Journal of Nutrition & Food Sciences

Ma et al., J Nutr Food Sci 2015, 5:6
DOI: 10.4172/2155-9600.1000420

Research Article

Open Access

Nutritional Regulation for Meat Quality and Nutrient Metabolism of Pigs Exposed to High Temperature Environment

Xianyong Ma, Zongyong Jiang*, Chuntian Zheng, Youjun Hu and Li Wang

Institute of Animal Science, Guangdong Academy of Agricultural Sciences, The Key Laboratory of Animal Nutrition and Feed Science (South China) of Ministry of Agriculture, State Key Laboratory of Livestock and Poultry Breeding, Guangdong Public Laboratory of Animal Breeding and Nutrition, Guangdong Key Laboratory of Animal Breeding and Nutrition, 510640, Guangzhou, PRChina

Abstract

High ambient temperatures not only affect animal production but also pig welfare. The decline of the production performances and meat quality of pigs during heat stress were traditionally considered to a cause of the decreased feed intake. However, it recently has been shown that heat stress disturbed the nutrients metabolism including protein, lipid and carbohydrate, and made the body reorganizes the utilization of the nutrition. High temperature also disturbed the cell function and antioxidant system. This paper reviewed the effect of heat stress on growth performance, meat quality and nutrients metabolism of pigs and their nutritional regulation for meat quality.

Keywords: Meat quality; Nutrient metabolism; Heat stress; Nutritional regulation; Growth performance

Introduction

According to the Food and Agriculture Organization of United Nations (FAO) statistics, over 50 percent of pig industries were in tropical and subtropical regions. The long-term hot weather of these regions would have a greater negative effect on pig production, especially with the development of intensive high density production, the effect of high temperature stress on pig production has become more and more serious, not only affecting the pig production performance, meat quality, but also affecting the sustainable development and economic benefits of the pig industry. In this paper, the effects of heat stress on pig production performance, meat quality and its molecular mechanism, and the nutritional regulation methods are reviewed, those results provide theoretical basis for reducing the effect of heat stress on the production and meat quality of pigs.

Effect of heat stress on growth performance of pig

Because the sweat gland of the pig is not developed, pigs maintain the body temperature mainly through breathing and stretching in the high temperature environment. the suitable environmental temperature of finishing pigs is 10-23.9°C, when the ambient temperature is higher than 24°C, finishing pigs begin cooling through breathing, and when the temperature continue to rise, the frequency of pigs lying on the ground increase and their activity decrease [1,2].

Le Dividich et al. [3] reported that when the environmental temperature was between 20°C and 30C, the feed intake decreased by 40-80 g per day with the temperature increasing by 1°C. The sensitivity of pig to the environment temperature in different stages is different, usually the effect of high temperature on the feed intake and daily gain of pigs increased with the increase of pig weight. Ai et al. [4] found that under high environmental condition (28-35°C), the daily feed intake of pigs in the phase of 15-30 kg, 30-60 kg and 60-90 kg decreased by 9%, 41% and 20%, and the daily gain decreased by 9%, 21% and 23% respectively. Guo et al. [5] studied the effects of different environmental temperature (23°C, 26°C, 29°C, 32°C and 3°C) on the daily feed intake of pigs at different weight stages (40-60 kg, 60-80 kg and 80-100 kg), and found that when the temperature rose, the feed intake decreased linearly with the temperature increasing from 23 to 32°C, the heavier the body weight, the greater the effect of temperature. When the temperature was over 32℃, the daily feed intake decreased by 101 g with the temperature increasing by 1°C.

Quiniou et al. [6] reported that the daily feed intake of 60-90 kg pig decreased by 128 g with the temperature increasing by 1℃ under the 22-29°C condition. Le Bellego [7] also found that the daily feed intake of 65-100 kg pig decreased by 78 g with the temperature increasing by 1°C under 22-29°C condition. Shi et al. [8] reported that the daily feed intake of 80-100 kg pig decreased by 116 g with the temperature increasing by 1°C under 24-35°C condition, the daily weight gain also decreased significantly. These results above were confirmed by Yang et al. [9].

In conclusion, the effect of environmental temperature on the growth performance of pigs was related with feed intake, but the relationship between the environmental temperature and the feed intake of pigs was different for the different temperature, feeding time and pig weight, it need to be analyzed according to the specific circumstances.

Effect of heat stress on meat quality

Meat quality also is influenced by environmental temperature. A large number of studies have reported that heat stress before slaughter stimulated the catecholamine secretion in finishing pigs, which caused muscle glycogen rapid decomposition, producing large amounts of lactic acid, the muscle pH decrease and PSE meat formation [10]. Yang et al. [9] reported that continuous high temperature significantly reduced the pH of longissimus muscle at 24 h postmortem, increased

---

***Corresponding author:** Zongyong Jiang, Institute of Animal Science, Guangdong Academy of Agricultural Sciences, The Key Laboratory of Animal Nutrition and Feed Science (South China) of Ministry of Agriculture; State Key Laboratory of Livestock and Poultry Breeding; Guangdong Public Laboratory of Animal Breeding and Nutrition; Guangdong Key Laboratory of Animal Breeding and Nutrition, 510640, Guangzhou, PR China, Tel: 862087596262; E-mail: jiangz28@qq.com

Received September 29, 2015; **Accepted** October 29, 2015; **Published** November 02, 2015

Citation: Ma X, Jiang Z, Zheng C, Hu Y, Wang L (2015) Nutritional Regulation for Meat Quality and Nutrient Metabolism of Pigs Exposed to High Temperature Environment. J Nutr Food Sci 5: 420. doi:10.4172/2155-9600.1000420

the drip loss at 48 h postmortem and shearing force of longissimus muscle. The environmental temperature in summer is usually higher than in winter, and the meat quality also is inferior to in winter [11]. High temperature also decreased the intramuscular fat content and increased the L^* value of the muscle in finishing pigs [12], but not in growing pigs [13], because the content of intramuscular fat in growing pigs is vey low. Le Dividich et al. [3] indicated that the fat deposition in muscle of finishing pig decreased significantly under high temperature condition, which may be related to the decrease of feed intake and energy consumption. Lefaucheur [14] found that compared with growing pigs less than 10C temperature condition, the metabolism of muscle fibers of semitendinosus muscle in growing pigs under 28°C condition changed obviously, the fiber types also changed accordingly. High temperature increased the sugar fermentation potential and changed the energy metabolism of the muscle fiber, with the change of the muscular fiber type [15]. Using C_2C_{12} cell line as research model, it was found that the sustained high temperatures induced muscle cells differentiation from fast to slow transformation [16]. Shi [8] reported that high temperature increased the MyHCIIx fiber and decreased the MyHCIIb fiber ratio. While in Mardies et al. [17] studies, higher temperature decreased the MyHCIIb gene. The reason for this difference may be due to the tolerance ability of the pig to heat stress, the setting of the environmental temperature and the duration of the treatment.

Effect of high temperature on nutritional metabolism of pigs

In acute or chronic heat stress conditions, animals reduced their feed intake by improving leptin, adiponectin and its receptor expression [18,19]. Leptin activated the hypothalamus axis, resulting in reduced feed intake [20], adiponectin also regulated feed intake through central and peripheral nervous system [21]. In addition, heat stress reduced feed intake and nutrient digestion and absorption partly through affecting insulin, cortisol and ghrelin secretion [22,23,8].

High temperature also decreased the body protein metabolism and deposition. When the environmental temperature reached 30°C, the amount of body protein deposition in growing pigs decreased directly or indirectly by the decrease of feed intake [7]. Kerr [24] also reported that high temperature (33°C) reduced the content of pig carcass protein. Short term heat stress increased protein degradation, reduced protein synthesis and retention; it also decreased the plasma level of aspartic acid, serine, tyrosine and cysteine in finishing pigs [25]. While long-term heat stress blocked protein synthesis, reduced the protein decomposition and amino acids level in blood (especially sulfur and branched chain amino acids), and increased the plasma level of aspartic acid, glutamic acid and phenylalanine [26,27]. Long-term heat stress reduced protein catabolism might by activating gluconeogenesis pathway, which increased the glucose level to provide more energy and reduce protein usage.

Long term heat stress also decreased the body lipid metabolism and fat distribution; the fat had a trend to transfer from the outer layer to the inner [3], which is more benefit for the body heat dissipation. Kouba [28] found that the high environmental temperature increased the activities of LPL in longissimus muscle and periphery kidney by 144.6% and 90.5%, respectively. Rinaldo and le Dividich [29] also found that high temperature reduced the content of back fat, the activities of malate dehydrogenase (ME) and glucose-6-phosphate dehydrogenase (G-6-PDH) in back fat and periphery kidney fat by 60%. Wu et al. [30] reported that high temperature (33°C) had a trend to decrease the intramuscular fat of longissimus muscle in finishing pigs, it also inhibited the fatty acids de novo synthesis ability by decreasing the activities of acetyl coenzyme A carboxylase enzyme (ACC), high temperature also decreased the content of FAS in the longissimus muscle and beta oxidation of fatty acids in skeletal muscle by decreasing the activity of L (+) P-hydroxyacyl CoA dehydrogenase (HAD). In addition, high temperature decreased the activity of lipolytic enzymes [26] and the level of non-esterificated fatty acids (NEFA) [31], which was independent of the reduction of feed intake. Under high temperature condition, the activity of lipolytic enzymes in adipose tissue decreased to limit heat production for adaptation to high temperature environment.

Carbohydrates could easily be converted into intermediate metabolites to generate ATP. The formation of ATP was regulated by three major signaling pathways: glycolysis, tricarboxylic acid cycle and oxidative phosphorylation. Mild heat stress activitied muscle glycogen phosphorylase and pyruvate dehydrogenase, but did not affect the content of glucose 6-phosphate, lactic acid, pyruvic acid, acetyl CoA, creatine and phosphocreatine and ATP [32]. Chronic heat stress reduced the plasma level of glucose, made more glucose enter the tissue from the blood to supply the energy, then the fat supplying energy decreased. As feed intake and blood glucose decreased, the glucose meet the need of the production decreased, so the energy in heat stressed pigs need to be rebalanced.

Effect of heat stress on cell and its stress protein

Heat stress interfered with the balance between oxidation and anti-oxidation in cells, resulting in excessive production of free radicals, damaging the body defense function [33], even producing cytotoxicity [34]. Heat stress also induced iron releasing from ferritin and reacting with H_2O_2 to produce ferric oxide ion, which was one of the important reasons for heat stress causing dark color of meat [35,36]. In addition, ROS was produced from NADP+ transformed to NADPH [37] by NADPH oxidase under high temperature condition. Shi [8] also found that high temperature enhanced the activity of NADPH oxidase. Moon et al. [38] reported that high temperature activated NADPH oxidase and increased the NADP+/NADPH ratio, NADPH prevented the biosynthesis of NADP+, acting as a cytochrome C reductase inhibitor, indicating that heat stress decreased the oxidation resistance of the body by destroying the oxidative respiratory chain.

Heat stress has cellular toxicity, because it disturbs the biological function and metabolism of the cell, leading to oxidative damage, and even apoptosis necrosis of the cells [39]. Although ROS was produced mainly from mitochondria, it first damaged mitochondria by disrupting oxide complex I, II, V and IV, resulting in destruction of respiratory chain and reduction of ATP [40]. In rodent animal, the morphology and structure of mitochondrial changed under high temperature condition, oxidative phosphorylation and energy production decreased, which could not meet the needs of cell metabolism, the mitochondrial membrane lipid also was oxidized and mitochondrial protein was degraded [41,42]. Under heat stress condition, free radicals activated the intrinsic apoptotic signaling pathway based on the mitochondrial pathway of mitochondrial membrane [43], once released, the cytochrome c moved to the cell fluid, activating the effective factor of apoptosis proteins (called apoptosis protease), resulting in programmed cell apoptosis. Although cell function and protein synthesis were disturbed under heat stress conditions, heat stress proteins synthesis were stimulated, including HSP 110, HSP 100, HSP 90, HSP70, HSP 60, HSP 40 and HSP 10. As heat stress proteins acted as molecular chaperone and contributed to the protein synthesis, folding, assembly, transportation and degradation of thermal stress degradation [44]. Among these heat stress proteins, HSP70 and HSP

90 were the most important [45]. Shi [8] also found that heat stress increased the expression of HSP70 gene in pig muscle. Heat stress damaged many proteins, while heat stress proteins helped to repair them. Heat stress also influenced the fluidity and stability of the cell membrane and inhibited the function of transporter protein [46] on the cell membrane. When the ambient temperature elevated from 25°C to 35°C or above, heat stress activated sphingomyelinase, phosphatase and phosphatidylinositol phosphate kinase [47], stimulating the accumulation of phosphatidic acid (PA) and phosphatidyl inositol (bisphosphate (PIP2). PIP2 is a signal molecule of fat, which delayed the activation of upstream signal of cell repair function. Under heat stress condition, the structure of the lipid material is decomposed to produce PA [48], which inserted into different cell membrane sites and decreased the cell membrane fluidity. The concentration of Ca2+, Na+ and K+ ions in the cells also increased with the decrease of cell stability [49] and destroy of the ion channels.

Nutritional regulation of improving meat quality

Protein and amino acids regulation: Under high temperature condition, decreasing dietary protein levels with balanced amino acids was one of the important methods alleviating the heat stress to pig, which did not reduce the pig net energy intake and production performance. Stahly et al. [50] reported that supplementation of synthetic lysine instead of natural protein in favor of pig production performance. Le Bellego et al. [51] reported that decreasing the dietary protein level of growing pigs and finishing pigs under high temperature condition reduced the pig protein deposition, but fed low protein level diet with balanced ideal amino acid pattern didn`t affect pig growth performance and carcass traits. Peng et al. [52] concluded (according to current literature review) that the appropriate dietary protein level of growing pigs under high temperature conditions was from 14% to 16%, with the equilibrium model of amino acid lysine, threonine, methionine, tyrosine, isoleucine, leucine, valine to dietary ratio was 1.02%, 0.74%, 0.29%, 0.23%, 0.85%, 1.62% and 0.96% respectively; the appropriate dietary protein level of growing pigs under high temperature conditions was from 12% to 13%, with the equilibrium model of amino acid lysine, threonine, methionine, tyrosine, isoleucine, leucine, valine to dietary ratio was 0.84%, 0.58%, 0.27%, 0.17%, 0.53%, 1.09% and 0.66% .

Supplementation with anti-stress agents

Supplementation with vitamin C, vitamin E or niacin: Pigs were nervous and their glucocorticoid secretion increased under heat stress condition, supplementation with vitamin C reduced glucocorticoid secretion and improved the ability to resist stress of pigs. Frei et al. [53] reported that vitamin C effectively resisted the active oxygen free radicals and prevented the damage of the biological membrane from the oxides. Vitamin C also was the most important antioxidants and improved the meat quality of pigs [54]. In order to reduce the occurrence of PSE meat, the content of vitamin C in the diet should be more than 50 mg/kg. Vitamin E played an important role in the stability of lipid, improving pork color and reducing water loss of pork [55,56]. Cheah et al. [57] showed that when vitamin E in the pig diet was higher than 500 mg/kg, it significantly decreased the drip loss of meat; when vitamin E was above 1000 mg/kg, the release of Ca2+ and the occurrence of PSE meat were significantly decreased. Buckley et al. [58] reported that dietary vitamin E increased from 10 mg/kg to 100-200 mg/kg, the quality of pork was positively correlated with the dose of vitamin E. Real et al. [59] reported that Niacin increased the pH value, reduced the drip loss and L value of longissimus muscle.

Regulation of electrolytes: The potassium and carbonate excretion increased, and the sodium and hydrogen discharge decreased in pigs under high temperature condition, which affected the mineral balance. Potassium chloride, chloride or sodium bicarbonate electrolyte should be added to the pig diets appropriately to reduce the damage caused by heat stress [60]. Supplementation of 0.1 to 0.2% sodium bicarbonate or 0.1 to 0.2% vitamin E to the pig diets had good effect on preventing heat stress. Wu et al. [61] found that compared with the control (under the heat stress condition), the average daily weight gain of piglets who drinking the electrolyte solution containing sugar (containing sugar, sodium chloride, potassium chloride, sodium bicarbonate, citric acid et al.) was significantly increased by 15.64%. Feng et al. [62] reported that the average daily gain of pigs was significantly increased by 5% with supplementation of 0.3% sodium bicarbonate, 0.2% potassium chloride and 0.02% chromium nicotinate respectively to the diets of finishing pigs under the high temperature condition. Ao et al. [63] reported that in the summer heat stress conditions, the average daily feed intake of finishing pigs who drinking 2% electrolyte balance agent at the first 5 days and drinking 1.25% electrolyte balance agent at the last 25 days increased by 10.14%, the average daily gain increased by 95 g and feed gain ratio decrease by 9 %, and there were no obvious thermal stress clinical indications of the pigs.

Supplementation with trace elements or minerals: Zhang et al. [64] supplemented 300 g/kg chromium picolinate to the diets of pigs under high temperature condition, the average daily gain and average daily feed intake was not different from the control group at the first two weeks; while the average daily feed intake increased by 10.2%, the average daily gain increased by 38.1% at the last 2 weeks, the chromium metabolism also was improved. Wang [65] reported that supplementation of 530 mg/kg zinc methionine and 200 mg/kg pyridine chromium carboxylate to pig diets increased the average daily feed intake and the average daily gain and decreased the feed gain ratio under the high temperature condition, increased the protein decomposition and gluconeogenesis, and improved the production performance. Liu et al. [66] reported that selenium (Se) had a synergistic effect with CAT and SOD in the removal of lipid peroxide, it also played antioxidant role coordinated with vitamin E. Mahan et al. [67] reported that the drip loss of dorsal muscle decreased by supplementation with 0.1 mg/kg Se and a certain amount of VE and VC. Torrent [68] reported that 0.3 mg/kg selenium (Se) in the growing pig diet reduced the occurrence of PSE meat. Alonso et al. [69] found that high level of magnesium (Mg) increased the pH value and decreased the speed of the glycogen, slow down the pH value and reduced the occurrence of PSE meat. Peeters et al. [70] reported that supplementation with Mg reduced stress, improved the muscle system hydraulic. Manganese also improved the meat quality of pigs.

To sum up, the production performance of pigs is affected by the reduction of feed intake, which is caused by the influence of the pig's nervous system under heat stress condition. The synthesis of protein, fat and carbohydrate also is affected by the heat stress. Under heat stress condition, pigs how to re-balance the protein, fat and carbohydrate metabolism to adapt the environment need to be further studied. In addition, heat stress affects the body's antioxidant system directly through the ROS, leading to the damage of cell function and decrease of the meat quality, but till now, there are no reports about the relationship between the environment temperature and PSE meat formation. Whether high temperature causing PSE meat just through ROS production also need to be further researched. Nutrients adjustment can reduce heat stress, slow down the oxidation and improve pork quality, which is also important for human health. In the further, more effective anti-heat stress additives need to develop to meet the need of pig production.

Acknowledgments

This work was supported by grants from Key project of Guangdong Province Natural Science Foundation (2014A030311010), the earmarked fund for Modern Agro-industry Technology Research System (CARS-36), the National ‘973’ Project of China (2012CB124706-4, 5).

References

1. Myer R, Bucklin R (2001) Influence of hot-humid environment on growth performance and reproduction of swine. Document AN, extension, Institute of food and agricultural sciences, University of Florida.
2. Huynh TTT, Aarnink AJA, Gerrits WJJ (2005) Thermal behaviour of growing pigs in response to high temperature and humidity. AABS 91: 1-16.
3. LE dividich J, Noblet J, Herpin P (1998) Thermoregulation. Progress in pig science 229-263.
4. Ai DY (1996) Study on main nutrients intake of finishing pigs in normal temperature and high temperature season. China feed 11: 9-11.
5. Guo CH, Chai YQ, Wang KN (2004) Effect of high temperature on feed intake of growing pigs at different weight. Pig feeding 4: 15-18.
6. Quiniou N, Dubois S, Noblet J (2000) Voluntary feed intake and feeding behaviour of group-housed growing pigs are affected by ambient temperature and body weight. Livestock Production Science. 63: 245-253.
7. LE Bellego L, Van milgen J, Noblet J (2002) Effect of high temperature and low-protein diets on the performance of growing-finishing pigs. JAS 80: 691-701.
8. Shi ZB (2015) Effects of Constant High Ambient Temperature on Performance and Meat Quality in Finishing Pigs and Related Mechanisms. Doctoral Dissertation of Zhongshan University.
9. Yang PG, Feng YJ, Hao Y, Gu XH, Yang CH et al. (2014) Effects of continuous high temperature stress on pig production performance, carcass traits, longissimus muscle nutrient content and muscle fiber characteristics. Journal of Animal Nutrition 26: 2503-2512.
10. Sandercock DA, Hunter RR, Nute GR, Mitchell MA, Hocking PM (2001) Acute heat stress-induced alterations in blood acid-base status and skeletal muscle membrane integrity in broiler chickens at two ages: Implications for meat quality. Poultry Science 80: 418-425.
11. Gregory NG (2010) How climatic changes could affect meat quality. Food Research International 43: 1866-1873.
12. Witte DP, Ellis M, McKeith FK, Wilson ER (2000) Effect of dietary lysine level and environmental temperature during the finishing phase on the intramuscular fat content of pork. JAS 78: 1272-1276.
13. Sugahaea M, Baker DH, Harmon BG (1970) Effect of ambient temperature on performance and carcass development in young swine. JAS 31: 59-62.
14. Lefaucheur L, Le Dividich J, Mourot J, Monin G, Ecolan P, et al. (1991) Influence of environmental temperature on growth, muscle and adipose tissue metabolism, and meat quality in swine. JAS 69: 2844-2854.
15. Spencer JD, Gaines AM, Berg EP, Allee GL (2005) Diet modifications to improve finishing pig growth performance and pork quality attributes during periods of heat stress. JAS 83: 243-254.
16. Yamaguchi T, Suzuki T, Arai H, Tanabe S, Atomi Y (2010) Continuous mild heat stress induces differentiation of mammalian myoblasts, shifting fiber type from fast to slow. AJPCP 298: C140-148.
17. Calkins CR, Dutson TR, Smith GC (1981) Relationship of fiber type composition to marbling and tenderness of bovine muscle. JFST 46: 708-710.
18. Bernabucci U, Basiricò L, Morera P, Lacetera N, Ronchi B et al. (2009) Heat shock modulates adipokines secretion in 3T3-L1 adipocytes. J Mol Endocrinol 42: 139-147.
19. Morera P, Basiricò L, Hosoda K, Bernabucci U (2012) Chronic heat stress up-regulates leptin and adiponectin secretion and expression and improves leptin, adiponectin and insulin sensivity in mice. JME 48: 129-138.
20. Rabe K, Lehrke M, Parhofer KG (2008) Adipokines and insulin resistance. Molecular medicine 14: 741-751.
21. Hoyda TD, Samson WK, Ferguson AV (2012) Central system roles for adiponectin inneuroendocrine and automic function. In: Adipokines, Preedy VR & Hunter RJ, Boca Raton FL, Eds USA: Science Publishers, CRC press 167-184.
22. Baumgard LH, Rhoads RP (2013) Effects of heat stress on post absorptive metabolism and energetics. Annual Review Animal Biosciences 1: 311-337.
23. Solinas G, Summermatter S, Mainieri D, Gubler M, Montani JP et al. (2006) Corticotropin-releasing hormone directly stimulates thermogenesis in skeletal muscle possibly through substrate cycling between de novo lipogenesis and lipid oxidation. Endocrinology 147: 31-38.
24. Kerr BJ, Southern LL, Bidner TD, Friesen KG, Easter RA (2003) Influence of dietary protein level, amino acid supplementation, and dietary energy levels on growing-finishing pig performance and carcass composition. JAS 81: 3075-3087.
25. Tabiri HY, Sato K, Takahashi K (2003) Effect of acute heat stress on plasma amino acids concentration of broiler chicken. JPS 37: 86-94.
26. Geraert PA, Padilha JC, Guillaumin S (1996) Metabolic and endocrine changes induced by chronic heat exposure in broiler chicken: growth performance, body composition and energy retention. Br J Nutr 75: 195-204.
27. Temim S, Chagneau AM, Peresson R, Tesseraud S (2000) Chronic heat exposure alters protein turnover of three different skeletal muscles in finishing broiler chickens fed 20 or 25% protein diets. JN 130: 813-819.
28. Kouba M, Enser M, Whittington FM, Nute GR, Wood JD (2003) Effect of a high-linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig. JAS 81: 1967-1979.
29. Rinaldo D, Le Dividich J (1991) Effects of warm exposure on adipose tissue and muscle metabolism in growing pigs. Comparative Biochemistry and Physiology A: Comparative Physiology 100: 995-1002.
30. Wu X, Feng JH, Zhang MH, Su HG, Jia AF (2015) Influence of constant high ambient temperature on fat metabolism of different parts in finishing pigs. Scientia Agricultura Sinica 48: 952-958.
31. Pearce SC, Gabler NK, Ross JW, Escobar J, Patience JF et al. (2011) Effects of heat stress on energic metabolism in growing pigs. FASEB J 25: 1052-1055.
32. Saunders PU, Watt MJ, Garnham AP, Spriet LL, Hargreaves M, et al. (2001) No effect of mild heat stress on the regulation of carbohydrate metabolism at the onset of exercise. J Appl Physiol 91: 2282-2288.
33. Ganaie AH, Shanker G. Bumla NA (2013) Biochemical and physiological changes during thermal stress in bovines. J Veterinar Sci Technol 4: 126.
34. Bernabucci U, Ronchi B, Lacetera N, Nardone A (2002) Markers of oxidative status in plasma and erythrocytes of transition dairy cows during hot season. J Dairy Sci 85: 2173-2179.
35. Freeman ML, Spitz DR, Meredith MJ (1990) Does Heat Shock Enhance Oxidative Stress? Studies with Ferrous and Ferric Iron. Radiation Res 124: 288-293.
36. Powers RH, Stadnicka A, Kalbfleish JH, Skibba JL (1992) Involvement of Xanthine Oxidase in Oxidative Stress and Iron Release during Hyperthermic Rat Liver Perfusion. Cancer Res 52: 1699-1703.
37. Segal AW, Abo A (1993) The biochemical basis of the NADPH oxidase of phagocytes. Trends Biochem Sci 18:43-47.
38. Moon EJ, Sonveaux P, Porporato PE, Danhier P, Gallez B et al. (2010) NADPH oxidase-mediated reactive oxygen species production activates hypoxia-induciblefactor-1 (HIF-1) via the ERK pathway after hyperthermia treatment. PNAS 107: 20477-20482.
39. Pandey N, Kataria N, Kumar Kataria A (2012) Extreme ambiances vis-à-vis endogenous antioxidants of Marwari goat from arid tracts in India. ELBA Bioflux 4: 29-33.
40. England K, O'Driscoll C, Cotter TG (2004) Carbonylation of glycolytic proteins is a key response to drug-induced oxidative stress and apoptosis. Cell Death Differ 11: 252-260.
41. Lewandowska A, Gierszewska M, Marszalek J, Liberek K (2006) Hsp78 chaperone functions in restoration of mitochondrial network following heat stress. Biochim Biophys Acta 1763: 141-151.
42. Song XL, Qian LJ, Li FZ (2000) Injury of heat stress to rat cardiomyocytes. Chin J Appl Physiol 16: 227-230.

43. Yang L, Tan GY, Fu YQ, Feng JH, Zhang MH (2010) Effects of acute heat stress and subsequent stress removal on function of hepatic mitochondrial respiration, ROS production and lipid peroxidation in broiler chickens. Comp Biochem Physiol C Toxicol Pharmacol 151: 204-208.

44. Morimoto RI, Tissieres A, Georgopoulos C (1990) Stress proteins in biology and medicine. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, NY.

45. Chen F, Yu Y, Qian J, Wang Y, Cheng B et al (2012) Opposing actions of heat shock protein 90 and 70 regulate nicotinamide adenine dinucleotide phosphate oxidase stability and reactive oxygen species production. rterioscler Thromb Vasc Biol 32: 2989-2999.

46. Hildebrandt B, Wust P, Ahlers O, Dieing A, Sreenivasa G (2002) The cellular and molecular basis of hyperthermia. CROH 43: 33-56.

47. Mishkind M, Vermeer JE, Darwish E, Munnik T (2009) Heat stress activates phospholipase D and triggers PIP2 accumulation at the plasma membrane and nucleus. The Plant Journal 60: 10-21.

48. Wang X (2005) Regulatory functions of phospholipase D and phosphatidic acid in plant growth, development, and stress responses. Plant Physiol 139: 566-573.

49. Balogh G, Maulucci G, Gombos I, Horvath I, Torok Z et al. (2011) Heat Stress Causes Spatially-Distinct Membrane Re-Modelling in K562 Leukemia Cells. PLoS ONE 6: e21182.

50. Stahly TS，Cromwell GL，Aviotti AJ (1979) The effect of environmental temperature and dietary lysine source and level on the performance and carcass characteristic of growing swine. Anim Sci 49: 1242-1251.

51. Peng DY, He J, Yang YF (2011) Effect of temperature in different seasons on the nutrients requirements of pigs. Western feed 10: 15-20.

52. Frei B, England L, Ames BN (1989) Ascorbate is an outstanding antioxidant in human blood plasma. Proc Natl Acad Sci USA 86: 6377-6381.

53. Pion SJ, van Heugten E, See MT, Larick DK, Pardue S (2004) Effects of vitamin C supplementation on plasma ascorbic acid and oxalate concentrations and meat quality in swine. J Anim Sci 82: 2004-2012.

54. Monahan FJ, Gray I, Booren AM, Miller ER, Buckley DJ et al. (1992) Influence of dietary treatment on lipid and cholesterol oxidation in pork. JAFC 40: 1310-1315.

55. Monahan FJ, Asghar A, Gray JI, Buckley DJ, Morrissey PA (1994) Effect of oxidized dietary lipid and vitamin E on the colour stability of pork chops. Meat Sci 37: 205-215.

56. Cheah KS, Chean AM, Krausgrill DL (1995) Effect of dietary supplementation of vitamin E on pig meat quality. Meat Sci 39: 255-264.

57. Buckley DJ, Morrissey PA, Gray JI (1995) Influence of dietary vitamin E on the oxidative stability and quality of pig meat. J Anim Sci 73: 3122-3130.

58. Real DE, Nelssen JL, Unruh JA, Tokach MD, Goodband RD et al. (2002) Effects of increasing dietary niacin on growth performance and meat quality in finishing pigs reared in two different environments. J Anim Sci 80: 3203-3210.

59. Haydon KD, West JW, McCarter MN (1990) Effect of dietary electrolyte balance on performance and blood parameter of growing-finishing swine fed in high ambient temperatures. J Anim Sci 68: 2400-2406.

60. Wu XX, Gong DC, Zhu M (1998) Effects of supplemental glucose electrolyte on growth of piglets under high temperature condition. Heilon gjiang animal science and veterinary medicine 11: 7.

61. Feng YL, Yang Y, Dong ZY, Fang GY, Fu Z (2004) Effect of dietary electrolyte and chromium on the growth and metabolism of finishing pigs under high temperature condition. Fujian journal of animal husbandry and veterinary medicine 26: 1-3.

62. Ao ZG, Wei HX, Fan FH (2004) Research on application of electrolyte balanced agent in finishing pigs. Pigs feed 2: 18-20.

63. Zhang MH, Zhang WH, Du R, Wang DL, Zhang ZY (2000) Effects of supplemental chromium on chromium metabolism, physiological and biochemical responses and performance in pigs exposed to heat exposure. Acta Veterinariaet Zoo technica Sinica 31: 1-8.

64. Wang SL, Lin YC, Jiang ZY, Jiang SQ, Yu DQ (2004) Effects of anti-heat-stress agents on growth performance and metabolism of pigs exposed to high temperature. CJAS 40: 28-30.

65. Liu W, Li G, Zhang X (1995) Effects of selenium and vitamin E on arachidonic acid metabolism in experimental myocardial ischaemia. CJPM 29: 279-282.

66. Mahan DC, Cline TR, Richert B (1999) Effects of dietary levels of selenium-enriched yeast and sodium selenite as selenium sources fed to growing-finishing pigs on performance, tissue selenium, serum glutathione peroxidase activity, carcass characteristics, and loin quality. J Anim Sci 77: 2172-2179.

67. Torrent GR (1996) The effect of selenium-enriched yeast and selenium on the performance of grower and finisher swine. J Anim Sci 445-454.

68. Alonso V, Provincial L, Gil M, Guillén E, Roncalés P et al. (2012) The impact of short-term feeding of magnesium supplements on the quality of pork packaged in modified atmosphere. Meat Sci 90: 52-59.

69. Peeters E, Driessen B, Geers R (2006) Influence of supplemental magnesium, tryptophan, vitamin C, vitamin E, and herbs on stress responses and pork quality. J Anim Sci 84: 1827-1838.

70. Apple JK, Maxwell CV, deRodas B, Watson HB, Johnson ZB (2000) Effect of magnesium mica on performance and carcass quality of growing-finishing swine. J Anim Sci 78: 2135-2143.