# Effects of Relative Humidity on Water Evaporative Heat Loss and Health in Poultry (Postprint)

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## Abstract

Relative humidity (RH), as a crucial factor in the thermal environment, interacts with temperature and wind speed to influence the thermoregulatory balance of poultry. Under optimal RH conditions, evaporative heat loss (EHL) is maximized; however, in high-temperature environments, elevated humidity impedes EHL, resulting in increased body temperature, accelerated respiration, reduced feed intake, and in severe cases, acid-base disturbances, heat exhaustion, and respiratory alkalosis. This review primarily synthesizes the critical role of evaporative water loss (EWL) in poultry thermoregulation, examines the effects of RH on EWL, and explores the practical significance of RH in commercial poultry production through its consequent impacts on poultry health.

## Full Text

# Effect of Relative Humidity on Evaporative Water Loss and Health of Poultry

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**Abstract:** Relative humidity (RH) serves as a critical parameter of the thermal environment, influencing poultry thermoregulatory balance in conjunction with ambient temperature and air velocity. At optimal RH levels, evaporative heat loss (EHL) reaches its maximum capacity. Under high-temperature conditions, elevated humidity impedes poultry EHL, leading to increased body temperature, accelerated respiration, reduced appetite, and in severe cases, acid-base imbalance, heat prostration, and respiratory alkalosis. This review synthesizes the essential role of evaporative water loss (EWL) in avian thermoregulation, examines the effects of RH on poultry EWL, and explores the consequent health implications to underscore the practical importance of RH management in poultry production.

**Keywords:** relative humidity; poultry; evaporative water loss; respiratory evaporative water loss; cutaneous evaporative water loss; health

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In modern intensive poultry production systems, the thermal environment comprises temperature, relative humidity (RH), and air velocity, with temperature being the predominant factor [1]. As a critical component of the thermal environment, RH interacts with temperature and air velocity to influence poultry thermoregulatory balance. Research on RH effects in poultry dates back to the 1930s, initially focusing on embryonic development, calcium metabolism, and mortality [2]. Since the 1970s, RH has been systematically incorporated into poultry thermal environment research, with most data emphasizing production performance impacts. In China, early investigations by Lin Hai, Gu Xianhong, and Tao Xiuping explored RH effects on broiler performance [3], body temperature, and plasma hormone levels [4-6].

In the 1960s, Freeman [7] first summarized that when temperatures reach or exceed the panting threshold and poultry rely primarily on evaporative cooling, RH becomes increasingly critical in the evaporative water loss process. However, no comprehensive review has yet addressed RH effects on poultry evaporative water loss (EWL). This paper synthesizes the fundamental role of EWL in avian thermoregulation, examines RH impacts on poultry EWL, and discusses the resulting health consequences to elucidate RH' s significance in practical poultry production.

## 1. EWL Methods and Their Role in Thermoregulation

Poultry maintain thermoregulatory balance through a dynamic equilibrium between heat production and dissipation. Under high-temperature conditions, evaporative heat loss (EHL) becomes the primary mechanism for maintaining thermal homeostasis. Evaporation converts body water from liquid to vapor at the skin and respiratory mucosal surfaces, making total evaporative water loss (TEWL) comprise two pathways: respiratory evaporative water loss (REWL) [8] and cutaneous evaporative water loss (CEWL) [9]. Campbell et al. [10] noted in their environmental biophysics text that evaporation rate from skin or respiratory surfaces depends on surface temperature, with higher temperatures generally facilitating faster water loss.

Hutchinson [11] pioneered the use of water evaporation loss as a fundamental assessment of heat stress in poultry during the 1950s. While water evaporation occurs through both cutaneous and respiratory routes, domestic research on CEWL in poultry under thermal stress remains scarce. Chinese textbooks such as *Livestock Environmental Hygiene* (2011 revised edition) [12] describe two skin evaporation mechanisms: insensible perspiration and sensible sweating, noting that pigs and chickens possess few functional sweat glands, resulting in minimal sensible sweating. A two-compartment metabolic chamber enables the separation of REWL and CEWL (Figure 1 [Figure 1: see original paper][13]). Numerous researchers have employed this method to isolate avian heads from bodies for independent measurement of REWL and CEWL. Studies across 16 avian species revealed that in dry air (20–35 °C), CEWL equaled or exceeded REWL in 13 species [14-21]. Richards [17] found that in Babcock 390 hybrid fowl (12–24 months, mean weight 2.04 kg), CEWL accounted for 78% of TEWL at 0 °C, 28% at 35 °C, and 25% at 40 °C. Despite the proportional decline with increasing temperature, CEWL remained physiologically significant. Wolf et al. [22] reported similar findings in yellow-headed titmice.

Bouverot et al. [16] demonstrated that in Pekin ducks, CEWL represented 67% of TEWL at 20 °C, 50% at 30 °C, and 25% at 35 °C. Bernstein [23] observed that CEWL exceeded REWL in both young and adult painted quail at 25 °C and 35 °C. Likewise, pigeons exhibited CEWL equal to or greater than REWL across temperatures ranging from 0–40 °C [24]. Subsequent research confirmed that CEWL contributes 40–75% of TEWL in these species [25-27], playing a crucial role in water and thermal balance. Webster et al. [28] investigated temperature and humidity dynamics of cutaneous and respiratory evaporation in pigeons (*Columba livia*), finding that CEWL significantly surpassed REWL at thermoneutral ambient temperatures and remained non-negligible at both high and low temperatures. These findings demonstrate that under high-temperature conditions, avian thermoregulation depends not only on REWL but also substantially on CEWL.

In summary, despite the absence of sweat glands and complete feather coverage, CEWL plays a non-negligible role in influencing water and thermal balance, even though its proportion of TEWL decreases with rising temperatures. However, whether CEWL exerts similarly critical effects in modern, rapidly growing broiler strains with high breast muscle yield and in high-producing laying hens remains uninvestigated.

## 2. Effects of RH on Poultry EWL and Its Pathways

Under high-temperature conditions, poultry rely primarily on evaporative cooling, with the driving force for water evaporation being proportional to the vapor pressure difference between the evaporative surface and ambient air—the latter represented by RH. Welch [29] found that evaporative loss from animal surfaces decreases linearly with increasing environmental RH under constant convection. Additionally, in humid environments, vasoconstriction changes and increased peripheral blood flow can elevate skin surface temperature, thereby increasing the driving force for CEWL.

Romijn et al. [30] reported that poultry TEWL remained unaffected by RH at 23.8 °C. However, when ambient temperature exceeds the upper critical limit, increasing RH from 40% to 90% nearly halved the proportion of TEWL in total heat dissipation [31]. Misson [32] demonstrated that broilers could survive at 43 °C with 20% RH, but succumbed at temperatures above 41.5 °C when RH reached 80%, as low humidity enabled 17% greater heat dissipation through evaporation. These findings indicate that low humidity facilitates broiler heat loss more effectively than high humidity, with Romijn et al. [13] reporting similar results.

At thermoneutral temperatures (20 °C), low and high RH exerted similar effects on adult poultry EWL. At 24 °C, adult poultry dissipated 28% more heat under low humidity, increasing to 41% at 34 °C. Table 1 presents the proportion of EWL in total EHL across different ambient temperatures and RH levels.

Only one publication addresses RH effects on the partitioning between CEWL and REWL. Webster [27] found that in pigeons, both REWL and CEWL decreased linearly and rapidly with increasing environmental RH at 20 °C and 30 °C (thermoneutral zone), with no significant difference in slope between the two pathways. Whether this trend holds true in newly selected modern poultry breeds remains unreported.

## 3. Effects of RH on Poultry Health

As established, EWL plays a dominant role in water and thermal balance regulation in high-temperature environments. Elevated humidity impedes poultry EWL, preventing adequate heat dissipation and consequently affecting body temperature regulation, respiration, acid-base balance, and feed intake.

### 3.1. Effects on Body Temperature Homeostasis

Poultry thermoregulation requires dynamic adjustments to maintain constant body temperature when exposed to thermal stimuli. Broiler core temperature and respiratory rate serve as important physiological indicators of thermoregulatory status [33]. Despite the absence of sweat glands and complete feather coverage, CEWL remains an important cooling mechanism, with correlation coefficients between featherless skin temperature and ambient temperature reaching 0.8 in broilers [34].

Prince et al. [35] reported that RH between 50–90% did not affect growth rate or feed intake in 4–8-week-old broilers at 12.6 °C and 23.8 °C. Milligan et al. [36] found that continuous high or low humidity did not affect performance at 15.6 °C, 21.1 °C, and 26.7 °C. Freeman [7] concluded in the late 1970s that environmental RH was not critical below 25 °C. Lin Hai [37] subsequently demonstrated that RH did not significantly affect broiler body temperature below 25 °C, using infrared thermometry for skin temperature (chest, back, toe, leg, wing) and thermistor probes for rectal temperature. These findings indicate minimal RH effects on poultry at low temperatures, allowing effective thermoregulation.

Yahav [38] measured broiler rectal temperature (RT) and skin temperature (featherless wing area) with digital thermometers, finding no significant differences in 4-8-week-old broiler body temperature across RH levels of 40-45%, 50-55%, 60-65%, and 70-75% at constant 28 °C. Adams et al. [39] reported that high humidity (80% vs. 40%) elevated body temperature in 4-8-week-old broilers at 29 °C. Wilson et al. [40] observed that White Leghorn hen skin temperature increased with RH (28%, 40%, and 72%) at 29.4 °C. Gu et al. [4] found that at 30 °C, high humidity (80% RH) significantly increased comb, wing, shank, and toe temperatures compared to low humidity (40% RH), with significant elevations in RT and chest temperature. Gu et al. [5] reported that at 32 ± 1 °C, broilers (23-37 days) at 90% RH exhibited significantly higher RT than those at 30% or 60% RH. Lin et al. [41] demonstrated that high humidity (85% vs. 60%) significantly increased core body temperature, back/wing temperature, and chest skin temperature at 35 °C. Lin et al. [42] found that both high temperature (35 °C) and high humidity (85% RH) elevated body temperature in newly hatched chicks, with the high temperature-high humidity group (35 °C, 85% RH) showing the highest temperatures, followed by high temperature-low humidity (35 °C, 35% RH), while control and low temperature (27 °C, 35% and 85% RH) groups maintained lower temperatures. Tao Xiuping [6] concluded that higher temperatures, greater humidity, and longer stress duration collectively increased body temperature. Kamar et al. [43] reported that adult poultry body temperature elevation correlated with RH increases under high temperature conditions. However, Yahav et al. [44] found that 5-8-week-old broilers exhibited maximal growth rate, feed intake, and partial pressure of carbon dioxide (PCO2) with minimal RT, skin temperature, and pH at 35 °C and 60-65% RH. Prinzinger et al. [45] explained that at 35 °C, long-term exposure to 60-65% RH allowed poultry to maintain normal body temperature, whereas both higher and lower RH caused hyperthermia.

These results demonstrate that when temperature exceeds the broiler thermoneutral zone, RH effects become increasingly critical. Both high and low humidity elevate body temperature, with high humidity exerting more pronounced effects, while 60-65% RH optimizes growth performance. The recent application of infrared thermal imaging technology for avian skin temperature measurement [46-50] may provide more precise data for future investigations of RH effects on poultry skin temperature while minimizing stress, though this requires further validation.

### 3.2. Effects on Respiration and Acid-Base Balance

The avian respiratory system serves dual functions: oxygen delivery and CO2 removal, and evaporative heat dissipation. Under high temperature, poultry increase evaporative cooling to prevent lethal hyperthermia, most notably by accelerating respiratory mucosal water evaporation up to 20-fold normal rates, which subsequently affects pulmonary gas exchange, increases CO2 elimination, and can cause respiratory alkalosis. Ota et al. [51] demonstrated that respiratory heat loss becomes increasingly important as ambient temperature rises.

Bouchillon et al. [52] subsequently developed a mathematical model showing that when ambient temperature approaches body temperature, poultry must dissipate heat evaporatively, with RH becoming a critical factor in heat dissipation. At 38 °C, 50% RH may be relatively low for poultry, but at 40.6 °C, the same RH may be excessive and cause heat prostration [53].

While high humidity impedes evaporative cooling under high temperature, excessive water loss can also hinder EHL, reduce panting rate, and cause heat stroke [54-55], compromising health. Chwallbog et al. [56] showed that EHL decreases linearly with increasing RH. Wilson [57] concluded that EHL in laying hens reaches maximum at 32 °C and 50–60% RH, indicating that RH above 60% impedes EHL.

Blood acid-base balance is fundamental to metabolic activity. Chronic heat stress causes acid-base disturbances and respiratory alkalosis in broilers [58-59], reducing growth rate [59-60] and altering physiological status. Under high temperature, the relationship between evaporative cooling and respiratory alkalosis involves hyperventilation from thermal panting [61-62], while increased water loss can restrict panting and prevent further alkalosis development [8]. Yahav et al. [44] reported that at 35 °C, decreasing RH to 40–45% with increasing rectal temperature may induce respiratory alkalosis. Altan et al. [63] exposed 35-day-old broilers to 38 °C for 2 hours, observing elevated RT without acid-base disturbance. Teeter et al. [64] noted that panting occurs intermittently during chronic adaptation, resulting in periodic rather than continuous alkalosis under prolonged heat stress. Additional research found no respiratory alkalosis at 35 °C and 60–65% RH, attributed to renal compensation of bicarbonate [52] and maintenance of acid-base balance by appropriate RH, thereby reducing respiratory alkalosis incidence.

Collectively, these findings indicate that RH is a critical factor for heat dissipation under high temperature, but levels exceeding 60% impede poultry EHL, accelerate respiration, and can cause heat prostration and respiratory alkalosis with acid-base imbalance.

### 3.3. Effects on Feed Intake

Feed intake represents the most fundamental activity for animal survival, with its level closely related to health status. As a key factor affecting feed intake, RH interacts with temperature to influence poultry health. Charles [65] concluded that at 27 °C, high humidity may reduce broiler feed intake and growth rate; at 29 °C, increasing RH from 40% to 80% significantly decreased feed intake and markedly reduced performance. Adams et al. [39] reported that at 29 °C, high humidity (80% vs. 40%) reduced feed intake and growth rate in 4–8-week-old broilers. Yahav et al. [38,44] demonstrated that 4-8-week-old broilers achieved maximal growth rate and feed intake at 60–65% RH across temperatures of 28 °C, 30 °C, and 35 °C. Winn et al. [66] found that at 32 °C, high humidity (90% vs. 40%) reduced growth rate in 3–5-week-old broilers. Gu et al. [3] reported that at 32 °C, broilers at 90% RH showed significantly lower final weight, weight gain, and feed consumption, with significantly higher feed conversion ratio compared to 60% and 30% RH groups, while no differences existed between 60% and 30% RH groups. These results demonstrate that high temperature combined with high humidity causes rapid performance decline [38,44].

In summary, when temperature exceeds the poultry thermoneutral zone, the optimal RH range for maximal feed intake is 60–65%, with levels above or below this range reducing feed intake, and high humidity exerting greater negative impact than low humidity.

At appropriate RH, EHL reaches maximum capacity; under high temperature, high humidity impedes poultry EHL, causing elevated body temperature, accelerated respiration, reduced appetite, and potentially acid-base imbalance, heat prostration, and respiratory alkalosis. Future research should investigate whether RH affects the partitioning of EWL pathways under high temperature and identify RH thresholds for physiological and respiratory functions to provide scientific guidance for optimal RH management in practical production.

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