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Article

Use of two novel trailer types for transportation of pigs to slaughter. I. Effects on trailer microclimate, pig behaviour, physiological response, and meat quality under Canadian summer conditions

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Abstract

A total of 3366 pigs were transported to slaughter in summer (six replicates/trailer type; July-August in southwestern Ontario) using three trailers: a modified triple-deck pot-belly (MPB), an advanced flat-deck (AFD), and a standard pot-belly (SPB). Within trailers, ambient conditions, temperature (T °C), relative humidity (RH%), and temperature-humidity-index (THI), were monitored in three compartments (bottom front, BF, middle deck, MM, and top rear, TR). A total of 162 pigs were selected for the analysis of hematocrit, lactate, and creatine kinase (CK) levels in exsanguination blood and for the evaluation of pork quality as assessed in the *longissimus* (LM), *semimembranosus* (SM), and *adductor* (AD) muscles. The AFD and MPB trailers presented lower ($P < 0.01$) T°C and THI compared to the SPB during transit. In the SPB trailer, pigs transported in the MM compartment showed higher ($P < 0.01$) blood CK concentrations than those transported in the BF compartment and lower pHu values in the SM and AD muscles ($P = 0.02$ and $P = 0.04$, respectively) than those transported in the TR compartment. Although the AFD trailer design provided a better microclimate for pigs, the improvements in the design of the novel trailers only slightly reduced stress in pigs during summer transits.

Key words: meat quality, behaviour, pigs, summer, stress, transport, trailer type

Résumé

Un total de 3366 porcs ont été transportés à l'abattoir en été (six répétitions/type de remorque; juillet-août dans le sud-ouest de l'Ontario) à l'aide de trois remorques : une remorque modifiée de type « potbelly » (MPB — « modified triple-deck potbelly ») à trois étages, une remorque de type « flat deck » de conception avancée (AFD — « advanced flat deck »), et une remorque de type « potbelly » standard (SPB — « standard potbelly »). Dans les remorques, les conditions ambiantes, la température (T °C), l'humidité relative (RH% — « relative humidity ») et l'indice de température et d'humidité (THI — « temperature-humidity-index ») ont été surveillés dans trois compartiments (avant inférieur [BF — « bottom front »], pont central intermédiaire [MM — « middle deck »] et arrière supérieur [TR — « top rear »]). Un total de 162 porcs ont été sélectionnés pour l'analyse des niveaux d'hématocrite, de lactate et de créatine kinase (CK) dans le sang d'exsanguination et pour l'évaluation de la qualité de viande dans les muscles *longissimus* (LM), *semimembranosus* (SM), et *adducteur* (AD). Les remorques AFD et MPB ont présenté des T °C et THI plus faibles ($P < 0,01$) par rapport à la remorque SPB pendant le transport. Les porcs transportés dans le compartiment MM de la remorque SPB présentaient des concentrations sanguines de CK plus élevées ($P < 0,01$) que ceux transportés dans le compartiment BF, et des valeurs de pHu inférieures dans les muscles SM et AD ($P = 0,02$ et $P = 0,04$, respectivement) que ceux transportés dans le compartiment TR. Bien que la conception de la remorque AFD ait fourni un meilleur microclimat pour les porcs, les améliorations apportées à la conception des nouvelles remorques n'ont que légèrement réduit le stress chez les porcs pendant les transports estivaux. [Traduit par la Rédaction]

Mots-clés : qualité de la viande, comportement, porcs, été, stress, transport, type de remorque

1 Introduction

Transporting pigs from the farm to the abattoir is one of the most stressful events a pig experiences in its life (Faucitano and Goumon 2018). The welfare of pigs during transport and final pork meat quality depends on a multitude of interacting factors, such as pre-transport fasting, loading, handling, facility design, space allowance, external ambient conditions, trailer ambient conditions, travel time, and truck driving conditions (Faucitano and Goumon 2018). These stress factors can have a significant impact on the pig's physiological condition, which can be seen in increased blood cortisol, lactate, and creatine kinase (CK) concentrations at slaughter, which can eventually result in meat quality defects (Faucitano and Lambooij 2019; Rioja-Lang et al. 2019).

Among other factors, the design of the trailer, defined in terms of loading/unloading system (ramps or hydraulic deck/tail-gate lift), deck/compartment position and microclimate control (Faucitano and Goumon 2018), plays a key role in the stress response of pigs during loading and transportation (Ritter et al. 2008; Correa et al. 2013; Weschenfelder et al. 2013; Conte et al. 2015). The pot-belly (PB) trailer is commonly used for swine transportation in Canada, mainly due to its versatility and large loading capacity, thereby decreasing transportation cost per animal (Correa et al. 2013; Weschenfelder et al. 2013). However, this trailer design has been associated with increased fatigued, injured, or dead-on-arrival (DOA) pigs compared to other trailer designs, such as flat-decked (FD) trailers featuring hydraulic decks (Dewey et al. 2009; Correa et al. 2013). A number of studies (Goumon et al. 2013; Torrey et al. 2013*a*, *b*; Correa et al. 2013, 2014; Weschenfelder et al. 2013; Conte et al. 2015; Sommavilla et al. 2017) associated stressed and fatigued pigs prior to slaughter with greater heart rate at loading, elevated gastro-intestinal tract temperature, and higher blood CK and lactate concentrations at slaughter, which likely result from longer loading and unloading times and more stressful handling, eventually resulting in poor pork quality, particularly in pigs located in critical compartments (*i.e.,* top rear, bottom front, and bottom rear) of the PB trailer.

In comparison to PB trailers, FD trailers have a similar load capacity, but feature semi- hydraulic middle and top decks which are easier and safer for both the pigs and the handler during loading and unloading. Therefore, FD trailers have been recommended specifically for short distance transport (less than 1 h) as pigs take less time to recover from the stress and fatigue of loading and transport as shown by the lower blood lactate and CK concentrations at slaughter (Weschenfelder et al. 2013). This physiological condition of pigs may explain the decreased incidence of animal losses in FD trailers compared to PB trailers (Sutherland et al. 2009; Correa et al. 2013), which suggests that FD trailers may be a welfare friendly alternative for pig transportation in comparison to traditional PB trailers. However, more overlaps and round-turns for pigs, and handler interventions have been reported when loading/unloading semi-hydraulic FD trailer models, plausibly caused by a step at the entrance onto the FD trailer (Weschenfelder et al. 2012, 2013). This step near the trailer gate results from the overlap of the middle and top deck floors on the bottom deck floor, when loading/unloading pigs from the middle and top decks (Weschenfelder et al. 2012, 2013). Furthermore, both standard PB and FD trailers assessed in transport trials were passively ventilated, which may result in elevated internal temperatures, of up to 9° C warmer, in certain compartments during prolonged stationary situations (Fox et al. 2014; Xiong et al. 2015). This elevated internal temperature would result in a greater risk of thermal stress and fatigue during transportation and animal losses upon arrival at the abattoir (Haley et al. 2008*a*; Sutherland et al. 2009). Improvements to trailer designs, such as evaporative cooling, via fan-assisted ventilation, combined with water misting and water drinkers, has been shown to be an efficient heat mitigating strategy to enhance pig welfare during Canadian summer transports (Fox et al. 2014; Pereira et al. 2018).

Overall, the results from these previous studies highlight the need for improvement in trailer design, which may include full moving decks without a step at the entrance to the trailer, better air-flow efficiency, and improved insulating and cooling systems, to improve the welfare of pigs during transport (Rioja-Lang et al. 2019). To this point, the novel designs of modified PB and European FD fully hydraulic triple-decked trailers recently introduced in Canada are raising significant interest among Canadian trucking companies. These novel trailer designs may allow for easier loading and unloading through hydraulic ramps and decks and ensure better thermal comfort for pigs during transport and during stops (at the farm or at the plant) due to the presence of in-built ventilation fans alone or in combination with water misters and drinkers.

Greater animal losses have been reported in summer than in winter transports (Faucitano and Goumon 2018), with the highest death rate (0.40%) being recorded at an ambient temperature peak of 34 °C in Canada (Haley et al. 2008*a*, *b*). Canadian transport studies conducted under warm ambient conditions have associated animal losses to a lower ease of handling at loading and unloading (Torrey et al. 2013a), as well as greater body temperature and heart rate during transport (Correa et al. 2013; Conte et al. 2015), and blood CK and lactate concentrations at slaughter (Correa et al. 2013; Sommavilla et al. 2017).

The objective of this study was to evaluate and compare the effects of these novel trailer designs against the current standard PB trailer on the internal trailer microclimate, the behavioural and physiological response of pigs, and meat quality of pork from pigs transported to slaughter under Canadian summer conditions.

2 Materials and methods

All experimental procedures performed in this study were approved by the institutional animal care committee (approval #561) at the Agriculture and Agri-Food Canada (AAFC) Sherbrooke Research and Development Centre (Sherbrooke, QC, Canada) based on the current guidelines of the Canadian Council of Animal Care (2009).

2.1 Animals and treatments

A total of 3366 crossbred pigs (Large White × Landrace × Duroc crosses) of mixed sexes were shipped from 5 commercial southwestern Ontario farms, all of which had similar design, housing, feeding, and handling systems. Pigs were shipped to a commercial slaughter plant located in southwestern Ontario (trips of 91 km for 122 min, on average, ranging from 40 to 138 km and 75 to 169 min) during summer conditions (July-August 2019; average temperature 24.4 °C, ranging from 19.2 to 30.0 °C). Pigs were transported from each farm using three different triple-decked trailer types, which included a Standard Pot-Belly (SPB; model #80MP2-HC 2015 Barrett Tri Axle 53 Ft Pot-belly Hog/Cattle combo trailer; Barrett Trailers, Purcell, OK, USA; Fig. S1), a Modified Pot-Belly (MPB; Luckhart Transport, Sebringville, ON, Canada; Fig. S2), and an advanced flat-deck trailer (AFD; model "SBA73Z semi-trailer" 2014 Pezzaioli Hydraulic 3 deck lift trailer; Carrozzeria Pezzaioli, Montichiari, Italy; Fig. S3). Pigs were transported over a six week period, and each replicate had all trailer types represented for each week of the study (total of 18 trailer loads of pigs, or six trailer loads of pigs/trailer type).

The SPB was a punch-hole passively ventilated trailer featuring two internal fixed ramps, one feeding the bottom deck (20° slope; length 2.0 m) and the other the top deck (21° slope; length 3.0 m). The MPB trailer featured a hydraulic ramp (18° slope; length 4.7 m) going up to the top deck and a fixed ramp (15° slope; length 2 m) descending to the bottom compartments. The MPB trailer was equipped with a total of 30 ventilation fans (25.4 cm in diameter each), with six fans spanning the top and middle decks and three fans spanning the bottom deck along the side walls on each side of the trailer. Fan operation was controlled by the driver in the cabin. A water drinker (water flow rate of 0.5 L/min) was also installed in each compartment. Water misters ($n = 36$) were evenly mounted inside the trailer wall compartments with a flow rate of 0.5 L/min which produced a fine mist that was remotely controlled by the driver. Water tanks (two 567 L capacity tanks) were located between the rear axles under the trailer. The AFD trailer was equipped with fully hydraulic middle and top decks and featured a total of 36 fans (six fans/deck, 18 fans/trailer side, 25.4 cm diameter each) remotely controlled by the driver, one water drinker per compartment with a flow rate of 0.5 L/min, and a total of 24 water misters mounted inside the trailer wall compartments with a flow rate of 0.5 L/min, which produced a fine mist that was remotely controlled by the driver during wait-at-farm and transit phases, at the driver's discretion. The AFD trailer had two water tanks (500 L capacity each) located at the front of the trailer. Additionally, the AFD trailer featured an adjustable rooftop (adding up to 35.6 cm more head space) to increase airflow across the top compartments.

The load size of each trailer and the distribution for groups of pigs across trailers and compartments, as well as the height of the test compartments, are described in Figs. 1*a*–1*c*. Within each trailer, three compartments were chosen for data collection based on previous results showing compartmental variations in microclimate, with warmer temperatures being reported in the front and bottom compartments (Weschenfelder et al. 2013; Fox et al. 2014; Pereira et al. 2018). Test compartments were the top rear (TR; C4 in all trailers), the middle middle (MM; C7 in SPB and AFD trailers, and C8 in the MPB trailer), and the bottom front (BF; C9 in the SPB trailer and C10 in the MPB and AFD trailers). Three focal barrows (130 ± 4.70 kg) were selected from each test compartment totalling nine focal pigs per trailer/week (total of 162 focal pigs). Focal pigs were randomly chosen the day prior to transport from the same finishing pen, weighed and tagged in both ears, and then kept together in a shipping pen close to the loading dock, separate from the non-focal pigs. This pre-sorting strategy was applied to minimize walking distance during loading that may have biased the physical condition of pigs at the time of departure from the farm (Ritter et al. 2007, 2008; Edwards et al. 2011). Feed was restricted from all pigs for 12–15 h before loading (total of 24 h from feed restriction to slaughter).

On the day of transportation, focal pigs were loaded onto the targeted compartments in groups of three pigs each using a plastic sorting board and paddle. The rest of the compartment group was also mostly loaded with sorting boards and paddles, while electric prods were only used when absolutely necessary. Focal pigs were mixed with unfamiliar pigs to best mimic commercial practice. Average space per pig in the test compartments of the trailer was 0.52 m^2/pig in the SPB and MPB trailers, and 0.53 m^2/pig in the AFD trailer (Figs. 1*a*–1*c*).

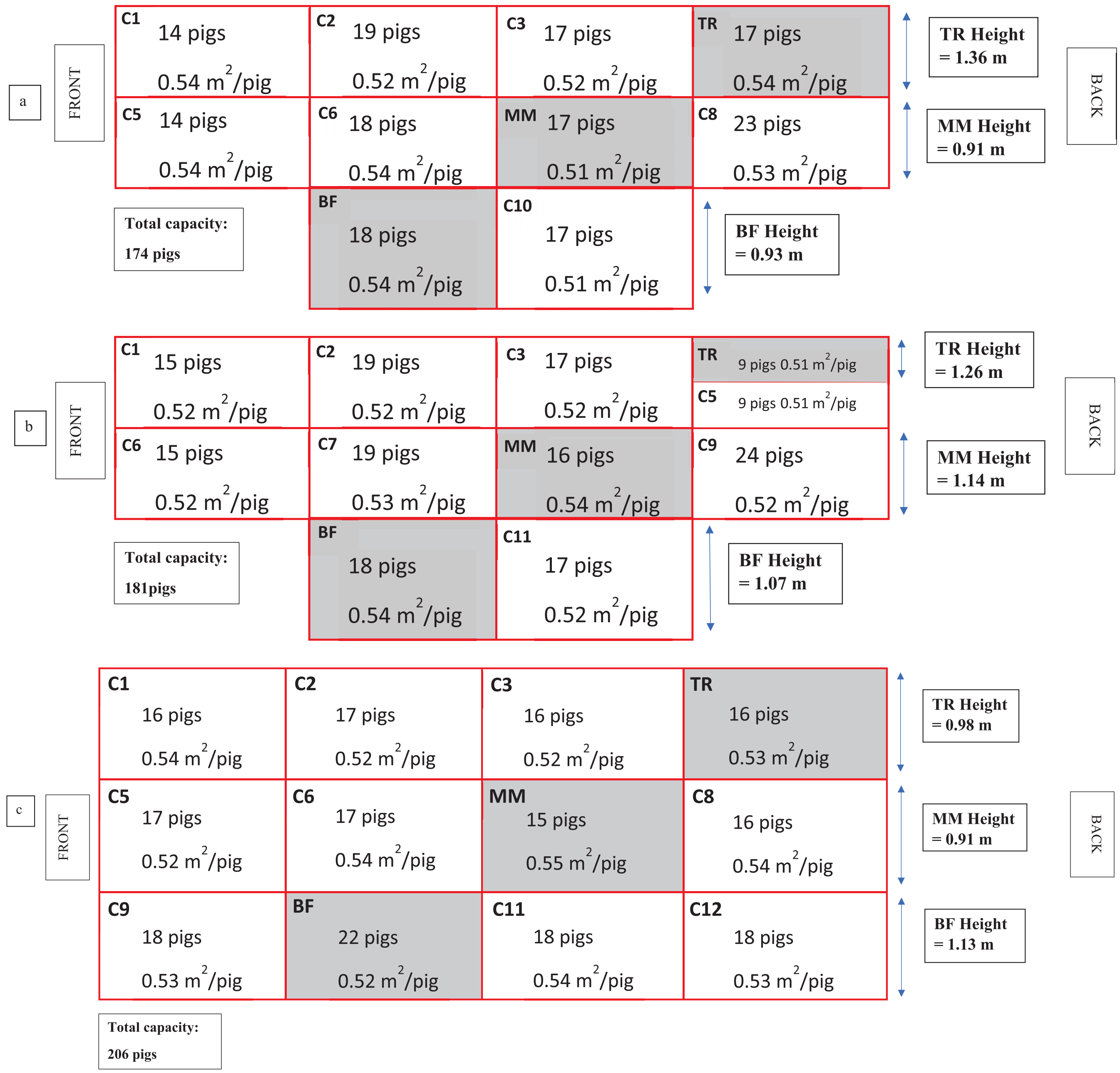
Loading started on average at 0942 and the loading order of the three trailers was randomized for each replicate to avoid the confounding effects of time of the day and related ambient conditions on the ease of handling and thermal stress. To keep unloading and lairage times consistent for each replicate, trailers, once loaded, waited on farm for a predetermined amount of time to control the arrival times at the slaughter plant. The average wait times applied at the farm before departure were as follows: 45 ± 11 min for the first trailer, 30 ± 14 min for the second trailer, and 16 ± 13 min for the last trailer. During this wait period and transit, pigs in the MPB and the AFD trailers had access to water and were cooled-off by fan-assisted ventilation. Misters were only activated when fan-assisted ventilation was active, at the discretion of the driver, depending on ambient temperature conditions.

During transit, side panels were 100% open in all trailers for passive ventilation, and all trailers were bedded with fresh wood shavings (1 cm thick bedding) prior to the start of loading. Due to unforeseen circumstances, drivers could not be equally randomized to trailer across replications.

On arrival at the slaughter plant, trailers were kept stationary in the yard before unloading and laterally exposed to a fan-bank system, with the sprinklers off, for ten minutes to comply with the requirements of the abattoir (L. Wormsbecher, Conestoga Meat Packers, personal communication, 2019).

Pigs were unloaded using paddles in groups of 5–10 pigs and driven to separate lairage pens based on trailer type and compartment of origin. No mixing of pigs between test compartments and trailers occurred. As the size of trailer compartments and lairage pens was different, to keep a constant stocking density (0.81 m^2/pig) in the lairage pen, the size of

Fig. 1. Location and identification of compartments, and load capacity and space allowance in the Standard Pot-belly (*a*), Modified Pot-belly (*b*), and Advanced Flat-deck (*c*) trailers. Test compartments are shaded in grey with the corresponding compartment height on the right. [Colour online.]



all test compartment groups was reduced to 12 pigs/group (including the three focal pigs) in each lairage pen. Pigs were kept in lairage for 104 min on average, ranging from 35 to 166 min, with free access to water. After lairage, pigs were driven to a CO_2 gas stunner (Marel Backloader G3-RelaX-XXL 7, Marel, Holbæk, Denmark) using paddles along the alleys and an automatic push gate system in the last chute feeding the stunner. To improve handling, lairage alleys and the chute feeding the stunner were illuminated by green lighting aimed at reducing shadows on the floor (Faucitano and Velarde 2021). Pigs were stunned in groups, ranging from five to seven pigs, and were shackled and exsanguinated in the vertical position immediately after exiting the stunner. Carcasses were dehaired, singed, eviscerated, split, and conventionally chilled (4–7 °C for at least 18 h) according to the standard operating procedures of the commercial pork processing facility.

2.2 Data collection

2.2.1 Ambient climate and trailer microclimate measurements

External and within trailer ambient air temperature and humidity data were collected using iButton data loggers

(DS1923 Hydrochron Temperature/Relative Humidity Logger, Maxim Integrated Products Inc., Sunnyvale, CA, USA) attached on each side mirror of each trailer cab and inside the test compartments (5 iButtons/compartment) of all trailers. The compartment iButtons were suspended approximately 8 cm from the ceiling with one positioned in the center of the compartment and the other four placed in the corner of the compartment 18 cm from where each adjoining wall meets. The iButtons were programmed to record temperature (T) and relative humidity (RH) data every minute from the beginning of loading to the beginning of unloading. The temperature range of the data logger was from -20 to $+85\,^{\circ}$C with a resolution of $\pm 0.0625\,^{\circ}$C and an accuracy of $0.5\,^{\circ}$C and a relative humidity range from 0 to 100% with a resolution of $\pm$0.6% and an accuracy of 5%.

Data were programmed and downloaded after each transport using the ExpressThermo software (ECLO Solutions, Leiria, Portugal).

2.2.2 Behavioural measures

During lairage, behaviour was continuously recorded at the group level using digital HD video camera recorders (HDRAS100 V, Sony Corp., Tokyo, Japan) installed on the pen walls. The recording started as soon as the pen was filled with pigs and the lairage gate was closed and ended after 30 min (minimum time for all treatments). Scan sampling every 2 min was used to record the number of pigs engaged in each posture (lying, sitting, standing, or other). Other behaviour was defined when a pig was neither standing, sitting, or lying, such as kneeling. The frequency of drinking bouts was also recorded using continuous sampling. A drinking bout was defined as any occurrence of a pig placing its mouth around the drinker for any duration of time. A new bout was recorded if the pig's mouth was off the drinker for at least 5 s before resuming the activity. Behavioural observations were performed by one trained observer using The Observer XT software, version 15 (Noldus Information Technology Inc., Wageningen, The Netherlands), and the intra-observer agreement was 100%.

2.2.3 Blood variables

During exsanguination, blood was collected from the bleeding wound of 27 focal pigs per replicate (three pigs/compartment/trailer/replicate; a total of 162 pigs) in serum tubes (BD Vacutainers®, VWR International Ltd., Montreal, QC, Canada). Whole blood lactate concentrations were immediately assessed in duplicate with a hand-held Lactate Scout Analyzer (Lactate Scout, EKF Diagnostic GmbH, Magdeburg, Germany) by dipping a test strip (two strips/animal) into a serum tube containing collected blood. Another blood sample was also collected in a second serum tube for CK analysis. Serum was collected after centrifugation at $1400 \times g$ for 10 min at $4\,^{\circ}$C and then stored at $-80\,^{\circ}$C until analysis. Serum CK concentration was analysed using a creatine kinase_SL kit (Creatine Kinase-SL Assay, SEKISUI Diagnostics, Charlottetown, PE, Canada) and determined with a spectrophotometer. The intra-assay coefficient of variation for log transformed blood CK was 2.31%. A third blood sample was collected in an EDTA tube (BD Vacutainers®; VWR International Ltd., Montreal, QC, Canada), refrigerated at $4\,^{\circ}$C and subsequently analyzed in duplicate for hematocrit determination according to the microhematocrit procedure described by Matte et al. (1986).

2.2.4 Carcass lesions and meat quality measures

Lesions were scored by a single trained observer on the whole carcass along the dressing line based upon a subjective five-point, photographic scale (from 1 = no to very minimal lesions to 5 = severe lesions; Meat and Livestock Commission (MLC) 1985).

All meat quality measurements were taken at 24 h *post-mortem* by measuring pH (pHu) in the *longissimus* muscle (LM), between the third and fourth last rib, and in the *semimembranosus* (SM) and *adductor* (AD) muscles using a portable pH-meter (Oakton Instruments Model pH 450 series, Nilis, IL, USA) fitted with a spear tip pH electrode (Cole Palmer Canada, Montreal, QC, Canada) and an automatic temperature compensation (ATC) probe (Oakton Instruments, Vernon Hills, IL, USA). Colour ($L*$, $a*$, $b*$; CIE 1976) was evaluated instrumentally with a CM700d Spectrophotometer (Konica Minolta Sensing Inc., Osaka, Japan) after exposing the LM and SM muscle surface to 10- and 15-min blooming times, respectively. The measurement was taken using an 8° viewing angle, 10° observer angle, D_{65} illuminant, SCI (specular component included) mode, and an illumination measurement area of 8 mm in diameter. Drip loss was evaluated in the LM (same location as pHu measurement) using the filter paper wetness (FPW) test as described by Kauffman et al. (1986). Briefly, a filter paper (Whatmann PK100, VWR International Co., Mont-Royal, QC, Canada) was placed on the LM cut surface after 10 min of air exposure and weighed using an analytical scale (Scout SPX, OHAUS, Parsippany, NJ, USA) after 3 sec of fluid accumulation on the paper. Percentage of drip loss was calculated by the following equation: [% drip loss$=-0.1+(0.06 \times$ mg fluid)] as described by Rocha et al. (2016).

2.2.5 Calculations and statistical analyses

Average T and RH values were calculated for each of the three transport phases (*i.e.*, the wait-at-farm phase, the transport phase, and the wait-at-plant phase) before unloading by averaging the five iButton logger data per compartment. Delta (Δ) T and RH were calculated using the average T and RH of each trailer compartment minus the average T and RH of the two external iButtons. The compartment within each trailer was the experimental unit. Temperature humidity index (THI), which is normally used as an indicator of ambient conditions in heat stress studies and livestock transport guidelines (Fox et al. 2014; National Pork Board 2017), was calculated according to the NRC (1971) formula: $\mathrm{THI}=(1.8\times \mathrm{T} + 32)-[(0.55 - 0.0055 \times \mathrm{RH})\times(1.8 \times \mathrm{T} - 26)]$, where T is in $^{\circ}$C and RH in %.

All trailer microclimate and pig physiological variables, behaviour during lairage and meat quality analyses were performed using SAS software (version 9.4; SAS Inst. Inc., Cary, NC, USA) where analysis was performed using the MIXED procedure with trailer type, compartment, and trailer type × compartment interaction as fixed factors in a 3 × 3 factorial design. Replicate was considered as a random effect. Results are presented as least squares means (LSM)±SEM. Compartment and trailer comparisons were performed using a Tukey adjustment. When appropriate, the slice effect was used to further analyze the interaction term between trailer and compartment. A probability level of $P \leq 0.05$ was chosen as the limit for statistical significance in all tests. Observed probabilities of $P \leq 0.10$ were considered as tendencies.

Drinking during lairage was analyzed for both bout duration and total duration of the drinking bout using a Friedman's test. Due to the low percentage of sitting (<5%) and other postures (<1%) during lairage, data for these postures failed to meet the assumptions for ANOVA analysis and were therefore presented as medians.

As a result of lost ear tags at the slaughter plant, one carcass (0.6%), six loins (4%), and three hams (2%) were lost throughout the whole study. Owing to difficulty in keeping pace with the speed of the bleed line on the kill floor, one blood lactate, blood hematocrit, and CK sample 0.6% for all) was lost throughout the whole study.

3 Results

3.1 Trailer microclimate

The average external ambient T, RH, and THI during the transports were 24.4 °C (ranging from 19.2 to 30.0 °C), 62.0% (ranging from 40.8 to 98.8%), and 71.2 (ranging from 65.7 to 78.4), respectively. The average trailer compartment T, RH, and THI during the transports were 26.1 °C (ranging from 21.0 to 31.9 °C), 64.2% (ranging from 43.3 to 91.6%), and 73.6 (ranging from 68.0 to 80.6), respectively.

Except for RH, the trailer type × compartment interaction affected all compartment ambient parameters (Table 1). During the wait-at-farm phase, there was a tendency for an interaction of compartment temperature ($P = 0.06$), with the BF compartment being warmer than the TR compartment in the SPB trailer ($P = 0.03$). The MM compartment temperature was intermediate and did not differ ($P > 0.10$) from the other compartments in the SPB trailer. The trailer type × compartment interaction was also significant during transit and the wait-at-plant phase ($P < 0.01$ for both), with the BF compartment of the SPB trailer being warmer than the MM and TR compartments ($P < 0.01$) during transit, but cooler ($P < 0.01$) during the wait-at-plant phase, while the MM and TR temperatures did not differ between each other ($P > 0.10$). Overall, during the wait-at-the farm phase, all trailers differed from each other ($P < 0.01$), where the SPB trailer was the warmest, followed by the MPB, with the AFD being the coolest trailer (26.07 °C vs 25.09 °C vs 23.85 °C; SEM = 0.48). During transit, the AFD and MPB trailers were still cooler than the SPB (25.20 °C and 24.69 °C vs. 26.16 °C; SEM = 1.24; $P = 0.01$ and $P < 0.01$, respectively) and did not differ from each other ($P > 0.10$). During the wait-at-plant phase, the MPB trailer was cooler than the SPB trailer (25.45 °C vs. 26.77 °C; SEM = 1.375; $P < 0.01$), with the AFD trailer temperature being intermediate ($P > 0.10$).

Table 1. Average temperature (T), relative humidity (RH), and temperature humidity index (THI)[1] of selected compartments in either Standard Pot-belly (SPB), Modified Pot-belly (MPB), or advanced flat-deck (AFD) trailers in summer

	SPB			MPB			AFD				*P*		
Compartment[2]	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × Compartment
Wait-at-farm													
T, °C	26.69^{a}	26.40^{ab}	25.12^{b}	24.37	25.29	25.61	24.36	23.48	23.57	1.38	<0.01	0.65	0.06
RH, %	63.97	63.64	63.79	71.83	69.27	65.47	72.26	70.80	63.77	4.73	<0.01	0.02	0.26
THI	75.57^{a}	75.20^{a}	73.09^{b}	73.02	74.28	74.16	73.11	71.61	71.08	1.98	<0.01	0.14	0.04
Transit													
T, °C	27.37^{a}	25.68^{b}	25.44^{b}	24.54	24.32	25.21	24.58	24.61	26.41	1.17	< 0.01	0.08	< 0.01
RH, %	59.55	60.11	59.53	74.07	68.81	64.53	69.31	64.55	57.18	5.75	< 0.01	0.02	0.12
THI	75.95^{a}	73.63^{b}	73.10^{b}	73.36	72.62	73.40	73.03	72.68	74.45	1.60	< 0.01	0.01	< 0.01
Wait-at-plant													
T, °C	26.03^{b}	26.66^{a}	27.61^{a}	25.99	25.31	25.05	25.76	25.67	27.07	1.30	0.01	0.55	< 0.01
RH, %	56.46	57.06	57.03	69.35	64.47	60.54	61.26	58.24	51.31	6.27	0.02	0.12	0.24
THI	75.90^{a}	74.65^{b}	73.67^{b}	73.68	73.64	74.04	73.92	73.48	74.64	1.74	< 0.01	0.31	< 0.01

[1]THI=(1.8 × T + 32)−[(0.55–0.0055∗RH)×(1.8 × T-26)]
[2]BF: bottom front, MM: middle middle, TR: top rear
[a,b]Within a row and trailer type, Lsmeans lacking a common superscript differ at $P < 0.10$.

During the wait-at-farm and transit phases, RH variation was affected by the trailer type and the compartment position ($P < 0.01$ and $P = 0.02$, respectively, for both phases). The SPB trailer was less humid than both the MPB and AFD trailers (63.80% vs. 68.86% and 68.94%; SEM = 4.73; $P < 0.01$ and $P < 0.01$, for both trailers) during the wait-at-farm phase. The latter two trailers did not differ from each other for this parameter ($P > 0.10$). During the wait-at-farm phase in all trailer types, the BF compartment was more humid than the TR compartment (69.30% vs 64.29%; SEM = 4.31; $P = 0.02$), with the RH of the MM compartment being intermediate ($P > 0.10$). During transit, the SPB trailer was less humid than the MPB trailer (56.73% vs. 69.13%; SEM = 5.75; $P < 0.01$), with the AFD trailer being intermediate ($P > 0.10$). Overall, the TR compartment was less humid than the BF compartment (60.42% vs 67.65%; SEM = 6.03; $P = 0.01$), with the RH of the MM compartment being intermediate ($P > 0.10$). During the wait-at-plant phase, there was a main effect of trailer on RH ($P = 0.03$), where the SPB continued to be less humid than the MPB (56.85% vs. 64.79%; SEM = 6.27; $P = 0.02$). The AFD did not differ from either the SPB or the MPB ($P > 0.10$).

Overall, the AFD trailer had a lower THI than the SPB trailer (71.98 vs. 74.62; SEM = 1.95; $P < 0.01$) with the THI of the MPB trailer being intermediate ($P > 0.10$) during the wait-at-farm phase. During transit, the AFD and MPB trailer had a lower THI than the SPB trailer (73.38 and 73.12 vs. 74.23; SEM = 1.62; $P = 0.04$ and $P < 0.01$, respectively). The AFD and MPB trailers did not differ from each other ($P > 0.10$). Overall, during the wait-at-plant phase, the MPB trailer had a lower THI than the SPB trailer (73.79 vs. 74.74; SEM = 1.75; $P = 0.03$) and tended to have a lower THI than the AFD trailer (73.79 vs. 74.01; SEM = 1.75; $P = 0.08$). However, similar to most ambient parameters, the effect of trailer type on THI was affected by the compartment position (trailer × compartment interaction) in all transport phases (from $P = 0.04$ to $P < 0.01$). During the wait-at-farm phase, THI was lower ($P < 0.05$) in the TR compartment than both the BF and MM compartments of the SPB trailer. The BF and MM compartments did not differ from each other ($P > 0.10$). During the transit phase, BF compartment had a higher ($P < 0.05$) THI than the MM and TR compartment in the SPB trailer. The THI was not different ($P > 0.10$) between the MM and TR compartments in this trailer type. During the wait-at-plant phase, the BF compartment had a higher ($P < 0.05$) THI than the MM and TR compartments in the SPB trailer. The MM and TR compartments of the SPB did not differ from each other ($P > 0.10$).

As shown in Table 2, trailer type affected ΔT value ($P < 0.01$) during the wait-at-farm phase, with the SPB trailer presenting a greater value than the MPB and AFD trailers (1.02 °C vs. −0.78 °C and −0.36 °C, SEM = 0.87; $P = 0.01$ and $P < 0.01$, respectively), which did not differ from each other ($P > 0.10$). During the transit phase, there was a trailer type × compartment interaction for ΔT value ($P = 0.01$), with the BF compartment having a greater ($P = 0.05$) value than the TR compartment in the SPB trailer. Overall, the SPB trailer had a greater ($P < 0.01$) ΔT value than the MPB (2.22 °C vs. 0.72 °C; SEM = 0.52), with the ΔT value of the AFD trailer being intermediate ($P > 0.10$). During the wait-at-plant phase, there was a tendency for a trailer × compartment interaction on

Table 2. Delta[1] temperature (ΔT°), relative humidity (ΔRH), and THI[2] (Δ) in selected compartments in either the Standard Pot-belly (SPB), Modified Pot-belly (MPB), or advanced flat-deck (AFD) trailers in summer.

	SPB			MPB			AFD				*P*		
Compartment[3]	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × Compartment
Wait-at-farm													
ΔT, °C	1.64	1.35	0.07	−1.5	−0.58	−0.26	0.19	−0.69	−0.60	0.99	<0.01	0.69	0.11
ΔRH, %	2.71	2.39	2.54	12.39	9.83	6.03	8.70	7.24	0.21	4.28	< 0.01	0.04	0.45
ΔTHI	3.12[a]	2.75[ab]	0.65[b]	−0.42	0.84	0.72	1.48	−0.02	−0.54	1.21	< 0.01	0.14	0.08
Transit													
ΔT, °C	3.43[a]	1.73[b]	1.50[b]	0.57	0.35	1.24	0.84	0.87	2.67	0.66	< 0.01	0.13	0.01
ΔRH, %	−3.12	−2.56	−3.14	10.45	5.19	0.91	5.68	0.92	−6.44	4.45	< 0.01	0.01	0.29
ΔTHI	4.87[a]	2.54[b]	2.02[b]	2.00	1.26	2.04	1.96	1.61	3.38	0.69	0.01	0.03	< 0.01
Wait-at-plant													
ΔT, °C	1.20	0.25	−0.38	−2.07	−1.81	−1.14	−2.00	−2.09	−0.69	1.08	<0.01	0.51	0.05
ΔRH, %	1.07	1.66	1.64	14.50	9.62	5.69	7.50	4.48	−2.45	5.59	<0.01	0.05	0.41
ΔTHI	2.24[a]	1.00[ab]	0.01[b]	−0.77	−0.80	−0.40	−1.26	−1.70	−0.53	0.99	<0.01	0.35	0.03

[1]Delta values refer to the difference between the internal trailer compartment and the ambient external trailer environment.
[2]THI=(1.8 × T + 32)−[(0.55−0.0055∗RH)×(1.8 × T-26)] (NRC 1971)
[3]BF: bottom front, MM: middle middle, TR: top rear.
[a,b]Within a row and trailer type, Lsmeans lacking a common superscript differ at $P < 0.10$.

compartment ΔT ($P = 0.05$), where the BF ($P < 0.01$) and the MM ($P = 0.02$) compartments of the SPB were warmer than the MPB and AFD trailers BF (1.20°C vs. −2.07 °C and −2.00 °C; SEM = 1.00) and MM (0.25 vs.−1.81 and −2.09; SEM = 1.00) compartments, which did not differ from each other ($P > 0.10$). Overall SPB trailer had a greater ($P = 0.01$) ΔT value than both the MPB and AFD trailer (0.36 °C vs. −1.67 °C and −1.59 °C; SEM 1.00), which did not differ from each other ($P > 0.10$).

Trailer type and compartment position affected ΔRH value in all transport phases (Table 2). During the wait-at-farm phase, the MPB trailer showed higher ($P < 0.01$) ΔRH value compared to the SPB trailer (9.42% vs. 2.55%; SEM = 3.67), with the AFD trailer presenting an intermediate ΔRH value ($P > 0.10$). The value of ΔRH continued to be greater in the MPB trailer than in the SPB trailer (5.51% vs. 2.94%; SEM = 3.81; $P < 0.01$), with the AFD trailer presenting an intermediate ΔRH value ($P > 0.10$), during the transit phase. Finally, during the wait-at-plant phase prior to unloading, the ΔRH value in the MPB trailer was greater ($P < 0.01$) than both the SPB and AFD trailers (9.93% vs. 1.45% and 3.18%; SEM = 5.04). The AFD and SPB trailers did not differ from each other ($P > 0.10$). During the wait-at-the farm period, the BF compartment presented a higher ($P = 0.04$) ΔRH value than the TR compartment (7.94% vs. 2.93%; SEM = 3.68) in all trailer types. The MM compartment did not differ from either the BF or TR compartments ($P > 0.10$). A greater ($P < 0.01$) ΔRH value was still recorded in the BF compartment compared with the TR compartment (4.34% vs.−2.89%; SEM = 3.80) during the transport phase, with ΔRH value in MM compartment not differing from that of either the BF or TR compartments ($P > 0.10$). During the wait period at the plant, the BF compartment presented a higher ($P = 0.05$) ΔRH than the TR compartment (7.69% vs. 1.63%; SEM = 5.04), whereas the MM compartment did not differ from either the BF or the TR compartments ($P > 0.10$).

A trailer type effect was also found for ΔTHI in all transport phases (from $P = 0.01$ to $P < 0.01$; Table 2). During the wait-at-farm phase the SPB trailer presented a higher ($P < 0.01$) ΔTHI value than MPB and AFD trailers (2.18 vs. −0.38 and 0.31; SEM = 1.02). No difference was found in ΔTHI values of MPB and AFD trailers ($P > 0.10$). During transport the SPB trailer still had a greater ($P = 0.01$) ΔTHI value than the MPB trailer (3.14 vs. 1.77; SEM = 0.55), with the ΔTHI value of the AFD trailer being intermediate ($P > 0.10$). There was a trailer type × compartment interaction for ΔTHI in all transport phases (Table 2). During the wait-at-farm phase, the SPB trailer tended to have a higher ΔTHI ($P = 0.08$) in the BF than in the TR compartment. The ΔTHI of the MM compartment did not differ from the BF or TR compartment ($P > 0.10$). The ΔTHI value of the BF compartment was also greater ($P < 0.05$) than that of the MM and TR compartments in the SPB trailer during transit. The ΔTHI also varied by trailer and compartment position during the wait-at-plant phase ($P = 0.03$), with the BF compartment presenting a greater ΔTHI value the TR compartment in the SPB trailer. The ΔTHI value of the MM compartment did not differ from that of the BF or TR compartments in this trailer type ($P > 0.10$). Overall, ΔTHI value also varied by trailer type and was higher ($P < 0.01$) in the SPB trailer than in the MPB and AFD trailers (1.08 vs. −0.66 and −1.16; SEM = 0.91). ΔTHI values did not differ between the MPB and AFD trailers ($P > 0.10$).

3.2 Behavioural observations during lairage

There was a trailer type × compartment interaction for the percentage of pigs lying and standing while resting in the lairage pens ($P = 0.01$ for both; Table 3). For pigs coming from the MPB trailer, those transported in the BF compartment lay down less and stood more than pigs that were in the TR compartment ($P < 0.05$), with pigs from the MM compartment being intermediate ($P = 0.10$). No difference in postures between compartments were observed for the SPB and AFD trailers ($P > 0.10$). Overall, pigs transported in the MPB lay down less ($P < 0.01$) than those transported in the SPB and AFD trailers (72.04% vs. 80.74% and 77.69%; SEM = 2.11) and stood more ($P < 0.01$) compared to pigs transported in the SPB and AFD trailers (25.63% vs. 18.15% and 20.92%; SEM = 2.11). Neither trailer type nor compartment affected drinking behaviour during lairage ($P > 0.10$).

3.3 Blood variables

Neither trailer type nor compartment position or their interaction had an effect on blood relative hematocrit percentage or lactate levels at slaughter ($P > 0.10$; Table 4). The interaction between trailer type and compartment affected blood CK concentration at slaughter ($P < 0.01$), with greater ($P < 0.05$) levels being found in pigs transported in the BF compartment compared to those located in the MM compartment of the SPB trailer. Blood CK concentrations of pigs transported in the TR compartment of the SPB trailer did not differ from those positioned in either the BF or MM compartments ($P > 0.10$).

3.4 Carcass lesion scores and meat quality traits

Neither trailer type nor compartment or their interaction affected carcass lesion scores ($P > 0.10$; Table 5). Except for drip loss % in the LM, pHu, L∗ and a∗ colour values in the SM muscle, and pHu value in the AD muscle, neither trailer type nor compartment or their interaction had an effect on meat quality traits ($P < 0.10$; Table 5).

Loins of pigs transported in the BF compartment were drier (lower drip loss percentage) compared to those from pigs transported in the MM compartment (1.45 vs. 1.90%; SEM = 0.16; $P = 0.03$) regardless of trailer type. Drip loss percentage of TR compartment loins did not differ from either the BF or MM compartment loins ($P > 0.10$).

There was a trailer type × compartment interaction on the pHu value of the SM and AD muscles, with lower pHu values being recorded in both muscles of pigs transported in the MM compartment compared with those transported in the TR compartment of the SPB trailer ($P = 0.02$ and $P = 0.04$, respectively). No difference in SM and AD muscles pHu values were found between pigs transported in the BF compartment and those located in the MM or TR compartments in the SPB trailer ($P > 0.05$). Compartment position tended to have an effect on SM muscle L∗ value ($P = 0.08$), with pigs transported in the MM compartment presenting a slightly

Table 3. Percentage of time spent by pigs in a given posture during lairage by trailer compartment in summer.

	SPB			MPB			AFD			P^2			
Compartment[1]	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × Compartment
Lying, %	75.63	89.89	78.90	66.09[b]	70.96[ab]	77.24[a]	80.65	74.91	72.63	3.04	< 0.01	0.54	0.01
Sitting[2], %	1.61	0.40	0.13	2.69	1.61	1.75	0.81	0.94	1.88	–	–	–	–
Standing, %	22.04	16.49	19.67	30.93[a]	26.99[ab]	20.66[b]	18.06	23.84	25.58	2.80	0.01	0.68	0.01
Other[2], %	0.54	0.13	0.27	0.40	0.40	0.27	0.00	0.00	0.00	–	–	–	–

[1]BF: bottom front, MM: middle middle, TR: top rear.
[2]Due to low percentage values associated with Sitting and Other, these two variables are presented as medians.
[a,b]Within a row and trailer type, Lsmeans lacking a common superscript differ at $P < 0.10$.

Table 4. Average blood relative hematocrit percentage, lactate, and creatine kinase (CK) concentrations of pigs transported in selected compartment of either the Standard Pot-belly (SPB), Modified Pot-belly (MPB), or advanced flat-deck (AFD) trailers in summer.

	SPB			MPB			AFD			P			
Compartment[1]	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × Compartment
Relative hematocrit, %	41.81	42.77	43.96	42.08	41.12	41.87	44.28	41.17	40.49	2.41	0.69	0.75	0.51
Lactate, mmol/L	8.44	7.65	8.03	7.40	8.64	8.94	8.03	8.59	8.15	0.70	0.76	0.56	0.22
CK, log UI/L	3.42[a]	3.20[b]	3.38[ab]	3.27	3.44	3.27	3.38	3.32	3.26	0.07	0.96	0.52	< 0.01

[1]BF: bottom front, MM: middle middle, TR: top rear.
[a,b]Within a row and within a trailer type, Lsmeans lacking a common superscript differ at $P < 0.10$.

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Table 5. Carcass lesion score and meat quality characteristics as assessed in the *longissimus* (LM), *semimembranosus* (SM), and *adductor* (AD) muscles of pigs transported in selected compartments of either the Standard Pot-belly (SPB), Modified Pot-belly (MPB), or advanced flat-deck (AFD) trailers in summer.

	SPB			MPB			AFD				*P*		
Compartment[1]	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × Compartment
Lesion Score[2]	1.31	1.38	1.31	1.39	1.25	1.42	1.47	1.31	1.33	0.077	0.86	0.60	0.61
LM													
pHu	5.52	5.48	5.55	5.48	5.49	5.47	5.49	5.48	5.48	0.04	0.13	0.62	0.35
L*	53.74	55.50	53.79	53.73	54.62	53.97	54.63	54.95	55.20	0.72	0.28	0.15	0.64
a*	1.79	2.05	2.09	2.00	1.41	2.28	1.86	2.29	2.05	0.33	0.74	0.44	0.23
b*	11.17	11.77	11.49	11.41	11.03	11.65	11.24	11.82	11.86	0.31	0.48	0.22	0.30
Drip loss[3], %	1.59	1.95	1.60	1.36	1.60	1.65	1.39	2.13	1.72	0.24	0.41	0.03	0.61
SM													
pHu	5.58^{ab}	5.52^{b}	5.66^{a}	5.57	5.62	5.56	5.59	5.53	5.59	0.04	0.74	0.21	0.02
L*	48.65	48.74	48.19	47.36	49.44	49.34	48.72	50.74	48.82	0.75	0.30	0.08	0.34
a*	2.22	2.34	2.30	2.22	1.80	2.69	2.27	2.12	2.28	0.32	0.96	0.36	0.55
b*	9.35	9.03	8.61	8.73^{a}	9.25^{ab}	9.64^{b}	9.18	9.67	9.64	0.33	0.11	0.55	0.07
AD													
pHu	5.67^{ab}	5.58^{b}	5.78^{a}	5.60	5.67	5.67	5.66	5.61	5.63	0.04	0.36	0.10	0.04

[1]BF: bottom front, MM: middle middle, TR: top rear.
[2]Based on photographic charts (from 1: none to 5: severe; MLC 1985) used here as a continuous variable.
[3]Drip loss=−0.1+(0.06 × mg fluid).
[a,b]Within a row and trailer type, Lsmeans lacking a common superscript differ at $P < 0.10$.

paler SM muscle compared to pigs transported in the BF compartments (49.64 vs. 48.24; SEM = 0.43). Colour L∗ values in the SM muscle of pigs transported in the TR compartment did not differ from those of pigs located in the BF or MM compartment ($P > 0.10$). Trailer type × compartment interaction tended to influence colour b∗ values in the SM muscle ($P = 0.07$), with pigs transported in the TR compartment of the SPB trailer presenting a greater b∗ value than pigs transported in the same compartment of the MPB and AFD trailers ($P = 0.06$ and $P = 0.07$, respectively).

4 Discussion

Under warm ambient conditions, improvements in trailer design, in terms of use of mechanical ventilation and water misting are recommended to ensure better thermal comfort of pigs during transport (Rioja-Lang et al. 2019).

In this study, the use of ventilation fans and water misters in specific compartments of the MPB and AFD trailers provided a better thermal environment for pigs compared to the passively ventilated SPB trailer, as shown by the lower temperature, THI and ΔT during the stationary and moving phases of transport. However, differences between these ambient variables were not of great magnitude. The benefit of combining the use of fan-assisted ventilation with water misting to remove excessive moisture and improve internal trailer ambient conditions have been previously reported (Pereira et al. 2018). However, during the wait-at-farm and transit phases of this study, the RH and ΔRH were higher in the MPB trailer, featuring fan-assisted ventilation, compared to the SPB trailer. This difference is most likely due to inefficiency of the ventilation fans installed in this trailer type or the poor internal design of the SPB trailer impeding a smooth and consistent airflow inside the vehicle. This latter explanation may confirm a previous interpretation of intercompartmental variation in T and RH in a stationary SPB trailer exposed to an external fan-water misting bank (Pereira et al. 2018). Either factor may have limited the removal of water vapour in the air generated by the water sprinklers, which may prevent efficient evaporative cooling on pigs.

Compartment location within a trailer is a key contributor to animal losses, poor welfare, and meat quality defects (Faucitano and Goumon 2018), through, among others, its effects on microclimate characteristics (Weschenfelder et al. 2012, 2013; Fox et al. 2014; Pereira et al. 2018). Consistent with other studies (Brown et al. 2011; Weschenfelder et al. 2013; Pereira et al. 2018), the BF compartment of the SPB trailer during summer was warmer and had a higher THI than other compartments when stationary at the farm and in motion. This ambient condition may be explained by proximity to external heat sources, such as truck engine, floor, and drive wheels (Brown et al. 2011) combined with heat stagnation in this compartment due to reduced exchange rate or internal airflow caused by the presence of a solid front wall and an imbalance of air pressure gradients around a moving vehicle (Kettlewell et al. 2001; Nannoni et al. 2014; Gilkeson et al. 2016). The lower compartment height in the bottom deck (0.93 vs. 1.06 and 1.10 m in the SPB, MPB and AFD trailers, respectively) might have contributed to limited air circulation as well (Brown et al. 2011). Based on the estimated maximum height of the market weight pig used in this study (0.80 m tall; Visser 2014), the headroom of 0.30 m (between the highest point on the animal body and the ceiling of the compartment) recommended to ensure sufficient airflow temperature to regulate humidity and remove noxious gases in passively ventilated vehicles (SCAHAW 2002) was not respected in this SPB trailer.

Studies have reported that the risk of in transit losses due to heat stress is exacerbated when passively ventilated vehicles are stationary, such as the SPB trailer during the waits before departure and unloading in this study, and this is thought to be a result of rising temperatures caused by minimal airflow (Ritter et al. 2009; Sutherland et al. 2009; Weschenfelder et al. 2012; Fox et al. 2014). In the present study, differences in temperature, RH, and THI between trailer and compartments within trailer did not result in any differences in hematocrit percentage, which is an indicator of heat stress-related dehydration (Waltz et al. 2014). Furthermore, neither trailer type nor compartment affected drinking behaviour during lairage, which confirms the lack of difference in the dehydration condition of pigs. Similarly to Pereira et al. (2018), this result would suggest that temperature differences observed between and within trailers were not sufficient enough to result in a difference in the dehydration state of pigs upon arrival at the slaughter plant which may explain the similar drinking behaviour in the lairage pen.

Studies have suggested the thermo-neutral zone during transport for market weight pigs, weighing between 111–160 kg, is 10–28 °C (Bracke et al. 2020). Every trailer type, during the wait-at-farm, transit, and wait-at-plant phases, was found to be in the thermo-neutral range for pigs during transport. Additionally, viewing the trailers as a whole, the average THI values did not exceed the alert THI threshold of 75 (NWSCR 1976). However, certain trailer compartments during some phases did exceed the alert THI threshold, specifically the BF compartment of the SPB during all phases, and the MM of the SPB during the waiting phase. These findings suggest that fan-ventilation and water misters, as those installed in the MPB and AFD trailers, may provide sufficient ventilation and cooling in BF compartments and the MM compartments during stationary periods. These cooling mechanisms keep internal trailer conditions in the safe THI zone for pigs transported during Canadian summer conditions, compared to the passive punch hole ventilation of the SPB trailer.

Elevated blood lactate and CK concentrations are typically observed when pigs are subjected to short- or long-term physical exertion, respectively, such as climbing or descending ramps in trailers during loading and unloading or fast walking/overlapping in response to poor handling (Knowles and Warriss 2000; Faucitano and Lambooij 2019). In this study, positive effects of improved design features, such as fully moving hydraulic decks in the AFD trailer or the hydraulic ramp feeding the TR compartment in the MPB trailer, on the physiological conditions of pigs at slaughter were anticipated. The CK concentration in pigs transported in the BF compartment of the SPB trailer were greater than those transported in the MM compartment, but the TR compartment was not observed as different from either the BF or MM compartments, suggesting that navigating internal ramps did not play a large role in the physiological conditions of pigs at the time of slaughter. However, this difference in CK concentration may be better explained by the higher temperatures and THI found in the BF compartment of the SPB trailer during the wait and transit phase. Sommavilla et al. (2017) also found higher blood CK concentrations in pigs transported in the bottom rear compartment of a SPB trailer, as well as the TR compartment, during warm ambient temperatures (*i.e.,* the summer), further highlighting the role that heat stress plays. However, the serum CK levels recorded at slaughter in this study are within the range of normal levels for pigs (2.4 to 1251 UI L^{-1}; Harapin et al. 2003) and their variation would, thus, only indicate a mild physiological response of pigs to transport and handling stress.

No difference in blood lactate concentration was found at slaughter between trailer types or compartments within trailer. This result is not surprising considering the time and optimal rest conditions provided to pigs in lairage to recover from transport and handling stress (as shown by the lack of difference in post-transport behaviours) in this study, and the half-life of lactate concentration in blood after stress (peak in 4 min and return to basal level in 2 h; Anderson 2010). Other studies also failed to find effects of trailer type and compartment during transport on blood lactate levels in pigs at the time of slaughter (Weschenfelder et al. 2013; Sommavilla et al. 2017). In contrast, Weschenfelder et al. (2012) and Correa et al. (2013, 2014) reported higher blood lactate concentrations in pigs either transported in a SPB trailer compared to hydraulic flat-decked trailer studies. The discrepancy in the results may be explained by the response of pigs to *peri-mortem* handling which may be influenced by the pigs' memory of previous negative handling experience (e.g., loading; Correa et al. 2010; Edwards et al. 2010*a*, *b*). In this study, focal pigs were loaded onto trailers gently and in pre-formed groups (no mixing) through shipping pens. Furthermore, pigs could rest from the stress of loading for 0.5 h, on average, before departure from the farm. They were also driven to slaughter in small groups using automatic push-gates and a group-wise stunning system, which have been reported to be stress-free handling tools (Christensen and Barton-Gade 1997; Franck et al. 2003).

In this study, pork meat quality as assessed in the LM was only affected by compartment location with effects limited to meat exudation rate, in terms of production of drier (drip loss percentage below the threshold of 2%) loins in pigs transported in the BF compartment than in those located in the MM compartment. The low height of the bottom deck, a shared feature between the three trailer types, may have contributed to the occurrence of this meat quality defect, based on its effects on BF compartment ambient conditions resulting from reduced airflow in the SPB trailer and potential handling issues caused by the uncomfortable crawling position of the handler (K. Moak, personal observation, 2019) during loading and unloading the bottom compartments across all trailers. The handler's physical fatigue may lead to increased and rougher handling interventions on pigs with effects on animal stress (Gosálvez et al. 2006; Ritter et al. 2006; Dalla Costa et al. 2019).

Greater effects of the studied factors were expected on pork meat quality as assessed in locomotory muscles, such as the SM and AD muscles. These muscles are, in fact, more prone to rapid glycogen exhaustion in response to physical stressors, such as negotiating ramps at loading and unloading and warmer and colder ambient conditions, compared to postural muscles (LM), resulting in greater risk for pork meat with DFD (dark, firm, dry) characteristics (Correa et al. 2013, 2014). However, in the present study, no differences were seen in either the SM or AD muscle pHu values between pigs transported in different trailers, suggesting limited effects of the hydraulic devices (ramp or decks) on physical stress in locomotory muscles in comparison to internal ramps. This result confirms the conflicting findings reported in past studies, with the effects of trailer type (hydraulic decks vs. fixed decks and ramps) on pork meat quality ranging from major differences (Correa et al. 2013; Weschenfelder et al. 2013) to minimal differences (Dalla Costa et al. 2007) or no differences (Weschenfelder et al. 2012). However, instead, greater pHu values were found in the SM and AD muscles of pigs transported in the TR compartment compared to those transported in the MM compartment in the SPB trailer. These results may suggest that pigs transported in this location of the SPB trailer experienced greater physical effort in their locomotory muscles than pigs transported in the middle deck compartment. This physical exercise can be associated with the need to negotiate the internal ramp accessing this location during loading and unloading (Goumon et al. 2013; Correa et al. 2014). These results agree with those reported by Scheeren et al. (2014) who also reported a greater pHu value in the AD muscle of pigs transported in the top front compartment compared to the middle and bottom front compartments of a SPB trailer. Correa et al. (2014) also registered greater pHu values in the AD muscle of pigs located in the upper deck compartment compared to the middle compartments of a SPB trailer, but found no difference in this meat quality trait between this location and the bottom deck compartments.

Overall, the few effects of transport factors on pork meat quality assessed in this study were of little biological and economical importance.

5 Conclusions

Overall, the results of this study indicate that trailer design improvements, such as fan-assisted ventilation and water misting, produced a better thermal environment, in terms of lowering temperature and THI, inside specific vehicle compartments under summer conditions, specifically in the BF compartment of the SPB trailer. However, these improvements had no impact on pigs' post-transport behaviour and physiological condition at slaughter, or pork meat quality, suggesting their inefficiency in providing biologically relevant cooling effects for pigs during the summer transport conditions of the present study.

Features of the SPB trailer, such as the low deck height, the solid front wall, and the steep internal ramps, should be redesigned to provide a better thermal environment in specific compartments of the trailer. By redesigning these compartments of the SPB trailer to allow for greater ventilation, the negative combined effects of compartment position and season on pork meat quality variation could be reduced, thereby improving the welfare and pork meat quality variation of market pigs transported to slaughter.

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Data availability

Data generated or analyzed during this study are provided in full within the published article and its supplementary materials.

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Competing interests

The authors declare there are no competing interests.

Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/CJAS-2022-0023.

References

Anderson, D.B. 2010. Relationship of blood lactate and meat quality in market hogs. Presentation at the 63rd Reciprocal Meat Conference of the American Meat Science Association. Lubbock, TX.

Bracke, M.B.M., Herskin, M.S., Marahrens, M., Gerritzen, M.A., and Spoolder, H.A.M. 2020. Review of climate control and space allowance during transport of pigs. Report of the EURCAW-Pigs. Available online: https://www.eurcaw.eu/en/eurcaw-pigs/dossiers/climate-control-and-space-allowance.htm.

Brown, J.A., Samarakone, S., Crowe, T., Bergeron, T.R., Widowski, T. Correa, J.A., et al. 2011. Temperature and humidity conditions in trucks transporting pigs in two seasons in eastern and western Canada. Trans. ASABE, **54**: 2311–2318. doi: 10.13031/2013.40650.

Canadian Council of Animal Care. 2009. Guidelines on the care and use of farm animals in research, teaching and testing. Canadian Council on Animal Care, Ottawa, Canada.

Christensen, L., and Barton-Gade, P. 1997. Neue Entwicklungen beim handling von Schweinen in Schlachtbetrieben. Fleischwirtschaft, **7**: 604–607.

CIE. 1976. Publication CIE No. (E-1.31), International Commission on Illumination, Colorimetry: Official Recommendation of the International Commission on Illumination. Bureau Central de la CIE, Paris, France.

Conte, S, Faucitano, L, Bergeron, R, Torrey, S, Gonyou, H.W. Crowe, T, et al. 2015. Effects of season, truck type and location within truck on gastrointestinal tract temperature of market-weight pigs during transport. J. Anim. Sci. **93**: 5840–5848. doi: 10.2527/jas.2015-9338. PMID: 26641194.

Correa, J.A., Gonyou, H.W., Torrey, S., Widowski, T.M., Bergeron, R., Crowe, T.G., et al. 2013. Welfare and carcass and meat quality of pigs being transported for 2 h using two vehicle types during two seasons of the year. Can. J. Anim. Sci. **93**: 43–55. doi: 10.4141/cjas2012-088.

Correa, J.A., Gonyou, H.W., Torrey, S., Widowski, T.M., Bergeron, R., Crowe, T.G., et al. 2014. Welfare of pigs being transported for long distance using a pot-belly trailer during winter and summer. Animals, **4**: 200–213. doi: 10.3390/ani4020200. PMID: 26480037.

Correa, J.A., Torrey, S., Devillers, N., Laforest, J.P., Gonyou, H.W., and Faucitano, L. 2010. Effects of different moving devices at loading on stress response and meat quality in pigs. J. Anim. Sci. **88**: 4086–4093. doi: 10.2527/jas.2010-2833. PMID: 20802143.

Dalla Costa, O.A., Dalla Costa, F.A., Feddern, V., Lopes, L.S., Coldebella, A., Gregory, N.G., and Monteiro de Lima, G.J.M. 2019. Risk factors associated with pigs pre-slaughtering losses. Meat Sci. **155**: 61–68. doi: 10.1016/j.meatsci.2019.04.020. PMID: 31077907.

Dalla Costa, O.A., Faucitano, L., Coldebella, A., Ludke, J.V., Peloso, J.V., dalla Roza, D.A., and Paranhos da Costa, M.J.R. 2007. Effects of the season of the year, truck type and location on truck on skin bruises and meat quality in pigs. Livest. Sci. **107**: 29–36. doi: 10.1016/j.livsci.2006.08.015.

Dewey, C., Haley, C., Widowski, T., Poljak, Z., and Friendship, R. 2009. Factors associated with in-transit losses of fattening pigs. Anim. Welf. **18**: 355–361.

Edwards, L.N., Engle, T.E., Correa, J.A., Paradis, M.A., Grandin, T., and Anderson, D.B. 2010*a*. The relationship between exsanguination blood lactate concentration and carcass quality in slaughter pigs. Meat Sci. **85**: 435–440. doi: 10.1016/j.meatsci.2010.02.012.

Edwards, L.N., Engle, T.E., Grandin, T., Ritter, M.J., Sosnicki, A., Carlson, B.A., and Anderson, D.B. 2011. The effects of distance traveled during loading, lairage time prior to slaughter, and distance traveled to the stunning area on blood lactate concentration of pigs in a commercial packing plant. Prof. Anim. Sci. **27**: 485–491. doi: 10.15232/S1080-7446(15)30523-4.

Edwards, L.N., Grandin, T., Engle, T.E., Porter, S.P., Ritter, M.J., Sosnicki, A.A., and Anderson, D.B. 2010*b*. Use of exsanguination blood lactate to assess the quality of pre-slaughter pig handling. Meat Sci. **86**: 384–390. doi: 10.1016/j.meatsci.2010.05.022.

Faucitano, L, and Lambooij, E. 2019. Transport of pigs. *In* Livestock Handling and Transport. *Edited by* T. Grandin. CABI Publ., Wallingford, UK, pp. 307–327.

Faucitano, L., and Goumon, S. 2018. Transport of pigs to slaughter and associated handling. *In* Advances in Pig Welfare. *Edited by* M. Špinka. Woodhead Publ., London, UK, pp. 261–293.

Faucitano, L., and Velarde, A. 2021. Optimising pig welfare during transport, lairage, and slaughter. *In* Understanding the behaviour and improving the welfare of pigs. *Edited by* S. Edwards. Burleigh Dodds Science Publ., Cambridge, UK, pp. 247–278.

Fox, J., Widowski, T., Torrey, S., Nannoni, E., Bergeron, R. Gonyou, H.W., et al. 2014. Water sprinkling market pigs in a stationary trailer. 1. Effects on pig behaviour, gastrointestinal tract temperature and trailer micro-climate. Livest Sci. **160**: 113–123. doi: 10.1016/j.livsci.2013.12.019.

Franck, M., Svensson, M., von Seth, G., Josell, A., Figwer, P.H., Poirel, M.T., and Monin, G. 2003. Effect of stunning conditions on occurrence of PSE defects in hams of rn+/RN⁻ pigs. Meat Sci. **64**: 351–355. doi: 10.1016/S0309-1740(02)00170-5. PMID: 22063114.

Gilkeson, C.A., Thompson, H.M., Wilson, M.C.T., and Gaskell, P.H. 2016. Quantifying passive ventilation within small livestock trailers using computation fluid dynamics. Comput. Electron. Agr. **124**: 84–99. doi: 10.1016/j.compag.2016.03.028.

Gosálvez, L.F., Averós, X., Valdelvira, J.J., and Herranz, A. 2006. Influence of season, distance, and mixed loads on the physical and carcass integrity of pigs transported to slaughter. Meat Sci. **73**. 553–558. doi: 10.1016/j.meatsci.2006.02.007. PMID: 22062551.

Goumon, S., Brown, J.A., Faucitano, L., Bergeron, R., Widowski, T.M., Crowe, T., et al. 2013. Effects of transport duration on maintenance behaviour, heart rate and gastrointestinal tract temperature of market-weight pigs in 2 seasons. J. Anim. Sci. **91**: 4925–4935. doi: 10.2527/jas.2012-6081. PMID: 23989882.

Haley, C., Dewey, C.E., Widowski, T., and Friendship, R. 2008*a*. Association between in-transit loss, internal trailer temperature, and distance traveled by Ontario market hogs. Can. J. Vet. Res. **72**: 385–389.

Haley, C., Dewey, C.E., Widowski, T., Poljak, Z., and Friendship, R. 2008*b*. Factors associated with in-transit losses of market hogs in Ontario in 2001. Can. J. Vet. Res. **72**: 377–384.

Harapin, I., Bedrica, L., Hahn, V., Šoštarić, B., and Gračner, D. 2003. Haematological and biochemical values in blood of wild boar (Sus scrofa ferus). Vet. Archiv, **73**: 333–343.

Kauffman, R.G., Eikelenboom, G., van der Wal, P.G., Merkus, G., and Zaar, M. 1986. The use of filter paper to estimate drip loss of porcine musculature. Meat Sci. **18**: 191–200. doi: 10.1016/0309-1740(86)90033-1. PMID: 22055647.

Kettlewell, P.J., Hoxey, R.P., Hampson, C.J., Green, N.R., Veale, B.M., and Mitchell, M.A. 2001. Design and operation of a prototype mechanical ventilation system for live- stock transport vehicles. J. Agr. Eng. Res. **79**: 429–439. doi: 10.1006/jaer.2001.0713.

Knowles, T.G., and Warriss, P.D. 2000. Stress physiology of animals during transport. *In* Livestock Handling and Transport, *Edited by* T. Grandin. CAB Int., Wallingford, UK, pp. 385–407.
Matte, J.J., Girard, C.L., and Brisson, G.J. 1986. Importance of folic acid administered during gestation on haemological status of piglets. Can. J. Anim. Sci **66**: 523–527. doi:10.4141/cjas86-054.
MLC. 1985. Concern at rindside damage in pigs. Meat and Marketing Technical Notes No. 4. Milton Keynes, Meat and Livestock Commission. Bletchley, UK, pp. 14–16.
Nannoni, E., Widowski, T., Torrey, S., Fox, J., Rocha, L.M., Gonyou, H.W., et al. 2014. Water sprinkling market pigs in a stationary trailer. 2. Effects on selected exsanguination blood parameters and carcass and meat quality variation. Livest Sci. **160**: 124–131. doi: 10.1016/j.livsci.2013.11.022.
National Pork Board. 2017. Transport Quality Assurance Handbook(National Pork Board, Des Moines, IA, USA version 5).
NWSCR. 1976. Livestock hot weather stress. Regional operations manual letter C-31}76. National Weather Service Central Region, Kansas City, MO, USA.
Pereira, T., Titto, E.A., Conte, S., Devillers, N., Sommavilla, R., Diesel, T., et al. 2018. Use of fan-misters bank for cooling pigs kept in a stationary trailer before unloading: effects on trailer microclimate, and pig behaviour and physiological response. Livest Sci. **216**: 67–74. doi: 10.1016/j.livsci.2018.07.013.
Rioja-Lang, F.C., Brown, J.A., Brockhoff, E.J., and Faucitano, L. 2019. A review of swine transportation research on priority welfare issues: a Canadian perspective. Front. Vet. Sci. **6**: 36. doi: 10.3389/fvets.2019.00036. PMID: 30854374.
Ritter, M.J.,Ellis, M., Brinkmann, J., DeDecker, J.M., Keffaber, K.K., Kocher, M.E. et al. 2006. Effect of floor space during transport of market-weight pigs on the incidence of transport losses at the packing plant and the relationships between transport conditions and losses. J. Anim. Sci. **84**: 2856–2864. doi: 10.2527/jas.2005-577.
Ritter, M.J., Ellis, M., Berry, N.L., Curtis, S.E., Anil, L., Berg, E., et al. 2009. Review: transport losses in market weight pigs: I. A review of definitions, incidence, and economic impact. Prof. Anim. Sci. **25**: 404–414. doi: 10.15232/S1080-7446(15)30735-X.
Ritter, M.J., Ellis, M., Bertelsen, C.R., Bowman, R., Brinkmann, J., DeDecker, J.M, et al. 2007. Effects of distance moved during loading and floor space on the trailer during transport on losses of market weight pigs on arrival at the packing plant. J. Anim. Sci. **85**: 3454–3461. doi: 10.2527/jas.2007-0232.PMID: 17785596.
Ritter, M.J., Ellis, M., Bowman, R., Brinkmann, J., Curtis, S.E., DeDecker, J.M., et al. 2008. Effects of season and distance moved during loading on transport losses of market-weight pigs in two commercially available types of trailer. J. Anim. Sci. **86**: 3137–3314. doi: 10.2527/jas.2008-0873. PMID: 18567725.
Rocha, L.M., Velarde, A., Dalmau, A., Saucier, L., and Faucitano, L. 2016. Can the monitoring of animal welfare parameters predict pork meat quality variation through the supply chain (from farm to slaughter)? J. Anim. Sci. **94**: 359–376. doi: 10.2527/jas.2015-9176.PMID: 26812341.
SCAHAW. 2002. The Welfare of Animals during Transport (Details for Horses, Pigs, Sheep and Cattle). Report of the Scientific Committee on Animal Health and Animal Welfare, European Commission, Brussels. Belgium.
Scheeren, M.B., Gonyou, H.W., Brown, J., Weschenfelder, A.V., and Faucitano, L. 2014. Effects of transport time and location within truck on skin bruises and meat quality of market weight pigs in two seasons. Can. J. Anim. Sci. **94**: 71–78. doi: 10.4141/cjas2013-136.
Sommavilla, R., Faucitano, L., Gonyou, H., Seddon, Y., Bergeron, R., Widowski, T., et al. 2017. Season, transport duration and trailer compartment effects on blood stress indicators in pigs: relationship to environmental, behavioural, and other physiological factors, and pork quality traits. Animals. **7**: 8. doi: 10.3390/ani7020008.
Sutherland, M.A., McDonald, A., and McGlone, J.J. 2009. Effects of variations in the environment, length of journey, and type of trailer on the mortality and morbidity of pigs being transported to slaughter. Vet. Rec. **165**: 13–18. doi: 10.1136/vetrec.165.1.13. PMID: 19578189.
Torrey, S., Bergeron, R., Widowski, T., Lewis, N., Crowe, T., Correa, J.A., et al. 2013*a*. Transportation of market-weight pigs: I. Effect of season, truck type, and location within truck on behaviour with a two-hour transport. J. Anim. Sci. **91**: 2863–2871. doi: 10.2527/jas.2012-6005.
Torrey, S., Bergeron, R., Widowski, T., Lewis, N., Crowe, T., Correa, J.A., et al. 2013*b*. Transportation of market-weight pigs 2. Effect of season and animal location in the truck on behaviour with a 8 hour transport. J. Anim. Sci. **91**: 2872–2878. doi: 10.2527/jas.2012-6006.
Visser, K. 2014. Note on minimum space allowance and compartment height for cattle and pigs during transport. Report 764.Wageningen UR Livestock Research, Wageningen, The Netherlands, 10p.
Waltz, X., Baillot, M., Connes, P., Bocage, B., and Renaudeau, D. 2014. Effects of hydration level and heat stress on thermoregulatory responses, hematological and blood rheological properties in growing pigs. PLoS One, **9**: e102537. doi: 10.1371/journal.pone.0102537. PMID: 25013960.
Weschenfelder, A.V., Torrey, S., Devillers, N., Crowe, T., Bassols, A., Saco, Y., et al. 2012. Effects of trailer design on animal welfare parameters and carcass and meat quality of three Pietrain crosses being transported over a long distance. J. Anim. Sci. **90**: 3220–3231. doi: 10.2527/jas.2012-4676. PMID: 22966081.
Weschenfelder, A.V., Torrey, S., Devillers, N., Crowe, T., Bassols, A., Saco, Y., et al. 2013. Effects of vehicle design on animal welfare parameters and carcass and meat quality of three Pietrain crosses being transported over a short distance. Livest. Sci. **157**: 234–244. doi: 10.1016/j.livsci.2013.07.004.
Xiong, Y., Green, A., and Gates, R.S. 2015. Characteristics of trailer thermal environment during commercial swine transport managed under U.S. industry guidelines. Animals, **5**: 226–244. doi: 10.3390/ani5020226. PMID: 26479232.