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Influence of housing air temperature on the behavioural acts, physiological parameters and performance responses of fattening pigs

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Abstract The objective of the present study was to investigate the influence of housing air temperature on the behavioural acts, physiological parameters and performance responses of fattening pigs. Animals were randomly allocated to 3 groups with 30 heads in each. During eight weeks of fattening, the animals of the two experimental groups were subjected to long-term technological temperature stress, provoked by a significant deviation of the microclimate parameters. The first control group of animals was kept following the Departmental Norms for Technological Design - Agro-Industrial Complex - 02.05 «Pig-breeding enterprises (complexes, farms, small farms)» at an air temperature of +17…+21 °C; pigs of the second experimental group were kept at a temperature of - +5…+8 °C, and the third experimental group - +28…+31 °C. During the experiment, the timing of behavioural acts and their index assessment, physiological parameters and productive characteristics of fattening pigs were studied. The experiment results showed that the thermoneutral zone for fattening pigs is + 17… + 21 °C. Animals 2nd experimental group showed less movement ($P < 0.001$), used huddling for decreasing body heat loss, more feed intake ($P < 0.01$), which increased its conversion, had reduced HR, RR, RT. Pigs of the 3rd experimental group showed increased movement ($P < 0.001$). This can be explained by their desire to find a cool place and rest lying on the side, consuming more water, having high HR, RR, and RT, showing signs of hyperthermia and were characterized by low-performance responses.

Keywords: microclimatic parameters, pigs, technological stress, thermoneutral zone, welfare

1. Introduction

In Ukraine, despite the hostilities, pork continues to be the most consumed meat, and its production takes place in regions subject to extreme temperatures. The profitability of enterprises using pig production technology should be associated with the welfare and health of animals (Marchant-Forde and Rodenburg 2016; Parois et al 2018; Garrido-Izard et al 2020). Therefore, knowledge of the features of the thermoregulatory behaviour of the fattening pigs is of considerable interest to producers (Garrido-Izard et al 2020).

The climate of the south of Ukraine, particularly the Odesa region, is characterized by temperate continental with mild winters with little snow and especially hot summers. Therefore, with deviations of microclimatic parameters in housing for keeping pigs (Gody et al 2020), there are technological stresses can occur, affecting the change in behavioural acts, reducing performance responses, health and welfare of pigs (Nienaber and Brown Brandl 2009; Lacetera 2019; Gourdine et al 2021). In this regard, we emphasize that obtaining high-quality pork is impossible without ensuring the normalized indicators of microclimatic parameters, even with full feeding.

Studies established that the physiological parameters of pigs are characterized by variability in body temperature, and compared to other animal species, they are relatively sensitive to high temperatures (Botto et al 2014). This statement is because the vascular reaction is poorly manifested in pigs, the sweat glands are not sufficiently developed (Farrell 1977; Bracke 2011), as well as a significant deposition of subcutaneous tissue (Zervanos and Hadley 1973; Souza 2009), which complicates the heat transfer due

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to the skin. In addition, as Bracke (2011) points out, domestic pigs have a shorter snout, which is the reason for reduced heat transfer due to reduced respiratory system capacity compared to wild animals. It should be noted that with age and increased weight, the body temperature of pigs decreases, and the effect of heat stress causes anxiety in fattening pigs compared to other technological groups of pigs (Adebiyi et al 2017). In this context, pig behaviour is an essential thermoregulatory factor, as pigs cannot sweat (Ingram 1965) and rely on various behavioural changes to lose or retain heat. Therefore, pigs must maintain a constant internal body temperature, produce heat, and the remaining excess heat must be released into the environment. This process of generating and dissipating heat is called thermoregulation (Kanis et al 2004). Nienaber and Brown Brandl (2009) noted that indoor climate control in animal housing will not always be within the pig's thermal comfort zone. Although the results available on the effect of temperature on behavioural changes in pigs in selected countries (Huynh et al 2005; Parois et al 2018; Kim et al 2021), especially in Ukraine, are limited. In connection with the previous, the objective of the experiment is to study the effect of different temperatures of housing on behavioural indicators, physiological parameters and performance responses of fattening pigs.

2. Materials and Methods

2.1. Ethics

The animal treatment in the experiment fully complied with the requirements. Conditions for feeding, watering, housing, care, prevention and treatment following European legislation on the protection of animals and their comfort (Council Directive 2008/120 / EU «On the establishment of minimum standards for the protection of pigs» of December 18, 2008) and the Order of the Ministry of Economy of Ukraine «On approval of the requirements for the welfare of farm animals during their housing» of February 18, 2021, were organized. The local Commission approved the experimental protocol on Bioethics of the National University of Life and Environmental Sciences of Ukraine.

2.2. Experimental design

Experimental studies were carried out in the period 2021-2022. In total, 90 heads of fattening pigs were used in the experiment. The maternal form was a combination of the Large White with Landrace breed, and the paternal form was the terminal line «Maxter». The animals were kept on the LLC «Tarutinska agrarian company» commercial farm in the Odessa region, Ukraine. During eight weeks of fattening, the animals of the two experimental groups were subjected to long-term technological temperature stress, provoked by a significant deviation of the microclimate parameters. The first control group of animals was kept following the Departmental Norms for Technological Design - Agro-Industrial Complex - 02.05 «Pig-breeding enterprises (complexes, farms, small farms)» at an air temperature of + 17… + 21 °C; pigs of the second experimental group were kept at a temperature of - +5… +8 °C, and the third experimental group - +28… +31 °C. Animals were grown up to a live weight of 100 kg. Fattening animals consumed 2.8-3.0 kg feed per head per day using a combined feed type of nutritional value with 146.7 g/kg crude protein and 13.411 MJ/kg exchange energy. The pigs were placed on a concrete slatted floor with an area of 0.85 m^2/head. Feeding was identical in all groups according to detailed feeding norms. It was carried out using bunker feeders with automated feed distribution, watering was carried out through automatic nipple drinkers, and ventilation was «supply and exhaust» type. The distribution of sex across all three groups was: 50% castrated boars and 50% gilts.

2.3. Behaviour

During the experiment, the timing of behavioural acts of pigs of three experimental groups was measured using Full HD 1080p video recorders (with a maximum resolution of 1920x1080, 30 frames/s) with AVI recording format. The visual observations of the animals were performed from 7.00 a.m. until 7.00 a.m. of the next day for three consecutive days to determine the duration (in minutes) of behavioural acts – rest (including sitting, lying), feed and water intake and movement. Based on the calculation of time for individual indicators of behaviour, the index of functional activity was integrated: $K = \Delta T/T$, where K - index of functional activity; ΔT - time of the act of behaviour; T - total observation time.

2.4. Data collection

The air temperature in the room for keeping pigs was determined three times a day (at 7:00 a.m., 2:00 p.m. and 10:00 p.m.), measured with a mercury thermometer of class I accuracy. During measurements, the thermometer was hung on a special tripod. The duration of the temperature measurement period at one point was at least 10 minutes.

2.5. Physiological data

Respiratory rate (RR): the number of uninterrupted flank movements (bpm) per minute (60 seconds) using a stopwatch. The heartbeats rate (HR) was measured in pigs using a portable veterinary pulse oximeter UT100V for pulse rate with a saturation interval of 25-350 bpm with an accuracy of ±2 bpm by fixing the device on the ears of the animal. Rectal temperature (RT): the rectal temperature (°C) was measured using a digital thermometer inserted 50mm into the rectum until the reading was constant.

2.6. Performance data

The age, live weight of 100 kg (days), average daily gain (g) and feed conversion (kg) were measured during the period of fattening.

2.7. Statistical analysis

Data were analyzed using Statistica 12.0 (StatSoft Inc., 2014, www.statsoft.com). Results are presented as mean ±

standard deviation (X ± SD). The following significance levels were used for the study: $P < 0.05$; 0.01, and 0.001.

3. Results and Discussion

Differences in the duration of behavioural acts of the experimental groups of pigs are shown in Table 1. Pigs of the second experimental group were distinguished by a shorter period of movement ($P < 0.001$), water intake ($P < 0.05$) and a large, mainly due to lying, rest time ($P < 0.001$) and feed intake ($P < 0.01$) compared with animals of the 1st control group. According to the analysis of the data of chronometric observations, it was found that the behavioural acts in animals of the 2nd experimental group were as follows: increased movements had a good appetite and more feed intake, gathered in search of a warm place to reduce heat consumption (Figure 1). Alberts (1978) and Gilbert et al (2010) determine the grouping of animals as one of the ways of cooperative group behaviour in social thermoregulation, which allows for minimizing heat consumption from the animal body (Kanis et al 2004; Spoolder et al 2012). In cold conditions, the muscles' metabolism increases, accompanied by the generation of thermal energy, and peripheral blood vessels narrow (Taylor et al 2014; Hines 2019).

Table 1 Duration of the behavior acts of pigs under various temperature in the housing, min, X ± SD.

Behavioural act	Group (n = 30)		
	1st control	2nd experimental	3rd experimental
Movement	345.6±12.45	144.0±11.74***	432.0±14.63***
Rest	820.8±11.42	979.2±16.29***	755.6±18.64**
including sitting	324.5±13.27	468.7±12.96**	90.2±14.32***
including lying	496.3±13.64	510.5±15.29	665.4±16.68***
Feed intake	241.1±11.12	306.6±10.89**	204.1±8,64**
Water intake	32.5±12.32	10.2±11.68*	48.3±11.94

N= number; Significant: *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$ (in comparison with animals of the first control group).

Pigs of the 3rd experimental group in conditions of elevated air temperature in the housing were characterized by increased movement (P<0.001), which, in our opinion, is explained by their desire to find a cool place. However, studies by other authors have noted that when it is hot, pigs become languid and seek damp places (Nienaber and Brown Brandl 2009).

An increased water intake time (48.3 min) was observed in fattening pigs, which is confirmed by the results of studies by other scientists (Kim et al 2021), who noted that the frequency of water intake of pigs relatively increases. The amount of water needed by the body is necessary; for example, to control body temperature, moisture that evaporates from the body and maintains blood homeostasis at high temperatures increases.

As expected, the time that the animals spent rest ($P < 0.01$) was significantly reduced compared to peers in the 1st control group. However, it should be noted that the pigs of the 3rd group rested mainly due to lying on their side, and compared to the animals of other groups, the time spent on this behavioural act turned out to be longer (P<0.001) (Figure 2).

Figure 1 Pigs the 2nd experimental group use huddling for decreasing body heat loss. Note: the red outline indicates the huddling process.

Figure 2 Lying behaviour on the side of pigs of the 3rd experimental group.

Lying can help pigs maintain thermal comfort as higher than normal temperatures affect the body. When the ambient temperature is high, pigs focus on cooling and increasing heat loss. Distinguishing some aspects of lying behaviour is essential for maintaining thermal comfort: huddling, the amount of lying, lying posture, and lying location (Huynh et al 2005; Dekker 2015). The authors also noted that the maximum time that pigs can lying is related to the time that pigs must get up to perform water intake and the act of defecation or urination, which occurs approximately once every 41 minutes (Aarnink et al 1996; Nielsen et al 1996) although in our study, the time spent on the act of defecation and urination of fattening pigs was not recorded. The time feed intake ($P < 0.01$) in the pigs of the 3rd experimental group a significant decreased compared to the 1st control animals, which is consistent with previous studies (Parois et al 2018; Rauw et al 2020; Gourdine et al 2021). A decrease in feed intake indicates a reduction in productivity due to heat stress in pigs (Ross et al 2015).

The above-mentioned behavioural features of pigs under different temperature conditions were reflected in the indices of functional activity (Table 2). The highest values of the movement activity index were inherent in the animals of the third experimental group, which were in conditions housing of high temperature, rest and feed activity - the pigs of the second experimental group, which were in conditions housing low temperature.

The temperature factor also affected the physiological parameters of pigs in the experimental groups (Figure 3). The response to heat stress begins with an increase in respiratory rate, continues with a decrease in feed intake, and leads to an increase in rectal temperature, which is an indicator of a reduction in the production of pigs (Ross et al 2015). As a result of the experiment, it was found that pigs of the 3rd experimental group, under the influence of elevated housing temperature, had a significantly higher respiratory rate (74.5 bpm). In contrast, the animals of the 1st control and 2nd experimental groups had lower, respectively.

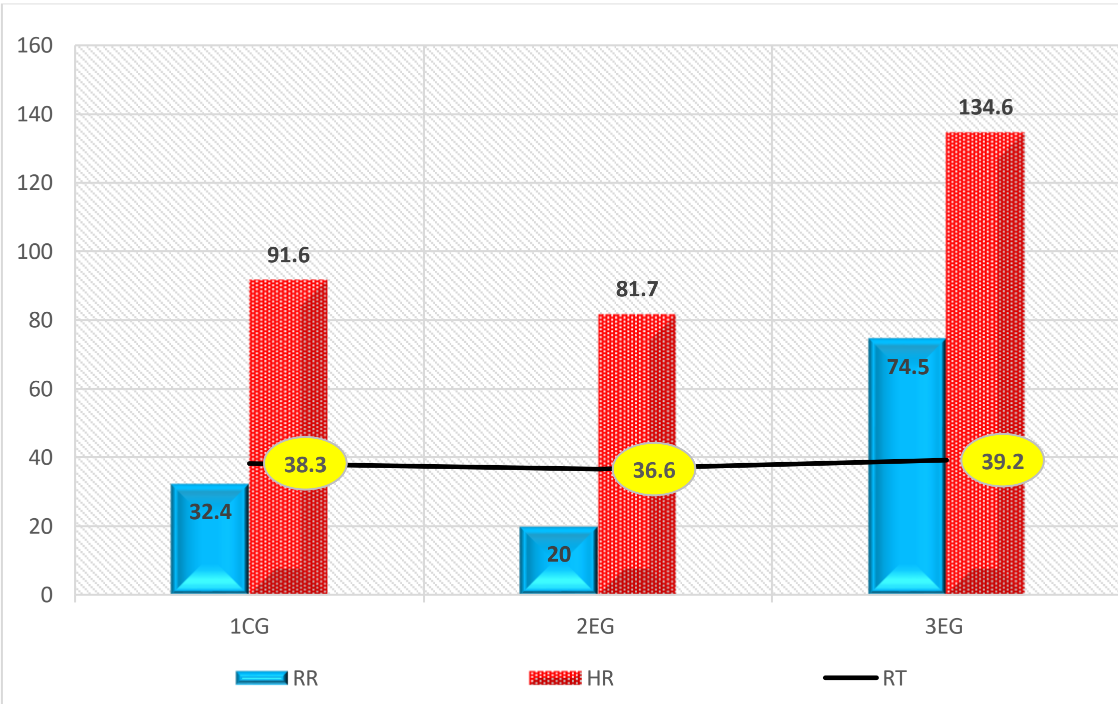

Figure 3 Physiological parameters of pigs depending on the air temperature in the housing pigs for fattening. Notes: 1CG – 1st control group; 2EG – 2nd experimental group; 3EG – 3rd experimental group; RR – respiratory rate; HR – heartbeats rate; RT – rectal temperature.

Huynh et al (2006) reported that the normal respiratory rate in pigs should range on average from 29.1 to 32.7 bpm. According to this experiment, such an increased respiratory rate is dangerous and indicates an emergency condition of the animals and can lead to hyperthermia and, as a result, death. Since sensible heat transfer becomes inefficient due to a decrease in the temperature gradient between the skin and the surrounding air, pigs rely primarily on evaporative heat loss by increasing the respiratory rate to maintain a constant body temperature (Huynh et al 2007).

The rectal temperature measurement in pigs showed that the highest value (39.2 °C) is typical for fattening pigs of the 3rd experimental group, which housing elevated temperature conditions. It was concluded that an increase in RT is an important indicator of heat stress in fattening pigs, consistent with studies by Adebiyi et al (2017). Accordingly, the heartbeats are higher (134.6 bpm) in the 3rd experimental group animals compared to the 1st control and 2nd experimental groups, indicating clear signs of hyperthermia.

Based on the conducted studies on the performance responses of the experimental groups of fattening pigs, a significant difference in the parameters of the age a live weight of 100 kg and average daily gain (Table 3).

Table 2 Index evaluation of behavioural acts of pigs of experimental groups.

Index of functional activity	Group (n = 30)		
	1st control	2nd experimental	3rd experimental
Index of movement activity	0.24	0.10	0.30
Index of rest	0.57	0.68	0.52
Index of feed activity	0.17	0.21	0.14

Table 3 Performance responses of fattening pigs, X ± SD.

Group (n = 30)	Age a live weight of 100 kg, days	Average daily gain, g	Feed conversion, kg
1st, control	155.7±0.58	894.3±5.88	2.85
2nd, experimental	158.7±0.80	868.1±5.96	3.39
3rd, experimental	161.7±0.56	826.6±7.66	2.64
+/- 2nd to 1st	+3.0**	-26.2***	+0.54
+/- 3rd to 1st	+6.0***	-67.7***	-0.21

N= number; Significant: ***P* < 0.01; ****P* < 0.001 (in comparison with animals of the first control group).

Pigs of the 1st control group were characterized by a lower age, a live weight of 100 kg - 155.7 days, and the animals of both experimental groups were significant, inferior to them by 3 ($P < 0.01$) and 6 ($P < 0.001$) days.

The animals of the second and third experimental groups were significant ($P < 0.001$) inferior to the pigs of the 1st control to the average daily gains of 26.2 g and 67.7 g, respectively.

The fattening pigs of the second experimental group intaken more feed by 0.54 kg, and animals in the 3rd group intaken less feed by 0.21 kg, compared to the 1st control. By voluntarily reducing feed intake, the pig attempts to reduce heat by reducing the heat that needs to be dissipated into the environment. Unfortunately, a reduction in feed intake leads to reduced growth parameters (Ross et al 2015; Rauw et al 2020).

It can be argued that farms are economically unprofitable when ignoring the technological parameters of the microclimate of premises for fattening pigs. A significant influence of the temperature regime of fattening pigs on performance responses has been revealed, which should be considered when designing ventilation and heating systems on-premises for housing animals.

The results obtained during the experiment make it possible to schematically reflect the effect of influence temperature (housing) on the metabolism of fattening pigs (Figure 4).

If metabolic heat generation is not affected by ambient temperature, animals are in their thermal neutrality zone, including the comfort zone, the warm zone, and the cool zone (Atrian and Shahryar 2012). In the thermoneutral zone, pigs easily adapt to ambient temperature to maintain body temperature by constricting and dilating blood vessels (Kanis et al 2004).

In the case of experimental research was found that the thermoneutral zone for fattening pigs is + 17… + 21 °C, although Hines (2019), in the article «Cold Temperature Management for Pigs» think that for fattening pigs, the thermoneutral zone is + 10… + 15.6 °C. In the cold zone, pigs have to take more extreme physiological measures to maintain their body temperature (Dekker 2015). If the temperature reaches the lower critical point (+5…0 °C), the pigs will suffer from cold stress and, as a result, a decrease in body temperature (hypothermia) - below 0 °C.

At higher comfort zone temperatures, pigs decrease their activity and change behavioural acts (Kanis et al 2004). Under the action of high temperatures, pigs prefer a humid environment (moisturizing the skin), which creates the possibility of increased heat transfer directly from the skin due to surface evaporation of water. Pigs are more sensitive to heat with age (Adebiyi et al 2017). At temperatures above 30 °C, thermoregulatory mechanisms fail, and the body temperature rises. At an ambient temperature of 35 °C, body temperature rises to 42 °C or more. Breathing becomes more frequent, and there is a refusal to feed; a coma quickly sets in and even death. Adult pigs are more tolerant of low temperatures (Gourdine et al 2021).

The lower and upper temperatures of the thermoneutral zone are called critical temperatures. At an air temperature above the upper critical limit, an increase in heat transfer is observed due to the release of sweat and increased respiration (Dekker 2015). Therefore, when the air temperature is less than the lower critical one, it is no longer possible to keep heat in the body by reducing heat transfer. In these conditions, muscle trembling is observed, and the animal is forced to increase the intensity of metabolism to generate heat.

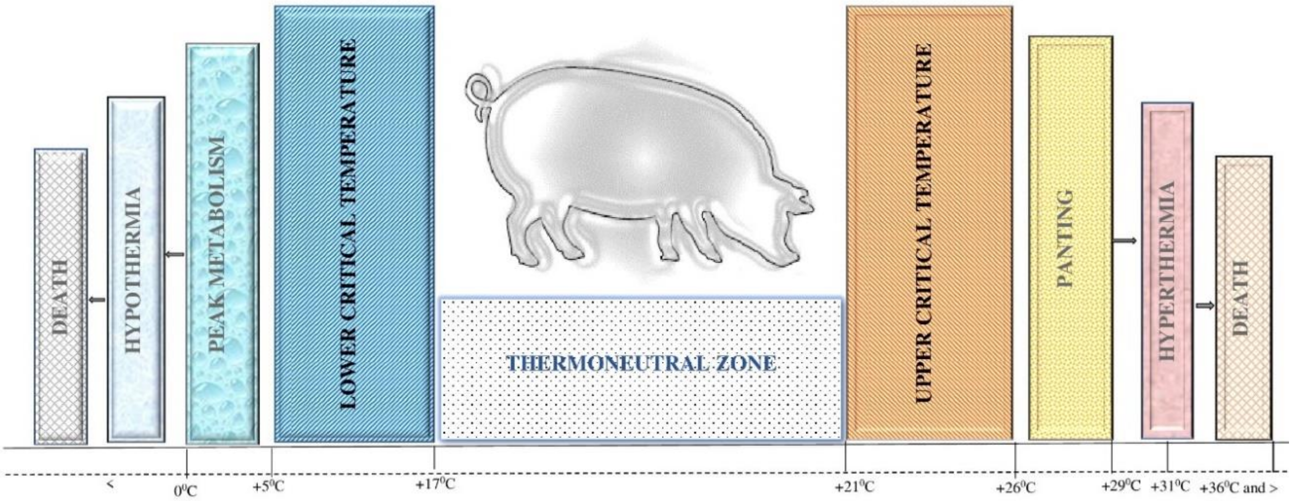

Figure 4 Influence of ambient temperature (housing) on fattening pig metabolism. Notes: a lower critical temperature is the ambient temperature below which pigs must increase heat production to maintain heat balance; the upper critical temperature is the ambient temperature above which pigs must increase their heat loss rate to achieve heat balance.

4. Conclusions

The temperature strongly influences the behaviour, physiological parameters and performance responses of fattening pigs in the housing. The significant influence of the temperature regime of fattening pigs on the indicated indicators revealed as a result of the experiment should be considered when designing ventilation and heating systems for housing animals.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

Aarnink AJA, Berg AJ, Keen A, Hoeksma P, Verstegen MWA (1996) Effect of slatted floor area on ammonia emission and on the excretory and lying behaviour of growing pigs. Journal of Agricultural Engineering Research 64:299-310.

Adebiyi OA, Muibi MA, Alaba O (2017) Nigerian Performance and behavioural characteristics of Pigs as affected by types and duration of evaporative cooling. Nigerian Journal of Animal Science 19:103-113.

Alberts JR (1978) Huddling by rat pups: Group behavioural mechanisms of temperature regulation and energy conservation. Journal of Comparative and Physiological Psychology 92:231-245.

Atrian P and Shahryar HA (2012) Heat Stress in Dairy Cows (A Review). Research in Zoology 2:31-37.

Botto Ľ, Lendelová J, Strmeňová A, Reichstädterová T (2014) The effect of evaporative cooling on climatic parameters in a stable for sows. Research in Agricultural Engineering 60:85-91.

Bracke MBM (2011) Review of wallowing in pigs: Description of the behaviour and its motivational basis. Applied Animal Behaviour Science 132:1-13.

Dekker M (2015) The effect of temperature and activity patterns on lying behaviour and space use in conventional housed fattening pigs. PhD Thesis. Wageningen University. Wageningen.

Farrell DJ (1977) Effects of high temperature on the biological performance of growing pigs. Proc. RAAN Conference.

Garrido-Izard M, Correa E-C, Requejo J-M, Diezma B (2020) Continuous Monitoring of Pigs in Fattening Using a Multi-Sensor System: Behavior Patterns. Animals 10:52.

Gilbert C, McCafferty D, Le Maho Y, Martrette JM, Giroud S, Blanc S, Ancel A (2010) One for all and all for one: the energetic benefits of huddling in endotherms. Biological Reviews 85:545-569.

Gody D, Herbut P, Angrecka S, Corrêa Vieira FM (2020) Use of Different Cooling Methods in Pig Facilities to Alleviate the Effects of Heat Stress – A Review. Animals 10:1459.

Gourdine J-L, Rauw WM, Gilbert H, Poullet N (2021) The Genetics of Thermoregulation in Pigs: A Review. Frontiers in Veterinary Science 8:770480.

Hines E (2019) Cold Temperature Management for Pigs. https://extension.psu.edu/cold-temperature-management-for-pigs

Huynh TTT, Aarnink AJA, Gerrits WJJ, Heetkamp MJH, Canh TT, Spoolder HAM, Kemp B, Verstegen MWA (2005) Thermal behaviour of growing pigs in response to high temperature and humidity. Applied Animal Behaviour Science 91:1-16.

Huynh TTT, Aarnink AJA, Truong CT, Kemp B, Verstegen MWA (2006) Effects of tropical climate and water-cooling methods on growing pigs' responses. Livestock Science 104:278-291.

Huynh TTT, Aarnink AJA, Heetkamp MJW, Verstegen MWA, Kemp B (2007) Evaporative heat loss from group-housed growing pigs at high ambient temperatures. Journal of Thermal Biology 32:293-299.

Ingram DL (1965) The effect of humidity on temperature regulation and cutaneous water loss in young pigs. Research in Veterinary Science 6:9-17.

Kanis E, van den Belt H, Groen AF, Schakel J, de Greef KH (2004) Breeding for improved welfare in pigs: a conceptual framework and its use in practice. Animal Science 78:315-329.

Kim YJ, Song MH, Lee SI, Lee JH, Oh HJ, An JW, Chang SY, Go YB, Park BJ, Jo MS, Lee CG, Kim HB, Cho JH (2021) Evaluation of pig behavior changes related to temperature, relative humidity, volatile organic compounds, and illuminance. Journal of Animal Science and Technology 63:790-798.

Lacetera N (2019) Impact of climate change on animal health and welfare. Animal Frontiers 9:26–31.

Marchant-Forde JN, Rodenburg TB (2016) Future directions for applied ethology. In: Brown J, Seddon Y, Appleby M, editors. Animals and Us: 50 Years and More of Applied Ethology. Wageningen: Wageningen Academic Publishers 297-318.

Nielsen BL, Lawrence AB, Whittemore CT (1996) Feeding behaviour of growing pigs using single or multi-space feeders. Applied Animal Behaviour Science 47: 235-246.

Nienaber JA, Brown Brandl TM (2009) Heat Stress Effects on Growing-Finishing Swine. In Proceedings of the 25th Annual Carolina Swine Nutrition Conference, Raleigh, NC, USA.

Parois SP, Cabezón FA, Schinckel AP, Johnson JS, Stwalley RM and Marchant-Forde JN (2018) Effect of Floor Cooling on Behavior and Heart Rate of Late Lactation Sows Under Acute Heat Stress. Frontiers in Veterinary Science 5:223.

Rauw WM, de la Peña E de M, Gomez-Raya L, García Cortés LA, Ciruelos JJ, Gómez Izquierdo E (2020) Impact of environmental temperature on production traits in pigs. Scientific Reports 10:2106.

Ross JW, Hale BJ, Gabler NK, Rhoads RP, Keating AF, Baumgard LH (2015) Physiological consequences of heat stress in pigs. Animal Production Science 55:1381-1390.

Spoolder HAM, Aarnink AAJ, Vermeer HM, van Riel J, Edwards SA (2012) Effect of increasing temperature on space requirements of group housed finishing. Applied Animal Behaviour Science 138:229-239.

Souza L (2009). How can heat stress affect production? The Pig site. https://www.thepigsite.com/articles/how-can-heat-stress-affect-your-production

Taylor NA, Tipton MJ, Kenny GP (2014) Considerations for the measurement of core, skin and mean body temperatures. Journal of Thermal Biology 46:72-101.

Zervanos S, Hadley NF (1973) Adaptational biology and energy relationships of the collared peccary (*Tayassu tajacu*). Ecology 54:759-774.