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Article

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

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Abstract

In total, 3654 market pigs were transported to slaughter in winter (six replicates/treatment; January–February in southwestern Ontario) using three trailers: a modified triple-deck pot-belly (MPB), an advanced flat-deck (AFD) trailer, 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 middle deck (MM), and top rear (TR)). In total, 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 SPB trailer overall was approximately 2.5 °C warmer ($P = 0.01$) compared to the MPB and AFD trailers while stationary at the farm. No differences ($P > 0.10$) in blood variables were found between trailers. The pHu value of the SM muscle was greater ($P = 0.05$) for pigs transported in the SPB trailer than in the AFD and MPB trailers. Given the few substantial effects of trailer models on animal welfare and meat quality, these three trailer models can be used indifferently for short-distance transportation in winter conditions in Canada.

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

Résumé

Un total de 3654 porcs de marché ont été transportés à l'abattoir en hiver (six répétitions/traitement; janvier-février 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 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). De façon générale, la remorque SPB était environ 2,5 °C plus chaude ($P = 0{,}01$) que les remorques MPB et AFD lorsqu'elles étaient stationnaires à la ferme. Aucune différence ($P > 0{,}10$) dans les variables sanguines n'a été trouvée entre les remorques. La valeur de pHu du muscle SM était plus élevée ($P = 0{,}05$) pour les porcs transportés dans la remorque SPB que dans les remorques AFD et MPB. Étant donné que peu de différences substantielles entre les remorques ont été notées sur le bien-être des animaux et la qualité de viande, on peut conclure que les trois modèles de remorques peuvent être utilisés pour le transport à courte distance en conditions hivernales au Canada. [Traduit par la Rédaction]

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

1 Introduction

In North America, the percentage of dead-on-arrivals (DOAs) and noninjured, nonambulatory (NANI) pigs has been reported to be greatest under early winter (≤5 °C) conditions (Schwartzkopf-Genswein et al. 2012; Peterson et al. 2017). The lowest suggested critical temperature during transport for market weight pigs, weighing between 111 and 160 kg, is 10 °C (Bracke et al. 2020). However, Canadian winter conditions often fall below this critical temperature threshold (Faucitano and Lambooij 2019), which likely has negative effects on pig welfare, carcass quality, and meat quality (Correa et al. 2014; Faucitano and Lambooij 2019). In Canada, the winter season presents a greater welfare challenge to pigs during transport compared to Canadian summer conditions as evidenced by decreased handling ease, increased heart rate during loading and unloading, greater exsanguination blood creatine kinase (CK) and lactate levels, and increased incidence of carcass bruising (Goumon et al. 2013*b*; Torrey et al. 2013*b*; Correa et al. 2014; Scheeren et al. 2014). Furthermore, pigs experiencing cold stress will shiver to generate heat, which can result in a higher incidence of dark, firm, and dry (DFD) pork quality defects as prolonged shivering can exhaust ante- and post-mortem muscle glycogen stores (Guàrdia et al. 2005; Correa et al. 2014).

Among other factors, the stress response of pigs during handling and transportation is affected by the design of the trailer, such as the loading/unloading system (ramps or hydraulic deck/tail-gate lift), deck/compartment position, microclimate control, and the interaction of these parameters with season (Faucitano and Goumon 2018). Loading/unloading is a crucial phase in pig transport due to the physical and psychological challenges pigs experience navigating ramps in the pot-belly (PB) trailer and from human handling (Goumon and Faucitano 2017). Loading pigs into compartments accessible by ramps, takes longer and there have been reports of greater pig vocalization, slipping, falling, and turning around during loading in PB trailers during Canadian winter transport compared with Canadian summer transport (Torrey et al. 2013*a*, *b*). Freezing temperatures result in slippery internal ramps decreasing the handling ease of pigs during loading and unloading (Torrey et al. 2013*b*), which may explain the greater number of handling-type bruises found on pigs transported during winter compared to summer (Dalla Costa et al. 2007). During transit, pigs tend to stand more to avoid contact with the cold trailer floor reducing the pig's in-transit resting behaviour, which, along with trailer design, may explain the greater heart rate recorded during the first phase of transport and the higher incidence of carcass bruises observed during this season (Dalla Costa et al. 2007; Torrey et al. 2013*b*; Correa et al. 2014; Scheeren et al. 2014). In addition, both lactate and CK concentrations, and pHu in the longissimus (LM), semimembranosus (SM), and adductor (AD) muscles were found to be higher in pigs transported in PB trailers during winter compared to summer (Correa et al. 2014), presumably in relation to slippery ramps (Torrey et al. 2013*b*) and cold stress (Goumon et al. 2013*b*).

These studies highlight the need for improvement in trailer design, which may include full moving decks, to improve the welfare of pigs during loading, transport, and unloading (Rioja-Lang et al. 2019). To this point, the novel designs of modified PB and fully hydraulic European triple flat-decked (FD) trailers recently introduced in Canada are raising significant interest among Canadian trucking companies. These novel trailer designs may allow for improved pig welfare and pork quality due to easier loading and unloading through hydraulic ramps and decks and may provide a better trailer microclimate during more extreme temperature conditions, such as the winter season in Canada.

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 from pigs transported to slaughter under Canadian winter conditions.

2 Materials and methods

All experimental procedures performed in this study were approved by the institutional animal care committee (approval no. 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 on Animal Care (2009).

2.1 Animals and treatments

A total of 3654 crossbred pigs (Large White × Landrace × Duroc crosses) of mixed sexes were shipped from five 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 67 km for 85 min, on average, ranging from 26 to 89 km and 47 to 131 min, respectively) during winter (January–February 2020; average transport temperature −0.6 °C, ranging from −5.9 to 8.3 °C). Pigs were transported from each farm using three different triple-decked trailer types, which included a standard pot-belly (SPB; model no. 80MP2-HC 2015 Barrett Tri Axle 53 Ft Pot-belly Hog/Cattle combo trailer, Barrett Trailers, Purcell, OK, USA), a modified pot-belly (MPB; Luckhart Transport, Sebringville, ON, Canada), and an advanced flat-deck trailer (AFD; model "SBA73Z semi-trailer" 2014 Pezzaioli Hydraulic three deck lift trailer, Carrozzeria Pezzaioli, Montichiari, Italy). Photos of the three trailer models are shown in the companion paper (Moak et al. 2022).

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 AFD trailer was equipped with fully hydraulic middle and top decks.

Pigs were transported over a six-week period (one replicate per week), and each replicate had all trailer types represented (total of 18 trailer loads of pigs, or six loads of pigs/trailer type).

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 ± 5.61 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. 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 loaded using sorting boards and paddles, while electric prods were used only 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 0.48, 0.49, and 0.46 m^2/pig in the SPB, MPB, and AFD trailers, respectively (Figs. 1*a*–1*c*).

Loading started on average at 0950 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. The average wait times applied at the farm before departure were as follows: 88 ± 13 min for the first trailer, 66 ± 10 min for the second trailer, and 27 ± 25 min for the last trailer.

During transit, only 10% of the side panels were open to provide air flow for air exchange in all trailers. All test compartments were partially open. All trailers were bedded with fresh wood shavings (1 cm thick bedding), with additional fresh straw bedding added 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 waited for 10 min in the unloading area prior to the start of the unloading procedure.

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 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 97 min on average, ranging from 20 to 163 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. Lairage alleys and the chute feeding the stunner were illuminated by green lighting aimed at improving handling by reducing shadows on the floor (Faucitano and Velarde 2021). Pigs were stunned in groups of five to seven 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

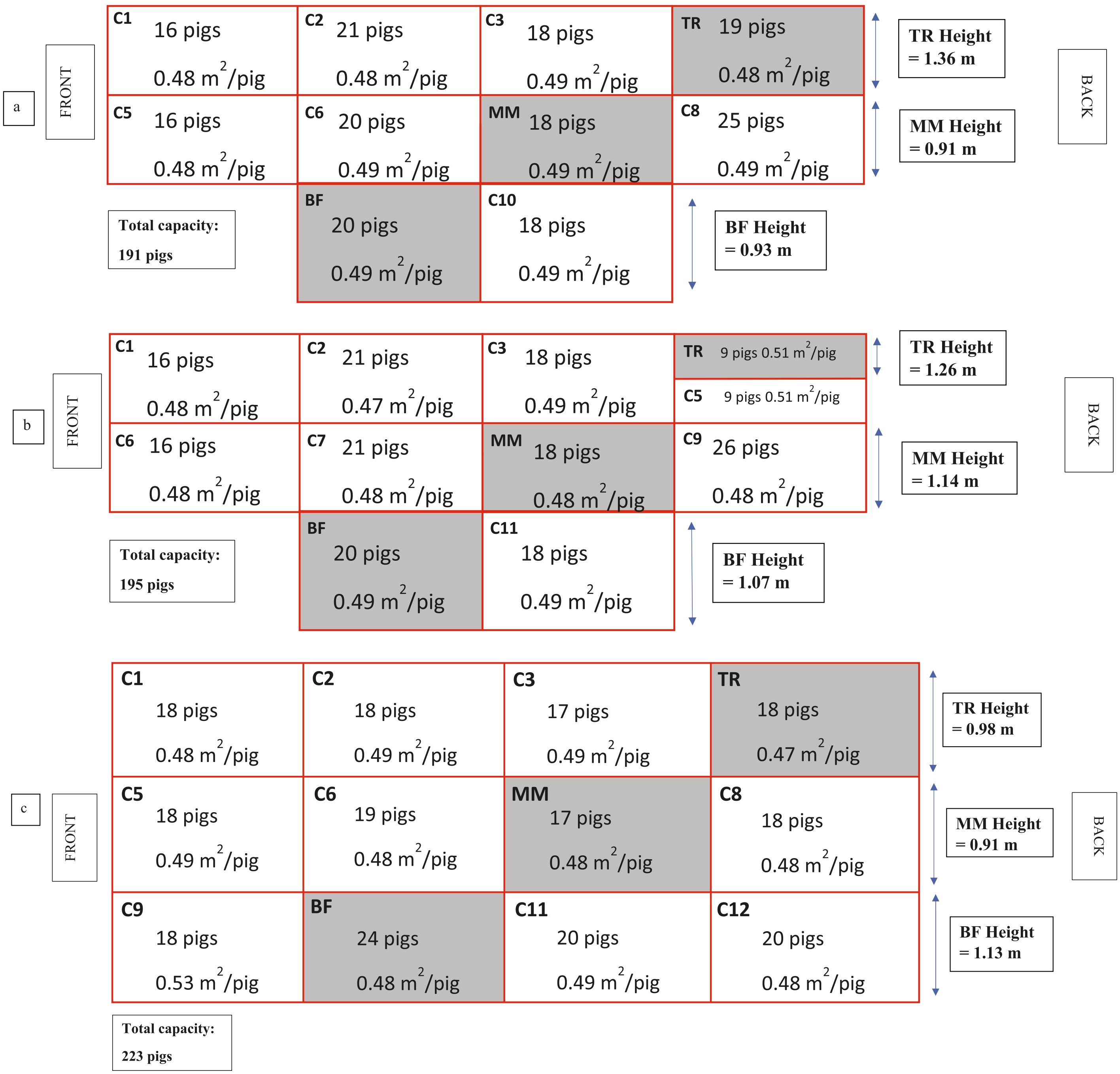
External and within trailer ambient air temperature and humidity data were collected using iButton data loggers (DS1923 Hydrochron Temperature/Relative Humidity Logger, Maxim Integrated Products Inc., Sunnyvale, CA, USA) attached on each side mirror of each trailer cab and inside the test compartments (five 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 °C with a resolution of ±0.0625 °C and an accuracy of 0.5 °C, and a RH range from 0% to 100% with a resolution of ±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 (HDRAS100V, Sony Corp., Tokyo, Japan) installed on the pen walls. The recording started as soon as the pen was filled

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.].



with pigs and the lairage gate was closed and ended after 30 min (minimum lairage time for all treatments). One video was excluded as the lairage duration was under 30 min. 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 (3 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 × *g* for 10 min at 4 °C and then stored at −80 °C until analysis. Serum CK concentration was analysed using a creatine kinase_SL kit (Creatine Kinase-SL Assay, SEKISUI Diagnostics, Charlottetown, PEI, 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 °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 5-point photographic scale (from 1 = no to very minimal lesions to 5 = severe lesions; Meat and Livestock Commission 1985).

All meat quality measurements were taken at 24 h postmortem by measuring pH (pHu) in the LM, between the third and fourth last rib, and in the SM and 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) with an 8° viewing angle, 10° observer angle, D65 illuminant, specular component included (SCI) mode, and an illumination measurement area of 8 mm in diameter, at three different points on the sample, after exposing the LM and SM muscle surface to 10 and 15 min blooming times, respectively. Drip loss was evaluated in the LM (same location as pHu measurement) using the filter paper wetness (FPW) test as described by Kaufmann 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 s of fluid accumulation on the paper. Percentage of drip loss was calculated by the following equation: [% drip loss = −0.1 + (0.06 × 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; Pereira et al. 2018), was calculated according to the NRC (1971) formula: $\mathrm{THI} = (1.8 \times T + 32) - [(0.55 - 0.0055 \times \mathrm{RH}) \times (1.8 \times T - 26)]$, where *T* is in °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, 8 carcasses (5%), 20 loins (12%), and 22 hams (14%) were lost throughout the whole study. Owing to difficulty in keeping pace with the speed of the bleed line on the kill floor, 10 blood lactate samples (6%) were missed, and due to sample mishandling, 18 blood hematocrit (11%) and 26 CK (16%) samples were lost throughout the whole study.

3 Results and discussion

3.1 Trailer microclimate

The average external ambient *T*, RH, and THI during transportation were −0.6 °C (ranging from −5.9 to 8.3 °C), 70.8% (ranging from 54.9% to 88.1%), and 35.2 (ranging from 28.8 to 47.6), respectively. The average trailer compartment *T*, RH, and THI during transports were 10.5 °C (ranging from 3.6 to 16.7 °C), 64.9% (ranging from 51.3% to 76.5%), and 52.3 (ranging from 41.5 to 61.1), respectively.

Despite no difference in the percentage of side panels open between trailer types and that all trailer types were passively ventilated, the SPB trailer overall was still approximately 2.0–

Table 1. Average temperature (T), relative humidity (RH), and temperature humidity index (THI)* of selected compartments in either standard pot-belly (SPB), modified pot-belly (MPB), or advanced flat-deck (AFD) trailers in winter.

	SPB			MPB			AFD			P			
Compartment*	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × compartment
Wait-at-farm													
T (°C)	14.75	14.04	11.61	11.85	12.34	10.16	9.67	10.66	12.60	1.68	0.01	0.71	0.24
RH (%)	73.19	64.38	60.77	63.88	67.69	78.54	71.39	69.52	76.36	2.94	0.01	<0.01	0.21
THI†	58.34	57.41	53.66	54.33	55.18	51.50	50.75	52.36	55.04	2.54	0.02	0.65	0.29
Transit													
T (°C)	13.07‡	11.19‡	8.57‡	11.29	9.49	8.67	9.12‡	13.29‡	9.71‡	1.14	0.22	0.23	<0.01
RH (%)	60.81	59.70	68.70	62.44	63.30	70.30	65.23	64.33	69.15	1.76	0.04	<0.01	0.36
THI	56.08‡	53.47‡	49.25‡	53.40	50.95	49.35	50.31	51.18	56.31	1.65	0.22	0.20	<0.01
Wait-at-plant													
T (°C)	9.64‡	11.40‡	13.42‡	11.96	11.11	9.85	9.20	9.81	13.56	1.21	0.60	0.66	<0.01
RH (%)	59.93	62.37	66.82	61.46‡	66.42‡	71.21‡	64.54	64.66	67.60	2.58	0.23	<0.01	0.08
THI	56.57‡	53.52‡	50.84‡	54.41	53.16	51.05	50.39	51.24	56.73	1.79	0.59	0.64	<0.01

*$THI = (1.8 \times T + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times T - 26)]$.
†BF, bottom front; MM, middle middle; TR, top rear.
‡Within a row and trailer type, least squares means lacking a common superscript differ at $P < 0.10$.

2.5 °C warmer (13.47 °C vs. 11.46 °C and 10.98 °C; SEM = 1.29; $P = 0.01$; Table 1) and had higher ΔT (11.97 °C vs. 8.66 °C and 8.75 °C; SEM = 1.18; $P = 0.02$; Table 2) and ΔTHI (17.68 vs. 12.85 and 12.50; SEM = 1.56; $P = 0.02$) compared to both the MPB and AFD trailer types during the wait-at-farm phase. This suggests that the design of the SPB trailer (i.e., solid walls and lower deck height) plays an important role in regulating compartment temperature while the vehicle is stationary. However, this effect was not seen during the wait-at-plant phase, which may be due to differential wind exposure between the farm and plant sites.

Compartment location within a trailer is a key contributor to animal losses, meat quality defects, and poor welfare (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). During transit, the trailer × compartment interaction influenced T, THI, ΔT, and ΔTHI values ($P < 0.01$ for all comparisons), with the BF of the SPB trailer presenting higher T and THI values ($P < 0.05$ for both comparisons) compared to the MM and TR compartments in this trailer, while ΔT and ΔTHI values were higher ($P < 0.05$ for both comparisons) in the BF compartment of the SPB trailer compared to the TR compartment. The ΔT and ΔTHI for the MM compartment of the SPB was intermediate and did not differ from that of the BF or TR compartments ($P > 0.10$). These results may be explained by the low height (0.93 m) of the BF compartment in the SPB trailer that might have contributed to limited air circulation during transit (SCAHAW 2002; 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. In the AFD trailer during transit, the MM compartment presented a higher T value ($P = 0.01$) compared to the BF and TR compartments in this trailer, while the ΔT value was higher ($P = 0.03$) in the TR compartment of the AFD trailer compared to the BF and MM compartments. The trailer × compartment interaction also influenced T and THI values ($P < 0.01$ for both comparisons) and ΔT and ΔTHI ($P = 0.02$ and $P = 0.03$, respectively) during the wait at the plant before unloading. Although, in this phase, the BF compartment was colder than the MM and TR compartments in the SPB trailer ($P < 0.05$), the THI was still higher ($P < 0.05$) in this compartment compared with the other two compartments in this trailer. During the same phase in the AFD trailer, higher ΔT and ΔTHI values ($P < 0.05$) were found in the TR compartment compared to the BF compartment, with ΔTHI being intermediate in the MM compartment.

The suggested lower critical temperature during transport for market weight pigs, weighing between 111 and 160 kg, is 10 °C (Bracke et al. 2020). Every trailer type overall, during all phases, were found to be in the thermo-neutral range for pigs during transport, with the exception of the MPB trailer during transit (average 9.8 °C). However, some compartments during certain phases did fall under this 10 °C temperature threshold. Although the ambient temperature values presented in this study were mild for a Canadian winter, compared to previous average Canadian ambient temperatures during winter transport studies (from −8.7 to −14.3 °C; Correa et al. 2013, 2014; Goumon et al. 2013*b*), those compartments failing to reach the thermo-neutral range for pigs during transport may require improved insulation for harsher Canadian winter transport conditions, especially those in western provinces where ambient temperatures are much lower.

3.2 Behavioural observations during lairage

Except for lying behaviour, neither trailer type nor compartment position or their interaction had an effect on

Table 2. Delta* temperature (ΔT, °C), relative humidity (ΔRH), and THI† (ΔTHI) in selected compartments in either the standard pot-belly (SPB), modified pot-belly (MPB), or advanced flat-deck (AFD) trailers in winter.

	SPB			MPB			AFD			P			
Compartment‡	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × compartment
Wait-at-farm													
ΔT (°C)	13.25	12.54	10.11	9.05	9.57	7.35	7.44	8.43	10.37	1.74	0.02	0.77	0.35
ΔRH (%)	−2.40	1.21	10.02	1.74	5.55	16.40	8.13	6.26	13.11	4.67	0.08	<0.01	0.70
ΔTHI‡	19.55	18.61	14.87	13.51	14.36	10.68	10.54	12.15	14.83	2.55	0.02	0.73	0.41
Transit													
ΔT (°C)	13.42§	11.54§	8.92§	12.24	10.44	9.62	10.49§	11.08§	14.66§	1.10	0.23	0.31	<0.01
ΔRH (%)	−7.97	−9.08	−0.08	−9.05	−8.19	−1.18	−9.42	−10.32	−5.50	3.50	0.50	0.01	0.94
ΔTHI	20.74§	18.14§	13.91§	18.79	16.28	14.68	16.70§	17.58§	22.70§	1.57	0.12	0.30	<0.01
Wait-at-plant													
ΔT (°C)	11.98	11.01	9.25	10.48	9.63	8.37	8.42§	9.02§	12.77§	1.30	0.41	0.91	0.02
ΔRH (%)	−5.31	−7.50	−3.05	−4.94	0.02	4.81	−5.83	−5.71	−2.77	4.87	0.09	0.13	0.70
ΔTHI	18.02	16.73	14.05	15.51	14.26	12.15	12.95§	13.08§	19.29§	2.25	0.29	0.92	0.03

*Delta values refer to the difference between the internal trailer compartment and the ambient external trailer environment.
†THI = $(1.8 \times T + 32) - [(0.55 - 0.0055 \times \text{RH}) \times (1.8 \times T - 26)]$.
‡BF, bottom front; MM, middle middle; TR, top rear.
§Within a row and type, least squares means lacking a common superscript differ at $P < 0.10$.

lairage behaviour ($P > 0.10$; Table 3). Trailer type tended to affect the average percentage of pig lying on the pen floor during rest ($P = 0.09$), where the effect of SPB trailer type produced a greater percentage of pigs lying down during lairage compared to the AFD trailer (77.9 vs. 68.8%; SEM = 3.0; $P < 0.05$). The tendency for a greater percentage of pigs transported in the SPB trailer lying during lairage compared to the AFD trailer may suggest that pigs transported in the SPB trailer were more fatigued than those transported in the AFD trailer due to the physical exertion required to navigate internal trailer ramps. Conversely, Torrey et al. (2013*a*) found that, although latency to rest did not differ, pigs transported during winter in a PB trailer spent less time lying in lairage compared to the flat-deck trailer. However, the percentage of pigs lying during lairage transported in the MPB trailer was intermediate and did not differ from either the SPB or AFD trailers. Although the MPB had a similar internal structure (i.e., ramps and bends) to that of the SPB, the lower slope of the ramps in the MPB trailer compared to the SPB trailer (bottom deck: 15° vs. 20° and top deck: 18° vs. 21°) may reduce the feeling of fatigue pigs experience during lairage.

3.3 Blood variables

Elevated blood lactate and CK concentrations are typically observed when pigs are subjected to short- or long-term physical exertion, respectively, such as ascending or descending ramps in trailers during loading and unloading, fast walking/overlapping in response to poor handling, and cold stress (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 hydraulic ramp feeding the TR compartment in the MPB trailer, on the physiological conditions of pigs at slaughter, were anticipated. However, neither trailer type nor compartment position or their interaction had an effect on blood lactate or CK concentrations at slaughter ($P > 0.10$; Table 4). Conversely,Correa et al. (2013) reported higher blood lactate concentrations at slaughter in pigs transported for 2 h in a PB trailer compared to a hydraulic flat-deck trailer under colder temperatures (−8.7 °C on average, ranging from −11.4 to −3.7 °C) and kept in lairage for a time similar (2 h) to that applied in this study. The different winter conditions experienced by pigs during transport may explain the discrepancy in their physiological condition at slaughter between the two studies.

3.4 Carcass lesion scores and meat quality traits

Carcass lesion scores were only affected by trailer type ($P < 0.01$; Table 5), with greater scores being found on the carcasses of pigs transported in the MPB trailer compared to the SPB and AFD trailer (1.57 vs. 1.27 and 1.39, respectively; SEM = 0.07; $P < 0.05$). Carcass lesion scores in pigs transported in the SPB and AFD trailers did not differ ($P > 0.10$). This result is hard to explain as the ramp in the BF compartment of both the SPB and MPB trailers are of the same length (2.0 m), but the ramp in the MPB has a reduced angle compared to the ramp in the SPB (15° vs. 20°). The lower ramp angle to access the TR compartment of the MPB trailer was obtained by extending the length of the ramp, which does not necessarily affect ease of handling, compared to the ramps in the SPB trailer (18° slope; length 4.7 m vs. 21° slope; length 3.0 m, respectively). Goumon et al. (2013*a*) reported no difference in heart rate and ease of handling (touches, slaps, and noise from the handler) in pigs navigating a 16° ramp (2.5 m long) compared to a 26° ramp (1.6 m long) at unloading. These results suggest that pigs find both longer ramps with a reduced ramp angle and shorter ramps with an increased ramp angle equally distressing. The difference

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

	SPB			MPB			AFD			$P^{\dagger}$			
Compartment*	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM†	Trailer	Compartment	Trailer × compartment
Lying (%)	73.23	78.49	81.88	73.81	72.50	82.93	70.82	60.79	74.65	5.03	0.09	0.11	0.67
Sitting† (%)	0.81	0.54	0.67	0.81	0.81	1.21	1.08	0.94	1.48	–	–	–	–
Standing (%)	25.79	20.47	17.04	24.62	26.13	17.49	26.36	37.69	23.47	4.95	0.13	0.10	0.59
Other† (%)	0.13	0.13	0.27	0.13	0.27	0.27	0.38	0.00	0.13	–	–	–	–

*BF, bottom front; MM, middle middle; TR, top rear.
†Due to low percentage values associated with Sitting and Other, these two variables are presented as medians.
Note: Within a row and trailer type, least squares means 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 winter.

	SPB			MPB			AFD			*P*			
Compartment*	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × compartment
Relative hematocrit (%)	46.41	43.14	44.71	45.58	45.14	44.44	44.85	45.33	43.55	1.45	0.88	0.32	0.52
Lactate (mmol/L)	7.76	8.24	8.29	7.32	9.16	6.82	7.99	7.37	7.28	0.78	0.51	0.24	0.13
CK (log UI/L)	3.53	3.43	3.36	3.53	3.34	3.40	3.50	3.47	3.43	0.09	0.78	0.12	0.81

*BF, bottom front; MM, middle middle; TR, top rear.

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 winter.

	SPB			MPB			AFD			*P*			
Compartment*	BF	MM	TR	BF	MM	TR	BF	MM	TR	SEM	Trailer	Compartment	Trailer × compartment
Lesion score†	1.19	1.38	1.25	1.44	1.64	1.63	1.44	1.44	1.30	0.07	<0.01	0.31	0.59
LM													
pHu	5.37	5.42	5.38	5.39	5.39	5.38	5.45	5.43	5.41	0.03	0.06	0.47	0.49
L^*	54.54	53.84	54.78	55.09	54.63	52.98	53.96	53.82	54.91	0.89	0.94	0.70	0.10
a^*	2.32	2.41	2.52	2.49	2.23	2.78	2.58	2.35	2.62	0.27	0.86	0.28	0.86
b^*	11.40	11.16	11.36	11.68	11.26	11.20	11.25	11.29	11.70	0.32	0.87	0.56	0.52
Drip loss‡ (%)	1.30	1.24	1.25	1.10	0.98	0.98	1.21	1.11	1.21	0.19	0.16	0.76	1.00
SM													
pHu	5.50	5.51	5.54	5.53	5.46	5.49	5.46	5.47	5.49	0.03	0.05	0.34	0.23
L^*	51.57	50.90	51.02	50.90	51.93	50.55	50.49	51.62	49.70	0.83	0.53	0.16	0.52
a^*	2.01	2.36	1.96	2.03	2.04	2.64	2.35	2.32	2.19	0.29	0.72	0.83	0.38
b^*	9.37	9.69	8.72	9.20	9.59	8.83	9.24	9.97	9.25	0.52	0.74	0.11	0.97
AD													
pHu	5.58§	5.64§	5.72§	5.69	5.59	5.58	5.57	5.62	5.63	0.04	0.32	0.50	0.01

*BF, bottom front; MM, middle middle; TR, top rear.
†Based on photographic charts (from 1: none to 5: severe; MLC 1985).
‡Drip loss= $-0.1 + (0.06 \times \text{mg fluid})$.
§Within a row and trailer type, least squares means lacking a common superscript differ at $P < 0.10$.

in carcass lesion scoring between the SPB and MPB trailers in the current study may be explained by the greater incidence of slips and falls observed during loading and unloading onto and from the MPB trailer (K. Moak, personal observation, 2020), regardless of the lower incline of the internal ramps in this trailer type compared with the SPB trailer. This increase incidence of slips and falls may be due to pigs rushing off the longer, less steep, ramp to decrease their time spent in a distressing situation. However, it is difficult to differentiate carcass lesions due to fighting, biting, and mounting and lesions due to other causes, such as slips and falls, using the carcass lesion scoring method used in this study.

Except for the pHu, neither trailer type nor compartment or their interaction had an effect on any meat quality traits ($P > 0.10$; Table 5). Loins from pigs transported in the MPB tended to have a lower pHu value compared to the loins from pigs transported in the AFD trailer (5.38 vs. 5.43; SEM = 0.01; $P = 0.06$). This result disagrees with Correa et al. (2013) who found a higher pHu value in the loins of pigs transported for a similar distance during winter in a PB trailer compared to a hydraulic flat-deck trailer.

Greater effects of the studied factors were expected on meat quality as assessed in locomotory muscles, such as the SM and AD muscles, compared to the LM. These muscles are, in fact, more prone to rapid glycogen exhaustion in response to physical stressors, such as navigating ramps at loading and unloading, compared to postural muscles (e.g., LM), resulting in significant depletion of muscle glycogen stores and higher incidence of meat with DFD characteristics (Guàrdia et al. 2005; Correa et al. 2013, 2014).

In this study, pHu value in the SM muscle of pigs transported in the SPB trailer was slightly higher compared to the AFD trailer (5.52 vs. 5.47; SEM = 0.03; $P = 0.05$), which may suggest that pigs experienced more physical stress when transported in the SPB trailer, through navigating internal ramps during loading and unloading, compared to pigs that navigated flat-decks in the AFD trailer. However, the pHu in the SM muscle of pigs transported in the MPB trailer (5.49; SEM = 0.03), which features reduced internal ramp angles in comparison to the SPB trailer, did not differ from either the SPB or the AFD trailers.

A trailer × compartment interaction affected the pHu value of the AD muscle ($P = 0.01$), with slightly greater pHu values ($P < 0.05$) being recorded in this muscle for pigs transported in the TR compartment of the SPB trailer compared to the BF compartment. This result may suggest that pigs transported in the TR compartment of the SPB trailer experienced greater physical effort in their locomotory muscles than pigs transported in the BF compartment of the SPB. This physical exercise can be associated with the need to negotiate the internal ramp accessing the top deck at loading and unloading (Goumon et al. 2013*b*; Torrey et al. 2013*b*). These results disagree with those reported by Correa et al. (2013) who only reported the effect of deck position within the PB trailer on meat quality variation (i.e., paler pork meat from the top and bottom decks) under similar handling and transport conditions in summer.

Overall, these differences in pHu values in the LM, SM, and AD muscles are of little, if no, biological significance.

4 Conclusions

Based on the results of this study obtained in hauls occurring under mild Canadian winter conditions, the SPB, MPB, and AFD trailers can be indifferently used for the transport of pigs to slaughter at no detriment to animal welfare, carcass quality, or meat quality. However, our results also confirm the impact of the SPB trailer design on microclimate control, with this trailer model being warmer compared to the MPB and AFD trailers while stationary on farm with all trailers being passively ventilated and no differences in the percentage of side panels open between trailer types. This suggests that features of the SPB trailer, such as punch-hole passive ventilation openings, low deck height, and the solid front wall, still play an important role in regulating compartment temperature while the vehicle is stationary.

Some compartments featured in all trailers during different transport events were seen to be below the lower thermoneutral threshold for pigs during transport, suggesting the need for an improvement in insulation in the trailers when used for Canadian winter transports.

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Data availability

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

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Competing interests

The authors declare there are no competing interests.

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