Research Progress on Broiler Chicken Welfare Assessment Indicators Postprint

Authors: SUN Yongbo, Wang Ya, Sarenna, Zhang Hongfu

Date: 2017-10-10T00:00:00+00:00

Abstract

With the development of high-density, intensive animal husbandry, animal welfare issues have become increasingly concerning, severely constraining the development of China' s livestock industry. This production model, which sacrifices animal welfare, induces adverse physiological and psychological responses in poultry, leading to outbreaks of respiratory diseases, ascites syndrome, and other conditions, thereby reducing production performance, economic efficiency, and product quality. In recent years, nations worldwide have placed growing emphasis on animal welfare issues. By summarizing and analyzing indicators for broiler welfare evaluation, this study aims to provide a theoretical foundation for establishing a poultry welfare evaluation system in China, enhance welfare standards in broiler production, and promote the healthy development of animal husbandry.

Full Text

Research Progress on Evaluation Indexes of Broiler Welfare

SUN Yongbo, WANG Ya, SA Renna*, ZHANG Hongfu
State Key Laboratory of Animal Nutrition, Institute of Animal Science, Chinese Academy of Agricultural Sciences, Beijing 100193, China

Abstract: With the development of high-density, intensive animal husbandry, animal welfare issues have become increasingly concerning, seriously restricting the development of China' s livestock industry. This production model, which sacrifices animal welfare, causes adverse physiological and psychological responses in poultry growth, leading to outbreaks of respiratory diseases and ascites, while reducing production performance, economic benefits, and product quality. In recent years, countries worldwide have attached greater importance to animal welfare issues. This paper summarizes and analyzes broiler welfare

evaluation indicators to provide theoretical guidance for establishing a poultry welfare evaluation system in China, improve broiler welfare standards, and promote the healthy development of animal husbandry.

Keywords: broilers; welfare; evaluation indicators

Corresponding author: SA Renna, associate professor, E-mail: sa6289@126.com

1 Overview of Poultry Welfare

In recent years, animal welfare has gradually gained attention from researchers, farmers, and consumers [8]. Improving animal welfare can reduce the incidence of respiratory diseases and ascites, promote healthy animal growth, improve livestock product quality, and increase economic benefits [9]. The concept of animal welfare is diverse and continuously evolving, but in simple terms, it refers to the healthy physiological and psychological development of animals in a comfortable state free from pain, disease, abnormal behavior, and stress [10]. As living beings, animals not only possess various sensory functions but also have rich emotions, requiring basic feed and water, as well as appropriate activity space and living environment [11-12]. Currently, there is international consensus that animal welfare encompasses both physical and psychological aspects, primarily including freedom from hunger and thirst, comfort, freedom from injury and disease, freedom from stress and fear, and freedom to express normal behavior [13-15].

The goal of animal welfare is to enable animals to grow healthily and happily, essentially treating them kindly by providing comfortable housing conditions, adequate nutrition, and humane management practices [16]. However, during production, factors such as feeding management, environmental conditions, nutrition, transportation, and slaughter all affect poultry welfare and lead to reduced production performance. Research shows that the physiological and psychological states of livestock can be directly or indirectly reflected through various physiological conditions, behavioral performances, immune functions, and production traits [17]. Therefore, animal health and welfare status can be evaluated using behavioral, physiological, and immune indicators. Four main principles guide poultry welfare assessment: good feeding, good housing, good health, and appropriate behavior [18-19]. Currently, welfare assessment systems primarily include two aspects: evaluating animal health status and assessing the living environment [20]. Only through scientific, objective, and comprehensive evaluation of poultry welfare can we understand poultry health status and promptly improve environmental and nutritional conditions to promote healthy broiler growth, which is significant for developing healthy farming practices.

2.1 Broiler Behavior

Animal behavior represents an organism' s response to its environment and can promptly reflect its health status [21]. Therefore, broiler behavior serves as an effective indicator for evaluating broiler health and welfare [22]. Broiler behaviors are mainly divided into state behaviors (standing, lying, walking, feeding, drinking, and preening) and event behaviors (pecking, dust bathing, and feather pecking) [23]. Under comfortable environmental conditions and adequate nutrition, broilers' physiological and psychological needs are met, and they express feelings of contentment through various behaviors [24]. However, with the development of high-density, intensive farming, broilers cannot express normal behaviors and exhibit many abnormal behaviors [25]. Installing surveillance cameras in chicken houses for remote observation records various broiler behaviors without causing disturbance stress to experimental birds while objectively reflecting their behavioral performance and welfare status. Mack et al. [26] reported that heat stress (32.6 °C) significantly increased wing spreading and resting behaviors while reducing feeding and locomotor activities. Hu et al. [27] used infrared cameras to record broiler behavior and found that heat stress at 30 °C significantly altered resting behavior, decreasing sitting rest and increasing prone rest. Li et al. [28] reported that ammonia concentration at 50 mg/kg significantly reduced lying duration, while 80 mg/kg significantly increased standing frequency and duration and walking frequency, and significantly decreased lying duration. These studies demonstrate that observing and recording broiler behavior can reflect welfare status.

Tonic immobility (TI) is a phenomenon where broilers experience accelerated heartbeat and respiration, muscle paralysis, and complete immobility when subjected to external stress [29]. TI duration serves as an indicator for evaluating fearfulness in poultry—the greater the fear, the longer the immobility period [30-31]. TI testing is conducted in a quiet, dimly lit room using methods described by Wang et al. [32] or Zhao [25], with higher TI values indicating greater fearfulness [33]. Tanaka et al. [34] found that enriched environments could reduce fearfulness in poultry. Jiang et al. [10] reported that broilers in perch and toy groups showed significantly reduced TI duration, indicating that environmental enrichment can reduce fearfulness and improve welfare. In summary, TI can reflect broiler welfare levels to a certain extent. Additionally, the avoidance distance test can evaluate the relationship between animals and humans. Following methods described by Graml et al. [35], this test indirectly reflects animal welfare through animals' approach or avoidance behavior toward humans [36]. Scoring criteria based on avoidance distance and avoidance rate are as follows [37]: avoidance distance of 0-30 cm: avoidance rate >40% scores 1 point, avoidance rate <40% scores 10 points; avoidance distance of 30-60 cm: avoidance rate >50% scores 4 points, avoidance rate <50% scores

2.2 Feather Quality

Broiler feathers provide both insulation and protection against dust and pathogens, with feather quality indirectly reflecting broiler comfort and welfare status [38]. Feather damage can trigger feather pecking and aggressive behavior from other individuals, reducing production performance and affecting welfare [39]. Feather condition (including breast, back, wings, tail, etc.) is generally scored on a 4-level scale [40-41]: extensive feather damage (damage area >1/3) scores 1 point; partial feather loss (damage area ~50%) scores 2 points; minor feather damage (damage area <1/3) scores 3 points; intact feathers score 4 points.

2.3 Bone Development

With advances in genetic breeding technology, broiler market age has gradually shortened while growth rate has significantly increased, causing broiler weight to exceed what their bones can support. This excessive leg burden leads to bone deformation, hindering normal activity and feeding, and reducing welfare levels [42]. Therefore, bone development status is an important welfare indicator.

Fluctuating asymmetry (FA) refers to minor random directional deviations when comparing bilaterally symmetrical traits [16,43]. FA serves as a behavioral parameter for evaluating environmental conditions and genetic stress, as well as an important indicator for assessing broiler welfare and comfort, reflecting growth status under specific environmental conditions. Larger FA values indicate poorer rearing environments and lower welfare levels [24].

Gait scoring (GS) is a widely applied and recognized method for assessing broiler leg health and walking ability [44]. Garner et al. [45] developed a 6-point gait scoring system: normal gait scores 0; slightly slow gait scores 1; moderately slow gait scores 2; moderately abnormal gait scores 3; severely abnormal gait with only small steps possible scores 4; complete inability to walk scores 5. Jiang [33] reported that net-reared broilers mainly scored 2-3 points, while free-range rearing significantly reduced gait scores, indicating that free-range activity benefits bone growth and development.

Elbow damage refers to dermatitis and bone deformation in the hock joint area, with severe cases showing skin ulceration, scabbing, and joint swelling. The elbow damage score uses a 5-point scale [7]: healthy hock joint with no damage, ulceration, or inflammation scores 0; small pinpoint erythematous lesions with inflammation scores 1; slightly larger hock damage (~0.1-0.5 cm diameter) scores 2; obvious inflammation and damage (~1 cm diameter) scores 3; severe hock damage (>2 cm diameter) scores 4 (Fig. 1 [Figure 1: see original paper]). Meng et al. [46] reported that ammonia concentrations of 75 and 50 mg/kg significantly increased elbow damage scores, indicating that ammonia stress exacerbates hock joint damage and is detrimental to bone growth.

Foot pad dermatitis is a skin inflammation on the bottom of broiler feet, ranging

from discoloration and black lesions to severe ulceration of subcutaneous tissue. The foot pad damage score uses a 5-point scale [47]: clean foot pad with no damage, ulceration, or inflammation scores 0; star-point lesions with inflammation scores 1; slightly larger foot pad damage (0.1-0.5 cm diameter) scores 2; obvious inflammation and damage (~1 cm diameter) scores 3; severe inflammation and damage (>2 cm diameter) scores 4 (Fig. 2 [Figure 2: see original paper]).

2.4 Gut Microbiota

The interaction between poultry gut microbiota and the host forms a dynamically balanced microecosystem that plays important roles in defending against pathogens and improving immune function. Cecal microbial growth status is an important indicator of poultry intestinal health and welfare. Peng et al. [48] reported that continuous moderate heat treatment at 31 °C reduced cecal microbiota diversity, inhibited colonization of *Ruminococus faecis* and *Faecalibacterium prausnitzii*, and promoted growth of *Lutisporathermophila*. Tuyttens et al. [49] reported that lactobacillus counts in broiler ceca could serve as a health parameter for evaluating broiler welfare. These studies demonstrate that gut microbiota can reflect poultry health and welfare status to some extent, though specific evaluation methods and standards require further research and discussion.

2.5 Blood Indicators

Measuring corticosterone (CORT) content in blood, feathers, or feces can serve as a method for evaluating broiler welfare [50]. Su et al. [51] reported that heat stress at 35 °C significantly increased fecal CORT content in broilers. The heterophil/lymphocyte (H/L) ratio is an indicator of hypothalamic-pituitary-adrenal (HPA) axis activity and a non-specific stress response indicator [52]. Stress factors such as poor environment, inadequate nutrition, and transportation can increase H/L ratios [10]. When muscles are intensely exercised or damaged, cell membrane function and permeability are compromised, releasing creatine kinase (CK) into the blood. CK is a marker of skeletal muscle damage and an important characteristic of stress response, making it a useful welfare indicator [53]. During early stress or infection stages, certain plasma protein levels change, collectively termed acute phase reaction (APR) proteins. C-reactive protein (CRP) content is a sensitive indicator of infection and can serve as an effective parameter for monitoring poultry health and welfare [54]. Additionally, immunoglobulin content can reflect immune function and, to some extent, broiler welfare levels.

2.6 Environmental Welfare

Housing environment quality directly affects animal health and welfare, subsequently influencing product quality. During broiler production, key environmental factors related to welfare include temperature and humidity, air quality,

litter quality, and lighting [55]. Poor environments affect broiler health, reduce welfare levels, and may even cause mortality. Therefore, environmental quality is also an important welfare indicator.

The optimal temperature for chicks is 32-35 °C, gradually decreasing daily based on chick response to maintain 26-27 °C by day 21. Excessively high or low temperatures cause heat or cold stress, leading to panting or huddling. Temperature assessment uses a 5-point scale based on broiler response [9]: no panting or huddling scores 0; panting or huddling in <20% of birds scores 1; panting or huddling in 50% of birds scores 2; panting or huddling in >50% of birds scores 3; panting or huddling in all birds scores 4.

Air quality is an important environmental indicator, with ammonia, hydrogen sulfide, and carbon dioxide concentrations being commonly used metrics. Evaluation standards are shown in Table 1 .

Additionally, the types and quantities of airborne microorganisms in poultry houses are important environmental indicators. Microorganisms such as *E. coli* and *Staphylococcus aureus* can invade broilers through the respiratory tract, causing tracheitis or bronchitis, with microorganisms reaching alveoli potentially causing pneumonia, seriously threatening animal health and welfare [16]. Indicator microorganisms (*E. coli*, hemolytic staphylococcus, *Clostridium perfringens*, etc.) are commonly used to represent microbial conditions in poultry houses [43]. Airborne bacterial endotoxins are important components of bioaerosols that produce toxic effects after entering the body, severely threatening animal health and welfare [16,56].

Litter quality is also an important factor affecting poultry welfare, as long-term contact with wet litter can trigger arthritis, breast blisters, and foot pad dermatitis [57]. Lighting also affects broiler welfare, influencing behavior and leg health [58]. Evaluation methods for litter quality, lighting, and other factors require further research.

Zhen et al. [59] found that the daily water-to-feed ratio in broilers was extremely significantly correlated with ambient temperature, core body temperature, and respiration rate, indicating that water-to-feed ratio reflects broiler thermal comfort under heat stress and can serve as a welfare evaluation indicator. Body temperature (core and surface) and respiration rate are commonly used to evaluate broiler welfare under hot and humid conditions. Zhou et al. [60] reported that under incremental heat stress, broilers at 85% relative humidity (RH) showed significantly higher respiration rates and core temperatures than those at 60% RH. Measuring eyeball transverse diameter, longitudinal diameter, and weight after enucleation can reveal eye development and indirectly reflect welfare status. Jensen et al. [61] reported that continuous light exposure increased chicken eyeball volume and weight. Deep et al. [62] found that broilers under 1 lx had significantly greater eyeball weight and volume than those under 10, 20, and 40 lx. Research shows that animal vocalizations convey rich information correlated with external stimuli, hunger, and other conditions, reflecting physical

condition and environmental stress to some extent, making vocalization assessment a reference indicator for animal welfare [63-64]. Additionally, production performance can reflect poultry welfare status [65]. Low welfare levels cause abnormal behavior, energy waste, reduced feed conversion efficiency, and daily weight gain. Respiratory diseases and ascites reduce poultry welfare, with some diseases even causing mortality [66]; therefore, disease incidence and mortality are also important welfare indicators.

Currently, various animal welfare evaluation standards exist, but they are inconsistent and evaluation methods remain somewhat one-sided. With scientific and technological development, we should actively explore sensitive, time-saving, and easy-to-operate broiler welfare indicators. By comprehensively considering these indicators, we can establish a scientific, objective, and comprehensive animal welfare evaluation system suitable for China' s livestock industry. Furthermore, we must strengthen and improve animal welfare laws and regulations, raise awareness among farmers, and improve animal welfare through nutrition, environment, feeding methods, and daily management to promote healthy farming development.

References

[1] CAULFIELD M P, CAMBRIDGE H, FOSTER S F, et al. Heat stress: a major contributor to poor animal welfare associated with long-haul live export voyages[J]. The Veterinary Journal, 2014, 199(2): 223-228. [2] DAVID B, MEJDELL C, MICHEL V, et al. Air quality in alternative housing systems may have an impact on laying hen welfare. Part —Ammonia[J]. Animals, 2015, 5(3): 886-896. [3] DAVID B, MOE R O, MICHEL V, et al. Air quality in alternative housing systems may have an impact on laying hen welfare. Part —Dust[J]. Animals, 2015, 5(3): 495-511. [4] BROOM D M. Indicators of poor welfare[J]. British Veterinary Journal, 1986, 142(6): 524-526. [5] DE JONG I C, HINDLE V A, BUTTERWORTH A, et al. Simplifying the welfare quality® assessment protocol for broiler chicken welfare[J]. Animal, 2016, 10(1): 117-127. [6] RODENBURG T B, TUYTTENS F A M, DE REU K, et al. Welfare assessment of laying hens in furnished cages and non-cage systems: assimilating expert opinion[J]. Animal Welfare, 2008, 17(4): 355-361. [7] 孟丽辉, 张晓迪, 卢庆萍, 等. 复合芽孢杆菌制剂对肉鸡福利的影响 [J]. 家畜生态学报, 2013, 34(11): 31-36. [8] MARTELLI G. Consumers' perception of farm animal welfare: an Italian and European perspective[J]. Italian Journal of Animal Science, 2009, 8(1S): 31-41. [9] 付文艳. 白羽肉鸡养殖福利状况的调查及慢性应激对肉鸡骨骼肌生长的影响 [D]. 硕士学位论文. 南京: 南京农业大学, 2013. [10] 姜旭明, 卢庆萍, 张宏福, 等. 环境富集材料对肉鸡福利指标的影响 [J]. 家畜生态学报, 2009, 30(2): 72-77. [11] MOURA D J, NÄÄS I A, PEREIRA D F, et al. Animal welfare concepts and strategy for poultry production: a review[J]. Revista Brasileira de Ciência Avícola, 2006, 8(3): 137-147. [12] 郭盈盈. 笼养方式和应激对蛋鸡生产性能和福利状态的影响 [D]. 硕士学位论文. 泰安: 山东农业大学, 2010. [13] PHILLIPS C. Animal welfare: a construct of positive and negative affect[J]. Veterinary Journal, 2008, 175(3): 291-292. [14] HOVI M, SUNDRUM A,

THAMSBORG S M. Animal health and welfare in organic livestock production in Europe: current state and future challenges[J]. Livestock Production Science, 2003, 80(1/2): 41-53. [15] 方瑞, 敖长金, 刘美丽, 等. 肉鸡生产中的福利问题 [J]. 家畜生态学报, 2009, 30(3): 101-104. [16] 秦梅. 养殖环境生物应激因素对肉鸡福利状况和生产性能的影响 [D]. 硕士学位论文. 泰安: 山东农业大学, 2010. [17] 顾宪红. 畜禽福利与畜产品品质安全 [M]. 北京: 中国农业科学技术出版社, 2005. [18] BUTTERWORTH A, ARNOULD C, NIEKERK T F V, et al. Welfare quality®, assessment protocol for poultry (broilers, laying hens)[M]. Lelystad, Netherlands: Welfare Quality® Consortium, 2009. [19] 马子力. 牛磺酸促进蛋鸡健康养殖的应用研究 [D]. 硕士学位论文. 南京: 南京农业大学, 2013. [20] 顾宪红, 李升生. 现代养猪生产中的福利问题 [C]//猪营养与饲料研究进展——第四届全国猪营养学术研讨会论文集. 北京: 中国农业科学技术出版社, 2003: 413-423. [21] 孙忠超, 贾幼陵. 论动物福利科学 [J]. 动物医学进展, 2014, 35(12): 153-157. [22] DAWKINS M S. Using behaviour assess animal welfare[J]. Animal Welfare, 2004, 13(1): 3-7. [23] 苏红光. 肉鸡舒适温度评价指标的研究 [D]. 硕士学位论文. 北京: 中国农业科学院, 2014. [24] 邹剑敏. 家禽福利的研究进展 [J]. 中国畜牧兽医, 2010, 37(10): 232-237. [25] 赵子光. 饲养方式对肉鸡福利状况的影响 [D]. 硕士学位论文. 哈尔滨: 东北农业大学, 2011. [26] MACK L A, FELVER-GANT J N, DENNIS R L, et al. Genetic variations alter production and behavioral responses following heat stress in 2 strains of laying hens[J]. Poultry Science, 2013, 92(2): 285-294. [27] 胡春红, 张敏红, 冯京海, 等. 偏热刺激对肉鸡休息行为、生理及生产性能的影响 [J]. 动物营养学报, 2015, 27(7): 2070-2076. [28] 李东卫, 卢庆萍, 白水莉, 等. 模拟条件下鸡舍氨气浓度对肉鸡生长性能和日常行为的影响 [J]. 动物营养学报, 2012, 24(2): 322-326. [29] 姜永彬. 福利饲养技术对肉仔鸡生产性能和福利状态的影响 [D]. 硕士学位论文. 泰安: 山东农业大学, 2010. [30] RIEDSTRA B, GROOTHUIS T G. Early feather pecking as a form of social exploration: the effect of group stability on feather pecking and tonic immobility in domestic chicks[J]. Applied Animal Behaviour Science, 2002, 77(2): 127-138. [31] 李蕾. 白羽肉鸡福利饲养技术研究 [D]. 硕士学位论文. 泰安: 山东农业大学, 2014. [32] WANG S, NI Y D, GUO F, et al. Effect of corticosterone on growth and welfare of broiler chickens showing long or short tonic immobility[J]. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 2013, 164(3): 537-543. [33] 姜旭明. 不同福利条件对肉鸡生产性能和肉质性状的影响 [D]. 硕士学位论文. 武汉: 华中农业大学, 2008. [34] TANAKA T, OZAKI T, WATANABE T, et al. Effects of perches on behavior and performance of caged hens[J]. Japanese Poultry Science, 1993, 30(3): 183-189. [35] GRAML C, NIEBUHR K, WAIBLINGER S. Reaction of laying hens to humans in the home or a novel environment[J]. Applied Animal Behaviour Science, 2008, 113(1/2/3): 98-109. [36] WINDSCHNURER I, BOIVIN X, WAIBLINGER S. Reliability of an avoidance distance test for the assessment of animals' responsiveness to humans and a preliminary investigation of its association with farmers' attitudes on bull fattening farms[J]. Applied Animal Behaviour Science, 2009, 117(3/4): 117-127. [37] 王强, 童海兵, 邵丹, 等. 浅析肉鸡福利养殖质量评分体系 [J]. 中国家禽, 2016, 38(8): 69-72. [38] HUBER-EICHER B, WECHSLER B. The effect of quality and availability of foraging materials on feather pecking in laying hen chicks[J]. Animal Behaviour, 1998, 55(4): 861-873. [39] KEELING J L. Social behavior in farm animals[M]. Wallingford: CABI Publishing, 2001. [40] ONBAŞILAR E E, AKSOY F T. Stress parameters and immune response of layers under different

floor density conditions[J]. Livestock Production Science, 2005, 95(3): 255-263. [41] HINRICHSEN L K, RIBER A B, LABOURIAU R. Associations between and development of welfare indicators in organic layers[J]. Animal, 2016, 10(6): 953-960. [42] 姜旭明. 不同福利条件对肉鸡生产性能和肉质性状的影响 [D]. 硕士学位论文. 武汉: 华中农业大学, 2008. [43] 张明亮. 养殖环境生物应激因素对肉鸭生产性能和免疫功能及福利状况的影响 [D]. 硕士学位论文. 泰安: 山东农业大学, 2012. [44] DAWKINS M S, DONNELLY C A, JONES T A. Chicken welfare is influenced more by housing conditions than by stocking density[J]. Nature, 2004, 427(6972): 342-344. [45] GARNER J P, FALCONE C, WAKENELL P, et al. Reliability and validity of a modified gait scoring system and its use in assessing tibial dyschondroplasia in broilers[J]. British Poultry Science, 2002, 43(3): 355-363. [46] 孟丽辉, 李聪, 卢庆萍, 等. 不同氨气浓度对肉鸡福利的影响 [J]. 畜牧兽医学报, 2016, 47(8): 1574-1580. [47] BILGILI S F, ALLEY M A, HESS J B, et al. Influence of age and sex on footpad quality and yield in broiler chickens reared on low and high density diets[J]. The Journal of Applied Poultry Research, 2006, 15(3): 433-441. [48] 彭骞骞, 王雪敏, 张敏红, 等. 持续偏热环境对肉鸡盲肠菌群多样性的影响 [J]. 中国农业科学, 2016, 49(1): 186-194. [49] TUYTTENS F, HEYNDRICKX M, DE BOECK M, et al. Broiler chicken health, welfare and fluctuating asymmetry in organic versus conventional production systems[J]. Livestock Science, 2008, 113(2/3): 123-132. [50] MORMÈDE P, ANDANSON S, AUPÉRIN B, et al. Exploration of the hypothalamic-pituitary-adrenal function as a tool to evaluate animal welfare[J]. Physiology and Behavior, 2007, 92(3): 317-339. [51] 苏红光, 张敏红, 冯京海, 等. 粪便皮质酮代谢产物含量作为一项肉鸡热舒适非侵入指标的研究 [J]. 动物营养学报, 2014, 26(6): 1563-1569. [52] ALM M, TAUSON R, HOLM L, et al. Welfare indicators in laying hens in relation to nest exclusion[J]. Poultry Science, 2016, 95(6): 1238-1247. [53] 白水莉. 饲养密度和环境富集材料对肉鸡福利状况、生产性能和肉品质的影响 [D]. 硕士学位论文. 扬州: 扬州大学, 2009. [54] 许美芳, 李永明, 徐子伟. 急性期蛋白及其用于动物健康状态的评价 [J]. 家畜生态学报, 2010, 31(3): 76-79. [55] BESSEI W. Welfare of broilers: a review[J]. World' s Poultry Science Journal, 2006, 62(3): 455-466. [56] 张彬. 狐狸场环境气载内毒素和细菌气溶胶的检测 [D]. 硕士学位论文. 泰安: 山东农业大学, 2007. [57] 邵丹, 贺姣, 王强, 等. 垫料厚度对黄羽肉鸡生产性能、免疫器官指数、血清生化指标和福利状况的影响 [J]. 动物营养学报, 2014, 26(8): 2357-2364. [58] 华登科. 不同光照强度和日粮营养水平对北京油鸡生产性能、肉品质及福利的影响 [D]. 硕士学位论文. 扬州: 扬州大学, 2014. [59] 甄龙, 张少帅, 石玉祥, 等. 水料比作为偏热环境肉鸡热舒适评价指标的研究 [J]. 动物营养学报, 2015, 27(6): 1750-1758. [60] 周莹, 张敏红, 冯京海, 等. 相对湿度对递增性偏热环境下肉鸡体热调节及下丘脑热休克蛋白 70 含量的影响 [J]. 动物营养学报, 2017, 29(1): 60-68. [61] JENSEN L S, MATSON W E. Enlargement of avian eye by subjecting chicks to continuous incandescent illumination[J]. Science, 1957, 125(3251): 741. [62] DEEP A, SCHWEAN-LARDNER K, CROWE T G, et al. Effect of light intensity on broiler production, processing characteristics, and welfare[J]. Poultry Science, 2010, 89(11): 2326-2333. [63] 李志忠, 滕光辉. 基于改进 MFCC 的家禽发声特征提取方法 [J]. 农业工程学报, 2008, 24(11): 202-205. [64] 李志忠, 滕光辉. 基于发声信息的动物福利评价研究现状 [C]//2005 年中国农业工程学会学术年会论文集. 广州: 中国农业工程学会, 2005: 446-450. [65] 方瑞. 持续外界高温对肉鸡生长、福利状况、肉品质的影响及其调控措施研究 [D]. 硕士学位论文. 呼和浩特: 内蒙古农业大学, 2009. [66] 全国畜牧总站体系建设与推广处. 家禽福利现状及评价体系 [J]. 中国畜牧业, 2015(4): 37-40.