quality, with effects similar to or less severe than those of constant high temperature at 31-32°C. The effects of lower cyclic temperatures (27–30°C) that reflect actual production conditions require further investigation. Under high temperature, increasing energy intake through fat supplementation may improve laying hen performance, while increasing dietary crude protein level may not effectively mitigate heat stress effects. The optimal energy, crude protein, and amino acid levels for laying hens under high temperature conditions warrant further research.

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