

## Impact of body truck's microclimate on pig skin temperature during pre-slaughter logistics

Impacto do microclima do caminhão na temperatura superficial de suínos durante a logística pré-abate

Impacto del microclima del camión en la temperatura de la superficie de los cerdos durante la logística pre-sacrificio

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### **Abstract**

Handling of pigs under hot weather conditions face a critical challenge in meeting thermal comfort and animal welfare standards. Moreover, climate variation affects production and pre-slaughter logistics. This study assesses the thermal comfort of pigs during pre-slaughter procedures under different weather conditions. The case study was conducted at two commercial pig farms in Southeastern Brazil. The bioclimatic index more accurately indicated the pigs' thermal comfort than the temperature-humidity index. The length of the transportation journey critically affected the pigs' thermal comfort, as shown by the rise in pigs' skin temperature (1.56 °C and 1.64 °C on pigs from Farm 2 and Farm 1, respectively). The pigs reached the critical upper limit of the thermoneutral zone under hot weather conditions. Adequate microclimate control during the pre-slaughter management procedures might improve pig welfare. To increase the animals' thermal comfort, both farms should reschedule their transportation to a cooler time of the day. Both farms should also improve their pre-slaughter management processes by training workers to comply with animal welfare requirements and reduce loss.

**Keywords:** Animal welfare; Livestock; Thermal comfort; Truck microenvironment.

### Resumo

O manejo de suínos sob condições de clima quente enfrenta o crítico desafio de atender o conforto térmico e os padrões de bem-estar animal. Considerando ainda, os efeitos da variação climática na produção e na logística pré-abate. Este estudo avalia o conforto térmico dos suínos durante os procedimentos pré-abate sob as diferentes condições climáticas. O estudo de caso foi conduzido em duas fazendas comerciais de suínos localizadas na região Sudeste do Brasil. Os resultados do conforto térmico dos suínos foram mais precisos com a utilização do índice bioclimático do que com o índice de temperatura-umidade. A duração da viagem de transporte afetou criticamente o conforto térmico dos suínos, conforme demonstrado pelo aumento da temperatura da pele dos suínos (1,56 °C e 1,64 °C dos suínos da Fazenda 2 e Fazenda 1, respectivamente). Os suínos alcançaram o limite superior da zona de temperatura em condições de clima quente. Dessa forma, o controle adequado do microclima durante o gerenciamento dos procedimentos pré-abate pode melhorar o bem-estar dos suínos. Para melhorar o conforto térmico dos animais, ambas as fazendas devem reprogramar as operações de transporte para horários mais frescos do dia. Ambas as fazendas devem também melhorar os processos de gestão pré-abate por meio de treinamentos dos funcionários para cumprir os requisitos de bem-estar animal e reduzir as perdas.

**Palavras-chave:** Bem-estar animal; Pecuária; Conforto térmico; Microambiente de caminhões.

### Resumen

El manejo de los cerdos en condiciones de clima cálido enfrenta el desafío crítico de cumplir con los estándares del confort térmico y bienestar animal. También considerando los efectos de la variación climática en la producción y la logística pre-sacrificio. Este estudio evalúa el confort térmico de los cerdos durante el procedimiento pre-sacrificio en diferentes condiciones climáticas. El análisis de caso se llevó a cabo en dos granjas de cerdos comerciales ubicadas en la Región Sudeste de Brasil. Los resultados del confort térmico de los cerdos fueron más precisos con el uso del índice bioclimático que con el índice temperatura-humedad. La duración del viaje de transporte afectó críticamente el confort térmico de los cerdos, como lo demuestra el aumento de la temperatura de la piel de los cerdos (1,56 °C y 1,64 °C de los cerdos de Granja 2 y Granja 1, respectivamente). Los cerdos han alcanzado el límite superior de la zona de temperatura en condiciones de clima cálido. De esta forma, un control microclimático adecuado durante la gestión de los procedimientos pre-sacrificio puede mejorar el bienestar de los cerdos. Para mejorar el confort térmico de los animales, ambas granjas deben reprogramar las operaciones de transporte para las horas más frescas del día. Las granjas también deben mejorar los procesos de gestión pre-sacrificio a través de la capacitación de los empleados para cumplir con los requisitos de bienestar animal y reducir las pérdidas.

**Palabras clave:** Bienestar animal; Ganadería; Confort térmico; Microambiente de camiones.

## 1. Introduction

Animals interact directly with their rearing environment and respond physically and behaviorally to harsh conditions (Brown-Brandl *et al.*, 2012; Renaudeau *et al.*, 2012; Fox *et al.*, 2014). Pig production in hot and warm regions requires environmental control investments to meet animal welfare standards. Farmers plan their management activities based on weather conditions and animal characteristics such as age, health conditions, and management. By controlling the environment, farmers can help their animals maintain thermoregulation and increase productivity (Renaudeau *et al.*, 2011).

Over the last two decades, the average environmental temperature in tropical countries such as Brazil has varied more widely than in previous decades (INMET, 2015). The consequences of climate change and its consequences, such as heatwaves, might endanger future livestock production (Naas *et al.*, 2010). Animals in developing countries are usually reared in side-opened systems relying on regional weather during reproduction, growing, and fattening (Renaudeau *et al.*, 2011). The cooling systems used in pig production units in Brazil typically combine axial fans and fogging systems and often rely on manual handling by skilled laborers (Sarubbi *et al.*, 2012).

The skin surface temperature is a function of air temperature (the air–skin temperature relationship is linear) (Mcglone *et al.*, 2014). Previous studies show critical loss during transportation to the slaughterhouse when the environmental temperature is above 30 °C (Haley *et al.*, 2008; Kephart *et al.*, 2014a; Mcglone *et al.*, 2014). The pigskin temperature might also depend on the truck microenvironment (temperature, RH, and WS) and other variables (stock density, physical efforts, fighting among the animals, and heart rate), the truck design, and the animals' locations inside the truck (Correa *et al.*, 2014; Mcglone *et al.*, 2014). The truck microenvironment depends on the location, time, and season of the transport and is affected by extreme air temperature, RH, and WS conditions (Mcglone *et al.*, 2014). Stocking density, animal size, the noxious gas concentration, and the truck parts'

materials might also impair the safe transportation of pigs (Marahrens *et al.*, 2011; Schwartzkopf-Genswein *et al.*, 2012; Fox *et al.*, 2014; Dalla Costa *et al.*, 2017).

Growing and finishing managements and pre-slaughter process are planned to meet the animal welfare guidelines, which is a demand in the swine market (Trienekens and Wognum, 2013). The trailer design can affect animal handling during transportation, the microenvironmental conditions, and the bruising and injury rate. In Brazil, pigs are transported on single or double-decker wooden open-top trucks, double-decker open-side roofed metal trucks, and triple-decker open-side roofed metal trucks (Triel-HT, 2016). Compassionate transportation relieves the animals' suffering, improves their welfare, meets the quality requirements, reduces losses, and increases the pork supply chain profits (Dalla Costa *et al.*, 2019b). There is information on handling pigs during transportation to the slaughterhouse in developed countries (Hakansson *et al.*, 2016; Dalla Costa *et al.*, 2019a); however, there is a gap in the literature related to these procedures in tropical countries. Therefore, the present study evaluates the impact of two different weather on the thermal comfort of pigs during the pre-slaughter logistics (PSL).

## 2. Methodology

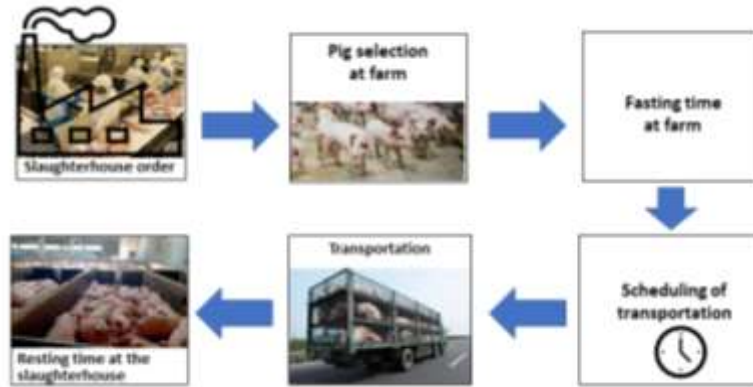
In order to evaluate the impact of two different weathers on the thermal comfort of pigs during the pre-slaughter logistics, we proceeded with a qualitative and quantitative research applying a Multiple Case designed based on collect data from an experiment conduct in two farms during pig transportation from farm to slaughterhouse. The animals were observed during loading, journey and unloading as explained in topic 2.1 and 2.2. Qualitative and quantitative research allow to better understand and explore the phenomenon that it is limited when to use just one method (Martins, 2012). To conduct this paper, we based on previous studies, such as: McGlone *et al.* (2014), Kephart *et al.* (2014a), Kephart *et al.* (2014b), Correa *et al.* (2014) and Dalla Costa *et al.* (2017).

Data collection took place in two commercial pig farms in southeastern Brazil located in Espírito Santo state (Farm 1, latitude 20°50'56" S and longitude 41°06'46" W) and São Paulo state (Farm 2, latitude 22°52'52" S and longitude 49°14'21"W). Farm 1 has a tropical climate with an average annual temperature of 23.6 °C and a rain index of 1200. Both farms were located in a region with two distinct seasons, dry from April to September and rainy from October to March (INCAPER, 2020). Farm 2 has a tropical climate with an annual average temperature of 20.8 °C and a rain index of 1353 mm with hot and dry winters (EMBRAPA, 2020). Farm 1 is an independent producer with a sales contract with a local slaughterhouse, and Farm 2 is an integrated system controlled by a supermarket chain in São Paulo state.

### 2.1 Pre-slaughter transport

In the present study, we monitored two pig shipments between the farm and the slaughterhouse, one for each farm. Both follow the same flow shown in Figure 1.

**Figure 1:** Flowchart of pig transportation from the farm to the slaughterhouse.



Source: Authors (2021).

The selected animals fasted for six hours before boarding the truck, and while waiting for boarding, they had access to drinking water (Dalla Costa *et al.*, 2019a). The farmer provides the vehicle, the stocking density, and the transport documentation. The transport stocking density is calculated using Equation 1.

$$D = \frac{P \times N}{A} \quad (1)$$

where D = stocking density (kg/m<sup>2</sup>), P = mean pig weight, N = number of pigs, and A = body truck area (m<sup>2</sup>). The calculated density was 251.0 kg/m<sup>2</sup> in Farm 1 and 245.0 kg/m<sup>2</sup> in Farm 2.

Finishing pigs (230 Landrace and White Large hybrids) were transported according to the slaughterhouse demand, and 144 were used to evaluate the body truck's microclimate. Table 1 details the operation.

**Table 1:** Characteristics of the vehicles and transportation.

Characteristics	Farm 1	Farm 2	Characteristics	Farm 1	Farm 2
Body truck	Wood	Steel	Compartments	4	16
Platform	Fixed	Fixed	Length (m)	7	16
Net weight (t)	8.61	19.3	Width (m)	2.45	2.45
Total area (m <sup>2</sup> )	17.2	39.2	Ventilation	Natural	Natural
Compartment area (m <sup>2</sup> )	8.6	4.9	Total of pigs	70*	160 <sup>+</sup>
Floors	2	2	Density (kg/m <sup>2</sup> )	251	245

\* 52 pigs were observed in Farm 1 from total; <sup>+</sup>92 pigs were observed in Farm 2 from total.  
 Source: Authors (2021)

The estimated pigs' growth cycle in Farm 1 and Farm 2 was and 156 and 160 days, respectively, with average slaughter weights of 123.0 kg and 120.6 kg. The pigs from Farm 1 were transported in a double-decker open-top wooden truck (7.00 m long and 2.45 m wide). The two floors were divided into two compartments. The pigs from Farm 2 were transported in a double-decker open-side roofed metal truck (16.00 m long and 2.45 m wide), with eight compartments per floor. The stocking densities were 0.40 and 0.41 m<sup>2</sup>/pig, respectively. During loading, the pigs from Farm 1 were guided in groups of six at a loading time of 2.06 min/group, while in Farm 2, pigs were guided in groups of ten, requiring 2.46 min/group. In both farms, the pigs were

loaded in the afternoon, at 13h11min and 13h47min, respectively. During loading, the pigs received water sprinkling to alleviate heat stress. After loading, the whole truck was watered to cool down the pigs.

The research was carried out by observing the animals and recording the data without interfering with the animals' routine. The study was approved by the Institutions' Committee on Animal Research, protocol n. 321/15.

## 2.2 Variables recorded and experimental procedure

The recorded variables were the dry-bulb temperature ( $T_a$ , °C), the relative humidity (RH, %), the wind speed (WS, m/s), the skin temperature of the finishing pigs (ST, °C). The temperature-humidity index (THI) was calculated using Equation 2 (Roller and Goldman, 1969), and the bioclimatic index (BI) was estimated using Equation 3 (Texier *et al.*, 1979).

$$\text{THI} = 0.45 \text{ wbt} + 1.35 T_a + 32 \quad (2)$$

where wbt = wet bulb temperature (°C).

$$\text{BI} = 0.89 T_a + 0.05 \text{ RH} - 1.81 \text{ WS} + 0.02 W - 21.15 \quad (3)$$

where W = weight of the pigs (kg),  $T_a$  = dry-bulb temperature (°C), RH = relative humidity (%).

The environment temperature and relative humidity (AT and RH) inside the truck were monitored during the three phases of transportation (1) loading at the farm, (2) the journey inside the truck and, (3) unloading at the slaughterhouse.  $T_a$  and RH's variations were recorded using a data logger (Testo model 172H, Testo Co., Germany) installed in the center of the truck body and recording data every 5 min. The WS was registered using an anemometer (Krestel, Nielsen-Kellerman Co., USA). The environmental data were recorded every 5 min (Mcglone *et al.*, 2014). The pigskin temperature was registered by a thermal infrared camera (Testo model 875, Testo Co., Germany), the emissivity index was set to 0.95 on all pictures (Brown-Brandt *et al.*, 2012). Thermal infrared images were taken from both laterals of the truck body, targeting the pigs during the loading, travel, and unloading phases. During loading, mid-journey, and unloading, the thermal images were registered (before the truck started moving) and after arrival at the slaughterhouse. The mid-journey distance was 22.5 km for pigs from Farm 1 and 30 km for pigs from Farm 2.

## 2.3 Statistical analysis

The PSL (loading, journey, and unloading, and the climate conditions at pig Farm 1 and 2) effects on the pigskin temperature were analyzed. The statistical analysis was based on the following mathematical model (Banzatto and Kronka, 2006, Equation 4):

$$Y_{ijr} = \mu + T A_i + C C_j + \epsilon_{ijr} \quad (4)$$

$Y_{ijr}$  is a variable dependent on  $T_a$ , RH, WS, THI, and BI,  $\mu$  is the general average,  $T A_i$  and  $C C_j$  represent the effects of transport activity  $i$  and climate condition  $j$ , respectively  $\epsilon_{ijr}$  is the random error in each observation. The ANOVA was applied using a general linear model, and the Tukey test was performed using the software SAS®, version 9.0, adopting a confidence level of 0.95 in all analyses.

## 3. Results

$T_a$  and BI results during the loading, journey and unloading management differed among the studied farms ( $P < 0.05$ ). The bioclimatic index (BI) estimates the pigs' thermal comfort more accurately than the THI, probably because the BI calculation

includes the WS variation. RH affected the length of the journey than the other studied activities ( $P < 0.05$ ). Both the loading process and the journey had similar effects on the pigskin temperature ( $P < 0.05$ ) (Table 2).

**Table 2:** Average air temperature ( $T_a$ ), relative humidity (RH), wind speed (WS), pigskin temperature (ST), temperature–humidity index (THI), and bioclimatic index (BI) during each transportation activity.

Variables	Loading	Journey	Unloading
n	59	50	35
$T_a$ (°C)	$30.6 \pm 0.1^a$	$29.1 \pm 0.1^b$	$28.4 \pm 0.1^c$
RH (%)	$60.4 \pm 0.7^b$	$59.0 \pm 0.9^a$	$60.4 \pm 1.0^b$
WS (m/s)	-	$0.86 \pm 0.0$	-
ST (°C)	$31.7 \pm 0.2^a$	$33.1 \pm 0.3^a$	$29.0 \pm 0.3^b$
THI	$83.7 \pm 0.2^a$	$81.1 \pm 0.2^b$	$79.7 \pm 0.2^b$
BI	$11.5 \pm 0.1^a$	$8.56 \pm 0.1^c$	$9.6 \pm 0.1^b$

a, b, c are significance indicators. Means with the same letter in the same line do not differ by the Tukey test ( $P > 0.05$ ); n = number of pigs. Source: Authors (2021).

During transport from Farm 1, the  $T_a$  and RH ranges were 33.2–41.4°C and 27.8–57.6%, respectively, and the pigskin temperature fluctuated from 34.8 to 40.3 °C (amplitude = 5.5 °C). The pigs transported from Farm 2 were exposed to  $T_a$ , ranging from 18.8 to 24.8 °C and RH, ranging from 74.8 to 95.7%. The pigskin temperature fluctuated between 17.7 and 33 °C (amplitude = 15.3 °C).

The surface temperature of the pigs was positively correlated with  $T_a$ , THI, and BI, with correlation coefficients of 0.8474, 0.8352, and 0.7867, respectively (all  $P < 0.05$ ), and was negatively correlated with RH (–0.8178,  $P < 0.05$ ). The THI and BI were positively correlated with  $T_a$  (respective correlation coefficients of 0.9954 and 0.91; both  $P < 0.05$ ) and negatively correlated with RH (–0.8028 and –0.7187, respectively; both  $P < 0.05$ ). Therefore, ST increased when  $T_a$ , THI, and BI increased and reduced by increasing RH.

### 3.1 Thermal comfort of pigs during pre-slaughter management

On the day of the transportation to the slaughterhouse, the weather conditions at Farm 2 were more favorable for the pigs' thermal comfort than those at Farm 1. During PSL management at Farm 2, the THI increased from 65.5 to 76.0 (amplitude = 10.5 °C), and the pigskin temperature increased by 8.16 °C. At Farm 1, the THI rose from 87.3 to 100.2 (amplitude = 12.9 °C), and the pigskin temperature decreased by 0.1°C. The pigs transported from Farm 2 (90.2%) were in a thermally neutral environment ( $THI < 75$ ), and 9.8% reached the alert to the critical thermal comfort zone ( $THI 75–79$ ). All pigs transported from Farm 1 were in the emergency zone, exposed to acute thermal stress ( $THI > 83$ ; Table 3). Although the skin temperature followed the increase in THI at Farm 2, it decreased at Farm 1 despite the increased THI. One interpretation of this result is the activation of a survival characteristic in the pigs that maintains a constant core body temperature.

**Table 3:** Average, standard deviation, and range of pigs' surface temperature (°C) for different THI during PSL at Farm 1 and Farm 2.

Farm 2 THI	n	Average (°C)	SD (°C)	Minimum (°C)	Maximum (°C)
65<68*	16	20.36 <sup>c</sup>	2.57	17.7	27.7
68<71*	33	25.37 <sup>b</sup>	2.42	20.0	29.3
71<74*	34	27.86 <sup>a</sup>	2.65	22.9	33.0
>74**	9	28.52 <sup>a</sup>	2.89	24.4	31.7
Farm 1 THI	n	Average (°C)	SD (°C)	Minimum (°C)	Maximum (°C)
87<90 <sup>++</sup>	7	37.7	1.95	35.2	39.9
90<93 <sup>++</sup>	21	38.5	1.05	36.6	40.3
93<96 <sup>++</sup>	10	37.5	1.25	35.9	39.5
>96 <sup>++</sup>	14	37.6	1.45	34.8	39.5

a, b, c, d are the significance indicators. The same letter in the same column means that the results do not significantly differ by the Tukey test ( $P>0.05$ ); n = number of pigs observed at the given *THI*; SD = standard deviation. \* thermal comfort (>75); \*\* (75–79) alert, critical thermal comfort; + (79–83) danger, critical thermal stress; and ++(>83) emergency, very acute thermal stress (Barbari and Conti, 2009). Source: Authors (2021).

The BI ranged from 11.5 to 19.9 (amplitude = 8.4) at Farm 1, and from 1.12 to 6.95 (amplitude = 5.8) at Farm 2. The BI at both farms was higher during loading than transportation or unloading. However, the pigs' surface temperature rose sharply (by 1.0°C and 1.4 °C, at Farm 1 and Farm 2, respectively) during the journey (Table 4). At Farm 2, the BI reduced throughout the PSL activities, from 4.8 during loading to 3.4 while unloading (amplitude = 1.4). However, BI decreased 5.4 from loading to journey during PSL at Farm 1 but increased 2.9 from the journey to unloading.

**Table 4:** Average, standard deviation, and range of pigs' skin temperature (°C) and bioclimatic index (BI) during PSL activities at Farm 1 and Farm 2.

PSL	Farm 1				Farm 2			
	BI	ST (°C)	BI	ST (°C)	BI	ST (°C)	BI	ST (°C)
Loading	Avg ± SD 18.2±1.2	Range 16.6-19.8	Avg ± SD 37.1±2.6	Range 34.8-39.5	Avg ± SD 4.8±0.7	Range 3.9-6.3	Avg ± SD 26.4±1.1	Range 22.9-29.3
Journey	12.8±0.7	11.4-13.9	38.1±1.7	35.2-40.3	4.2±1.5	1.1-6.9	27.8±2.8	24-33
Unloading	15.7±0.0	15.7-15.8	38.0±0.8	36.6-39.2	3.4±0.6	2.7-4.5	19.9±1.2	17.7-21.6

Source: Authors (2021).

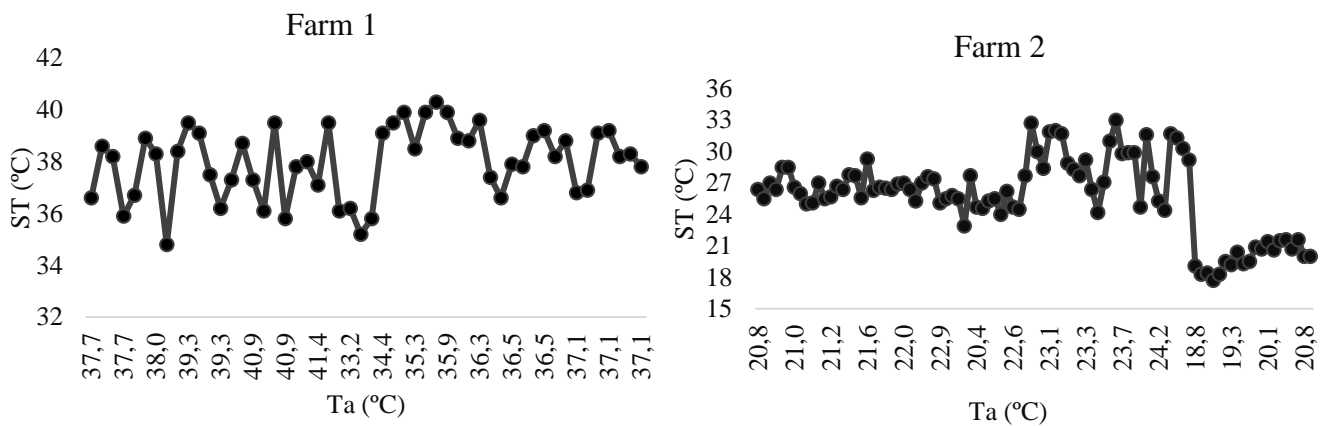
### 3.2 Loading, journey from the farm to the slaughterhouse and Unloading

During loading, transport, and unloading, the pigs from Farm 1 were exposed to more variable temperatures than Farm 2. The ambient dry-bulb temperature increased by 4.1 °C during the first 20 minutes of the journey from Farm 1 to the slaughterhouse. After the water sprinkling process, the temperature decreased by 8.2°C but then gradually climbed by 2.5 °C. During unloading, the dry-bulb temperature increased by 1.0 °C. On the other hand, during the first 20 minutes after loading from Farm 2, the dry-bulb temperature decreased 2.1°C, and then gradually increased 1.7 °C. The initial decline in air temperature resulted from the evaporative cooling effect of the sprinkling water before and after loading. During transportation, the air temperature varied from 20 to 24.8 °C (averaging 22.8 °C). The air temperature was slightly higher during the first 30 minutes

of transport than after 85 minutes. After 85 min of transportation, the air temperature had gradually decreased by 4.2 °C. During unloading, the air temperature was further reduced by 2.0 °C.

The dry-bulb temperature increased while loading the pigs at Farm 1. During the loading, it varied from 37.7 to 41.4 °C. The surface temperature of the pig skins also rose 1.27 °C during loading. The temperature rise was credited to the overcrowding of pigs in the truck, but the sprinkling process did not begin 20 minutes later. On the other hand, the temperature decreased during loading at Farm 2 and varied from 20.8 to 22.9 °C, implying a 0.80 °C reduction of the pigs' surface temperature (Figure 2). Unlike the Farm 1 counterpart, the pigs from Farm 2 were sprinkled before loading, and the whole truck was watered. After loading the pigs into the truck, the handlers applied a second water sprinkling. The decrease in the temperature readings during loading was attributed to the first sprinkling process. In both farms, the loading process was performed quickly (0.24 min per animal at Farm 1 and 0.34 and Farm 2, respectively).

**Figure 2:** Average air temperature (Ta) and pig skin temperature (ST) during loading, the journey and unloading.



Source: Authors (2021).

During pig transportation, the temperature increased from 33.2 to 36.3 °C at Farm 1 and 20 to 24.8 °C at Farm 2. The pigskin temperature increased by 1.56 °C from Farm 2 and 1.64 °C from Farm 1 during transport. In addition, during the unloading process, the air temperature ranged from 36.8 to 37.2 °C at Farm 1 and 18.8 to 20.8 °C at Farm 2 (Figure 2). During unloading at the slaughter plant in Farm 1, the pigs' skin surface temperature decreased by 0.25 °C because the sprinkling process was applied shortly before unloading. In contrast, the skin surface temperature of pigs unloaded in the Farm 2 region increased by 1.45 °C. The findings of the present study reflect the time and the handling applied during the unloading process. The pigs from Farm 1 were unloaded by two workers; while one handler wetted the pigs, the other opened the truck door and encouraged them out of the truck. Pigs from Farm 2 were handled by a single worker who opened the truck and waited for them to exit. If the pigs remain in the truck after 10 minutes, the employee began stimulating them to leave the truck.

#### 4. Discussion

In the present study, we evaluated the impact of two different weather on the thermal comfort of pigs during the pre-slaughter. The whole process was done in the afternoon when the temperature is high in the tropical climate. The association of high temperature and high relative humidity is detrimental to pigs (Brown-Brandl *et al.*, 2012). Large variations in air temperature affect the thermal comfort of pigs and compromise meat quality (Ludtke *et al.*, 2010). Loading is considered a stressful action during PSL, as it exposes the animals to an unfamiliar environment. In the Brazilian animal welfare guidelines, the stocking



density is limited to 230 kg/m<sup>2</sup> or 0.43 m<sup>2</sup>/pig (Dias *et al.*, 2011). The stocking density is also restricted in Canada, European countries, and the United States (Correa *et al.*, 2014; Kephart *et al.*, 2014a), under different climatic conditions. Schwartzkopf-Genswein *et al.* (2012) suggested that lowering the loading stocking density in warmer temperatures would reduce the heat stress and improve animal welfare during transport. The use of sprinkling water during loading was beneficial to the pigs. Fox *et al.* (2014) also measured the truck ambient temperature during the departure and unloading processes using sprinklers and reported a similar result.

We found an increase in ambient temperature and pigskin temperature during the journey. Kephart *et al.* (2014a) found that the pigskin temperature ranged from 29.3 to 36.2 °C (amplitude = 6.9 °C) and from 30.1 to 38.7 °C (amplitude = 8.6°C), respectively. In the present study, during loading, the pigskin temperature presented a varying amplitude from 15.3°C to 5.5°C, a broader range than previously studied. Results from the current study suggest that during the journey, the BI is affected by wind speed. Consequently, the BI varied more at Farm 1 than at Farm 2. A near-zero BI indicates that the ambient temperature is close to the thermal neutral zone, whereas large BIs indicate harsh thermal conditions (Texier *et al.*, 1979). According to Texier *et al.* (1979), a BI between 0 and 4 (temperature 17–21°C) favors good animal performance. Pigs transported from the Farm 2 were within the thermal comfort zone, but those transported from Farm 1 were exposed to thermal stress.

We found a positive correlation between pigskin temperature and Ta, THI, and BI. Pigskin temperature rises when Ta, THI, and BI increases and reduces when RH increases. Similarly, Kephart *et al.* (2014a) reported an increase in the pigs' skin temperature after the THI increased during warm and hot weather. During loading, the pigs' heart rate is higher in summer than in winter (Correa *et al.*, 2014). Loading activity is associated with distress factors such as transfer from a familiar to an unfamiliar environment, the presence of ramps, physical effort, human interaction, increased density, and trailer design. Correa *et al.* (2014) propose an association of the high heart rate of pigs waiting for loading during summer with the physical effort of accessing the truck compartments. The increased heart rate might raise the blood flow to the skin, increasing the skin temperature (Kephart *et al.*, 2014b); therefore, the skin temperature rise observed in the present study could be due to both the increase in ambient temperature and the pigs' physiological response to the loading and transportation distress.

The pigs' thermal comfort was similar in both transport scenarios. The journey's length is associated with many stressors, such as truck vibration, road paving, and exposure to sun and rain (Ludtke *et al.*, 2010). Haley *et al.* (2008) found that temperatures above 30 °C increase the losses during transport, indicating that pigs transported from Farm 1 presented more loss risk to the pork industry than those transported from Farm 2. The transport time from Farm 2 was similar to the 138 min reported by Kephart *et al.* (2014b). In European law, the transportation time of animals is limited to 8 h. The Canada welfare code specifies that animals intended for a trip exceeding 12 h must have access to feed and water during the journey (FAWC, 2009). Such a procedure is quite challenging in continental countries as Canada and Brazil.

Whether the decrease in air temperature during pre-slaughter transportation was more delayed under Farm 2 conditions than under Farm 1 is not clear by the present results. However, applying the sprinkling process at the moment of temperature increase, as implemented at Farm 1, was efficient.

Although transported pigs can adapt to the process, the animals are exposed to several risks, such as inappropriate floor surfaces, overcrowding, and inexperienced handlers risk injuries such as bruising, wounds, and fractures. Other aggravating risk factors are dehydration from lack of drinking water and aggression when mixing with new animals (Marahrens *et al.*, 2011). These unsafe conditions incur losses in the Brazilian pork industry. The loading, transport, and unloading processes almost double the skin injury rate relative to resting periods (Dalla-Costa *et al.*, 2019b). Ferguson and Warner (2008) stated that distress is an expected consequence of transferring an animal from farm to slaughter.

The unloading period is stressful for animals. Kephart *et al.* (2014b) reported an average unloading period of 16 minutes, more than double the unloading period applied by the Farm 1 workers, and less than the unloading period of Farm 2. The

unloading distress is related to physical pig effort, the transfer of the pigs from a new environment, human interaction (animal handling and inspection), ramps, the climate conditions at the slaughter plant, and industrial machinery's noise. Pigs become agitated during unloading, causing additional losses. According to Kephart *et al.* (2014b), bedding can minimize the distress signs during pigs' transportation.

Poor transportation conditions lead to low meat quality and increased loss (Kephart *et al.*, 2014b), as well as the inadequate pre-slaughter period, disrupts the animals' homeostasis, triggering an adaptive response that restores the thermal balance (Ferguson and Warner, 2008). Such combined stressors might degrade the animals' welfare and meat quality post-transport (Schwartzkopf-Genswein *et al.*, 2012). Fear, dehydration, and hunger increase physical activity, and pre-slaughter management can fatigue and injure the animals (Ferguson and Warner, 2008). Pig transportation planning must overcome several problems, such as meeting animal welfare standards, ensuring consumers' health, and satisfying traceability and sustainability demands (Marahrens *et al.*, 2011; Trienekens and Wognum, 2013). During transportation, pigs are exposed to several distress factors. Variations in these factors can disturb the animals' behavior and compromise the meat quality and contribute to losses in the pork industry (Dalla Costa *et al.*, 2017). Strategic planning using the best solutions for animal transportation has promising improvement in animal welfare, as it may reduce transportation time (Hakansson *et al.*, 2016).

Companies involved in the meat industry can reduce animal stress by following the pre-slaughter recommendations of animal welfare standards and observing best animal handling practices during the PSL process. As a balance between economic restrictions and animal welfare standards, they recommended shipping the pigs at night. Fox *et al.* (2014) also reported the reduced welfare and increased losses incurred by stressful conditions during pig transport. Previous studies have also recommended rescheduling transport to the coolest time of the day (Ludtke *et al.*, 2010; Marahrens *et al.*, 2011; Schwartzkopf-Genswein *et al.*, 2012). Improving the transportation conditions and reducing losses and providing proper animal welfare will likely improve the quality of meat sold to customers (Trienekens and Wognum, 2013).

## 5. Conclusion

Pigs in hot climates are exposed to heat stress, often reaching the thermoneutral zone's critical upper limit. Handlers should control the ambient dry-bulb temperature, which is the primary step of the pre-slaughter logistic to improve the animal welfare conditions. Among the loading, transportation, and unloading activities, the journey presents the most significant hazard to pigs transported towards the slaughterhouse. Adequate control of the truck microclimate might increase the pork quality by reducing thermal stresses. The results of this case study indicate that rescheduling transportation from afternoon to morning or night would improve the pre-slaughter management methods, as proposed in previous studies. By adopting compassionate pre-slaughter processes results in an improvement in the wellbeing of the animals and reduce losses to the industry.

This paper showed the importance to reduce microclimate truck thermal stress during pre-slaughter logistics; however, it is necessary new studies that integrated the pre-slaughter logistics parameters and thermal comfort with carcass yield to evaluate the financial impact on pork industry.

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