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Effects of tropical climate and water cooling methods on growing pigs' responses

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Abstract

We report a study on crossbred growing pig ((Duroc × Pietrain) × Large White) that measured the effect of tropical conditions on respiration rate (RR), skin temperature (ST), rectal temperature (RT) and productivity and determined the efficacy of two simple cooling methods. The experiment was a randomized complete block design using 120 growing pigs. The factors were cooling system and pen design. The effects of two cooling systems (water bath (WB) and sprinkling (S)) were evaluated and compared with a control (CON). Cooling systems were tested in pens with (Y) or without an additional outdoor yard (NY). The pens were similar to those used in small-scale pig keeping in South-East Asia. The inside pen size was 2.5 × 3 m, the yard was 2.5 × 2 m. The same experimental design was used in two blocks: one block was in the wet season with average ambient temperature (T) of 27.5 °C and average relative humidity (RH) of 74.7% and the other was in the dry season with average T of 28.7 °C and average RH of 62.8%. In each block a batch of 60 pigs was reared in 12 pens (five pigs per pen). Pigs had free access to feed and water. Results showed that cooling and pen type significantly affected most parameters. The bath and S reduced RR by 4.2 and 5.2 min^{-1}, respectively ($P<0.01$), and ST by 0.3 and 0.4 °C, respectively, ($P<0.05$). Rectal temperature was not influenced by any treatment. The bath significantly reduced number of defecations and urinations in the resting area in pens NY ($P<0.001$). A yard reduced the number of excretions in the resting area ($P<0.01$). There were significant interaction effects of cooling and pen type on lying, lateral lying, and huddling ($P<0.01$; $P<0.001$; $P<0.01$, respectively). Daily weight gain was 6 g d^{-1} more with WB and 50 g d^{-1} more with S ($P<0.05$). The biggest daily weight gain was achieved when S was combined with a pen NY ($P<0.01$).

We conclude that the physiologic and behavioral responses and hence productivity of group-housed growing pigs raised under tropical climate conditions benefited from the simple cooling systems tested and were affected by the

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presence of a yard. A fall in the high respiration rate indicated that cooling with the bath or sprinkling alleviated the pigs' heat stress.

Keywords: Cooling; Heat stress; Pig; Yard; Tropical climate

1. Introduction

Though many advanced techniques are available to alleviate cold-stressed swine in temperate conditions, solutions to alleviate the heat stress of pigs kept in hot climates are still being studied. To date, studies have been done on the efficacy of various cooling methods (e.g. cool pad, fogging, spraying, mechanical and natural ventilation) that require major investments, are complicated to install, costly to operate, and in some cases have produced a high humidity inside the animal house or have failed to reduce the indoor air temperature (Hahn, 1985; Seedorf et al., 1998). World regions in which pig production is important to national economies and in which the climate is hot for at least part of the year are Southern Europe, Central and Eastern Europe, Central and South America, Africa and Asia. A study done in one of these regions would provide valuable insights into the effect of heat stress on growing pigs.

The country of Vietnam in South-East Asia, which lies between latitudes 23 1/2° North and 8 1/2° South is suitable for such a study. The climate in Vietnam is humid tropical: relative humidity (RH) averages 80%. Pigs kept in this climate are generally exposed to ambient temperatures that exceed their thermo neutral zone (Steinbach, 1978; Christon, 1988; Serres, 1992). Exposure to high ambient temperature has been shown to affect daily feed intake (Black et al., 1993; McGlone, 1998; McGlone et al., 1988; Collin et al., 2001), which finally results in lower body weights (Brown-Brandl et al., 1998; Rinaldo et al., 2000).

In a study in the temperate climate of The Netherlands, Huynh et al. (2004) found that a floor cooling system significantly affected pig behavior and performance during the hot period in summer. The floor cooling reduced the number of pigs lying on the slatted floor and increased voluntary feed intake. Floor cooling is too expensive for small-scale pig farmers in South-East Asia, but a suitable alternative might be to offer the pigs a cooling system with a sprinkler or a bath. In controlled climatic experiments, Brown-Brandl et al. (1998, 2001), and Nienaber et al. (1996) found when ambient temperature and RH remained high throughout the day, the performance and physiologic and behavioral responses of finishing pigs were detrimentally affected. Brown-Brandl et al. (2001) and Huynh (2005) found different inflection point temperatures (IPt; critical temperatures) for respiration rate (RR), rectal temperature (RT), feed intake, ratio of water to feed intake and heat production. In addition, Collin et al. (2001) reported that the maximum VFI of group-housed growing pigs of approximately 20 kg was between 19 and 25 °C of the ambient temperature. The authors also found out that at above 33 °C of the ambient temperature, the body weight and VFI decreased by 30% to 37%. It is not known whether these IPt values for pigs exist in practical situations in the tropics. Furthermore, the effect of actual hot humid conditions with variations between days on responses of growing pigs is still undetermined. Given the importance of pig production in the tropics, there is a need to ascertain the impact of this climate on physiology and behavior and how this is related to animal performance. This knowledge could be used worldwide to develop practical management tools to prevent heat stress. The aim of the experiment we report here was therefore to determine the influence of two types of simple cooling systems (bath (WB) versus sprinkler (S)) with a control group (CON) on the physiologic, behavioral and performance responses of pigs housed on small-scale farms with or without an outside area, in a tropical climate.

2. Materials and methods

2.1. Experimental design

A total of 120 growing to finishing crossbred pigs ((Duroc × Pietrain) × Large White) were used in two batches, each of 60 pigs. The animals were considered to be free from OIE list A and B diseases (World Organization of Animal Health). The study was conducted in 12 pens, each housing 5 pigs, at the experimental farm in Ho Chi Minh city, Vietnam, which experiences a hot humid climate (FAO country profiles and mapping information system, 2005). Each trial was preceded by a 10-day period in which the pigs could habituate to their new accommodation. The main testing period was 47 days for trial 1 and 48 days for trial 2.

In trial 1 the ambient temperature inside the animal house (T) ranged from 24.3 to 29.7 °C and the relative humidity inside the animal house (RH) from 65% to 86.7%. In trial 2, the T ranged from 25.9 to 32.8 °C and RH ranged from 43.8% to 82.6%. During daytime, air velocity varied from 0.2 (usually at noon) to 0.4 m s^{-1}. Air velocity at animal level was below 0.2 m s^{-1}.

Table 1 shows the composition of the dry feed the pigs received throughout the finishing period. The composition was based on local ingredients and on Vietnam standard (TCVN) for finishing pig feed composition.

Table 1
Feed composition from the start of the experiment to the date of finishing the experiment

Ingredients	
Rice meal	46.5%
Corn meal	24%
Coconut oil	4%
Fish meal	3.5%
Molasses	5%
Soy meal	14%
Limestone	1.5%
Minerals and vitamins	1.5%
Resulting in energy and protein analyses	
D.E (MJ/kg)	13.5
Crude protein (%)	16
Crude fibre (%)	4.8
Crude fat (%)	6
Lysine (%)	0.65
Methionine (%)	0.25
Calcium: (%)	0.86
Phosphorus: (%)	0.5
Salt (%)	0.3

(TCVN — Vietnam Animal Feed Standard — 1547–1994).

2.2. Housing and cooling systems

2.2.1. Pen

The 12 pens were designed to mimic those used in small-scale pig keeping in the rural areas of the tropics (Serres, 1992). The indoor pen (NY) was 2.5 × 3 m, the outdoor yard (Y) was 2.5 × 2 m. The space allocation was 1.5 m^2 per pig in pen NY; pigs in pens with a Y had an extra area of 1 m^2 per pig. The building had a typical roof for that area: V-shaped, fibrocement sheeting, with an open ridge that served as an air outlet, allowing natural ventilation. The slope of the roof was 30°. The roof ridge was 4.5 m from the floor; the eaves were 2.5 m from the floor. There were cement outer walls 1.0 m high. Alongside the building at the back of each pen, a curtain made from feed sacks protected the animals from direct sunshine and rain. The pen floor was 100% solid concrete and had a 4% slope to the back (see Fig. 1).

The yard was surrounded by a 1 m high concrete wall. The pigs in this pen type could freely access the yard through an opening of 0.8 m width, located in the defecation area (see Fig. 1).

Pens were cleaned manually twice daily before feeding time. Manure was removed from the pen and transported to a composting unit; the urine ran off into a channel outside the pen wall.

2.2.2. Sprinkler

In four of the 12 pens a simple S system was installed at the back of the pen (see Fig. 1), fixed at 1.2 m above floor level. The water tank supplying water to the system was placed inside the animal house at 3 m above floor level and connected to the S by pipes (21 mm diameter × 10 m long). A water pump was used to increase the water pressure to the six showers in each S system. The showers were spaced approximately every 0.30 m, to achieve overlapping coverage. Droplet size was between fog and mist (100–500 μm). Each shower sprayed approximately 3.5 l of water per minute. A timer was used to control the S schedule, which was based on the diagram of Ingram (1965a,b) who

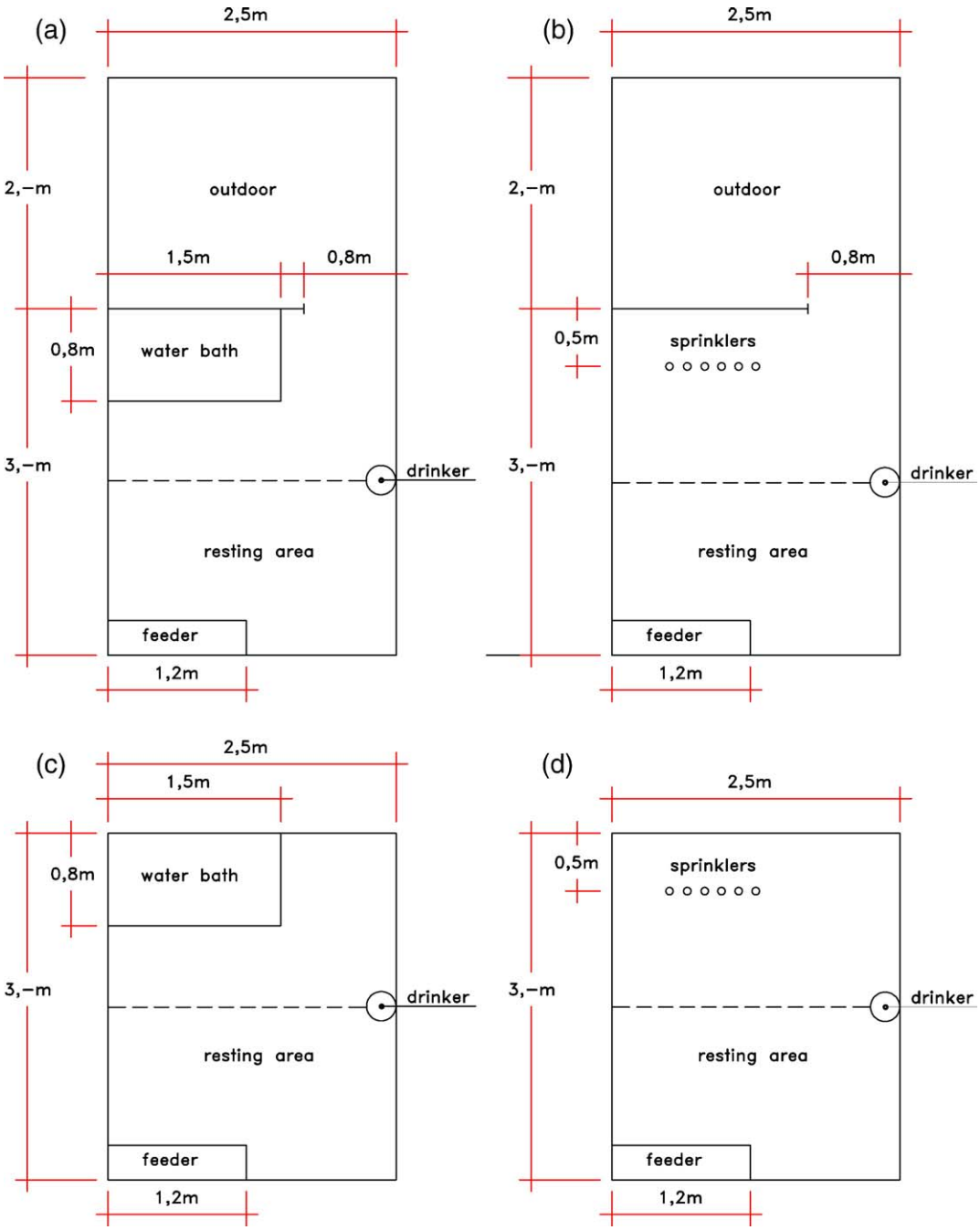

Fig. 1. Pen layout with and without yard, and cooling system. (a) pen with yard and bath; (b) pen with yard and sprinklers; (c) pen with bath without yard; (d) pen with sprinkler without yard.

reported that it takes approximately 30 min for water to evaporate from the skin of a wet pig. The sprinklers were activated for 2 min every 30 min during the hottest period of the day only, i.e. from 10.00 h in the morning until 16.00 h in the afternoon (see Fig. 2). Prior to activating the sprinkler a

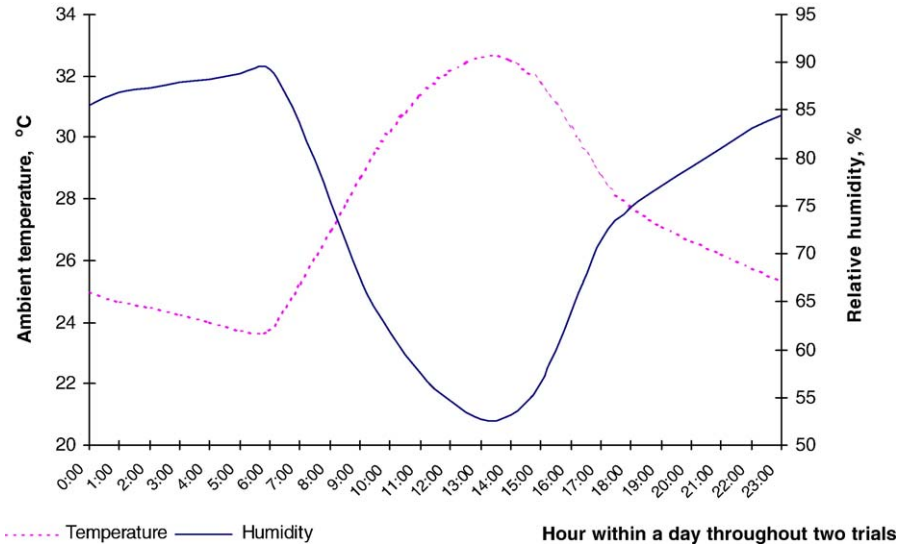

Fig. 2. Diurnal temperature and humidity per hour, derived from hourly means throughout the experimental period.

bell was rung for 1 min to alert the pigs. The water was approximately 22 °C at source, but by the time it reached the sprinkler it was approximately 25 °C.

2.2.3. Bath

A bath (0.3 × 0.8 × 1.5 m) was placed at the back of the indoor area in four of the 12 pens (see Fig. 1). It was large enough to accommodate two pigs at the same time. During the 10-day adaptation period we noticed that the bath soon became dirty, so in the main experimental period the bath was filled to a depth of 20 cm with clean water twice a day, once at 08.00 h in the morning and once at 14.00 h in the afternoon. On hot days, when the pigs emptied the bath more often, the bath was also refilled late in the afternoon, normally at 16.00 h. The bath was cleaned twice a week.

2.2.4. Animal

In each trial, a batch of 60 pigs of average starting weight of 57.1 ± 5.4 kg in trial 1 and 58.6 kg ± 5.4 kg in trial 2, and end weights of 93.0 kg ± 8.7 kg and 94.2 kg ± 8.9 kg, respectively, was randomly assigned to one of the 12 experimental pens (two pens per treatment combination). The pigs were weighed at the start and finish of the experiment.

2.3. Measurements

2.3.1. Climatic condition

Temperature and RH were measured at 1.5 m above floor level in the feeding path, using a combined instrument HygroLog (Rotronic HygromerTM C94, sensors Pt100 RTD (1/3 DIN), Switzerland). Temperature and RH were recorded every 30 min.

2.3.2. Physiology

Physiologic data were collected twice a day at 06.30 h in the morning and at 13.30 h in the afternoon. The timing was to ensure that data were collected when the *T* was likely to be the lowest and highest (see Fig. 2). In each pen, three randomly chosen pigs were marked for measurement of skin temperature (ST), RR, and RT. Skin temperature was measured using a radiant thermometer (CHINO IR-AH, Japan). Measurements of ST and RR as well as RT were taken similar to as described in Huynh et al. (2005b). Skin temperatures were measured at three marked positions (shoulder, loin and ham) (Huynh et al., 2005b). The ST was taken on dry skin; when this was not possible because of wetness and dirtiness, the measurement was repeated about 1 h later. As the skin markings washed off during bathing and sprinkling,

we re-marked frequently. Respiration rate was determined by counting flank movements using a stopwatch. After these two measurements, RT was taken using a thermometer (BARCHEN YS-723, Switzerland). We assume that the frequent physiologic measurements did not prevent the pigs from performing their normal activities, as pigs kept in small-scale systems in the tropics are used to direct and frequent contact with people.

2.3.3. Behavior

Behavioral data were collected by four cameras (Panasonic WV-BL 200 with a 2.8 mm fisheye lens), each mounted above the indoor area of each pen and with a range of view covering both the indoor and outdoor areas of the pen. Video observations were made in random order for 24 h on three consecutive days. The set-up was similar to the work done by Aarnink et al. (2001) and Huynh et al. (2004, 2005a). This entailed moving all four cameras to four other pens after each three-day period. In total, each pen was monitored for 16 days in trial 1 and for 33 days in trial 2. The images recorded by the cameras were stored digitally in a computer for behavioral analyses (Huynh et al., 2004, 2005a).

Absolute and relative frequencies of the behaviors were analyzed at group level. As a result of power cuts, approximately 2% data were lost and could therefore not be analyzed.

In this study, different areas were defined as follows:

(a) The indoor area consisted of feeding, resting and excreting areas. Feeding and resting areas were adjacent and were located at the front of the pen. The excreting area was located at the back of the pen, furthest away from the feeding area. The yard remained empty for free activity of the pigs.
(b) Lying and excreting behavior were determined in each area. Lying behavior was determined by scan sampling at 60 min intervals, resulting in 24 observations per pen per day. Excreting behavior was determined by continuous observations. The ethogram of lying postures, excretions and thermoregulatory behaviors consisted of behavioral elements described in detail elsewhere (Huynh et al., 2004, 2005a).

Lateral lying: the pig was lying flat on one side, not supported by the legs.
Huddling: pigs lying in contact with more than 50% of their flanks touching.
Defecation: relative frequency of defecation in resting area. This area at the front of the pen was half the size of the indoor pen and included the feeding area.
Urination: relative frequency of urination in resting area.
Excretions: in bath: frequency of defecation and urination in the bath.

Furthermore, thermoregulatory behavior was determined by analyzing the frequency at which the pigs used the bath and sprinkler.

2.3.4. Animal performance

Each pen had a concrete feed trough ($1.20 \times 0.40 \times 0.30$ m) and one drinking nipple. The feed troughs, which were fixed at the front of the resting area (see Fig. 1), were similar to those used in small-scale pig housing in Vietnam. The semi ad libitum feeding method was the same as that used in small-scale pig keeping in Vietnam. Feed was weighed and given four times per day at 07.30 h, 11.30 h, 15.30 h, and 19.30 h. Before new feed was added to the trough, any leftover feed was collected, weighed and recorded. Pigs had free access to water via the drinking nipple installed at the back of the resting area on the wall that connected indoor and outdoor area, as illustrated in Fig. 1. Water intake was recorded twice a day by reading a scale marked on the water container.

When calculating voluntary feed intake we assumed that the dry matter content of the leftovers was similar to that of the added feed. We calculated the rate of daily gain from live weights recorded at the start and end of each experiment.

2.4. Statistics

This experiment was a randomized complete block design, with treatments arranged in a 3×2 factorial design. From block 1 to block 2, each pen had the same treatment. The treatments were cooling systems WB, and S with a control (CON); and pen type: with yard (Y) or without an outdoor yard (NY). The effects

of treatments were determined by submitting data to ANOVA (GenStat, Release 7.1, 2002). We tested differences between treatments by using Fisher's test. The following data were analyzed:

1. For physiologic data analysis we used means of RR per minute, RT and ST of the three individual pigs per pen in each trial.
2. In the analysis we used means of behavioral data, such as lateral lying, total lying pigs, defecation in resting area, urination in resting area and the frequency at which the pigs used the bath and sprinkler.
3. We analyzed performance per pen over the whole period in each trial.

The model included the factors pen type (Y and NY), cooling system (WB and S), control (CON) and the interaction effects of cooling system and pen type. Trial was used as a block factor in the statistical model, so therefore the differences between treatment factors (cooling and pen type) were corrected for trial influences. Three-way interaction between pen type, cooling system and blocks was not significant and so was excluded from the model. The model was:

$Y_{ijkl} = \mu + Block_i + Cooling_j + Pen\ \ type_k + [Cooling * Pen\ type]_{jk} + \varepsilon_{ijkl}$.

In which Block is: Trial/(Cooling+Pen type); ε is: residual error.

Experimental unit is pen within trial.

3. Results

3.1. Ambient conditions

Air temperature and RH inside the animal house fluctuated throughout the experimental period and within a day. Air temperature averaged 27.5 °C (range from 24.3 to 29.7 °C) in trial 1, and 28.7 °C (range from 25.9 to 32.8 °C) in trial 2. The RH varied between 65.0% and 86.7% (average 74.7%) in trial 1, and between 43.8% and 82.6% (average 62.8%) in trial 2. Throughout the two trials the highest average *T* was recorded at 13.00 h (32.6 °C), and the lowest at 05.00 h (23.8 °C); the highest RH was at 06.00 h (89.3%), and the lowest at 13.00 h (52.7%) (Fig. 2).

3.2. Physiologic responses

In this study the pigs had an average RR of 50.9 min^{-1}. Mean RR was higher in the afternoon than in the morning (64.8 vs. 36.9 min^{-1}, respectively, $P<0.05$; Table 2). In the morning the differences between cooling and CON were smaller than in the afternoon. In the afternoon, RR was high, with strong effects of cooling, especially in Y pens. The sprinkler had more effect in the Y pens; the bath had more effect in NY pens ($P<0.05$).

The RT of pigs in this study averaged 39.2 °C. No effect of pen type was found in the morning. In the afternoon, however, pen type affected the RT of pigs (Table 2); in Y pens, pigs had a higher RT than pigs in NY pens ($P<0.05$). There was no significant interaction effect on RT between treatments.

On average, the ST of pigs in this study was 35.6 °C. The WB and S reduced ST by 0.3 and 0.4 °C, respectively ($P<0.05$). Note that cooling strongly affected ST in the afternoon but had no effect in the morning (Table 2). In the morning, pigs in Y pens had a lower ST than those in NY pens ($P<0.05$); this effect was not found in the afternoon. There were no significant interaction effects on ST.

3.3. Behavioral responses

3.3.1. Lying

Table 3 shows the results on the lying behavior of the pigs. On average, at any one time in the experimental period, 85.8% of pigs were lying. Significant interaction effects were found between cooling and pen type for a few variables (Table 3). The interaction showed that the effects of the WB on number of pigs lying depended on the presence of a Y. The number of lying pigs was highest in the CON with Y ($P<0.01$). The pens with a WB had the lowest number of lying pigs ($P<0.05$). By contrast, the highest number of lying pigs in the resting area was found in pens with a WB. The number of pigs lying laterally was higher in the CON than in the pens with cooling ($P<0.05$). The fewest pigs lying on their sides were recorded in pens with WB plus Y ($P<0.001$). The most huddling was recorded in the pens with S and pens NY ($P<0.01$). The least huddling was in CON with pen NY.

Table 2
Physiologic and performance parameters of ad lib, fast-growing group-housed finishing pigs: means and effect of pen type

Response variables	Cooling[†]	Pen type[‡]		Effects of factors with S.E.M[a] and F. prob[b]		
		Y	NY	Cooling rep.[c]=8	Pen type rep.=12	Cooling *pen type rep.=4
Respiration rate morning, min^{-1}	CON	$37.9^{a,I}$	$38.6^{a,I}$	0.91	1.11	1.41
	WB	$37.8^{a,I}$	$33.6^{b,II}$	**	n.s	**
	S	$34.9^{b,II}$	$38.6^{a,I}$			
Respiration rate afternoon, min^{-1}	CON	$74.5^{a,I}$	$65.3^{a,I}$	1.42	7.42	3.23
	B	$64.7^{b,I}$	$62.7^{a,I}$	**	n.s	*
	S	$58.5^{c,I}$	$63.3^{a,I}$			
Rectal temperature morning, °C	CON	39.0	39.0	1.20	1.08	1.28
	WB	39.1	39.1	n.s	n.s	n.s
	S	39.0	39.1			
Rectal temperature afternoon, °C	CON	$39.5^{a,I}$	$39.4^{a,I}$	1.31	0.06	1.24
	WB	$39.2^{a,I}$	$39.1^{a,I}$	n.s	*	n.s
	S	$39.5^{a,I}$	$39.4^{a,I}$			
Skin temperature morning, °C	CON	$34.1^{a,I}$	$34.5^{a,I}$	0.68	0.21	0.53
	WB	$34.1^{a,I}$	$34.4^{a,I}$	n.s	*	n.s
	S	$34.2^{a,I}$	$34.7^{a,II}$			
Skin temperature afternoon, °C	CON	$37.5^{a,I}$	$37.1^{a,I}$	0.47	1.41	0.48
	B	$36.9^{b,I}$	$36.7^{a,I}$	*	n.s	n.s
	S	$36.3^{b,I}$	$36.5^{a,I}$			

[†] Cooling=CON: pen with no cooling; B: pen with bath; S: pen with sprinklers; within cooling systems (within column) [a,b,c] values with different superscripts differ, $P<0.05$.
[‡] Pen type=Y: with outdoor yard; NY: without outdoor yard; between pen types (within row) [I, II] values with different superscripts differ, $P<0.05$.
[a] S.E.M=Standard Errors of Means.
[b] F. prob.=Fisher test probability; *=$p<0.05$; **=$p<0.01$; ***=$p<0.001$.
[c] rep.=the replications.

Table 3
Lying behavior of ad lib, group-housed finishing pigs: means and effects of pen type and cooling method

Response variables	Cooling[†]	Pen type[‡]		Effects of factors with S.E.M[a] and F. prob[b]		
		Y	NY	Cooling rep.[c]=8	Pen type rep.=12	Cooling*Type pen rep.=4
Lying, %	CON	$92.7^{a,I}$	$84.1^{a,I}$	1.38	5.08	5.36
	WB	$79.1^{b,I}$	$82.5^{a,I}$	*	n.s	**
	S	$88.7^{b,I}$	$87.8^{b,I}$			
Pigs lying in resting area, %	CON	$40.8^{a,I}$	$38.7^{a,I}$	7.17	2.94	7.81
	WB	$75.2^{b,I}$	$66.4^{b,I}$	0.09	n.s	n.s
	S	$52.2^{a,I}$	$45.4^{c,I}$			
Lateral lying, %	CON	$78.5^{a,I}$	$76.0^{a,I}$	2.20	1.63	2.97
	WB	$56.2^{b,I}$	$67.9^{b,I}$	*	n.s	***
	S	$69.3^{c,I}$	$62.0^{c,I}$			
Huddling, %	CON	$19.2^{a,I}$	$16.2^{a,I}$	0.47	2.05	2.26
	WB	$16.8^{b,I}$	$22.3^{b,II}$	*	n.s	***
	S	$17.5^{b,I}$	$23.8^{c,II}$			

[†] Cooling=CON: pen with no cooling; B: pen with bath; S: pen with sprinklers; within cooling systems (within column) [a,b,c] values with different superscripts differ, $P<0.05$.
[‡] Pen type=Y: with outdoor yard; NY: without outdoor yard; between pen types (within row) [I, II] values with different superscripts differ, $P<0.05$.
[a] S.E.M=Standard Errors of Means.
[b] F. prob.=Fisher test probability; *=p<0.05; **=$p<0.01$; ***=$p<0.001$.
[c] rep.=the replications.

3.3.2. Excretion

Table 4 shows frequencies of defecation and urination in the resting area. There was a clear interaction effect between cooling and pen type on defecation and urination ($P<0.001$, for both variables). Pigs defecated and urinated in the resting area much more often in NY pens than in Y pens, except for pens with a B. All pens with a WB had few excretions in the resting area (Table 4).

The data in Table 4 show that if a WB was present, pigs often defecated and urinated in it, especially in NY pens. Defecations in the WB were 64.5% in NY pens and 15.9% in Y pens ($P<0.01$). There was no significant difference between pen types for urination in the WB.

3.3.3. Use of cooling facilities

On average, each pig used the S 4.7 times of the 12 sprinkling periods daily between 10.00 h and 16.00 h. The minimum per pig was 1 sprinkling per day and the maximum was 11 sprinklings per day. No differences were found between pen type. The pigs used the WB on average 7.4 times per day. The intensive bathing time was between 14.00 h and 17.00 h. The shortest time the pig stayed in a WB was 1 min and the longest time was 9 min. The WB could contain a maximum of two pigs at the same time. The minimum use by a given pig was once per day and the maximum was 15 times per day. No differences were found between pen types.

3.4. Productivity performance

Table 5 shows the performance data. Cooling affected voluntary feed intake ($P<0.05$). Pigs in CON pens drank more, especially when compared with pigs in pens with a WB ($P<0.001$). Pen type also affected water intake; pigs in NY pens drank more ($P<0.001$). Pigs in pens with S had higher daily gain than pigs in other pens ($P=0.06$). However,

Table 4
Excretion behaviors of ad lib, fast-growing group-housed finishing pigs: means and effects of pen type and cooling method

Response variables	Cooling[†]	Pen type[‡]		Effects of factors with S.E.M[a] and F. prob[b]		
		Y	NY	Cooling rep.[c]=8	Pen type rep.=12	Cooling*pen type rep.=4
Defecation in resting area,%	CON	$7.7^{a,I}$	$62.3^{a,II}$	0.4	0.3	1.8
	WB	$3.5^{b,I}$	$5.4^{b,I}$	***	**	***
	S	$3.0^{b,I}$	$58.8^{a,II}$			
Urination in resting area,%	CON	$4.9^{a,I}$	$62.6^{a,II}$	1.7	1.2	2.8
	WB	$2.8^{a,I}$	$7.7^{b,I}$	**	*	***
	S	$1.2^{a,I}$	$62.4^{a,II}$			
Defecation in bath, %	CON				5.9	
	WB	15.9	64.5		**	
	S					
Urination in bath, %	CON				17.7	
	WB	18.4	60.4		n.s	
	S					
Sprinklers used frequency, time pig^{-1} d^{-1}	CON					
	WB				4.70	
	S	4.8	4.6		n.s	
Bathing frequency, time pig^{-1} d^{-1}	CON				2.68	
	WB	7.2	7.7		n.s	
	S					

[†] Cooling=CON: pen with no cooling; B: pen with bath; S: pen with sprinklers; within cooling systems (within column) [a,b,c] values with different superscripts differ, $P<0.05$.
[‡] Pen type=Y: with outdoor yard; NY: without outdoor yard; between pen types (within row) [I, II] values with different superscripts differ, $P<0.05$.
[a] S.E.M=Standard Errors of Means.
[b] F. prob.=Fisher test probability; *=$p<0.05$; **=$p<0.01$; ***=$p<0.001$.
[c] rep.=the replications.

Table 5
Performance of fast-growing group-housed finishing pigs: effects of cooling and pen type

Response variables	Cooling[†]	Pen type[‡]		Effects of factors with S.E.M[a] and F. prob[b]		
		Y	NY	Cooling rep.[c]=8	Pen type rep.=12	Cooling*pen type rep.=4
Voluntary feed intake, g pig^{-1} d^{-1}	CON	2074^{a,I}	2063^{a,I}	0.11	0.09	0.16
	WB	2068^{a,I}	1991^{b,II}	*	n.s	n.s
	S	2147^{b,I}	2198^{a,II}			
Drinking water, liter pig^{-1} d^{-1}	CON	10.160^{a,I}	11.150^{a,II}	0.04	0.02	0.40
	WB	5.830^{b,I}	8.800^{b,II}	***	***	**
	S	8.620^{c,I}	11.290^{a,II}			
Daily gain, kg^{-1} d^{-1}	CON	0.562^{a,I}	0.507^{a,I}	0.05	0.04	0.07
	WB	0.560^{a,I}	0.512^{a,I}	0.06	n.s	0.09
	S	0.566^{a,I}	0.606^{b,II}			

[†] Cooling=CON: pen with no cooling; B: pen with bath; S: pen with sprinklers; within cooling systems (within column) [a,b,c] values with different superscripts differ, $P<0.05$.
[‡] Pen type=Y: with outdoor yard; NY: without outdoor yard; between pen types (within row) [I, II] values with different superscripts differ, $P<0.05$.
[a] S.E.M=Standard Errors of Means.
[b] F. prob.=Fisher test probability; *=p<0.05; **=$p<0.01$; ***=$p<0.001$.
[c] rep.=the replications.

there was a tendency for interaction between cooling system and pen type. The pigs in NY pens with S had the highest daily gain ($P=0.09$).

4. Discussion

Fundamental and practical research approaches are necessary to solve heat stress problems in pig production. Recently, Aarnink et al. (2001), Brown-Brandl et al. (1998, 2001), and Huynh et al. (2005a,b) reported behavioral and physiologic changes in growing and finishing pigs when T gradually increased above a certain critical threshold. Huynh et al. (2005a,b) also estimated the upper critical temperature for reduced feed intake. This IPt was at above 25.5 °C of the ambient temperature. In addition, above a range of T from 21.3 to 23.4 °C, pigs raised their RR; finally, above a T of 24.6 to 27.1 °C their RT increased at a large deviation (from 0.11 to 0.15 °C per degree Celsius rise in T), indicating the upper limit of heat stress tolerance. It should be emphasized that in the present study, pigs experienced natural fluctuation within a day, whereas in the previous study of Huynh et al. (2005a,b) the pigs were exposed to a constant daily T and RH. In the present study, the pigs showed a consistently high RR and ST, which seemed to be their reaction to tropical conditions. This trait is more important in very lean fast-growing pigs and in the fattening period (Mount, 1979). The pigs' responses to the tropical climate will be discussed point by point in the following paragraph.

4.1. Behavioral benefits

Aarnink et al. (2001) reported that when T increased above 20 to 25 °C for animals in the weight range from 25 to 105 kg, pigs increased the number of excretions in the resting area. Huynh et al. (2004, 2005a) found that the number of instances of huddling of pigs decreased with increasing T. They found that above 18.8 °C, lying on a slatted floor increased, above 20 °C excretions on solid floor increased, and above 24.2 °C the activity-related heat production was reduced. As shown in Table 2, at constant high T above 25 °C, pigs in NY pens fouled their resting area. The effects of the Y on excretion and lying behavior emphasize the importance of allocating sufficient space to fattening pigs in a hot tropical climate. With an extra Y, pigs would benefit significantly with regard to cleanliness and comfort. According to Huynh et al. (2005a), increasing lying behavior indicates heat stress, because lying animals avoid

expending energy on movement and therefore reduce their total heat load. However, as indicated in the result, pigs gained weight the most in pen NY with S. Clearly, a future study is needed to investigate which type of pen with Y and with WB or S would best achieve productivity and comfort for the animals.

As the pigs excreted in the WB, especially in NY pens, in this treatment we recorded fewer excretions in the resting area. In previous studies, Aarnink et al. (2001) and Huynh et al. (2004, 2005a) showed that a 60 kg pig provided with 1 m^2 floor space (with 40% slatted floor) in hot conditions did not discriminate between its resting and defecation areas at all. In addition, Hacker et al. (1994) reported that the pig's basic instinct is to excrete in a wet, cool place. These findings might explain the high frequency of excretion in the WB. This is undesirable with respect to hygiene and health. In practice, the problem might be solved by locating the WB away from the excretion area, e.g. in the yard.

4.2. Physiologic benefits

On average, a normal RR in growing pigs ranges from 29.1 to 32.7 min^{-1} (Huynh et al., 2005b), which is very close to the RR we measured in the morning. However, on average the mean RR in the present study was 51.2 min^{-1}. Christon (1988) found that in tropical conditions, 25 to 50 kg pigs increased their RR by 366% when T were consistently above the thermo neutral zone. In previous controlled climate studies, Huynh et al. (2005b) had shown that the RR of ad lib fed, group-housed finishing pigs started to increase when T was in the range from 21.3 to 23.4 °C. In this field study, morning measurements revealed the T was at its lowest point (23.8 °C) and close to these IPts. However, in the afternoon when T was high, the RR increased significantly and the pigs could experience heat stress. According to Brody (1945), when animals must employ their thermoregulatory devices, e.g. increase RR, they are out of their thermo neutrality and in stressful temperature. The temperature and RH in our field study fluctuated greatly. There was a clear diurnal pattern, causing a high RR in the afternoon and moderate RR in the morning. In this state the cooling system had the effect of lowering the RR. Importantly, the high RR enabled the pigs to maintain a RT in the normal range. Heitman and Hughes (1949) reported that in 90 kg pigs kept under controlled conditions with T in the range from 5 to 39 °C, an elevated RR was immediately followed by a rise in RT. We did not see this in our study, not even in the afternoon, when the pigs' RR was much higher than in the morning. In another study with a highly controlled climate, Huynh et al. (2005b) reported that the RT of growing pigs increased when T exceeded a certain IPt (range from 24.6 to 27.1 °C). At this level, RT increased at a large deviation until the end of the experimental temperature set-up (32 °C) (Huynh et al., 2005b). It was concluded that increased RT is an important indicator of heat stress in fattening pigs. Bull et al. (1997) showed that when gilts were exposed to one of three cooling facilities, their RT did not differ from that of control pigs without cooling. It is clear that by responding with a high RR, the pigs in our study maintained a constant RT throughout changes in T. This sheds light on whether the pigs in our study were coping with heat stress. Though they responded to high T in the afternoon by increasing their RR, the pigs did not exhibit a similar response for RT.

Despite their constant RT, the ST of pigs in the CON pens was significantly higher than those of pigs in the other treatments with cooling facilities. At the high T in our study, pigs had a consistently high ST (average of 35.6 °C). Several studies have reported the normal ST of finishing pigs: Geers et al. (1987), for example, reported that the comfort ST of homeothermic animals ranges from 32 to 35 °C. This is similar to the finding reported by Huynh et al. (2005b) that within T ranging from 16 to 22 °C, the ST of 60 kg ad lib fed, group-housed pigs ranged from 33 to 35 °C. In the current study, the T in the morning when ST was measured was comparable and the response of pigs' ST was markedly similar. However, in the afternoon with higher T, ST was higher than in the morning. It is interesting to see that when T varied within a day, the change of ST distinctly harmonized with the findings of Huynh et al. (2005b). The high ST of pigs in the present study shows that pigs raised under tropical conditions not only reacted by maintaining a high RR but also by maintaining a high ST. This is logical, because vasodilatation of epidermal blood vessels allows deep body heat load to be dissipated more easily to the cooler environment (Yousef, 1985).

4.3. Performance effects

In this field study, feed intake was significantly different between treatments. In our study we assumed that the leftover feed had the same dry matter as the given feed. Though this was probably not so, any difference would have been minor, as the feed always remained dry. In an earlier study (Huynh et al., 2005b) ratio of water to feed intake was lower than in the present study (2.4 vs. 4.4). Ingram and Legge (1969–1970) calculated that when *T* increased between 5 and 25 °C, the body temperature of the pig is 39 °C and under these conditions between 33 and 41 mg of water would be contained in each litre of air exhaled. The heat required to evaporate this water at body temperature is 0.574 cal/mg and the evaporative loss is thus estimated at 217–281 cal/min. In another study Ingram and Stephens (1979) reported a 40% increase in drinking water when the hypothalamus warmed up and the pig's ST rose. In addition, Aarnink et al. (1992) reported an increase of the ratio of latent heat loss (heat loss by evaporation) to total heat loss at increasing *T*. The authors calculated that at *T* about 38.5 °C, that ratio is equal to 1. This meant that at that *T*, all body heat must be lost by evaporation. Thus, because of evaporative heat regulation, the heat-stressed pigs probably needed a large surplus of water, independent from feed intake. Additionally, pigs in the WB group frequently drank water from the WB, hence a low water intake was observed in this group, as well as a low daily gain that was a negative effect of poor hygiene.

4.4. Summary of the effects of cooling and housing facilities

Cooling systems in pig housing are beneficial for reducing animal heat stress in warm climates. According to Kunavongkrit and Heard (2000), pig producers in South-East Asia try to reduce the detrimental effects of high *T* in animal houses in many ways, such as air conditioning and evaporative cooling (e.g. water dripping and fogging systems for boar and sow houses). Though all these systems are helpful, they involve high investments and some can cause adverse effects like increased humidity. It is known that high RH depresses pig production (Lucas et al., 2000). A cooling system should avoid introducing surplus water into the air of animal houses. In addition, our pigs were free to choose whether to use the cooling system.

A bath contributed to reduce heat stress, as can be seen from the lower ST and RR. Bull et al. (1997) reported that RT could be used as thermoregulatory assessment. If RT is taken as a crucial indicator of animal comfort, a bath clearly contributes importantly to this comfort under tropical conditions. Direct observation on bathing of pigs in this study showed that a pig stayed in a WB for an average of 3 min (the shortest was 1 min and the longest 9 min). With this duration of bathing, the resulting lower RT was unsurprising. However, it should be noted that maintaining a WB is costly in terms of labor for cleaning and refilling. In developing areas, it is possible to recommend farmers to clean the WB more frequently than twice a week, but for Western intensive production systems this is an impractical recommendation. Therefore, to improve the use of this cooling system, further studies should investigate the optimal location of the WB, pen size and cleaning frequency.

A yard significantly increased the RT of pigs during the afternoon. As reported, in our study the diurnal *T* fluctuation was about 8.8 °C. In the afternoon, *T* (32.6 °C) was very close to the controlled temperature (32 °C) in previous studies by Huynh et al. (2005a,b), in which experimental pigs had increased their RT up to 40 °C. Furthermore, pigs exposed to sunshine could gain heat from radiation (Heitman and Hughes, 1949). According to Blackshaw and Blackshaw (1994), when *T* was above 25 °C, more than 80% of pigs lay in the shade when they were in the yard. In our study no shade was available. Shade in the yard probably reduces heat stress and might contribute to the effects of cooling on pigs' productivity.

An important finding in our study was that pigs in NY pens with an S gained weight fastest. This is an interesting finding because these pigs had limited space and had a high frequency of huddling. The pigs in pens with a S not only benefited from S by showering but also by lying on the floor wetted by S. With 12 sprinkling periods at 30 min intervals, the floor stayed wet almost for the whole period between 10.00 h and 16.00 h. As discussed, within a limited space, animals benefited more from S than from WB. A possible reason for this may be that in pen NY, with less evaporative effect from air moving in and out the pen, the floor remained wet longer after sprinkling

than in pen Y. Animals therefore could cool themselves for a longer time. Ingram (1965b) presented evaporative water loss from the skin of pigs, reporting that evaporation could last up to 30 min (from water) and from 90 min to 120 min (from mud). Thus, in tropical conditions, pens with a freely accessible area (or more space per pig) can facilitate alleviation of heat stress by increasing the opportunity for eliminating heat loss, and thus giving many more benefits for the pigs in terms of behavioral comfort and environment (a cleaner pen). In a limited area, however, an S system could increase pig productivity.

5. Implications

From this study we conclude that ad libitum, fast-growing, crossbred group-housed pigs raised in a tropical climate clearly responded physiologically and behaviorally to this climate. The pigs seem to have responded to tropical conditions by maintaining a high respiration rate. Cooling systems like water bath or sprinklers and also an outdoor yard had positive effects on the physiologic responses, behavior and productivity of the pigs in a small-scale farming situation. Interaction effects between cooling systems and pen type were present. The combination of sprinkling and provision of an outdoor yard gave the lowest respiration rate in these pigs, while the combination of sprinkling and a pen without an outdoor yard gave the highest daily gain.

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