Behavioural and physiological indicators of heat stress in fattening pigs

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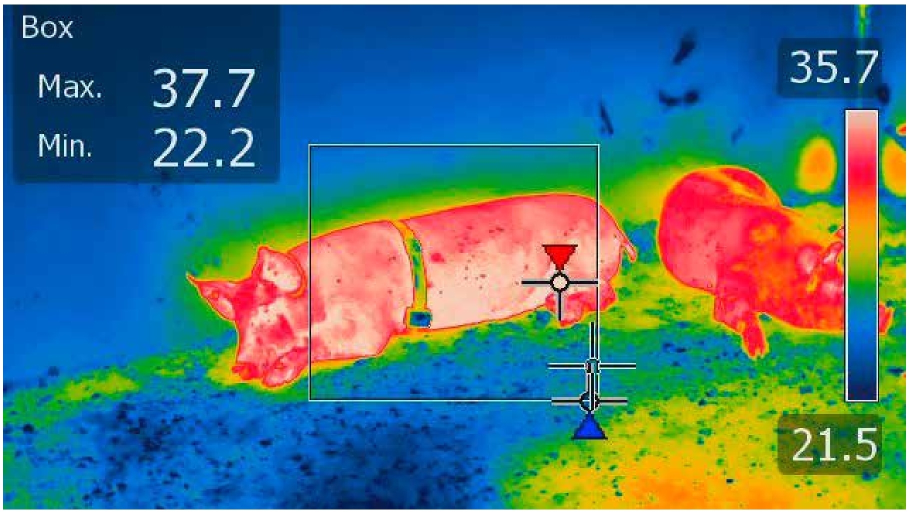

Heat-stressed fattening pigs seek cool, humid floor surfaces and increase the area of skin contact with the floor. (Photo: Madeleine F. Scriba, BLV)

Abstract

Extreme climatic conditions constitute a challenge for the adaptability of fattening pigs. Heat stress poses major problems for pig production and welfare because it leads to a prolonged fattening period, reduced fertilization success and higher overall mortality. Indicators need to be established for farmers to be able to recognize heat stress at an early stage and to respond by providing cooling measures. In this study, several behavioural and physiological parameters were measured in 72 fattening pigs of three weight classes (40–100 kg) during one summer month. The measured ambient pen temperature ranged from 17 to 30 °C. The core body temperature (*n* = 7) measured with a vaginal logger showed large inter-individual variability, and no rise was detectable with increasing ambient temperature, probably because the highest ambient temperatures were still moderate and lasted for only a short period. The respiration rate (*n* = 24) was highly variable and increased only in the heaviest pigs at 26–27 °C, whereas the body surface temperature (*n* = 24) increased with higher ambient temperatures in pigs of all weight classes. The measured behaviour (*n* = 72) was largely independent of the ambient temperature. However, the percentage of pigs lying in sternal recumbency increased with rising ambient temperatures in the afternoon. To summarize, the results of this study suggest that respiration rate and skin surface temperature are reliable indicators of heat stress in fattening pigs.

Key words: skin surface temperature, lying behaviour, core body temperature, thermography, respiration rate.

Introduction

Periods of prolonged heat can lead to impaired pig welfare (Mayorga *et al.*, 2019). Moreover, heat stress is associated with a reduction in performance, which causes high costs (St-Pierre *et al.*, 2003). Pigs in particular are very susceptible to heat stress because they have no functional sweat glands and can only give off heat by panting (Ingram, 1965; Bracke, 2011). As a result, heat can quickly become critical for the individual. Pigs reduce their activity and feed intake to avoid an increase in body temperature due to digestive heat (Verstegen *et al.*, 1987). Another strategy used by pigs is to avoid physical contact with conspecifics, which can only be effective if there is enough space so that the animals can keep their distance when lying (Huynh *et al.*, 2005a). To release more heat, pigs seek cooling floor surfaces (perforated or humid floors) and optimize the lying position by stretching out to the side to have more contact with the floor surface as compared with lying in sternal recumbency (Huynh *et al.*, 2005a).

Pigs in the finishing stage are particularly affected by heat stress because they have a fast metabolic activity due to the high daily weight gain and they can give off heat poorly owing to the less favourable ratio of body surface area to body volume (Renaudeau *et al.*, 2012). In the event of heat stress, fattening pigs try to increase heat dissipation through the skin to remain in the thermo-neutral zone (Huynh *et al.*, 2005a). To estimate the body temperature, the surface temperature of various parts of the body can be measured with the help of thermography (Brown-Brandl *et al.*, 2012). If the ambient temperature rises sharply (e.g. from 24 to 27 °C, depending on the humidity), there will be a point at which the maximum heat release through the skin is reached and the core body temperature of the pigs begins to rise (Johnson & Shade, 2017; Kpodo *et al.*, 2020). The rise in core body temperature can be recorded, for example, with a vaginal temperature logger (Johnson & Shade, 2017). As a further indicator of heat exposure, the respiratory rate increases in fattening pigs at temperatures between 19 and 24 °C (Huynh *et al.*, 2005a).

This experimental study was designed to investigate how the above-mentioned parameters can be measured reliably in fattening pigs to determine early heat stress in animals of different weight categories. The aim was to develop and validate indicators that are suitable to assess the effect of exposure to elevated temperatures on pig welfare in later investigations covering a wide range of farms with different types of barn buildings, housing systems and cooling systems. Due to climate change, the problem of heat stress will become even more acute in the future, and it is crucial to adapt the housing conditions for fattening pigs to the changing climatic situation in a suitable manner. Therefore, it is necessary to validate indicators with which the heat load of the animals can be assessed in relation to air temperature and humidity.

Methods

Animals and data collection

At the experimental farm of Agroscope in Tänikon, Switzerland, fattening pigs of 40–100 kg (three weight classes, 24 pigs per class, mixed sexes) were kept in three groups of randomly selected animals. Pigs of Group 1 were weighing 80 kg at the start of the experiment and 103 kg at the end, with a mean value of 89,2 ± 12,0 kg (± SEM). Pigs of Group 2 had a body weight of 47 and 87 kg (mean 63,4 ± 17,0 kg), and pigs of Group 3 had a body weight of 34 and 70 kg (mean 48,1 ± 13,7 kg) at the start and end of the investigation, respectively. Experiments took place from 14 August until 23 September 2020. The three pens (one per group) had a size of 30,3 m² (9,46 × 3,32 m), were partly slatted and were cleaned twice daily. Each pen had two automatic feeders, each with two feeding places, offering food ad libitum, and three times three drinking nipples. Hay racks were regularly replenished. Each pen was equipped with one temperature and humidity logger at a height of 1 m (with one measurement every 15 min). In each pen, eight randomly selected animals (24 pigs in total) were equipped around the belly with a belt containing an accelerometer (MSR Logger 145, MSR Electronics GmbH, Seuzach, Switzerland) to record their activity (one value of acceleration per second). In addition, the core body temperature of seven female pigs in Group 1, from the 80–103 kg weight class, was recorded with a vaginal temperature logger (1921H iButton, https://www.ibuttonlink.com/products/ds1921h; in combination with EAZI-BREED™ CIDR® Sheep Insert, https://www.zoetisus.com/products/sheep/eazi-breed-cidr-sheep-insert.aspx; one value per 10 min). The respiration rate of all animals equipped with an accelerometer was measured from the distance twice per day (at 8.00 and 14.00; breaths per minute). Using a thermal imaging camera (FLIR T620, evaluation software FLIR Tools+ Version 5.13), photos were taken of the teats or the part between the hind legs of one side of the body (see Fig. 1) of between 6 and 23 pigs per pen twice per day (8.00 and 14.00). The photos were taken from outside the pens, and the distance between camera and pig was registered as about 50, 100, 200 or 300 cm. The behaviour of all pigs was video recorded with cameras fixed to the ceiling of each pen. For behavioural analysis, twelve photos per hour (every 5 min one photo) were extracted for the periods 8.00 to 9.00 and 14.00 to 15.00.

Analyses

The temperature and humidity data of the three loggers in the pens were averaged to mean values per date and hour. A temperature humidity index (THI) was calculated according to the formula of the National Weather Service Centre Region (1976) as used in Wegner *et al.* (2014). Because the effects of humidity and the THI on the assessed indicators of heat stress were about identical to those of the temperature, we report only data on the average ambient temperature per date, but not on the THI or humidity. Temperatures were averaged per 24-hour period, and per period of 12.00–16.00 to capture the highest temperatures each day. The temperatures were assigned to temperature categories with two degrees Celsius per category (e.g. 21–22, 23–24, 25–26 °C). The activity was analysed for 31 complete 24-hour periods. The core body temperature was measured in five female fattening pigs for 8 days and in two female fattening pigs for 10 days. Activity and core body temperature were averaged for each individual animal per 24-hour period, and additionally, we calculated the mean per period of 12.00–16.00. The body surface temperature at 8.00 and at 14.00 was determined for 4 days (n ranged from 6 to 23 photos per time point and group, $n_{total}=200$ photos). To determine if the distance of the camera to the pig was correlated with the body surface temperature, a Spearman correlation coefficient was calculated ($n=200$). The respiration rate was determined on 14 days at 8.00 ($n_{total}=308$ measurements) and on 7 days at 14.00 ($n_{total}=140$ measurements). Standing, sitting and lying behaviour, as well as the percentage of all pigs per pen lying with body contact (in total 67 individuals at the beginning of the experiment and 60 individuals at the end of the experiment due to diseases and removal of seven pigs) was analysed for 6 days ($n_{total}=2376$; i.e. $n=132$ photos per pen and date).
Correlations were calculated of the ambient temperature with all measured animal-based data (activity, core body temperature, respiration rate, body surface temperature, and behaviour; for sample sizes see above) using R (Version 1.4.1717-3). To analyse dependencies between parameters, correlations were calculated for each recorded physiological parameter with all other physiological parameters.

Results

During the experimental period from 14 August until 23 September 2020, the measured ambient temperatures in the pens ranged between 17 and 30 °C (Table 1). The recorded physiological parameters (activity, core body temperature, respiration rate, body surface temperature) were not correlated with each other.

Table 1 | Mean values (± SEM) of all environmental, physiological and behavioural parameters measured in three groups (1–3) of fattening pigs differing in body weight. Values are presented per 24-hour period as well as for measurements made at 8.00 and at 14.00.

Parameter measured	24-hour mean per group			Mean of all groups at 8.00	Mean of all groups at 14.00
	1	2	3		
Ambient pen temperature (range) (°C)	23,4 ± 2,3 (17,3–30,6)	22,2 ± 1,9 (18,0–27,6)	24,5 ± 2,2 (19,1–30,3)		
Body weight (kg)	89,2 ± 12,0	63,4 ± 17,0	48,1 ± 13,7	not applicable	not applicable
Activity	306,2 ± 24,1	312,1 ± 29,6	374,1 ± 18,5	not applicable	not applicable
Core body temperature (°C)	39,2 ± 0,2	not measured	not measured	not applicable	not applicable
Respiration rate (breaths per minute)	64,7 ± 26,8	59,9 ± 23,1	62,4 ± 24,6	56,6 ± 20,5	71,4 ± 28,1
Body surface temperature (°C)	38,1 ± 0,5	38,1 ± 0,5	38,5 ± 0,6	38,0 ± 0,5	38,4 ± 0,6
% pigs lying	78,6 ± 5,4	74,3 ± 7,3	70,8 ± 10,0	73,6 ± 6,9	75,4 ± 9,3
% pigs standing	17,7 ± 4,5	22,0 ± 5,5	25,8 ± 8,9	23,0 ± 6,1	20,9 ± 8,0
% pigs sitting	3,5 ± 2,1	3,6 ± 2,5	3,3 ± 1,5	3,3 ± 2,0	3,6 ± 2,0
% pigs lying on the side	48,0 ± 10,8	47,2 ± 11,6	41,9 ± 11,6	42,7 ± 11,6	48,2 ± 10,8
% pigs lying in sternal recumbency	30,7 ± 6,0	27,2 ± 5,8	28,7 ± 6,1	30,9 ± 6,2	27,2 ± 5,4
% pigs lying with body contact	39,0 ± 11,0	28,7 ± 7,4	43,9 ± 12,4	38,8 ± 11,5	35,9 ± 12,6
% pigs lying on slatted floor	38,3 ± 5,6	40,3 ± 24,8	24,8 ± 6,6	31,5 ± 8,1	35,9 ± 9,6

Activity

The mean activity of the pigs did not change with different ambient temperatures. Considering the three weight classes, the lightest animals were on average more active than those of the heavier weight classes (Table 1). This increase in activity was independent of the ambient temperature (Fig. 1).

Core body temperature and respiration rate

The core body temperature measured with a vaginal logger showed large inter-individual variability (Fig. 2). Some pigs showed a consistent higher vaginal temperature than other pigs. These inter-individual differences in vaginal temperature cannot be explained by differences in weight (Spearman correlation coefficient = 0,18). A rise in core body temperature with increasing ambient temperatures was not detectable. The mean respiration rate increased only in the heaviest pigs at 26–27 °C; at lower temperatures, it did not show an increase in any of the three weight classes (Fig. 3).The inter-individual variance in the respiration rate was overall high, and it was higher in values measured at 14.00 than in values measured at 8.00 (Table 1). Furthermore, the average respiration rate was higher at 14.00 than at 8.00 (Table 1).

Body surface temperature

The body surface temperature measured with a thermal imaging camera increased with higher ambient temperatures in pigs of all weight classes (see Fig. 4 for summarized body surface temperatures of all pigs). It was independent of the distance from which the photo was taken (50–300 cm; Spearman correlation coefficient = 0,17).

Behaviour

The percentage of pigs lying did not differ between 8.00 and 14.00 (Table 1), and no increase in the percentage of pigs lying was observed with increasing ambient temperatures (data not shown). Similarly, the percentage of

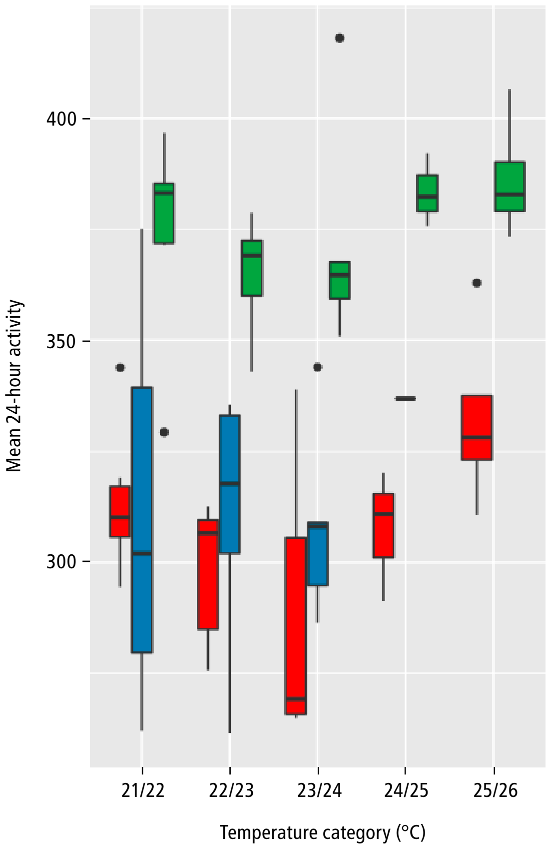

Figure 1 | Mean activity of fattening pigs during 24-hour periods in relation to the mean 24-hour ambient pen temperature (in categories). Green bars represent pigs of Group 3 (lightest pigs, mean body weight ± SEM: 48,1 ± 13,7 kg), blue bars pigs of Group 2 (medium heavy pigs: 63,4 ± 17,0 kg) and red bars pigs of Group 1 (heaviest pigs: 89,2 ± 12,0 kg).

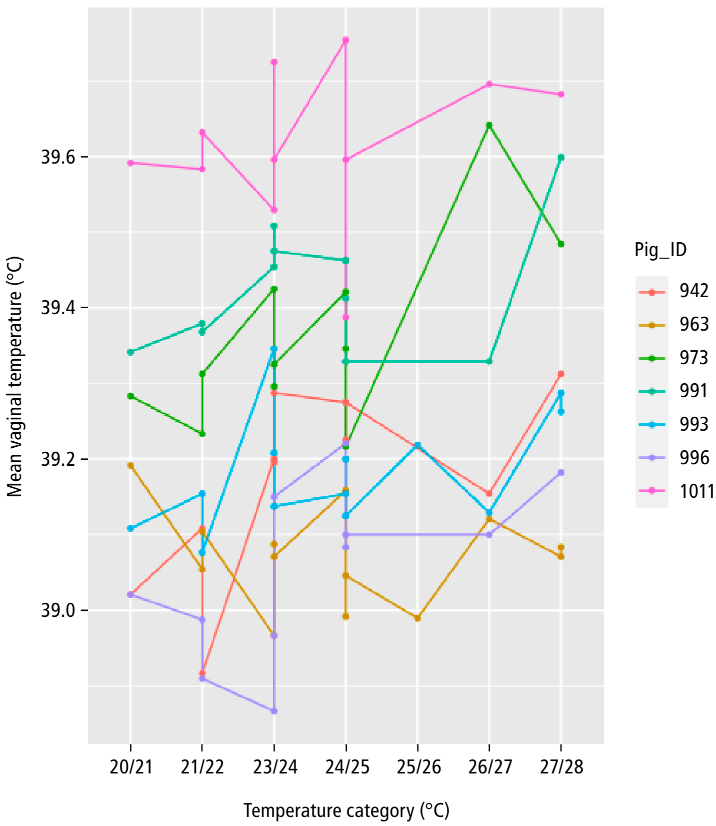

Figure 2 | Mean individual core body temperature (vaginal temperature) of seven female fattening pigs of Group 1 (heaviest pigs, mean body weight ± SEM: 89,2 ± 12,0 kg) in relation to the mean 24-hour ambient pen temperature (in categories).

pigs standing was similar at 8.00 and at 14.00 (Table 1), and no change with ambient temperature was visible in the data. The lighter pigs tended to stand for longer times than the heavier pigs (Table 1). The percentage of pigs sitting did not differ between pigs of different weight classes (Table 1) or in relation to ambient temperatures (data not shown). The percentage of pigs lying on the side did not depend on the ambient temperature (Fig. 5). Compared with the heavier pigs, the lighter pigs spent less time lying on the side (Table 1). The mean percentage of pigs lying in sternal recumbency showed an increase with rising ambient temperatures at 14.00, but not at 8.00 (Fig. 5). The percentages of pigs lying with body contact and of pigs lying on the slatted floor did not change with ambient temperature (data not shown), and no clear pattern was visible in the data for pigs of different weight classes (Table 1).

Discussion

Four physiological and seven behavioural parameters were measured in male and female fattening pigs and analysed in relation to the ambient temperature, which ranged from 17 to 30 °C. We found no correlations between the physiological parameters (activity, core body temperature, respiration rate, body surface temperature), probably because the sample size was too small.

Activity

The mean activity did not change with rising ambient temperatures, maybe because the general level of locomotion is low in fattening pigs. Therefore, activity did not decrease further with increasing ambient temperatures because the pigs moved mainly for feeding, drinking or defecating. In other studies, a decrease in activity was found (Pedersen *et al.*, 2003), but compared with our study, activity had been measured over a larger temperature range. The ambient temperature range (mean 21–26 °C) during our experiment might have been too small to detect an effect. Even the lighter pigs, which were more active than the heavier ones, did not decrease their activity at higher temperatures. Interestingly, the heavier pigs with mean weights of 89,2 and 63,4 kg (Groups 1 and 2, respectively) were similar in their level of activity, but the pigs with a mean weight of 48,1 kg (Group 3) were overall more active.

Core body temperature

Overall, the core body temperature did not rise with increasing ambient temperatures, probably because the highest temperatures were still moderate and lasted for only a short period. Huynh *et al.* (2005b) showed that the rectal temperature of fattening pigs increased only above 26 °C ambient temperature, a temperature which was exceeded for only short periods in our study. The core body temperature was highly variable between individuals. Maybe individual female fattening pigs differed in their core temperature, or the insertion depth of the loggers differed between pigs. In another study that used vaginal loggers in gilts, the mean vaginal temperature was lower with 38,6 °C at an ambient temperature of 24,9 °C as compared with 39,2 °C in our study (Johnson & Shade, 2017). However, it was described that breeding sows have a lower core body temperature than fattening pigs (Huynh *et al.*, 2004; Malmkvist *et al.*, 2012).

Respiration rate

The respiration rate can only be measured when the pigs are lying, but the behaviour just before the measurement (short or long time spent lying, sleeping or in

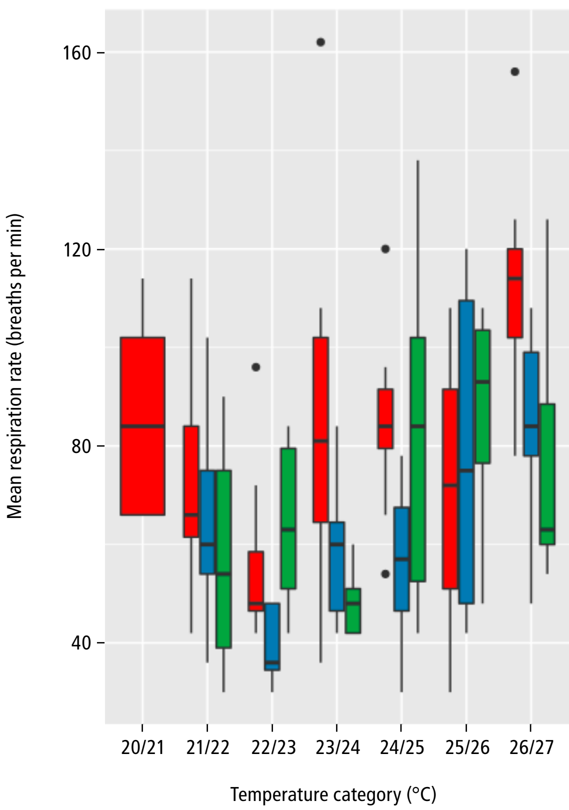

Figure 3 | Mean respiration rate (breaths per minute) of fattening pigs at 14.00 depending on the mean ambient pen temperature (in categories) in the period of 12.00–16.00. Green bars represent pigs of Group 3 (lightest pigs, mean body weight ± SEM: 48,1 ± 13,7 kg), blue bars pigs of Group 2 (medium heavy pigs: 63,4 ± 17,0 kg) and red bars pigs of Group 1 (heaviest pigs: 89,2 ± 12,0 kg).

interaction with conspecifics) can have an influence on the respiration rate. Therefore, this indicator is difficult to measure in a standardized way, and the sample size needs to be large to detect an effect of the ambient temperature. We found a slight increase in respiration rate in the heaviest pigs at the highest ambient temperatures, but no increase was detectable at the lower temperature range in any of the three weight classes. However, the inter-individual variance was considerably large and may have masked potential rises in respiration rate. The large variation might show the difficulties in measuring the respiration rate in a standardized way. Interestingly, the respiration rate was higher at all ambient temperatures compared with measurements in other investigations (mean of 62,3 ± 24,8 breaths per minute in this study at a temperature range from 20 to 27 °C compared with 30 breaths per minute up to an ambient temperature of 21 °C, and, depending on the humidity, with about 75 breaths per minute at 26 °C; Huynh *et al.*, 2005b). In our investigation, the pigs were of a wide range of body weights, whereas other studies observed only specific body weight classes (60–70 kg in Huynh *et al.*, 2005b), which might explain the discrepancy in respiration rates.

Body surface temperature

The body surface temperature seems to be a good indicator of heat stress because we found a rise in body surface temperature with increasing ambient temperatures, despite our small sample size and difficulties to standardize the area taken for the measurement. The researcher did not enter the pen when taking thermal images to not disturb the pigs. Therefore, the distance to the pig differed as well as the position of the pig. We aimed to take photos of the teats or the part between the hind legs, but the angle differed between pictures. In most studies using thermal images of pigs, the individuals were moved into individual pens for taking the picture, and thus the distance and angle were kept constant (e.g. Brown-Brandl *et al.*, 2012). We found a rise in body surface temperature when comparing the mean ambient temperature of 20–21 °C with 23–24 °C. The results of our study agree with findings of another study on fattening pigs showing that at an ambient temperature of 21,6 °C the body surface temperature started to increase (Brown-Brandl *et al.*, 2012).

Behaviour

The number of pigs lying was large during all measurements at 14.00 (75,4 % ± 9,3 %), and this might explain why there was no further increase with rising ambient temperatures. Other studies showed that fattening pigs rest between 88 % and 90 % of the time irrespectively of the ambient temperature (Ekkel *et al.*, 2003; Huynh *et al.*, 2005a). Interestingly, the percentage of pigs lying in sternal recumbency increased with rising ambient temperatures, which is the opposite effect compared with results described in other studies (Huynh *et al.*, 2005a). Most studies found that pigs at higher ambient temperatures prefer to lie on their side to better give

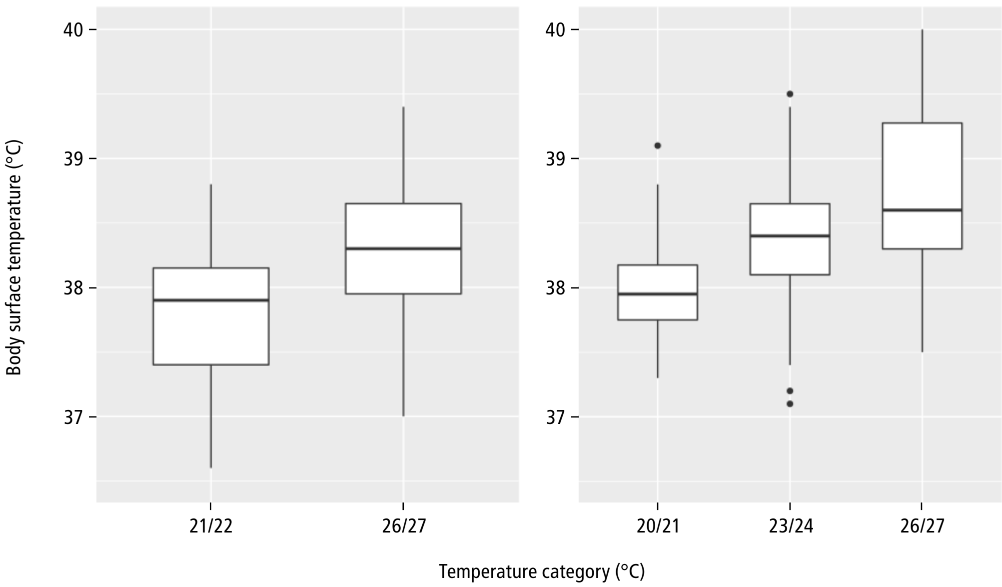

Figure 4 | Mean body surface temperature of fattening pigs at 8.00 (left) and at 14.00 (right) depending on the mean ambient pen temperature (in categories) in the period of 12.00–16.00.

off heat to the ground (Close *et al.*, 1981; Huynh *et al.*, 2005a). The pigs in our study might have changed to a sternal lying position owing to the presence of the researcher taking measurements at 14.00. The ambient temperature did not have an influence on the number of pigs lying with body contact; maybe the pigs perceived all temperatures occurring during the experiment as heat stress and therefore kept distance. However, at 8.00, the pigs were lying more often with body contact than at 14.00, which might have been caused by a circadian change in preference. Compared with the heavier pigs, the lighter pigs stood for a longer time and spent less time lying on their side, which is in line with previous research. Thus, lighter pigs may be less affected by heat stress than heavier conspecifics. The behavioural parameters might be dependent on factors such as body weight, group size and available space and might be too variable to be used for the detection of early heat stress.

Conclusions for on-farm studies

This investigation had the aim to find indicators of early heat stress in fattening pigs, which can be used on farms to evaluate the efficacy of cooling systems. Overall,

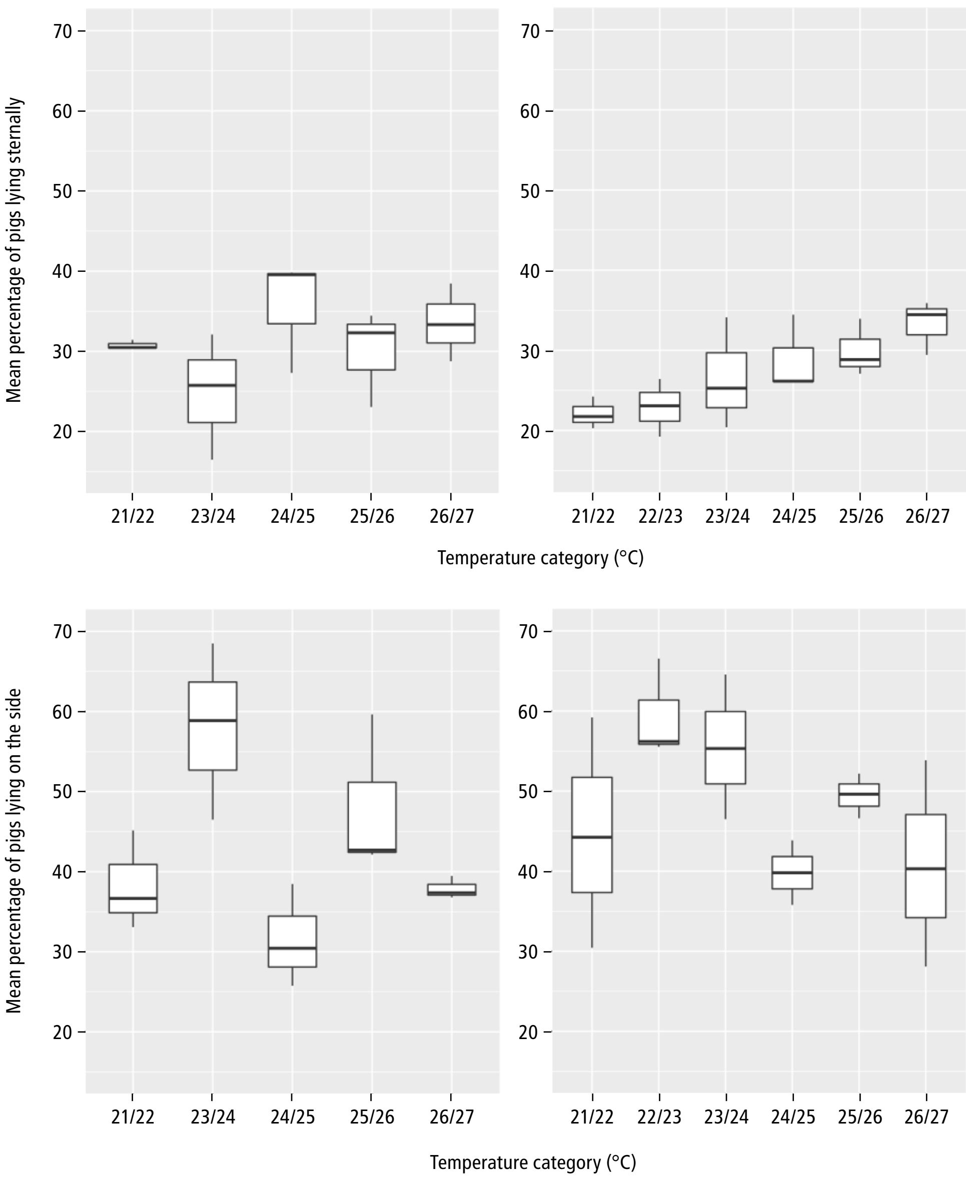

Figure 5 | Mean percentage of fattening pigs lying in sternal recumbency (upper graphs) or on the side (lower graphs) at 8.00 (left) and at 14.00 (right) depending on the mean ambient pen temperature (in categories) in the period of 12.00–16.00.

measuring the body surface temperature with a thermal imaging camera proved to be a good method for measuring heat stress in fattening pigs. In addition, the respiration rate increased with rising ambient temperatures, resulting in valid indications of heat stress. The level of activity, however, did not change in response to rising ambient temperatures and thus might not be a usable parameter to assess heat stress in fattening pigs. However, it might be that the level of activity would change clearly when comparing a wider temperature range. The core body temperature, as well, was not modulated by mean ambient temperatures ranging from 20 to 28 °C, but in more extreme and longer lasting heat, it would probably increase. However, at extreme temperatures, heat stress already has consequences on welfare and production. Therefore, this parameter is not suitable for an early detection of heat stress. The percentage of pigs lying was not an indication of heat stress. Furthermore, the percentage of pigs standing, sitting, lying on the slatted floor or lying with body contact did not change with different ambient temperatures, but with daytime. Of the behavioural parameters, only the percentage of pigs lying in sternal recumbency increased with rising ambient temperatures. Overall, the parameters suitable to recognize heat stress at an early stage still need to be elaborated in a larger sample and over longer periods of high temperatures. Based on the results of this study, thermography and the measurement of the respiration rate seem to be promising methods to assess heat stress in fattening pigs. For farmers, however, thermography is not practical and the method too expensive for measuring heat stress. For the usage of the respiration rate as an indicator of heat stress, the number of animals sampled would need to be large, which renders this indicator not practicable for farmers, too. However, for research purposes, the body surface temperature and the respiration rate yield good results on heat stress in fattening pigs and can be used to assess the exposure at elevated temperatures. Further efforts should be made to identify and validate indicators that allow farmers to recognize heat stress at an early stage and to respond by providing cooling measures. ■

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