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Transport distance influenced the proportion of skin lesions in finishing pigs and negatively affected animal welfare

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Abstract Transport is a relevant process during pigs' lives because of its impact on animal welfare. Considering commercial conditions, several factors vary between journeys; therefore, it is important to establish the influence of transport distance on skin lesion scores in finishing pigs, considering weather and vibration conditions. Skin lesion score was assessed in 649 finishing pigs at the farms before loading, with a five-point scale (0= none to 4 = ≥ 16 superficial lesions or > 10 deep lesions), and at the slaughterhouse after unloading. Three transport distances were evaluated (short, intermediate and long), in which microclimatic and vibration conditions were monitored from the vehicle's compartments. Intermediate distances showed higher proportions of worst score (4) at the front part, whereas long distances presented worst score at the middle and hind quarters. Short distances displayed higher proportions of worst score at ears. Temperatures inside the vehicle were above the thermal comfort limit for pigs, providing a heat stress condition. Vibrations were higher sideways than in the vertical and longitudinal directions. Transport under tropical conditions negatively affected the skin injuries score, indicating a higher incidence of skin wounds at the slaughterhouse than in the farms. Body parts can be affected differently by distance, considering skin lesion scores.

Keywords: animal transportation, trailer vibration, animal welfare, skin lesions

1. Introduction

Although the transportation of animals is a common practice in pig productive cycles, the operation itself is inherently complex when it comes to promoting animal welfare and minimizing production losses within the pork industry (Machado et al., 2022). During transportation, numerous factors pose risks that can induce stress in animals, leading to alterations in physiological and behavioral responses and contributing to productive losses (Nielson et al., 2022, Faucitano 2018; Goumon, 2018), such as mortality and injury – ambulatory and non-ambulatory – rates (Dalla Costa et al., 2019b). Thus, pig transportation stands out as one of the critical pre-slaughter phases which demand careful attention, requiring meticulous and effective planning (Machado et a., 2022).

Many transport factors might induce stress in animals, such as distance and duration, microclimatic conditions, trailer design (Schwartzkopf-Genswein et al., 2012) and stocking density (Warriss et al., 1998; Pilcher et al., 2011), as well as the location inside the trailer (Barton Gade et al., 1996; Dalla Costa et al., 2007), mixing of unfamiliar animals at loading (De jong et al., 2000; Barton Gade, 2008a and 2008b), microclimatic conditions inside the trailer (Driessen, et al., 2020) loading/unloading systems (Faucitano & Goumon, 2018), trailer vibration (Stephens et al., 1985; Gebresenbet et al., 2011; Alambarrio et al., 2022).

Not only transport processes, but also the farm of origin (Grandin, 2017; Faucitano, 2018) and the facilities at the slaughterhouse (Lammens et al., 2007) are involved in such issues, consisting a multifactorial cause (Barton Gade, 2008a). In addition to animal welfare concerns, economic losses affect producers, hauliers, industry (Faucitano, 2018) and retailers from the pork supply chain, caused mostly by transport processes (Dos Reis et al., 2015), representing an important issue. Such losses can be attributed to skin damage and its depreciation (Faucitano, 2001), pigs which die during transport and the inability to move or stand at the slaughterhouse (Ritter et al., 2009). Several studies evaluate the influence of transport aspects on the incidence of skin injuries in pigs (Barton Gade at al., 1996; Correa et al., 2013; Dalla Costa et al., 2017; Driessen et al., 2020; Mota-Rojas et al., 2006), since this can be used as an animal welfare indicator (Carroll et al., 2015; Bottacini et al., 2018), indicating its importance in the swine industry.

It is also important to emphasize that the conditions of the roads and the orientation of the animals determine the vibration levels, as well as the vibration transmission from

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the vehicle chassis to the floor where the animals are placed, so that the vibration levels are perceived under different directions (Gebresenbet et al., 2011). The movement of the vehicle has participation in animal welfare, which causes stress, sickness to the animals (Santurtun and Phillips, 2015), effects on the emotional responses of pigs, such as fear and an aversive character to the animals due to vibration (Stephens et al. al., 1995). The adaptation of animals in relation to vibration can be optimized under lower accelerations and the absence of sudden braking preceded by high acceleration rates, as well as the proper suspension of vehicles combined with driver training can provide better welfare conditions for animals.

Furthermore, the consumer profile has changed over time, which now demands more information about the supply chain of the products they buy and shows that consumers are willing to pay more for higher quality and healthier products (Chulayo and Muchenje, 2015; Mkwanazi et al., 2019). Thus, animal welfare policies, sustainability and traceability are expected to compose food industry practices, especially for the animal segment (Van de Weerd and Ison, 2019), indicating the need for further research involving pre-slaughter conditions of livestock.

This study aimed to evaluate the effect of transportation distance and vehicle vibration under tropical conditions on the level of skin lesions in finishing pigs, with the hypothesis that transportation distance and vibration levels increase the incidence of skin injuries in pigs proportionally.

2. Material and methods

2.1. Animals and study description

This observational study complies with ARRIVE guidelines. A total of 649 crossbred pigs, females and castrated males, approximately 5 months and 110 kg, were used, with the approval of the Ethics Committee on Animal Use (ESALQ/USP protocol number: 2019-24). Animals came from five different commercial farms and were distributed into three distinct distances (groups) – short, intermediate and long – to the slaughterhouse (groups 1, 2 and 3, respectively). All pigs received the same protocol for management and feeding until the finishing phase and were fasted from 12 hours before the scheduled loading. Water was provided ad libitum until loading. Transportation trials occurred during the summer, between February and March 2020, varying between 03:10-06:00 h of duration, 19.8-26.2°C of ambient temperature and 73-92% of relative humidity. Stocking density varied between 0.35-0.41 m^2/100 kg of live weight (Table 1). Transport data from the third journey from group 1 farms were disregarded due to unexpected mechanical issues at the vehicle during the journey, which have expressively prolonged the time of travel.

Considering the three different categories of distance, facilities diversified slightly. The furthest farms presented pens with water blades (or shallow pools), and facilities located at intermediate distances presented semi slatted concrete floors, whereas the closest farms had a full concrete floor.

One day before slaughter, 80 pigs (half of the load scheduled to transport) were randomly selected from pens and, before the skin evaluation, were marked with an individual tattoo number at both sides of the hindquarter. Those numbers provided the identification of the animals from farm until abattoir, after slaughter. To ensure better visibility of the injuries, animals were showered with a hose before the evaluation at the farms. Approximately at 4 pm, pigs were handled with plastic nets to leave the pens, dividing them into groups of 4-5 animals until reaching the loading facilities.

Table 1 Distance, duration and stocking density conditions from commercial transport between farms; groups of distances (1: short, 2: intermediate and 3: long) and slaughterhouse.

Farms		Distance (km)	Duration (h)	Stocking density at transport (m^2/100kg of body weight)	Number of pigs transported
	A	167	03:10	0.38	80
Group 1	A	167	03:25	0.40	80
Short distance					
Mean		167	03:17	0.39	80
Group 2	B	200	04:20	0.39	80
intermediate	B	200	04:00	0.41	80
distance	B	200	04:30	0.40	80
Mean		200	04:16	0.40	80
Group 3 long	C	353	06:00	0.38	81
distance	D	340	05:35	0.35	84
	E	344	05:20	0.38	84
Average		346	05:38	0.37	83

2.2. Loading and transport conditions

Once pigs left the pens, unfamiliar animals were mixed during loading and transport and were distributed into 5 compartments per deck inside the trailer, holding 8 pigs each at an average stocking density of 261 kg/m^2, totaling 160 animals per trip. As a common practice in all farms, animals were showered with a hose right before departure (3000 liters of water). Journeys from the furthest farms had commercial agreements with a slightly larger number of animals, causing the transport of 162 and 168 animals, the latter twice (evaluation of 81 and 84 animals, respectively).

Transports conducted animals from farms with similar double-decked trucks to a commercial slaughter plant with average distances of 157 km, 200 km and 346 km, corresponding to short, intermediate and long distances, respectively. All trips were performed in a truck, with a two-story Triel®—HT (2004) body model, containing 10 compartments (height = 4,2 m, length = 2,60 and width = 0,9 m, total area of 10,92 m) per deck/level.

The trailers had metallic structures with open sides and grid cross slating floor in aluminum. Ventilation was provided naturally during transport and animals allocated at the upper decks had a propylene net (Sombrite®) with 80% shading to prevent direct insolation, which remained folded while not in use (Figure 1).

Figure 1 Truck model used in transport trials from farms to slaughterhouse during the experiment. The yellow arrow indicates the propylene net (Sombrite® 80%) folded.

2.3. Unloading and handling procedures at the slaughterhouse

The truck arrived at the slaughterhouse between 20:00 and 01:00. Pigs were showered with a low pressure (sprinkling) cooling method at arrival at the plant and unloaded as soon as possible through a metal ramp (15° – ramp slope) with an adjustable slope and nonslip floor. Electric prods were used for animal conduction if necessary. At the arrival pens, animals were showered with water aspersion and a pressured hose to facilitate the second skin lesion evaluation before weighing and splitting the group into the resting pens. All pens had a concrete floor and walls with stainless steel, drinking nipples in a proportion of 1 to 12 animals and sprinkler systems. Ventilation was naturally provided.

Slaughter operations were in accordance with the provisions of current legislation, considering the technological operations and animal welfare requirements (BRASIL, 2000, 1995). At the end of the lairage, pigs were conducted to the stunning area with paddles and compressed air jets by the employees of the abattoir, which were continuously submitted to animal welfare training as a policy of self-control programs of the establishment. Animals were electrically stunned with a three-point electrode (forehead and heart, 400 V, 1, 2 A, 6 s, Sulmaq) inducing cardiac ventricular fibrillation at a restrainer before exsanguination within 30 seconds.

2.4. Data collection

2.4.1. Skin lesion assessment

The animals' sides were evaluated on a five-point scale, ranging from 0= none to 4= ≥16 superficial lesions or >10 deep lesions on the skin, adapted from the literature (Turner et al., 2006; Melotti et al., 2011; Tönepöhl et al., 2012), Welfare Quality® Protocol (2009) and Castro (2016), as illustrated in Figure 2. Superficial injuries were defined as injuries which go into the skin but do not penetrate it completely (scratches) and deep injuries were defined as gashes or openings that completely penetrate the skin (open wounds), according to the National Pork Board (2019). In order to standardize the assessment, each 5 cm of a scratch or a bruise was accounted for as 5 superficial injuries. Skin injuries from contact dermatitis, characterized by circular and focal structures, were not considered.

Skin lesion scores were assessed at two different moments: before loading procedures at the farm (A1) to disregard the previous effects of pre-slaughter operations, e.g., handling procedures of the farms, and immediately after unloading at the slaughterhouse (A2) to express the isolated effect of transport and its related processes, such as loading and unloading.

2.4.2. Microclimatic and vibration data record during transportation

Microclimatic characteristics, such as air temperature and relative humidity, were measured and recorded every 5 minutes with data loggers (HOBO U12-012, Onset®). Sensors were set between compartments 1, 3, 5, 6, 8, and 10 from right and left sides approximately 5 cm under the ceiling and covered with a meteorological shelter, totaling 6 sensors. The Temperature Humidity Index (THI) was calculated using the formula by Berman et al. (2016). Vibrations from three axles were also measured with data loggers (HOBO Pendant G, UA-004-64, Onset®) but recorded every minute from 4 distinct positions in the trailer. Sensors were set under deck levels of compartments 1, 5, 6 and 10 (schematic presentation of the trailer is illustrated in Figure 3). To calculate the root mean square (RMS), given by the vertical (RMSx), sideways (RMSy) and longitudinal (RMSz) directions (m/s2) and, therefore, the root sum square (RSS), providing the three combined effects (m/s2), the following formula was used, described by Griffin (1990) and used by Randall (1992) and Garcia et al. (2008):

$$RMS_j = \left(\frac{\sum_t aj(t)^2}{N}\right)^{1/2} \quad (1)$$

$$RSS = (RMS_X^2 + RMS_Y^2 + RMS_Z^2)^{1/2} \quad (2)$$

Where: $aj\ (t)$ is the instant acceleration in axle $j\ (x, y\ or\ z)$ at time $t\ (1, 2, 3, \dots N)$, in which N represents the total number of observations performed at each axle, observed at formula (1).

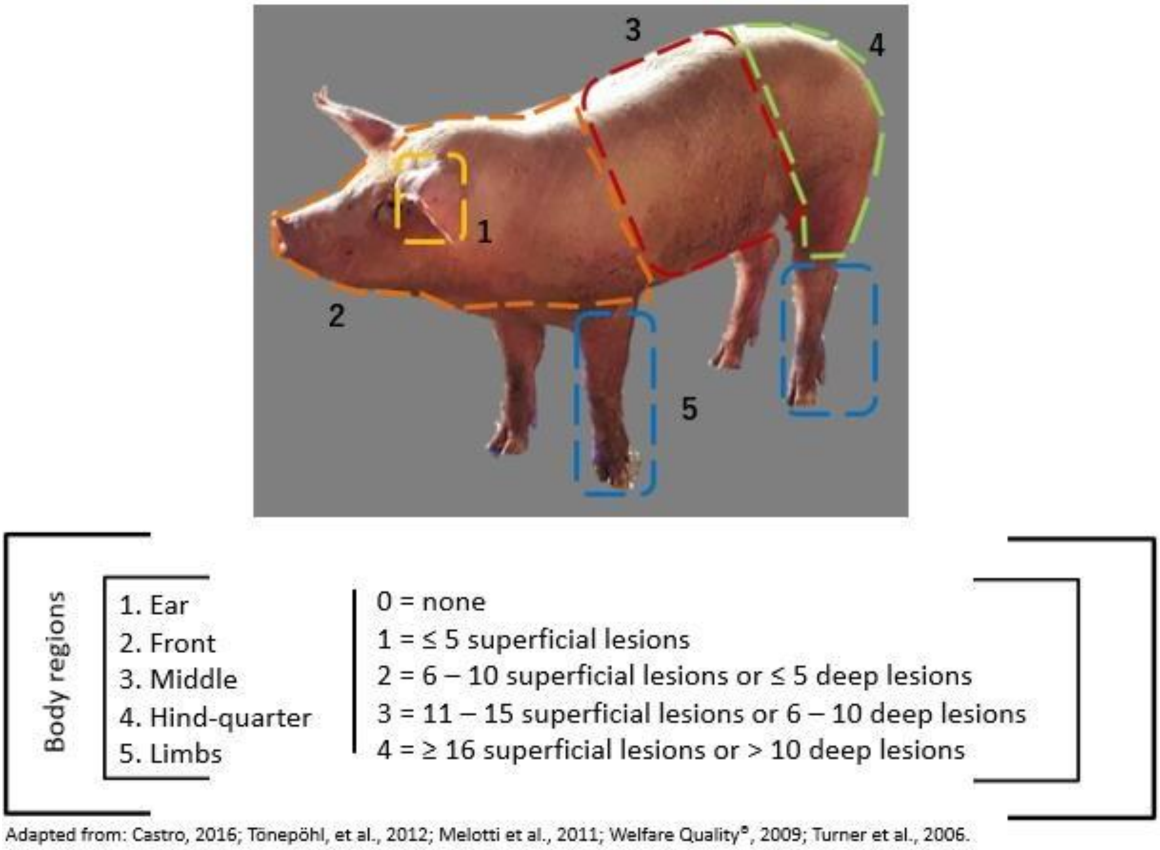

Figure 2 Injury scoring scheme of pigs at the left side of the body, divided into 5 regions: (1) ear; (2) front, considering the head to back of shoulder; (3) middle, back of shoulder to hind-quarter; (4) hind-quarter and (5) limbs.

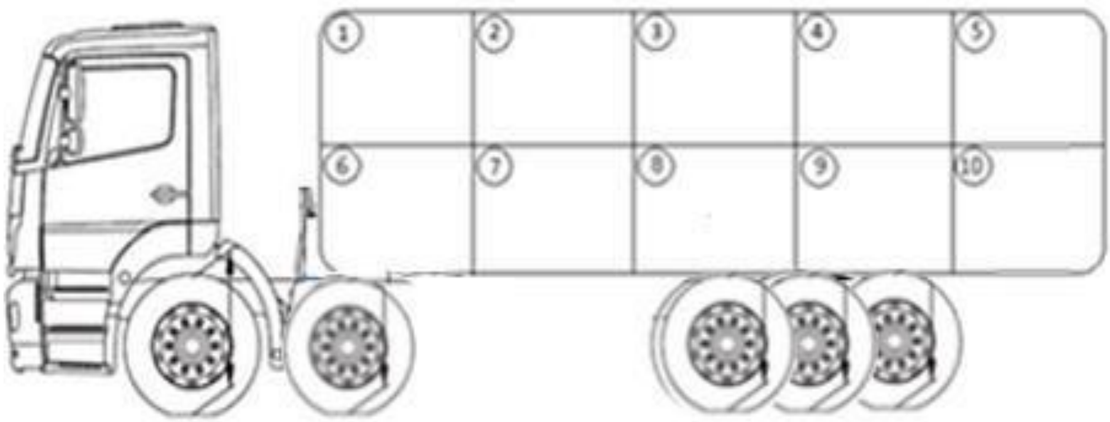

Figure 3 Illustration of the left side of the truck's model used in all farms of the experiment. The same numeric identification was used onto the right side.

2.4.3. Transport distance and duration

The distance was calculated using the difference between the final (abattoir) and initial (farm) mileage of the vehicle, while the duration was always monitored when leaving the farms until arriving at the slaughterhouse. The time spent loading and unloading was not considered for the latter. Considering a commercial reality, transports from the same farm showed a variation in travel time, as observed in Table 1, due to traffic and complications related to the vehicle as well as different drivers between farm transports.

2.5. Statistical analysis

All statistical analyses were performed in R Software, version 4.0.3. In order to analyze whether or not the severity of skin injuries, assessed by the injury scoring scheme (0 to 4), of each response variable, represented by the ears, front, middle, hindquarters and limbs, was influenced by distance (short, intermediate and long) and treatment (farm or transport), type-II analysis-of-variance for the cumulative logit models with proportional odds was used.

Firstly, distances and transport were tested to evaluate whether or not there was an interaction effect. If no effect was observed between them (distances and transport), the main effect of each one was evaluated with pairwise comparison tests using Tukey’s test. If interaction was observed between distance and treatment, the interaction was split for each main factor of the model. Secondly, the acceleration and density variables were tested with the Kruskal–Wallis test, also known as the H test. In the first case, it was tested whether there was a difference between the average values of axle acceleration – or axle vibration – (RMSx, RMSy and RMSz) and overall ride values for each measured point (RSS) as a function of the position of the sensor inside the truck. In the latter, it was tested whether there was a difference between the average density as a function of the three distances.

3. Results

3.1. Skin lesions

In this study, no interaction was observed between treatments, ie., handling (farm and slaughterhouse) and transport distance, subdivided into short, intermediate and long distances, on skin injury score at ear, front, middle and hind-quarter parts of pigs’ body, as presented in Table 2. However, a significant effect was observed on skin injury score of the limbs by the interaction between treatment and transport distance ($p<0.001$). Thus, evaluating the isolated effect of treatment on parts that did not present an interaction, based on A1 vs. A2 skin lesion score assessments, a significant effect was detected in ear ($p=0.0041$), front ($p<0.001$), middle ($p<0.001$) and hind-quarter ($p<0.001$), indicating a significant increase in the proportion of pigs presenting skin lesions between the departure of farms and arrival at slaughterhouse. Isolated effects of transportation distance were obtained in front ($p<0.001$) at long distances and in the middle ($p<0.001$) and hindquarters ($p<0.001$) at all three distances (data not shown).

An increase of skin injury score proportions was observed for scores 2, 3 and 4 in the middle and hindquarters at all three distances, while no score 3 increases were observed in the ear at intermediate and long distances and no score 4 increases were observed in any distances in this body part (Table 3). Additionally, no score 3 and 4 increases were detected in limbs at intermediate and long distances. In the front part, score 3 remained with the same proportion at the slaughterhouse compared to the farm at intermediate distance. At short distances, middle and hind quarters presented higher increases in scores 2 and 3 compared to the other distances, and the front part demonstrated higher increases in score 3. On the other hand, at long distances, middle and hind quarters showed greater proportions of score 4. Numerical decreases were observed to score 0 at all three distances, indicating a negative impact on the severity of skin lesions by transport (Table 3). However, an unexpected pattern occurred into the front and limbs at short and long distances, respectively, in which the front part presented a decrease in score 4 and in limbs and an increase in score 0 (no lesions) was detected. Such incoherence may be explained by the difficulty to assess injuries proportioned by the animals’ movement and the difficulty of removing dirt from the body, especially in limbs. Furthermore, animals from group 1 farm displayed a higher incidence of dirt encrusted in the body, expressing a major obstacle to skin injury assessment compared to animals from the other farms.

At short distances, the most affected body part, considering the worst score (4) increase after transport (A2), was the hind-quarter (2.22%), followed by the middle (1.11%) and limbs (1.11%). At intermediate distances, the front was the most affected (3.81%) followed by the middle (2.38,%) and at long distances, the most affected was the middle (2.38%) followed by the hindquarters (2.54%). Thus, regardless of the distance traveled, the middle part was more exposed to skin lesions than other body parts. Conversely, ear and limbs were the least affected parts at all distances, indicating a lower probability of skin injury during transportation. Additionally, smaller decreases of score 0 were noted in front at intermediate (-2.85%) and long distances (-4.06%), showing less exposure to formation of skin injuries compared to ear, middle hind-quarter and limbs at short, intermediate and long distances. Finally, pigs from group 3 farms (long distance) showed better proportion of animals with no skin injuries (score 0) in the front, middle, hind-quarter and limbs at A1, whereas a smaller proportion of score 0 was detected in ear, front and middle from group 2 farms (intermediate distance) and hind-quarter and limbs from group 1 (short distance) at A1.

Table 2 Statistical significance between body parts and interaction treatment vs. distance and its isolated effects from distance and treatment.

Body parts	Interaction(distance xtreatment)	Distance	Treatment
Ear	0.9248	0.6438	0.0041**
Front	0.9056	<0.001***	<0.001***
Middle	0.4554	<0.001***	<0.001***
Hind-quarter	0.9421	<0.001***	<0.001***
Limbs	0.0027**	<0.001***	0.0017**

[1]Significance levels: *p<0.05; **p<0.01; ***p<0.001.

Table 3 Proportion (%) of skin injury score assessed at the farms before unloading (A1) and at the slaughterhouse after unloading (A2) in five parts of the left side of the finishing pig's body (ear, front, middle, hind-quarter and limbs).

		Skin injury score assessment – Proportion of animals (%)								
Body parts	Injury score	Group 1 - Short distance			Group 2 - Intermediate distance			Group 3 - Long distance		
		Farm (A1)	Slaughterhouse (A2)	Δ (A2-A1)	Farm (A1)	Slaughterhouse (A2)	Δ (A2-A1)	Farm (A1)	Slaughterhouse (A2)	Δ (A2-A1)
Ear	0	57.78	53.33	-4.45	50.95	41.91	-9.04	51.27	42.64	-8.63
	1	32.22	32.22	0.00	46.19	54.29	8.10	47.72	51.27	3.55
	2	8.89	13.33	4.44	2.86	3.81	0.95	1.02	6.09	5.07
	3	0.69	2.78	2.09	0.00	0.00	0.00	0.00	0.00	0.00
	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Front	0	8.89	4.44	-4.45	7.14	4.29	-2.85	14.72	10.66	-4.06
	1	55.56	41.11	-14.45	65.24	52.38	-12.86	68.53	59.90	-8.63
	2	31.11	42.22	11.11	20.95	32.86	11.91	14.72	21.83	7.11
	3	2.22	11.11	8.89	5.24	5.24	0.00	2.03	6.60	4.57
	4	2.22	1.11	-1.11	1.43	5.24	3.81	0.00	1.02	1.02
Middle	0	15.56	7.78	-7.78	7.14	2.38	-4.76	24.37	11.68	-12.69
	1	43.33	30.00	-13.33	70.95	60.95	-10.00	59.90	57.87	-2.03
	2	34.44	46.67	12.23	18.57	25.71	7.14	14.21	20.81	6.60
	3	5.56	13.33	7.77	2.86	8.10	5.24	1.52	5.58	4.06
	4	1.11	2.22	1.11	0.48	2.86	2.38	0.00	4.06	4.06
Hind-quarter	0	17.78	11.11	-6.67	22.86	10.00	-12.86	43.65	28.43	-15.22
	1	55.56	38.89	-16.67	68.57	67.14	-1.43	53.30	53.81	0.51
	2	18.89	36.67	17.78	6.67	16.67	10.00	3.05	12.69	9.64
	3	7.78	11.11	3.33	1.90	4.29	2.39	0.00	2.54	2.54
	4	0.00	2.22	2.22	0.00	1.90	1.90	0.00	2.54	2.54
Limbs	0	37.78	25.56	-12.22	64.29	45.71	-18.58	50.76	54.32	3.56
	1	37.78	38.89	1.11	34.29	50.48	16.19	47.72	43.66	-4.06
	2	21.11	30.00	8.89	1.43	3.81	2.38	1.52	1.52	0.00
	3	2.22	3.33	1.11	0.00	0.00	0.00	0.00	0.00	0.00
	4	1.11	2.22	1.11	0.00	0.00	0.00	0.00	0.51	0.51

3.2. Microclimatic and vibration data from transport

Journeys from groups 1, 2 and 3 lasted on average 198, 257 and 338 minutes, respectively, and were at an average distance from the abattoir of 167, 200 and 346 km (Table 1). Considering the microclimatic conditions of transport, temperature varied from 24.1 to 26.4°C, and relative humidity (RH) ranged from 76 to 87% at short distances, 19.8 to 24.7°C and 74 to 92% at intermediate distances and 20.4 to 25.3°C and 80 to 91% at long distances. In general, compartments in the lower deck (8 and 10) presented higher temperatures compared to the upper ones (1, 3 and 5) at all three distances. Compartment 6, also in the lower deck, presented higher temperatures at short and long distances. Regarding RH, compartments 1 and 5 from short and intermediate distances displayed greater values compared to compartments 3, 6, 8 and 10, whereas compartments 1 and 10 from long distances presented higher values (Table 4). As a consequence of a commercial unviability to control stocking density during transport trials, an unexpected significant difference was observed between average stocking densities from short- and long-distance transport ($p<0.05$) and between intermediate- and long-distance transport ($p<0.05$).

Farms from group 3 (long distance), which presented the highest density (average 0.37 m^2/100 kg), showed a higher increase in proportions of worst skin lesion score (4) in front, middle and hind-quarter in comparison with short distance and presented, as well, a higher proportion of score 4 in middle, hind-quarter and limbs in relation to intermediate distance. Animals transported from intermediate distances, under the lowest average density (average 0.40 m^2/100 kg), presented a smaller increase in scores 3 and 4 compared to short and long distances, except for a higher incidence of score 4 in front compared to other distances and for a higher incidence of score 3 in middle in relation to long distance and score 4 in the same body part in relation to short distance (average 0.39 m^2/100 kg).

Table 4 Microclimatic and vibration conditions from transport distances (short, intermediate and long) obtained from selected compartments (1, 3, 5, 6, 8 and 10 for microclimatic conditions and 1, 5, 6 and 10 for vibration conditions) in this experiment.

Distance	Compartments	Microclimatic conditions			Vibration conditions (m/s^2)			
		Average Temperature (T°C)	Average Relative humidity (UR%)	THI	RMSx	RMSy	RMSz	RSS
Short	1	26.2	85	78.47	1.31	10.22	1.99	10.49
	3	25.5	76	75.62				
	5	24.1	87	73.52	0.92	10.68	2	10.9
	6	25.5	-	-	0.89	10.61	2.02	10.84
	8	26.4	79	78.12				
	10	26.3	82	78.30	1.16	7.96	2.75	8.5
Intermediate	1	23.1	88	71.12	-	-	-	-
	3	22.7	74	69.01				
	5	22.8	92	70.70	1.33	10.44	2.32	10.78
	6	19.8	-	-	0.8	10.86	1.68	11.02
	8	24.7	78	74.00				
	10	23.8	82	72.29	1.32	8.01	3.17	8.71
Long	1	21.9	91	68.32	-	-	-	-
	3	22.7	73	68.93				
	5	20.4	81	64.08	1.14	10.31	1.78	10.53
	6	24.4	-	-	0.88	9.33	2.64	9.74
	8	23.3	80	70.91				
	10	25.3	83	76.02	1.94	9.25	4.37	10.41

Data from the relative humidity data logger installed in compartment 6 and from the vibration sensor installed in compartment 1 were unavailable to access and thus disregarded (Table 4). The animals' showering process with a pressured hose at the departure of the vehicle at the farms and at the arrival of the slaughterhouse may have compromised the relative humidity sensor, even though all of them were protected with a plastic shelter to avoid getting wet. The issue which occurred with to the vibration data logger may have been caused by a malfunction problem. Vibration in vehicle differed statistically ($p<0.05$) in sideways (left to right) direction (RMSy) in intermediate transport distance, considering the different RMS measured in axles directions (RMSx, RMSy and RMSz) and positions from compartments evaluated (1, 5, 6 and 10) from group 2 transports (data not shown). No effect from vibration levels (m.s-2) from three axles in all four vehicle compartments was observed at short and long distances ($p>0.05$). Similarly, compartment positions did not present a significant effect on RMSx, RMSy, RMSz and RSS considering the three distances studied ($p>0.05$). In other words,the front and rear compartments of the vehicle, both upper and lower deck, showed no significant difference in the vibration felt by the animals under short, intermediate and long transport distance conditions.

Vibration levels did not seem to be linear in relation to the position in the truck. The lowest vibration values from the vertical (RMSx) and sideways (RMSy) directions occurred in compartment 6 (0.89, 0.80 and 0.88 m/s^2) and 10 (7.96, 8.01 and 9.25 m/s^2) at all three distances, whereas greater values for the longitudinal vibration (RMSz) direction were observed in compartment 10 (2.75, 3.17 and 4.37 m/s^2). Sideways vibration levels presented higher values in compartment 6 at an intermediate distance (10.86 m/s^2) and in compartment 5 at short (10.68 m/s^2) and long distances (10.31 m/s^2). Such results indicate a smaller proportion of up and down and left to right movements in the front lower deck and rear lower deck compartments, respectively, as well as greater proportions of backward and forward movements in the rear lower deck compartments of the vehicle. Additionally, higher proportions of sideways vibration movements may occur in the front lower deck during intermediate distances, while during short and long distances, rear upper deck compartments may present greater values.

The overall ride value for each measured point (RSS) in the trucks exerted lower vibration values in pigs in compartment 10 during short (8.50 m/s^2) and intermediate distances (8.71 m/s^2) and in compartment 6 during long distances (9.74 m/s^2). Conversely, higher values were obtained in compartment 6 at intermediate distances (11.02 m/s^2) and in compartment 5 at short (10.90 m/s^2) and long distances (10.53 m/s^2). In other words, the worst vibration conditions for pigs were detected in the front lower deck at intermediate distances and in the rear upper deck at short and long distances. Left to right vibration values (RMSy) were more frequent during all transport trials compared to up and down (RMSx) and backward and forward (RMSz) movements, indicating the main movement experienced by the pigs during transit.

4. Discussion

In this experiment, transport processes caused a negative impact on the incidence of skin injury in pigs, which has also been observed in other studies in Brazil (Dalla Costa et al., 2007a; Dalla Costa; Lopes; Dalla Costa, 2017, Melo et al., 2023). In addition to reports in literature on the negative effect of greater distances of transport on mortality rate, live weight yield, animal welfare (Gosálvez et al., 2006; Barton Gade, 2008b, 2008a) and between greater transport duration and injuries (Mota-Rojas et al., 2006; Sutherland et al., 2009), in this experiment, higher increase proportions of elevated scores (3 and 4) were not linear according to distance and duration (Table 3). Our results are important in order to define new management, due to greater distances found in countries like Brazil.

Considering the proportions of scores 2, 3 and 4 observed at A1 and A2, the worst skin conditions in general were detected in group 1 farms (short distance). Those findings corroborate the importance of the assessment of skin lesions at slaughterhouses, since they can indicate animal welfare conditions applied to the production units and transport (Dalla Costa et al., 2019b, Rocha et al., 2020). Moreover, it is well known that transport is a stressful process for pigs (Bozzo et al., 2020; Gerritzen et al., 2013; McGlone et al., 2014;), which can compromise animal welfare according to several factors, of which transport distance and duration can be cited (PÉREZ et al., 2002; MOTA-ROJAS et al., 2006; Brandt & Aaslyng, 2015; Bozzo et al., 2020), despite the fact that no effects from distance to the incidence of skin lesions have been reported in Belgian (Driessen et al., 2020), Canadian (Scheeren et al., 2014) and Mexican studies (Becerril-Herrera et al., 2007), contrary to what was observed in this study. Furthermore, it is important to highlight that due to the interaction between many factors involved in pre-slaughter operations, such as loading and unloading, microclimatic conditions, journey duration, stocking density, vehicle floor type, vibration and fasting (Brandt & Aaslyng, 2015), it is difficult to assess transport impact by itself (Stajković et al., 2017).

In an experiment in commercial conditions in Spain, the short distance transport (15 min) caused more stress to pigs than a moderately long transport (180 min), because in reduced time transport, pigs probably didn't have the opportunity to adapt to the new environment and recover from previous operations, and so, could not rest (Pérez et al., 2002). On the other hand, journeys shorter than 60 minutes presented a decreased percentage of injured animals compared to journeys longer than 270 minutes in American commercial evaluations (Sutherland et al., 2009). Similarly, another report states that the longer the journey, the more injured animals will appear, compromising economic gains (Machado et al., 2021). The average duration of transport distances in this study (198, 257 and 338 minutes) indicates that pigs were more exposed to a higher risk of injuries in group 3 journeys (long distance), especially in the middle and hind-quarter parts, as detected by higher increase proportions of score 4.

The vehicle model is an important factor to be considered for transport duration (Brandt & Aaslyng, 2015), mortality rate, injury incidence (Sutherland et al., 2009) and its relation with animal welfare. Models can vary from small single deck trucks to large three deck trucks, and the application of animal welfare is related to the global location and available resources (Garcia et al., 2019). Loading system, floor type and microclimate control represent important issues to animal welfare during transportation as well (Mcglone et al., 2014a; Xiong; Green; Gates, 2015; Faucitano; Goumon, 2018). In Brazil, trailers with one and two decks are commonly used in commercial practices (Dalla Costa et al., 2007a, 2007b; Ludtke et al., 2012), and reports show higher proportions of skin lesions caused by handling and fights in pigs transported in single deck trucks compared to double-deck trucks due to the greater number of animals per compartment (11 vs. 6 pigs, respectively) (Dalla Costa et al., 2007a). Thus, the vehicle model used in this study (double deck) may have provided a slightly lower incidence of skin damage.

Microclimate conditions during transport are important factors to be considered since pigs are exposed to several environmental variations and have more heat dissipation difficulty (Bracke et al., 2020; Cervantes et al., 2018). Moreover, high ambient temperature increases pigs' body temperature and may seriously affect their health (Cervantes et al., 2018), considering the combination between high temperature and relative humidity of the air obtained in Brazil (Silva et al., 2009). Machado et al (2021) reported that compartments located in the front region of the trailer present more severe microclimatic conditions, especially on the lower deck, with responses associated with thermal stress in weaned piglets. The authors also state that the use of fans in the truck would be essential to reduce the impact of thermal stress.

Thus, several studies have evaluated effects of microclimate conditions on animal welfare and mortality during transport (Nannoni et al., 2014; Xiong; Green; Gates, 2015; Machado et al., 2021), in which temperatures above 20°C represented a higher risk for thermal stress in pigs (Christensen; Blaabjerg; Hartung, 2007; Sutherland et al., 2009; Fox et al., 2014; Nannoni et al., 2014). Unfortunately, in this study, pigs were transported under higher temperatures in all journeys (Table 4), which may have compromised animal welfare but did not contribute to a higher skin injury incidence, as observed by Dalla Costa et al. (2007). Animal behavior may be influenced by farm management and mixing unfamiliar animals during pre-slaughter operations (De Jong et al., 2000; Barton Gade, 2008b, 2008a; Silva et al., 2009), which can cause stress and increase the number of fights, and hence, greater proportions of skin lesions may be observed (Barton Gade, 2008b; Bottacini et al., 2018). Repeated regrouping not only affects resting behavior, but also promotes mounting and aggressive posture between pigs (Brandt & Aaslyng, 2015). However, under commercial conditions, pigs are mixed in many productive stages to create homogeneous batches and during loading for transport to fill the truck (Faucitano, 2001; Mota-Rojas et al., 2006), since the more animals loaded, the lower the transport cost (Warriss, 1998; Warriss et al., 1998; Dalla Costa et al., 2019b).

Different information from literature regarding the effect of density at transport on the level of skin lesions is reported. At low density (>0.5 m^2/100 kg of live weight), pigs presented the highest skin lesion score in comparison with medium (0.3-0.5 m^2/100 kg) and high (<0.3 m^2/100 kg) density as a consequence of excessive space allowance in the truck, compromising their balance during transport, especially under poor road conditions and during curves (ČOBANOVIĆ et al., 2016a). Additionally, a higher frequency of fighting and confrontations can occur under higher space availability (Guàrdia et al., 2004). Similarly, the worst skin damages were reported at stocking density of 0.42m^2/100 kg compared with densities of 0.50, 0.39 and 0.35m^2/100 kg of body weight (Gade & Christensen, 1998) and a higher probability of bruises was observed at carcasses' hind-quarters under low densities (>0.6m^2/100 kg), while an increased propensity of bruises was observed at front and middle parts under higher densities (<0.4m^2/100 kg), although little effect was obtained on carcasses injuries under the latter conditions (Nanni Costa et al., 1999).

Conversely, other studies mention the benefit to pig welfare by the provision of lower densities than that used in commercial conditions (Becerril-Herrera et al., 2012; Gerritzen et al., 2013). Besides, no statistical influence of space availability on skin damage has yet been reported in the literature, although the incidence of bruises decreased numerically with more space during transportation (Becerril-Herrera et al., 2007). Considering the effect of climatic conditions (summer vs. winter) on stocking densities at transport, lower skin damage risk was reported at low density in winter (31.1 to 3.4% for 0.30 to 0.60 m^2/100 kg), whereas a higher risk was observed in summer (32.2 to 37.6% for 0.30 to 0.60 m^2/100 kg) (Guàrdia et al., 2009). The greater proximity of animals in winter, which tend to group together and thus increase the probability of fighting between them, is related to a higher incidence of lesions and bruises on pig carcasses (Gosálvez et al., 2006). In addition, high densities may be associated with greater physical stress and influence mortality (Warriss et al., 1998; Pilcher et al., 2011). In this study, executed in summer, higher proportions of skin lesions were observed in transports with lower space availability (average of 0.37 m^2/100 kg) and fewer in transports with higher available space (average 0.40 m^2/100 kg).

Animals may experience different conditions of vibrations than human drivers once the former stand or lie in close contact with the vehicle floor, which usually has an unyielding metallic or wooden surface; many of them are unfamiliar and unaware of transport conditions and might give distinct responses to discomfort (Randall, 1992). Moreover, hunger induces a more aversive stimulus to vibration (Stephens et al., 1985), which represents a routine practice in commercial transportation; that is, pigs are commonly subjected to stressful situations during transportation, similarly to the animals from this study. Finally, truck suspension can influence the number of skin injuries in particular parts of the pig's body (back and hind-quarter), especially mounting injuries, which are directly correlated with vibration levels and loss of balance during transport (Dalla Costa; Lopes; Dalla Costa, 2017). Finally, pigs from this study were subjected to aversive conditions of vibration at all transport distances, particularly those in compartments 6 (short and intermediate distance) and 5 (long distance), which presented higher root sum square (RSS) values.

In all transport distances, more than 97% of the route was represented by asphalted highways. Although highways present smoother road conditions than off-road, long transportation time may affect the quality of the product in transport (Soleimani; Ahmadi, 2014), corroborated by the detection of higher increase proportions of score 4 in specific parts of pigs' bodies (middle and hind-quarter) transported under long distances in this study, although other body parts presented worse skin conditions under short and intermediate distances. Such results may be related to structural conditions of trucks, caused by possible sharp surfaces that could have injured the animals' skins, since the vehicle models used in all trials were the same. Microclimate conditions may also have contributed negatively to the incidence of skin lesions due to animals' attempt to lose heat when changing position and consequently increased the number of conflicts. In short distances, higher average temperature was found (25.7°C), considering microclimatic conditions from all compartments, compared to intermediate (22.8°C) and long distances (23.0°C).

According to Brazilian regulatory standards (Brasil, 2014), vibration conditions above 1.1 m/s^2 are considered unhealthy for humans, and above 0.5 m/s^2, actions should be taken to prevent health problems. Similarly, European regulatory standards (EC, 2002) consider 1.15 m/s^2 as the exposure limit and 0.5 m/s^2 as the level of action. Although it would be appropriate to use specific parameters for animals instead of humans (RANDALL, 1992), in this case specifically pigs, it is not possible due to the lack of these parameters. In both cases, most parts of the compartments presented in this study, considering all three distances, have vibration values above the maximum tolerance limit. Only compartment 6 from short, intermediate and long distances (0.78, 0.80 and 0.88 m/s^2, respectively) and compartment 10 from a short distance (0.98 m/s^2) were inside the tolerance limit for the RMSx, but it should have been investigated for preventive actions. All other axles showed unacceptable values, including their combined effect (RSS), which may have induced a higher skin injury incidence by the elevated vibration levels and, consequently, higher stress levels.

5. Conclusions

Based on the data of this study, transportation distance under tropical conditions influenced the proportion of skin injuries in finishing pigs and affected animal welfare negatively. The front part of the animals' bodies was more susceptible to skin injuries at intermediate distances, while the middle and hind quarters were more susceptible at long distances. Although no significant effect was observed between vibrations from compartments in short, intermediate and long distances on skin lesion level, commercial transport conditions of finishing pigs were outside tolerance limits for health issues, especially vibration in sideways directions.

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Ethical considerations

This research is approval of the Ethics Committee on Animal Use (ESALQ/USP protocol number: 2019-24).

Conflicts of interest

The authors declare that they have no conflicts of interest.

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References

Alambarrio DA, Morris BK, Benjamin Davis R, Turner KK, Motsinger LA, O'Quinn TG, et al. 2022. Commercial straight-deck trailer vibration and temperature profiles during market-weight pig transport during summer. Front Anim Sci. 3:1051572

Barton Gade, P., 2008a. Effect of rearing system and mixing at loading on transport and lairage behaviour and meat quality: Comparison of free range and conventionally raised pigs. Animal 2:1238–1246. https://doi.org/10.1017/S1751731108002565

Barton Gade, P., 2008b. Effect of rearing system and mixing at loading on transport and lairage behaviour and meat quality: Comparison of outdoor and conventionally raised pigs. Animal 2:902–911. https://doi.org/10.1017/S1751731108002000

Barton Gade, P., Warris, P.D., Brown, S.N., Lambooij, E., 1996. Methods of improving pig welfare and meat quality by reducing stress and discomfort before slaughter methods of accessing meat quality. Proceedings European Seminary "New information on welfare and meat quality of pigs as related to handling transport and lairage conditions". Braunschweig-Voelkenrode, Germany, 23-34.

Bottacini, M., Scollo, A., Edwards, S.A., Contiero, B., Veloci, M., Pace, V., Gottardo, F., 2018. Skin lesion monitoring at slaughter on heavy pigs (170 kg): Welfare indicators and ham defects. PLoS One 13:1–16. https://doi.org/10.1371/journal.pone.0207115

Bozzo, G., Padalino, B., Bonerba, E., Barrasso, R., Tufarelli, V., Zappaterra, M., Ceci, E., 2020. Pilot study of the relationship between deck level and journey duration on plasma cortisol, epinephrine and norepinephrine levels in italian heavy pigs. Animals 10:1–13. https://doi.org/10.3390/ani10091578

Berman, A., Horovitz, T., Kaim, M., Gacitua, H., 2016. Uma comparação dos índices THI leva a um índice sensível de estresse por calor baseado no calor para bovinos sombreados que alinha o estresse por temperatura e umidade. Int. J. Biometeorol. 60:1453-1462. https://doi.org/10.1007/s00484-016-1136-9.

Bracke, M. B. M., Herskin, M. S., Marahrens, M., Gerritzen, M. A., Spoolder, H. A. M., 2020. Review of climate control and space allowance during transport of pigs. EURCAW-Pigs, January, v.1.0.

Brandt, P. & Aaslyng, M.D. 2015. Welfare measurements of finishing pigs on the day of slaughter: A review. Meat Sci. 103:13–23. https://doi.org/10.1016/j.meatsci.2014.12.004

BRASIL, 2000. Instrução Normativa Nº 3, de 17 de janeiro de 2000. Aprova o regulamento técnico de métodos de insensibilização para o abate humanitário de animais de açougue. Diário Oficial [da] República Federativa, Brasília, DF, 24 de janeiro de 2000.

BRASIL, 2014. Portaria MTE Nº 1297, de 13 de agosto 2014. Aprova o Anexo 1- Vibração – da Norma Regulamentadora nº 9 – Programas de Prevenção de Riscos Ambientais (PPRA), altera o Anexo 8 – Vibração – da Norma Regulamentadora nº 15 – Atividades e Operações Insalubres, e dá outras providências.

BRASIL, 1995. Portaria Nº 711, de 1º de novembro de 1995. Aprova as normas técnicas de instalações e equipamentos para abate e industrialização de suínos. Diário Oficial [da] República Federativa, Brasília, DF, 03 de novembro de 1995.

Carroll, G.A., Boyle, L.A., Teixeira, D.L., Van Staaveren, N., Hanlon, A., O'Connell, N.E. 2015. Effects of scalding and dehairing of pig carcasses at abattoirs on the visibility of welfare- related lesions. Animal 10:460–467. https://doi.org/10.1017/S1751731115002037

Castro, A.C. De, 2016. Comportamento e desempenho sexual de suínos reprodutores criados em ambientes enriquecidos 153.

Cervantes, M., Antoine, D., Valle, J.A., Vásquez, N., Camacho, R.L., Bernal, H., Morales, A., 2018. Effect of feed intake level on the body temperature of pigs exposed to heat stress conditions. J. Therm. Biol. 76:1–7. https://doi.org/10.1016/j.jtherbio.2018.06.010

Christensen, L., Blaabjerg, L., Hartung, J., 2007. Investigation of pig transports for more than 8 hours in cold and warm weather conditions and of the requirements for ventilation during the transport.

Chulayo, A.Y., Muchenje, V., 2015. A balanced perspective on animal welfare for improved meat and meat products. South African J. Anim. Sci. 45:452–469. https://doi.org/10.4314/sajas.v45i5.2

Čobanović, N., Bošković, M., Vasilev, D., Dimitrijević, M., Parunović, N., Djordjević, J., Karabasil, N., 2016. Effects of various pre-slaughter conditions on pig carcasses and meat quality in a low-input slaughter facility. South African J. Anim. Sci. 46:380–390. https://doi.org/10.4314/sajas.v46i4.6

Correa, J.A., Gonyou, H.W., Torrey, S., Widowski, T., Bergeron, R., Crowe, T.G., Laforest, J.P., Faucitano, L., 2013. Welfare and carcass and meat quality of pigs being transported for two hours using two vehicle types during two seasons of the year. Can. J. Anim. Sci. 93:43–55. https://doi.org/10.4141/CJAS2012-088

Dalla Costa, F.A., Lopes, L.S., Dalla Costa, O.A., 2017. Effects of the truck suspension system on animal welfare, carcass and meat quality traits in pigs. Animals 7:4–6. https://doi.org/10.3390/ani7010005

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

Dalla Costa, O.A., Faucitano, L., Coldebella, A., Ludke, J. V., Peloso, J. V., dalla Roza, D., 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. https://doi.org/10.1016/j.livsci.2006.08.015

Dalla Costa, O.A., Ludke, J.V., Costa, M.J.R.P. da, Faucitano, L., Peloso, J.V., Dalla Roza, D., 2007. Modelo de carroceria e seu impacto sobre o bem-estar e a qualidade da carne dos suínos. Ciência Rural 37:1418–1422. https://doi.org/10.1590/s0103-84782007000500031

De Jong, I.C., Prelle, I.T., Van De Burgwal, J.A., Lambooij, E., Korte, S.M., Blokhuis, H.J., Koolhaas, J.M., 2000. Effects of rearing conditions on behavioural and physiological responses of pigs to preslaughter handling and mixing at transport. Can. J. Anim. Sci. 80:451–458. https://doi.org/10.4141/a99-130

Dos Reis, J.G.M., Machado, S.T., Santos, R.C., Nääs, I.DA., Oliveira, R. V., 2015. Financial losses in pork supply chain: A study of the pre-slaughter handling impacts. Eng. Agric. 35:163– 170. https://doi.org/10.1590/1809-4430-Eng.Agric.v35n1p163-170/2015

Driessen, B., Van Beirendonck, S., Buyse, J., 2020. Effects of transport and lairage on the skin damage of pig carcasses. Animals 10:1–15. https://doi.org/10.3390/ani10040575

EC, 2002. Council Directive (2002/44/EC) of 25 june 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) (sixteenth individual Directive within the meaning of Article 61(1) of Directive 89/391/EEC).

Faucitano, L., 2001. Causes of skin damage to pig carcasses. Can. J. Anim. Sci. 81:39–45. https://doi.org/10.4141/A00-031

Faucitano, L., Goumon, S., 2018. Transport of pigs to slaughter and associated handling, Advances in Pig Welfare. https://doi.org/10.1016/B978-0-08-101012-9.00009-5

Fox, J., Widowski, T., Torrey, S., Nannoni, E., Bergeron, R., Gonyou, H.W., Brown, J.A., Crowe, T., Mainau, E., Faucitano, L., 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. https://doi.org/10.1016/j.livsci.2013.12.019

Gade, P.B., Christensen, L., 1998. Effect of different stocking densities during transport on welfare and meat quality in Danish slaughter pigs. Meat Sci. 48: 237–247. https://doi.org/10.1016/S0309-1740(97)00098-3

Garcia, A., Johnson, A. K., Ritter, M. J., Calvo-Lorenzo, M. S., McGlone, J. J., 2019. Transporto f market pigs: Improvements in welfare and economics. Livestock Handling and Transport, 5th edition, 328-346.

Garcia, D.B., Silva, I.J.O., Barbosa Filho, J.A.D., Vieira, F.M.C., Dias, C.T.S., 2008. Evaluation of the effect of vibration in simulated condition of transport of broiler chickens. Livest. Environ. VIII - Proc. 8th Int. Symp. 644–650. https://doi.org/10.13031/2013.25564

Gebresenbet, G., Aradom, S., Bulitta, F.S., Hjerpe, E., 2011. Vibration levels and frequencies on vehicle and animals during transport. Biosyst. Eng. 110:10–19. https://doi.org/10.1016/j.biosystemseng.2011.05.007

Gerritzen, M.A., Hindle, V.A., Steinkamp, K., Reimert, H.G.M., Van Der Werf, J.T.N., Marahrens, M., 2013. The effect of reduced loading density on pig welfare during long distance transport. Animal 7:1849–1857. https://doi.org/10.1017/S1751731113001523

Gosálvez, L.F., Averós, X., Valdelvira, J.J., 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. https://doi.org/10.1016/j.meatsci.2006.02.007

Grandin, T., 2017. On-farm conditions that compromise animal welfare that can be monitored at the slaughter plant. Meat Sci. 132:52–58. https://doi.org/10.1016/j.meatsci.2017.05.004

Griffin, M. J., 1990. Handbook of human vibration. London: Academic Press, 350p.

Guàrdia, M.D., Estany, J., Balasch, S., Oliver, M.A., Gispert, M., Diestre, A., 2009. Risk assessment of skin damage due to pre-slaughter conditions and RYR1 gene in pigs. Meat Sci. 81, 745–751. https://doi.org/10.1016/j.meatsci.2008.11.020

Guàrdia, M.D., Estany, J., Balasch, S., Oliver, M.A., Gispert, M., Diestre, A., 2004. Risk assessment of PSE condition due to pre-slaughter conditions and RYR1 gene in pigs. Meat Sci. 67, 471–478. https://doi.org/10.1016/j.meatsci.2003.11.020

Kephart, K.B., Harper, M.T., Raines, C.R., 2010. Observations of market pigs following transport to a packing plant. J. Anim. Sci. 88, 2199–2203. https://doi.org/10.2527/jas.2009-2440

Lammens, V., Peeters, E., Maere, H. De, Mey, E. De, Paelinck, H., Leyten, J., Geers, R., 2007. A survey of pork quality in relation to pre-slaughter conditions, slaughterhouse facilities, and quality assurance. Meat Sci. 75, 381–387. https://doi.org/10.1016/j.meatsci.2006.08.001

Ludtke, C.B., Antonio, O., Costa, D., Tadeu, E., Silveira, F., 2012. S0103-84782012000300024 532–537.

Machado, N.A.F., Martin, J.E., Barbosa-Filho, J.A.D., Dias, C.T.S., Pinheiro, D.G., Oliveira, K.P.L., Souza-Junior, J.B.F., 2021. Identification of trailer heat zones and associated heat stress in weaner pigs transported by road in tropical climates. Journal of Thermal Biology,. https://doi.org/10.1016/jtherbio.2021.102882

Machado NAF, Barbosa-Filho JAD, Souza-Junior JBF, Ramalho GLB, Parente M de OM. Use of pupillometry in the diagnosis of stress in piglets transported in a tropical climate. Eng Agríc. 2021Jul;41(4):402–8. Available from: https://doi.org/10.1590/1809-4430-Eng.Agric.v41n4p402-408/2021

Machado, N.A.F., Barbosa-Filho, J.A.D., Martin, J.E. *et al.* Effect of distance and daily periods on heat-stressed pigs and pre-slaughter losses in a semiarid region. *Int J Biometeorol* **66**, 1853–1864 (2022). https://doi.org/10.1007/s00484-022-02325-y

Melo, K. K. de S. V., Machado, N. A. F., Barbosa Filho, J. A. D., Peixoto, M. S. M., Andrade, A. P. C. de ., Costa, J. A. da ., Oliveira, A. B. A., & Sales, J. J. de M.. (2023). Pre-slaughter management in Northeast Brazil and the effects on thermophysiological indicators in pigs and pH45 . Revista Brasileira De Engenharia Agrícola E Ambiental, 27(4), 287–292. https://doi.org/10.1590/1807-1929/agriambi.v27n4p287-292

Mkwanazi, M.V., Ncobela, C.N., Kanengoni, A.T., Chimonyo, M., 2019. Effects of environmental enrichment on behaviour, physiology and performance of pigs - A review. Asian-Australas. J. Anim. Sci. 32(1), 1-13. https://doi.org/10.5713/ajas.17.0138

McGlone, J., Johnson, A., Sapkota, A., Kephart, R., 2014. Temperature and relative humidity inside trailers during finishing pig loading and transport in cold and mild weather. Animals 4, 583–598. https://doi.org/10.3390/ani4040583

Melotti, L., Oostindjer, M., Bolhuis, J.E., Held, S., Mendl, M., 2011. Coping personality type and environmental enrichment affect aggression at weaning in pigs. Appl. Anim. Behav. Sci. 133, 144–153. https://doi.org/10.1016/j.applanim.2011.05.018

Mota-Rojas, D., Becerril, M., Lemus, C., Sánchez, P., González, M., Olmos, S.A., Ramírez, R., Alonso-Spilsbury, M., 2006. Effects of mid-summer transport duration on pre- and post- slaughter performance and pork quality in Mexico. Meat Sci. 73, 404–412. https://doi.org/10.1016/j.meatsci.2005.11.012

Nanni Costa, L., Lo Fiego, D.P., Dall'Olio, S., Davoli, R., Russo, V., 1999. Influence of loading method and stocking density during transport on meat and dry-cured ham quality in pigs with different halothane genotypes. Meat Sci. 51, 391–399. https://doi.org/10.1016/S0309-1740(98)00160-0

Nannoni, E., Widowski, T., Torrey, S., Fox, J., Rocha, L.M., Gonyou, H., Weschenfelder, A. V., Crowe, T., Martelli, G., Faucitano, L., 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. https://doi.org/10.1016/j.livsci.2013.11.022

Nielsen, S,S,, Alvarez, J., Bicout D. J., Calistri P., Canali E., Drewe, J. A., Garin-Bastuji B., Jose Luis Gonzales Rojas, et al., (2022) European Food Safety Authority. *EFSA Journal* https://doi.org/10.2903/j.efsa.2022.7445

National Pork Board, 2019. Common swine industry audit: instructions, standards and audit tool. Des Moines, IA, USA.

Pérez, M.P., Palacio, J., Santolaria, M.P., Aceña, M.C., Chacón, G., Gascón, M., Calvo, J.H., Zaragoza, P., Beltran, J.A., García-Belenguer, S., 2002. Effect of transport time on welfare and meat quality in pigs. Meat Sci. 61, 425–433. https://doi.org/10.1016/S0309- 1740(01)00216-9

Pilcher, C.M., Ellis, M., Rojo-Gómez, A., Curtis, S.E., Wolter, B.F., Peterson, C.M., Peterson, B.A., Ritter, M.J., Brinkmann, J., 2011. Effects of floor space during transport and journey time on indicators of stress and transport losses of market-weight pigs. J. Anim. Sci. 89, 3809–3818. https://doi.org/10.2527/jas.2010-3143

Randall, J.M., 1992. Human subjective response to lorry vibration: Implications for farm animal transport. J. Agric. Eng. Res. 52, 295–307. https://doi.org/10.1016/0021-8634(92)80068- 4

Ritter, M.J., Ellis, M., Berry, N.L., Curtis, S.E., Anil, L., Berg, E., Benjamin, M., Butler, D., Dewey,

Ritter, M.J., Ellis, M., Brinkmann, J., DeDecker, J.M., Keffaber, K.K., Kocher, M.E., Peterson, B.A., Schlipf, J.M., Wolter, B.F., 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. https://doi.org/10.2527/jas.2005-577

Scheeren, M.B., Gonyou, H.W., Brown, J., Weschenfelder, A. V., 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. https://doi.org/10.4141/CJAS2013-136

Schwartzkopf-Genswein, K.S., Faucitano, L., Dadgar, S., Shand, P., González, L.A., Crowe, T.G., 2012. Road transport of cattle, swine and poultry in North America and its impact on animal welfare, carcass and meat quality: A review. Meat Sci. 92, 227–243. https://doi.org/10.1016/j.meatsci.2012.04.010

Silva, B.A.N., Noblet, J., Donzele, J.L., Oliveira, R.F.M., Primot, Y., Gourdine, J.L., Renaudeau, D., 2009. Effects of dietary protein level and amino acid supplementation on performance of mixed-parity lactating sows in a tropical humid climate. J. Anim. Sci. 87, 4003–4012. https://doi.org/10.2527/jas.2008-1176

Soleimani, B., Ahmadi, E., 2014. Measurement and analysis of truck vibration levels as a function of packages locations in truck bed and suspension. Comput. Electron. Agric. 109, 141–147. https://doi.org/10.1016/j.compag.2014.09.009

Stajković, S., Teodorović, V., Baltić, M., Karabasil, N., 2017. Pre-slaughter stress and pork quality. IOP Conf. Ser. Earth Environ. Sci. 85. https://doi.org/10.1088/1755- 1315/85/1/012034

Stephens, D.B., Sharman, D.F., Ingram, D.L., Bailey, K.J., 1985. an Analysis of Some Behavioural Effects of the Vibration and Noise Components of Transport in Pigs. Q. J. Exp. Physiol. 70, 211–217. https://doi.org/10.1113/expphysiol.1985.sp002904

Sutherland, M.A., McDonald, A., 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. https://doi.org/10.1136/vetrec.165.1.13 Tönepöhl, B., Appel, A.K., Welp, S., Voß, B., König von Borstel, U., Gauly, M., 2012. Effect of marginal environmental and social enrichment during rearing on pigs' reactions to novelty, conspecifics and handling. Appl. Anim. Behav. Sci. 140, 137 145.https://doi.org/10.1016/j.applanim.2012.05.002

Turner, S.P., Farnworth, M.J., White, I.M.S., Brotherstone, S., Mendl, M., Knap, P., Penny, P., Lawrence, A.B., 2006. The accumulation of skin lesions and their use as a predictor of individual aggressiveness in pigs. Appl. Anim. Behav. Sci. 96, 245–259. https://doi.org/10.1016/j.applanim.2005.06.009

Van de Weerd, H., Ison, A., 2019. Providing effective environmental enrichment to pigs: How far have we come? Animals, 9, 254. https://doi.org/10.3390/ani9050254

Warriss, P.D., 1998. Choosing appropriate space allowances for slaughter pigs transported by road: A review. Vet. Rec. 142, 449–454. https://doi.org/10.1136/vr.142.17.449

Warriss, P.D., Brown, S.N., Knowles, T.G., Edwards, J.E., Kettlewell, P.J., Guise, H.J., 1998. The effect of stocking density in transit on the carcass quality and welfare of slaughter pigs: 2. Results from the analysis of blood and meat samples. Meat Sci. 50, 447–456. https://doi.org/10.1016/S0309-1740(98)00057-6

Welfare Quality®, 2009. Welfare Quality® assessment protocol for pigs (sows and piglets, growing and finishing pigs). Welfare Quality® Consortium, Lelystad, Netherlands.

Xiong, Y., Green, A., Gates, R.S., 2015. Characteristics of trailer thermal environment during commercial swine transport managed under U.S. industry guidelines. Animals 5, 226– 244. https://doi.org/10.3390/ani5020226

Rocha, L.M.; Devillers, N.; Maldague, X.; Kabemba, F.Z.; Fleuret, J.; Guay, F.; Faucitano, L. Validation of Anatomical Sites for the Measurement of Infrared Body Surface Temperature Variation in Response to Handling and Transport. *Animals* 2019, *9*, 425. https://doi.org/10.3390/ani9070425