Effects of Thermal Environment on Thermoregulation in Finishing Pigs (Postprint)

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Abstract

Environmental temperature and humidity are important factors affecting the welfare, growth, and health of fattening pigs. Pigs are homeothermic animals that can maintain the balance between heat production and heat dissipation by adjusting thermoregulatory indicators such as heat production, feed intake, respiratory rate, skin temperature, and core body temperature when environmental temperature and humidity change, thereby sustaining a constant body temperature within a certain range. This paper summarizes and analyzes the sequence in which thermoregulatory indicators of fattening pigs drastically change under different environmental temperature and humidity conditions, evaluates the comfort status of fattening pigs at different temperatures, and provides a reference for future research on establishing comfortable environmental parameters for pigs and scientifically regulating the thermal environment in pig houses.

Full Text

Regularities of Thermoregulation in Finishing Swine Affected by Thermal-Humidity Environment

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Abstract: Environmental temperature and humidity are critical factors affecting the welfare, growth, and health of finishing swine. As homeothermic animals, pigs can adjust various thermoregulatory indicators—including heat production, feed intake, respiratory rate, skin temperature, and core body temperature—to maintain thermal balance and constant body temperature within a certain range when ambient conditions change. This paper summarizes and analyzes the sequential patterns of abrupt changes in thermoregulatory indicators of finishing pigs under different thermal-humidity conditions, assesses their comfort status at various temperatures, and provides references for establishing comfortable environmental parameters and scientifically regulating thermal-humidity conditions in pig housing.

Keywords: temperature; humidity; finishing swine; thermoregulation
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High-temperature environments inflict substantial economic losses on the swine industry, with global damages estimated in the billions of dollars annually [1]. In recent years, as pig production in China has become more intensive and large-scale, most facilities have been equipped with cooling systems such as fans, wet curtains, and misting devices, which significantly improve the thermal environment [2]. However, temperature control in pig barns often relies on producers' experience, and even large-scale facilities with automated monitoring systems lack sufficient scientific basis for regulating thermal-humidity conditions. Appropriate environmental control directly affects pig growth and health [3-4] while also influencing energy consumption and production costs [5-6]. As homeothermic animals, pigs can adjust their heat production and dissipation to maintain constant body temperature within a certain range when environmental temperature and humidity change [7]. Consequently, changes in thermoregulatory indicators serve as important measures of pig comfort.

This review summarizes the patterns of how thermal-humidity environments affect swine thermoregulation, providing references for future research on establishing comfortable environmental parameters and scientifically regulating barn conditions.

1 Thermoregulation of Heat Production and Dissipation in Swine

Like other mammals, pigs primarily collect information about ambient temperature changes through peripheral temperature receptors located in the skin [8], which transmit signals via the nervous system to thermoregulatory centers. While these centers span the entire nervous system from the spinal cord to the cerebral cortex, the fundamental regulation hub resides in the preoptic anterior hypothalamus [9]. After processing by the thermoregulatory center, signals are transmitted through neural and endocrine pathways to various effectors [8,10] that modulate heat production and dissipation.

Total heat production (THP) in pigs comprises four components: basal metabolic heat production, heat increment from feeding, activity-related heat production, and production-related heat production. The heat increment from feeding can be further subdivided into heat from feed ingestion and heat from digestion and absorption [11]. In intensive production systems where pig activity is minimal, changes in feed intake primarily reflect alterations in heat production through neural regulation of nutrient metabolism, though respiration chambers can also directly measure heat production changes. Heat dissipation occurs through sensible and evaporative pathways [12]. Pigs regulate sensible heat loss by altering cutaneous blood flow to adjust skin temperature, making skin temperature a useful indicator of sensible heat dissipation changes. Cutaneous evaporative heat loss is temperature-dependent; when ambient temperature rises from 16°C to 29°C, cutaneous evaporative heat loss doubles. Another evaporative heat loss pathway is panting, with the correlation coefficient between respiratory rate and evaporative heat loss reaching 0.7-0.8 at 30°C [13]. Evaporative heat loss can be measured directly by determining water vapor content changes in respiration chamber inlet and outlet gases or estimated indirectly from respiratory rate changes.

2.1 Effects on Heat Production

Due to limited capacity for cutaneous evaporative cooling [14], pigs primarily maintain constant body temperature by reducing heat production when ambient temperature exceeds the upper limit of the thermoneutral zone. Consequently, the temperature at which heat production begins to decline rapidly is generally used to determine the upper critical temperature. Quiniou et al. [15] found that for 60–90 kg pigs, heat production remained essentially constant between 16–22°C, decreasing by only 0.02 MJ/d per 1°C increase. However, in the 12–16°C and 22–29°C ranges, heat production decreased significantly by 0.42–0.47 MJ/d per 1°C increase, suggesting the thermoneutral zone for 60–90 kg pigs likely lies between 16–22°C. Huynh et al. [16] housed 61.7 kg pigs at 16°C and increased temperature by 2°C daily until reaching 32°C. Nonlinear regression analysis revealed an inflection point for THP at 22°C, indicating that heat production began declining rapidly above this temperature and suggesting the upper critical temperature for 60 kg pigs is approximately 22°C—consistent with the aforementioned results. In contrast, Brown-Brandl et al. [17] measured THP in 83 kg pigs at 18, 24, 28, and 32°C, observing a slow decline between 18–24°C but a rapid decrease between 24–28°C, leading them to conclude the upper critical temperature is near 24°C. Similar findings in other studies [18-19] may be attributable to relatively large temperature intervals in experimental designs. Overall, research indicates the upper critical temperature of the thermoneutral zone for finishing pigs, based on THP measurements, ranges from 22–24°C.

When ambient temperature continues rising beyond the thermoneutral zone upper limit, the rate of heat production decline slows and may even reverse. Brown-Brandl et al. [17-18] reported that THP in 80 kg finishing pigs began increasing above 28°C. Similarly, Brown-Brandl et al. [20] found THP in 60–120 kg finishing pigs showed little further decline beyond 28°C. This phenomenon likely results from increased muscular activity from rapid panting and the van' t Hoff effect. When ambient temperature reaches this threshold, pigs exhibit clear signs of heat stress.

2.2 Effects on Feed Intake

Pigs can adjust THP by regulating feed intake to maintain body temperature, making feed intake changes indicative of thermal adaptation while also being closely linked to production performance. Nichols et al. [21] investigated feed intake changes across 0-35°C, finding that for 72.6 kg pigs, feed intake decreased by 272 g per 1°C increase between 0-5°C, changed slowly (36 g per 1°C) between 5-20°C, and declined rapidly (113 g per 1°C) between 20-35°C, suggesting a thermoneutral zone of 5-20°C. Quiniou et al. [15] examined metabolizable energy intake across 12-29°C, observing that 60-90 kg pigs maintained relatively constant intake between 14-22°C (decreasing only 0.16 MJ/d per 1°C), but showed rapid reductions of 0.76 and 1.70 MJ/d per 1°C in the 12-14°C and 22-29°C ranges, respectively, suggesting a thermoneutral zone of 14-22°C for 60-90 kg pigs. These two studies employed wide temperature ranges with large intervals and extended experimental periods, resulting in less precise thermoneutral zone estimates. Brown-Brandl et al. [20] studied feed intake changes in 60-120 kg pigs across 16-32°C, noting slow decline between 16-24°C but rapid decrease between 24-32°C, suggesting 24°C as the likely upper critical temperature. Huynh et al. [16] used nonlinear regression analysis to identify an inflection point for feed intake at 25.6°C in 61.7 kg pigs, above which intake declined rapidly—consistent with other studies [18-22]. These findings indicate the upper critical temperature of the thermoneutral zone for finishing pigs, based on feed intake, likely ranges from 24-26°C.

3.1 Effects on Evaporative Heat Loss

When ambient temperature exceeds the thermoneutral zone, evaporative heat loss becomes the primary cooling mechanism [13], making it a key indicator for determining the upper critical temperature. Huynh et al. [16] used respiration chambers to study evaporative heat loss across 16-32°C, with nonlinear regression analysis revealing that evaporative heat loss began increasing rapidly above 21°C, suggesting the upper critical temperature for 60 kg pigs is approximately 21°C. However, Brown-Brandl et al. [20] found that evaporative heat loss in 60-120 kg finishing pigs increased slowly between 16-24°C but rose rapidly between 24-32°C, suggesting the upper critical temperature is near 24°C. Brown-Brandl et al. [17] similarly observed that evaporative heat loss in 80 kg pigs increased significantly above 24°C. These discrepancies may stem from large temperature intervals in experimental designs. Overall, research indicates the upper critical temperature for finishing pigs, based on evaporative heat loss, ranges from 21-24°C.

3.2 Effects on Respiratory Rate

Due to poorly developed sweat glands and limited cutaneous evaporative cooling capacity [14], pigs rely primarily on panting to enhance evaporative heat loss above the thermoneutral zone upper limit, making respiratory rate a valuable indicator for determining this threshold. Brown-Brandl et al. [18] found that respiratory rate in 80 kg finishing pigs showed little change between 18–24°C (increasing only 0.46 breaths/min per 1°C) but rose rapidly between 24–32°C (increasing 3.0–3.3 breaths/min per 1°C). Brown-Brandl et al. [17] similarly observed that respiratory rate in 83 kg pigs followed an exponential curve across 18–32°C, increasing sharply above 24°C. These results suggest the upper critical temperature is near 24°C. Huynh et al. [16] used nonlinear regression analysis to identify an inflection point for respiratory rate at 22.6°C, above which it increased rapidly. Collectively, these studies indicate the upper critical temperature for finishing pigs, based on respiratory rate, ranges from 22.6–24.0°C.

3.3 Effects on Body Surface Temperature

Within the thermoneutral zone, pigs rely primarily on sensible heat loss, regulating cutaneous blood flow to adjust skin temperature and control sensible heat dissipation. Bond et al. [23] reported that skin temperature increased linearly with ambient temperature across 21.1–42.5°C. Huynh et al. [16] similarly observed a linear increase in skin temperature with ambient temperature for 60 kg pigs across 16–32°C. Renaudeau et al. [24] found that skin temperature increased linearly with ambient temperature between 24–32°C but the rate of increase slowed above 32°C. Brown-Brandl et al. [25] used thermal imaging to measure skin temperature changes in production environments ranging from 21.3–36.6°C, revealing a cubic curve relationship with relatively stable skin temperatures in the 20–23°C and 38–41°C ranges. These studies demonstrate that skin temperature generally increases linearly with ambient temperature, though inflection points may exist—requiring detection of large datasets under undisturbed conditions.

4 Effects of Ambient Temperature on Core Body Temperature

When ambient temperature is excessively high and pigs cannot maintain thermal balance through heat production and dissipation adjustments, core body temperature rises [26-28]. Brown-Brandl et al. [18] found that rectal temperature in 80 kg finishing pigs increased by only 0.013°C per 1°C ambient temperature increase between 18–28°C, but rose by 0.118°C per 1°C between 28–32°C, indicating that core temperature began increasing rapidly near 28°C. Renaudeau et al. [29] similarly observed that rectal temperature in 50 kg pigs began rising sharply around 28°C. Huynh et al. [16] studied rectal temperature changes in 60 kg pigs across 16–32°C (increasing by 2°C daily), with nonlinear regression analysis revealing an inflection point at 27.08°C. These findings suggest the upper critical temperature of the thermoneutral zone for finishing pigs, based on core body temperature, ranges from 27-28°C.

5 Effects of Ambient Humidity on Swine Thermoregulation

The influence of humidity on swine thermoregulation is temperature-dependent. At low temperatures, humid air' s high thermal conductivity may increase sensible heat loss, whereas at high temperatures, high humidity impairs evaporative cooling efficiency [30-31]. Most research has focused on high-temperature conditions. Morrison et al. [26] investigated humidity effects at 22.0, 27.5, and 33.0°C, finding no significant impact on weight gain at 22.0°C but significantly reduced gain at 27.5°C and 33.0°C under high humidity. The study detected no significant effects on core or surface temperatures, suggesting pigs may mitigate humidity impacts by reducing feed intake. Other studies have shown that at temperatures above 30°C, high humidity (90% vs. 30%) significantly increases respiratory rate, skin temperature, and rectal temperature [30,32], with similar findings reported by Lopez et al. [33]. Huynh et al. [34] examined the effects of increasing temperature under different humidity levels (50%, 65%, 80%), finding that high humidity shifted the inflection points for respiratory rate and rectal temperature to lower temperatures. This indicates that high humidity reduces evaporative cooling efficiency, causing respiratory rate and rectal temperature to increase at lower ambient temperatures.

In summary, as ambient temperature gradually increases, thermoregulatory indicators in finishing pigs—including heat production, feed intake, evaporative heat loss, and respiratory rate—exhibit sequential abrupt changes. The inflection points where these indicators change dramatically can be used to determine the upper critical temperature of the thermoneutral zone. However, because most studies have employed few temperature points, estimates of the upper critical temperature lack precision. Additionally, as temperature continues rising, some indicators such as heat production and skin temperature exhibit second inflection points, indicating entry into severe heat stress. Based on these patterns, temperature ranges corresponding to comfortable, safe, and dangerous conditions can be established.

Notably, most research on temperature effects has used constant temperatures, whereas production environments rarely maintain stable conditions for extended periods. Physiological data obtained under strictly controlled stable temperatures cannot predict pig responses to continuously changing temperatures in practice. Therefore, further research is needed on thermoregulatory responses to diurnal temperature variations to guide scientific regulation of barn thermal environments.

References

[1] ST-PIERRE N R, COBANOV B, SCHNITKEY G. Economic losses from heat stress by US livestock industries[J]. Journal of Dairy Science, 2003, 86(1S):

E52–E77.

[2] 雷明刚, 王金勇, 夏伟, 等. 传统猪舍改造工艺与新式环境调控猪舍设计及应用 [J]. 中国畜牧杂志, 2015, 51(12): 50–54.

[3] 杨培歌, 冯跃进, 郝月, 等. 持续高温应激对肥育猪生产性能、胴体性状、背最长肌营养物质含量及肌纤维特性的影响 [J]. 动物营养学报, 2014, 26(9): 2503–2512.

[4] NIENABER J A, BROWN-BRANDL T M. Heat stress effects on growing-finishing swine[C]//25th Annual Carolina Swine Nutrition Conference Proceedings. North Carolina: Carolina Feed Industry, 2009.

[5] NIENABER J A, HAHN G L. Livestock production system management responses to thermal challenges[J]. International Journal of Biometeorology, 2007, 52(2): 149–157.

[6] LUBER G, MCGEEHIN M. Climate change and extreme heat events[J]. American journal of preventive medicine, 2008, 35(5): 429–435.

[7] ROLLER W L, GOLDMAN R F. Response of swine to acute heat exposure[J]. Transactions of the ASAE, 1969, 12(2): 164–169.

[8] BURGGREN W W. Role of the central circulation in regulation of cutaneous gas exchange[J]. American Zoologist, 1988, 28(3): 985–998.

[9] BOULANT J A. Hypothalamic neurons: mechanisms of sensitivity to temperature[J]. Annals of the New York Academy of Sciences, 1998, 856: 108–115.

[10] MORRISON F. Central pathways controlling brown adipose tissue thermogenesis[J]. Physiology, 2004, 19(2): 67–74.

[11] VAN MILGEN J, NOBLET J. Modelling energy expenditure in pigs[M]//MCNAMARA J P E, FRANCE J, BEEVER D E. Modelling nutrient utilization in farm animals. Wallingford: CABI Publishing, 2000: 103–114.

[12] BAKKEN G S. A heat transfer analysis of animals: unifying concepts and the application of metabolism chamber data to field ecology[J]. Journal of Theoretical Biology, 1976, 60(2): 337–384.

[13] HOLMES C W, MOUNT L E. Heat loss from young pigs, individually and in groups, at ambient temperatures degrees C[J]. The Journal Physiology, 1966, 186(2): 75P–77P.

[14] INGRAM D L. Evaporative cooling in the pig[J]. Nature, 1965, 207(4995): 415–416.

[15] QUINIOU N, NOBLET J, VAN MILGEN J, et al. Modelling heat production and energy balance in group-housed growing pigs exposed to low or high ambient temperatures[J]. British Journal of Nutrition, 2001, 85(1): 97–106.

[16] HUYNH T T T, AARNINK A J A, VERSTEGEN M W A, et al. Effects of increasing temperatures on physiological changes in pigs at different relative

humidities[J]. Journal of Animal Science, 2005, 83(6): 1385–1396.

[17] BROWN-BRANDL T M, NIENABER J A, TURNER L W. Acute heat stress effects on heat production and respiration rate in swine[J]. Transactions of the ASAE, 1998, 41(3): 789–793.

[18] BROWN-BRANDL T M, EIGENBERG R A, NIENABER J A, et al. Thermoregulatory profile of a newer genetic line of pigs[J]. Livestock production science, 2001, 71(2/3): 253–260.

[19] RINALDO D, LE DIVIDICH J. Assessment of optimal temperature for performance and chemical body composition of growing pigs[J]. Livestock Production Science, 1991, 29(1): 61–75.

[20] BROWN-BRANDL T M, NIENABER J A, EIGENBERG R A, et al. Heat and moisture production of growing-finishing gilts as affected by environmental temperature[C]//2011 ASABE Annual International Meeting Presentation. Louisville, KY: American Society of Agricultural and Biological Engineers, 2011: 1111183.

[21] NICHOLS D A, AMES D R, HINES R H. Effect of temperature on performance of finishing swine[J]. Animal Sciences and Industry, 1980: 14-16.

[22] QUINIOU N, DUBOIS S, NOBLET J. Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight[J]. Livestock Production Science, 2000, 63(3): 245–253.

[23] BOND T E, KELLY C F, HEITMAN H, Jr. Physiological response of swine to cycling environmental conditions[J]. Animal Production, 1967, 9(4): 453–462.

[24] RENAUDEAU D, KERDONCUFF M, ANAÏS C, et al. Effect of temperature level on thermal acclimation in Large White growing pigs[J]. Animal, 2008, 2(11): 1619-1626.

[25] BROWN-BRANDL T M, EIGENBERG R A, PURSWELL J L. Determining heat tolerance in finishing pigs using thermal imaging[C]//2012 International Livestock Environment Symposium (ILES) Presentation. Louisville, KY: American Society of Agricultural and Biological Engineers, 2012: ILES121433.

[26] MORRISON S R, HEITMAN H, Jr, BOND T E. Effect of humidity on swine at temperatures above optimum[J]. International Journal of Biometeorology, 1969, 13(2): 135–139.

[27] GOURDINE J L, BIDANEL J P, NOBLET J, et al. Rectal temperature of lactating sows in a tropical humid climate according to breed, parity and season[J]. Asian Australasian Journal of Animal Sciences, 2007, 20(6): 832–841.

[28] PEARCE S C, MANI V, BODDICKER R L, et al. Heat stress reduces intestinal barrier integrity and favors intestinal glucose transport in growing pigs[J]. PLoS One, 2013, 8(8): e70215.

[29] RENAUDEAU D, GOURDINE J L, ANAÏS C, et al. Effet du niveau de température sur l' acclimatation à court et moyen terme du porc en croissance[J]. Journées Recherche Porcine, 2007, 39: 69–76.

[30] HEITMAN H, HUGHES E H. The effects of air temperature and relative humidity on the physiological well being of swine[J]. Journal of Animal Science, 1949, 8(2): 171–181.

[31] SMITH W C, TONKS H M. The effect of a high-temperature, high-humidity indoor environment on the performance of bacon pigs[C]//Programme and Abstracts of the 9th International Congress of Animal Production, Edinburgh: Oliver & Boyd, 1966: 104–105.

[32] RANDALL J M. Humidity and water vapour transfer in finishing piggeries[J]. Journal of Agricultural Engineering Research, 1983, 28(5): 451–461.

[33] LOPEZ J, JESSE G W, BECKER B A, et al. Effects of temperature on the performance of finishing swine: . Effects of a hot, diurnal temperature on average daily gain, feed intake, and feed efficiency[J]. Journal of Animal Science, 1991, 69(5): 1843–1849.

[34] HUYNH T T T, AARNINK A J A, GERRITS W J J, et al. Thermal behaviour of growing pigs response temperature humidity[J]. Applied Animal Behaviour Science, 2005, 91(1/2): 1–16.

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