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Temperature gradients in trailers and changes in broiler rectal and core body temperature during winter transportation in Saskatchewan

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Knezacek, T. D., Olkowski, A. A., Kettlewell, P. J., Mitchell, M. A. and Classen, H. L. 2010. **Temperature gradients in trailers and changes in broiler rectal and core body temperature during winter transportation in Saskatchewan.** Can. J. Anim. Sci. **90:** 321–330. Temperature conditions inside commercial trailers transporting market-age broilers during four winter journeys were measured, and changes in the rectal and core body temperature of birds were quantified. Pre-selected modules were equipped with data loggers recording temperature every 72 s. Rectal temperatures were taken from eight birds in each of four modules immediately before and after each trip, and two or three birds, with temperature recording implants, were placed in each of two selected modules. Temperature heterogeneity was found among modules on all loads with average crate temperatures ranging from 10.9 to 30.7, 8.9 to 28.1, 2.5 to 26.1 and −0.7 to 16.5°C for transportation times of 191, 193, 178 and 18 min and ambient temperatures of −7.1, −27.1, −28.2 and −18.4°C, respectively. Wet birds, condensation and frost provided evidence for moisture accumulation during transportation. Body temperature recordings indicated the potential for the development of both hypothermia and hyperthermia, showing that cold stress can occur near air inlets and heat stress in poorly ventilated areas. Passive ventilation inside trailers resulted in crate temperatures 17.7 to 55.2°C above outside temperature. Mortality ranged from 0.7 to 1.4% but several deaths occurred during lairage, prior to processing. A heterogeneous distribution of airflow resulted in undesirable temperate and humidity conditions for some birds.

Key words: Broiler, transportation, temperature gradient, mortality, cold weather

Knezacek, T. D., Olkowski, A. A., Kettlewell, P. J., Mitchell, M. A. et Classen, H. L. 2010. **Gradient de température dans les remorques et variation de la température rectale et de la température interne chez les poulets de chair pendant leur transport en hiver, en Saskatchewan.** Can. J. Anim. Sci. **90:** 321–330. Les auteurs ont mesuré la température à l'intérieur des remorques qui transportaient des poulets de chair prêts pour le marché durant quatre journées d'hiver, puis ont quantifié la variation de la température rectale et interne des oiseaux. Des enregistreurs de données ont été installés dans des modules présélectionnés et relevaient la température toutes les 72 secondes. On a noté la température rectale de 8 volatiles dans 4 modules, immédiatement avant et après chaque voyage, tandis que deux ou trois oiseaux pourvus d'un implant thermométrique ont été placés dans chacun de deux modules sélectionnés. La température dans les modules était hétérogène durant tous les voyages, et la température moyenne a fluctué de 10,9 à 30,7°C, de 8,9 à 28,1°C, de 2,5 à 26,1°C et de −0,7 à 16,5°C pendant les 191, 193, 178 et 18 minutes du transport, aux températures ambiantes de of −7,1, −27,1, −28,2 et −18,4°C, respectivement. Les oiseaux trempés, la condensation et le givre indiquent que l'humidité s'accumule pendant le transport. Les relevés de la température corporelle révèlent qu'il y a des risques d'hypothermie et d'hyperthermie, un stress dû au froid pouvant survenir près des bouches d'air et un stress thermique, aux endroits mal aérés. Le système de ventilation passive des remorques hausse la température dans les cageots de 17,7 à 55,2°C, comparativement à celle de l'extérieur. Le taux de mortalité varie de 0,7 à 1,4%, mais plusieurs décès surviennent durant l'attente, avant l'abattage. La distribution hétérogène de l'air engendre des conditions indésirables sur le plan de la température et de l'humidité, pour certains oiseaux.

Mots clés: Poulets de chair, transport, gradient de température, mortalité, temps froid

The thermal environment within the transportation trailer is the most significant stressor broilers are exposed to in transit (Kettlewell 1989; Mitchell and Kettlewell 1994, 2004, 2008; Mitchell 2006). Temperature at any location inside the trailer is dictated by the interaction of outside air temperature, heat and moisture within the trailer, and airflow through the transporter. Passively ventilated broiler carriers often have inadequate and poorly controlled ventilation which can lead to unfavourable conditions for the birds (Mitchell and Kettlewell 1993, 1998, 2004, 2008; Mitchell 2006).

Pressure distribution on the outside surface of the trailer and the dense packing inside the trailer influence the airflow (Hoxey et al. 1996). The headboard of the trailer has a positive pressure greatest near the top leading edge and decreasing down the headboard (Götz 1987). Therefore, an opening in the headboard will become an air inlet when the truck is in motion. Flow separation occurs at the leading edge of the top of the trailer and at the leading edges of both sides, thereby creating large negative pressures on the top and sides of the front end of the trailer (Götz 1987; Hoxey et al. 1996). This negative pressure along the top and sides declines towards the tailboard or back end of the trailer. Air flows from high-pressure to low-pressure areas. Because the largest negative pressure occurs at the top of the trailer just behind the headboard, vents open in this area will act as exhausts and openings at the back of the trailer will act as air inlets. The high bird density and dense packing of the crates within the trailer creates an obstruction for air movement within the load and limits air mixing. With the transporter curtains lowered, air may short circuit between vents on the roof, or between openings at the bottom of the curtains and the vents in the roof directly above those openings. This pressure distribution is typical of blunt, sharp-edged objects and becomes useful when interpreting the temperature and humidity data collected from broiler transporters.

Thermal mapping of the interior microenvironment has been achieved by equipping broiler carriers in the United Kingdom with data loggers (Kettlewell et al. 1993). In summer months with curtains in an open configuration, passive ventilation was sufficient to prevent temperature gradients in the trailer if the vehicle was in motion. During winter months with curtains in the closed configuration, large temperature and moisture gradients developed due to reduced air movement. Areas immediately behind the headboard were exposed to high temperature and humidity conditions capable of causing heat stress to the birds.

Mitchell et al. (1997) suggested that if birds remain dry they can maintain body temperature in external temperatures as low as $-4°C$, and therefore, transportation conditions in the United Kingdom are normally acceptable. There is a lack of data on transporting broilers in ambient temperatures below $-4°C$. Conducting transportation studies under the range of winter temperatures occurring in Saskatchewan will provide data relevant to cooler climate regions around the world. Therefore, the objectives of this study were to characterize the thermal environment imposed on broilers transported in Saskatchewan winter conditions by recording temperature conditions within transport vehicles, and to quantify the effects of transportation on the birds by collecting rectal temperatures immediately before and after transportation, monitoring the deep body temperature of sentinel birds previously implanted with recording devices, and reviewing mortality data associated with the journeys.

MATERIALS AND METHODS

Four broiler journeys from commercial farms were monitored to quantify temperature and humidity conditions within 16-m transport trailers used by the Saskatchewan broiler industry.

Trailer

The dimensions for the 16-m passively ventilated broiler carriers are included in Table 1. All trailers had a solid floor, with a step in the trailer frame located 3.74 m from the headboard. Vents were centred through the headboard, roof and tailboard of the trailer (Fig. 1) and adjusted manually according to ambient conditions and driver experience. Three centrally located vents on each of the headboard and tailboard of the trailer could be opened by sliding wooden panels horizontally along tracks attached to the trailer. These wooden panels were solid, with the exception of a small hand-sized hole (14.5 cm $\times$ 7.0 cm) located on the top headboard vent. Running continuously along the centre line of the trailer roof were eight hinged wooden panels, numbered from the headboard to the tailboard of the trailer (Fig. 1), which were secured in position with latches. The width of all roof vents was 0.235 m, but the length varied (vents 1 and 8 were 1.22 m long; vent 5 was 1.50 m; and vents 2, 3, 4, 6 and 7 were 2.43 m long). Birds could be protected from adverse weather conditions by covering the open sides of the trailer with a retractable solid curtain that was permanently attached to the roof and fastened to the floor with a bungee cord. For each journey monitored, curtains on both sides of the trailer were lowered, all headboard and tailboard vents were closed and roof vents were adjusted by the truck drivers.

Modules and Crates

The modules are a component of the Anglia Autoflow modular system (Wortham Ling, Norfolk, England, IP22 1SR) and were stacked in pairs on the trailer. They were positioned transversely so the crates could not be opened until the modules had been unloaded at the processing plant. When loaded, the trailers had six modules on the raised floor immediately behind the headboard and 20 modules in the remaining portion of the trailer (Fig. 1). The six modules behind the headboard each had 12 crates, whereas the stacks of modules positioned after the step in the trailer frame had 12-crate

Table 1. Dimensions of the 16-m commercial broiler transportation trailers, modules and crates used in Saskatchewan

Component	Section	Length (m)	Width (m)	Height (m)
Trailer	In entirety	16.01	2.50	–
	Anterior step in frame	3.74	2.50	2.80
	Posterior step in frame	12.27	2.50	3.10
Module	12 crates	2.44	1.17	1.15
	15 crates	2.44	1.17	1.40
Crate	–	1.11	0.71	0.20

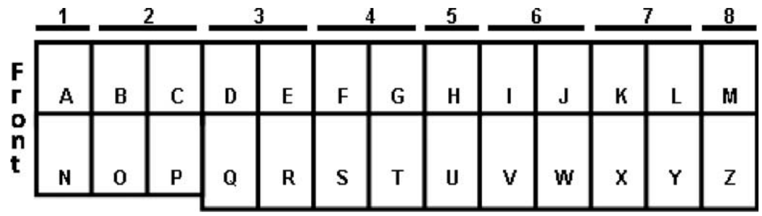

Fig. 1. Trailer schematic showing arrangement of drawer modules (letters). The numbered horizontal lines show positions of adjustable air vents in the trailer roof.

modules on the top and 15-crate modules on the bottom of the stack (Fig. 2). In total, there were 342 crates. Free space between the roof of the trailer and the top of the modular stacks facilitated loading and unloading. Modules were labelled alphabetically from the front of the trailer (Fig. 1) and the dimensions are included in Table 1.

Each crate was approximately 0.71 m wide, 1.11 m deep and 0.20 m high (Table 1). The crates were constructed of durable plastic with blunt edges to minimize injury to the birds. Ventilation was achieved through perforations on the floor (1 cm × 1 cm) and sides (5 cm × 2.5 cm) of the containers. Crates in the top row of the modules were covered by thin sheet metal to keep the birds contained and to prevent excess faecal material from falling into the modules at the bottom of the stack. When viewing the stack of modules from the back of the trailer, crates were labelled numerically with crate 1 positioned on the driver side of the vehicle, nearest the top (Fig. 2). Stocking density, determined by the procurement manager at the processing plant, was 24 birds per crate (8208 birds per trailer) for the first three journeys and 22 birds per crate (7524 birds per trailer) for the last journey.

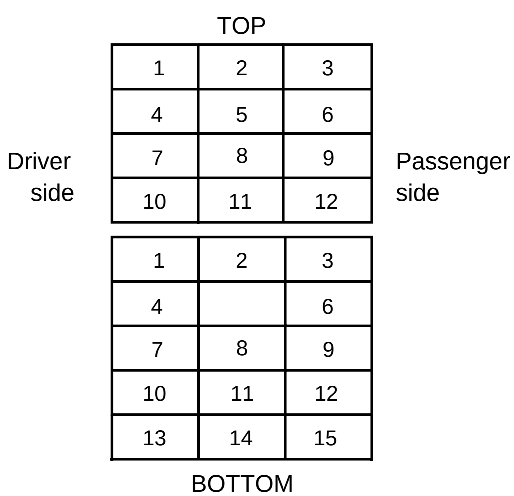

Fig. 2. Crates within each module were numbered from the driver side of the vehicle, nearest the top.

Data Loggers

Continual recording of temperature and relative humidity was achieved with the use of Gemini Tinytag Ultra data loggers [Gemini Data Loggers (UK) Limited, Chichester, England] that were programmed to record data at 72-s intervals. The data loggers were attached to a wire frame and clipped onto the front of the crates as modules were being loaded onto the trailer. The monitored modules and crates changed for each journey. Journey 1 had data loggers in crate 5 of modules A, C, E-G, I, K, M, O, Q, S, U, W, Y and Z. The loggers were placed in crate 2 of modules A, C, E, G, I, K, M, O, Q, S, U, W and Z for Journey 2. Logger placement for Journeys 3 and 4 was in crate 2; however, the modules monitored were A-I, K, M, N, P, Q, S, U, W and Y for Journey 3 and modules A-I, K, M, Q and Z for Journey 4. The position of the loggers ensured that the conditions being monitored were in the core of the trailer at bird level, with the exception of five data loggers attached to the top of modules A, C, D, F and H in Journey 4. Two loggers, one fastened to each of the side view mirrors of the truck cab, recorded ambient conditions of each journey. Times of departure from the production site and arrival at the abattoir were documented so journey duration and average temperature and humidity conditions for the entire journey could be calculated.

Temperature variations throughout the whole trailer were visualized using Tecplot software (Version 10, Amtec Engineering Inc, USA, 2003). Mean temperature values from the on-board logging devices were used by the software to estimate temperature in other parts of the trailer. These interpolated values were applied to construct two dimensional thermographs representing the central axis of the trailer.

Bird Measurements

Rectal temperatures of eight birds from four pre-selected modules on each journey were recorded immediately before and after transportation. An electronic temperature probe was inserted 3 cm into the cloaca of each bird until the temperature reading stabilized. In addition, sentinel birds were previously implanted with devices to continuously monitor deep body temperature according to the procedure by Kettlewell et al. (1997). The data loggers were based upon the basic sensor, printed circuit board and power supply of Gemini Tinytalk data loggers

(Hunter et al. 2004). This unit was housed in a 35-mm film cassette which could be sealed "water tight". The units were implanted into the peritoneal cavity under general anaesthesia, birds were allowed to recover for 7 d before transportation, and the implanted units were recovered at slaughter (Hunter et al. 2004). Groups of two or three sentinel birds were placed in two selected modules per trip and core body temperature was recorded every 4 min. Each sentinel bird was used for two journeys. Modules containing the birds from which rectal and deep body temperatures were taken varied for each journey (Table 2).

Upon arrival at the processing plant, the broiler transport vehicle was driven into the live receiving area located adjacent to the shackling equipment where the modules were unloaded. Rectal temperatures of the broilers were recorded within 45 min of unloading. Data loggers and sentinel birds were retrieved and bird mortality records were obtained after processing, which occurred within 4.5 h of arrival for the first three journeys and within 9.25 h for Journey 4. Mortality losses for Journeys 1, 2 and 4 reflected losses taking place during the transportation and lairage periods because the carcasses were counted at the shackling line. In comparison, bird deaths occurring during the transportation and lairage periods were separated for Journey 3, as dead birds were tallied upon arrival at the processing plant, and then again at shackling.

The experimental procedures of this study were approved by the Protocol Review Committee of the University Committee on Animal Care and Supply at the University of Saskatchewan and followed the guidelines of the Canadian Council on Animal Care (1993).

Statistical Analysis

Ambient and crate temperature data, as well as bird core body temperatures, were descriptively analyzed (mean, SD, maximum and minimum). Rectal temperature data were subjected to a one-way analysis of variance ($P < 0.05$) to establish differences between temperatures taken before and after transportation. Duncan's multiple range test was applied to separate significantly different means.

Relating broiler core body temperature and change in rectal temperature to ambient temperature, crate temperature and journey length was performed using the CORR, REG and RSREG procedures of SAS software.

RESULTS

The trailer unit, vent configuration and crate to which the data loggers were mounted for each journey are shown in Table 2, along with the module and crate location from where broiler rectal and deep body temperatures were recorded. Ambient temperature, transportation times, ranges in average crate temperature, temperature lifts (internal trailer temperature minus ambient temperature) and mortality percentage for each transportation trip are included in Table 3. The average crate temperatures monitored in each journey are presented in Table 4. Average temperatures from additional logger locations monitored during Journeys 1, 2 and 4 are shown in Table 5. Figure 3 shows the temperature variations within the trailer during each journey as calculated by Tecplot software. Market age and average bird weight for Journeys 1, 2 and 4 were 1.81 kg at 37 d, 1.92 kg at 38 d and 1.77 kg at 38 d, respectively. Bird information was not available for Journey 3, though the target weight and market age would have been similar.

Journey 1

The average external temperature for Journey 1, which lasted 191 min, was −7.1°C. Roof vents 2 and 4, respectively situated above modules B/C and F/G, were open. Loggers were mounted in crate 5 of selected modules; thus, the average crate temperatures ranging from 10.9 to 30.7°C reflected conditions within the core of the load. Crate temperatures were 18.0 to 37.8°C higher than the ambient temperature.

Observations made in transit of water vapour escaping from the trailer roof supported the notion that the roof vents were acting as air outlets. The curtains at the back of the trailer were unattached to the tailboard and observed billowing in and out, likely in response to vehicle motion and crosswinds. Curtain movement and the nature of the frost formation on modules inspected at the plant substantiated the belief that air entered from the rear of the trailer and travelled forward. High temperatures around the step in the trailer frame

Table 2. Trailer unit, vent configuration, logger placement and module/crate location where broiler rectal and deep body temperatures were taken

Journey	Trailer unit	Open vents	Logger location (crate)	Rectal temp. bird location (module/crate)	Sentinel bird location (module/crate)
1	1	2,4	5	A5, F5, U5, Z5	A5, U5
2	1	4	2	C2, I1, K2, Q2	I1, Q2
3	1	4	2	D2, H2, I2, Q2	D2, H2
4	8	4	2	A2, D2, I2, Q2	I2, Q2

Table 3. Ambient temperature, journey length, ranges in average crate temperature, temperature lift (internal trailer temperature minus ambient temperature) and mortality data for four broiler transportation journeys

Journey	Ambient temp. (°C)	Journey length (min)	Range of avg. crate temp. (°C)	Temperature lift (°C)	Mortality (%)
1	−7.1	191	10.9 to 30.7	18.0 to 37.8	0.7
2	−27.1	193	8.9 to 28.1	36.0 to 55.2	1.4
3	−28.2	178	2.5 to 26.1	30.7 to 54.3	0.9
4	−18.4	18	−0.7 to 16.5	17.7 to 34.9	0.9

Table 4. Average temperatures recorded from four broiler transportation journeys conducted in Saskatchewan

Logger Location	Journey 1[z] Temperature (°C)				Journey 2[y] Temperature (°C)				Journey 3[y] Temperature (°C)				Journey 4[y] Temperature (°C)			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Ambient 1	−7.1	0.8	−8.7	−4.0	−27.0	2.1	−31.5	−18.9	−28.3	2.5	−32.6	−18.9	−18.5	2.0	−21.0	−14.6
Ambient 2	−7.1	1.0	−8.7	−1.8	−27.2	2.0	−31.5	−21.7	−28.1	2.4	−32.6	−22.5	−18.3	1.5	−21.0	−16.4
Module A	17.6	2.0	14.0	22.7	24.3	4.2	13.7	29.8	13.8	17.5	−32.8	26.9	4.3	1.5	2.8	8.3
Module B									26.1	4.0	14.2	30.3	13.7	0.9	12.4	14.9
Module C	30.7	3.9	16.2	34.3	24.3	4.8	11.5	30.2	24.9	4.2	12.8	29.8	13.5	2.7	10.1	17.1
Module D									24.0	3.9	12.6	28.5	16.5	1.0	15.3	18.5
Module E	27.7	2.9	15.7	30.2	28.1	5.3	11.7	33.5	21.8	3.8	11.5	26.1	14.0	0.8	12.6	15.4
Module F	24.9	1.4	20.2	27.4					17.7	3.2	10.2	22.0	14.4	0.6	13.8	15.3
Module G	19.5	1.4	14.4	22.6	21.9	3.1	11.4	27.7	12.4	2.9	5.4	16.8	10.7	1.4	8.6	13.5
Module H									6.9	4.0	−3.5	15.6	4.9	2.9	0.7	9.5
Module I	10.9	1.9	6.9	14.9	8.9	2.8	5.0	17.4	3.9	6.5	−12.3	14.2	−0.7	2.8	−4.0	3.9
Module J																
Module K	12.7	2.2	9.5	18.1	14.6	3.2	9.5	20.9	2.5	4.8	−10.2	11.0	7.4	2.3	4.3	11.0
Module L																
Module M	15.4	1.5	10.2	18.4	11.9	2.9	5.0	18.1	2.8	5.0	−7.7	11.3	1.4	1.1	−1.4	3.1
Module N									12.3	4.1	3.0	17.8				
Module O	29.9	4.0	14.5	33.7	20.8	5.9	6.5	28.8								
Module P									22.3	3.6	14.4	26.5				
Module Q	29.5	4.0	14.5	32.2	26.6	4.3	13.1	31.4	25.1	3.5	16.7	29.2	11.6	1.2	9.9	13.8
Module R																
Module S	29.8	4.4	13.8	33.3	26.6	4.9	9.9	32.6	20.6	3.4	11.0	25.2				
Module T																
Module U	28.4	3.1	16.0	31.1	25.2	4.7	9.1	31.8	15.9	3.3	7.7	19.8				
Module V																
Module W	23.8	2.9	12.8	26.6	22.3	3.4	14.2	29.2	11.5	3.3	4.6	18.4				
Module X																
Module Y	19.7	2.1	10.5	23.0	20.2	1.6	16.5	23.0	7.6	3.7	−0.1	15.0				
Module Z	16.0	1.8	11.7	19.1									4.8	1.1	2.7	6.9

[z]Loggers were located in crate 5 for journey 1.
[y]Loggers were located in crate 2 for journeys 2–4.

(modules C, E, O and Q) and a 0.6°C increase in rectal temperatures from birds in F5 (Table 6) indicated that the area was poorly ventilated. The average temperature in module A (17.6°C) was lower than other modules in the vicinity and was possibly caused by an ingress of air through the small opening in the top headboard vent. Modules I and K had average crate temperatures below 15°C.

Table 5. Average temperatures for additional logger locations from journeys 1, 2 and 4

Journey	Location	Mean (°C)	SD (°C)	Min (°C)	Max (°C)
1	X4 ext[z]	5.2	1.5	2.7	8.3
	X6 ext	6.1	0.8	4.0	8.6
2	I1	10.9	2.6	4.3	16.0
	I1 ext	5.3	1.5	3.3	8.9
	I2 top[y]	2.9	2.2	−1.3	8.0
	I3	11.4	3.2	5.4	18.8
	I3 ext	4.1	2.4	−0.1	10.0
4	A top	2.7	0.7	1.5	3.5
	C top	2.2	1.7	−0.1	5.0
	D top	3.6	1.4	2.0	5.9
	F top	4.0	1.4	1.7	6.4
	H top	−8.3	3.3	−12.0	−1.8

[z]Loggers attached to exterior crates to monitor conditions close to curtains and away from the trailer core.
[y]Loggers attached to the top of the module.

Additional data loggers were attached to exterior crates X4 and X6, such that they recorded conditions closer to the curtains and away from the core of the trailer. The average temperature in crates X4 and X6 was 5.2 and 6.1°C, respectively (Table 5). Temperature was not monitored in X5, but average journey temperature in W5 (23.8°C) and Y5 (19.7°C) suggest large variability in on-board trailer temperatures between the core and exterior.

Though average rectal temperatures taken from all four crate locations increased, they were significantly higher after transportation for broilers located in modules A and F (Table 6). Deep body temperature recordings from sentinel birds (Table 7) were representative of domestic fowl at rest, under thermoneutral conditions (Dawson and Whittow 2000).

Journey 2

Although the travel time was similar to Journey 1, the ambient temperature was 20 degrees lower (−27.1°C); therefore, only the fourth roof vent was open. Loggers were positioned in crate 2 of specific modules so

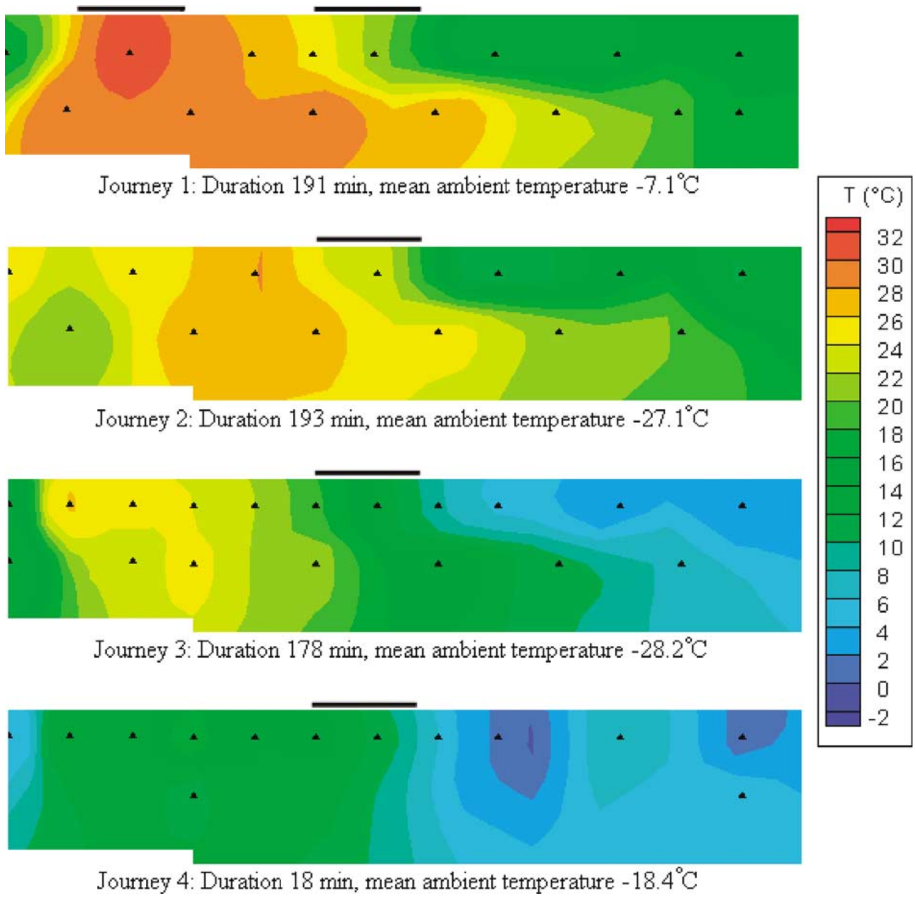

Fig. 3. Interpolated temperature variations along the centre of a 16-m trailer during four winter journeys. Dark dashes above each image indicate locations of open air vents. Small black triangles within each image indicate locations of temperature sensors.

conditions in the core of the trailer continued to be monitored, although closer to the top of the module.

The average crate temperatures (8.9 to 28.1°C) were similar to Journey 1, but due to the drop in external temperature, the on-board temperatures ranged from 36.0 to 55.2°C warmer than the ambient temperature. Figure 3 shows a temperature pattern resembling the first journey existed, with the highest temperatures situated at the step in the trailer frame and the lowest temperatures occurring in the top tier of the modules at the back of the trailer (modules I, K and M).

Supplementary loggers were placed in the centre and at the front of crates I1 and I3, between these exterior crates and the trailer curtains (I1 ext and I3 ext), and on top of module I above crate 2 (I2 top). Average temperatures recorded from the front of the crates were similar (10.9 and 11.4°C); however, the temperatures recorded near the curtains and at the top of the module were lower (Table 5). This trend suggests that a temperature gradient is created across the trailer during transportation and that cold air may travel from the back of the trailer along the top of the modules and exit through the open roof vent.

Insignificant changes in rectal temperatures were noted (Table 6). Changes in core body temperature were slight but more variable than those from Journey 1 (Table 7).

Journey 3

Journey 3 was conducted in an average external temperature of −28.2°C and again, only the fourth roof vent was opened. The journey time was 178 min and included a 15-min stop. This delay may have skewed the average crate temperatures, which ranged from 2.5 to 26.1°C, because no additional vents were opened during the period of time the trailer remained stationary. Air flow through the trailer would have been minimized; therefore, heat and moisture accumulating during this period would have increased the temperature and humidity of the on-board environment.

Logger placement was concentrated in the top tier of modules at the front of the trailer, where it appeared from preceding trips that a thermal core developed. Again, high temperatures were noted around the step in the trailer frame (Fig. 3). Several modules had crate temperatures below 15°C including modules A, G–I, K and M from the top tier, as well as modules N, W and Y

Table 6. Average rectal temperatures from broilers measured immediately before (T_1) and after (T_2) transportation

Journey	Bird location (module/crate)	Average T_1 (°C)	Average T_2 (°C)	SE
1	A5	40.4*a*	40.6*b*	0.0536
	F5	40.4*a*	41.0*b*	0.1074
	U5	40.6	40.8	0.0748
	Z5	40.5	40.7	0.1123
2	C2	40.6	40.6	0.0826
	I1	40.4	40.2	0.1048
	K2	41.1	40.7	0.0861
	Q2	40.6	40.9	0.0912
3	D2	40.0*a*	40.3*b*	0.0658
	H2	39.8	38.7	0.4325
	I2	40.1*a*	39.1*b*	0.1714
	Q2	40.2	40.5	0.0758
4	A2	40.4	40.1	0.1010
	D2	40.1	39.9	0.0774
	I2	40.1*a*	39.2*b*	0.2002
	Q2	40.3*a*	39.4*b*	0.1604

a, *b* Means within rows with no common superscript differ significantly ($P < 0.05$).

from the bottom tier, which had previously been warmer. This temperature trend implied cold air entered from the rear of the trailer.

Birds situated in crates H2 and I2, which recorded low average temperatures of 6.9 and 3.9°C, respectively, all had reduced rectal temperatures after transportation. The average decline in temperature for these birds was 1.0°C; however, the difference between rectal temperatures before and after transportation was only significant for birds in module I (Table 6). Birds in crates D2 and Q2 showed smaller increases in rectal temperature, yet the difference was significant for D2 birds (Table 6). Deep body temperatures from sentinel birds in crates D2 and H2 remained relatively stable during transportation (Table 7).

Journey 4

The last broiler journey was performed using a different trailer unit and decreased stocking density, and was only 18 min in duration. The average ambient temperature was −18.4°C and only the fourth roof vent was open. Average crate temperatures were lower compared with previous trips, ranging from −0.7 to 16.5°C, which implied that the short journey did not allow sufficient time for a thermal core to develop (Fig. 3).

Additional loggers were fastened to the top of modules A, C, D, F and H. Mean temperatures from the front four loggers ranged from 2.2 to 4.0°C and the temperature from the logger attached to the top of module H was −8.3°C (Table 5). These temperatures are comparatively lower than the temperatures recorded from crates located just beneath the module covers.

Table 7. Deep body temperatures of sentinel birds from all four transportation journeys

Journey	Location	Bird ID	Mean (°C)	SD (°C)	Min (°C)	Max (°C)
1	A5	988	41.8	0.6	40.6	42.4
		992	41.2	0.2	41.1	41.5
		994	41.5	0.3	41.1	41.9
	U5	996	41.6	0.2	41.1	41.9
		998	41.5	0.1	41.1	41.5
		999	41.5	0.4	40.6	41.9
2	I1	989	41.1	0.5	39.8	41.5
		991	41.1	0.2	40.6	41.5
		997	40.3	1.0	37.3	41.1
	Q2	993	42.3	0.3	41.5	42.8
		995	40.6	0.7	38.9	41.5
3	D2	992	40.6	0.2	40.2	41.1
		994	41.2	0.2	41.1	41.5
	H2	988	40.7	0.3	40.2	41.1
		998	41.0	0.2	40.6	41.5
		999	41.3	0.3	40.6	41.5
4	I2	993	41.3	0.2	41.1	41.5
		996	41.1	0.3	40.6	41.5
	Q2	991	40.2	0.0	40.2	40.2
		995	38.9	0.3	38.5	39.4
		997	40.0	0.2	39.8	40.2

Though core body temperature remained stable during transportation (Table 7), rectal temperatures taken from broilers in all locations were reduced when compared with pre-journey values (Table 6). Although this reduction in rectal temperatures was only significant in I2 and Q2, the data imply that due to the short transportation distance and reduced time in transit, the trailer had not developed a thermal load comparable to the previous journeys. Because conditions in the trailer were colder, the birds exhibited lower rectal temperatures from all four locations.

Bird Temperature Measurements

Table 8 shows the relationships between broiler core body temperature or change in rectal temperature with ambient temperature, crate temperature or journey length. Change in rectal temperature was positively correlated to ambient temperature, crate temperature and journey length, with crate temperature having the strongest relationship to change in rectal temperature ($r^2 = 0.5737$, $P < 0.0001$). The correlation between core body temperature and ambient or crate temperature was not significant, however there was a relationship between core body temperature and journey length ($r^2 = 0.5634$, $P = 0.0078$). These correlations were further examined using regression analysis.

Linear relationships existed between change in rectal temperature and crate temperature, as well as core body temperature and journey length (Table 9). Quadratic equations described the relationship between change in rectal temperature and ambient temperature, change in

Table 8. Broiler core body temperature or change in rectal temperature as correlated with ambient temperature, crate temperature or journey length

	Change in rectal temp.[z]		Core body temp.[y]	
	r^2	P	r^2	P
Ambient temp.	0.2261	0.0103	0.2615	0.2522
Crate temp.	0.5737	<0.0001	0.3136	0.1662
Journey length	0.3264	0.0002	0.5634	0.0078

[z]Rectal temperature of birds ($n = 128$) was taken before and after transportation.
[y]Core body temperature of sentinel birds ($n = 21$) was recorded every 4 min for the entire journey length. The mean deep body temperature was used.

rectal temperature and journey length, and core body temperature and ambient temperature (Table 9).

Broiler Mortality

Bird mortality was 0.7% and 1.4% for the first two journeys and 0.9% for each of the third and fourth journeys (Table 3). The plant average for birds found dead at shackling in January 2000 was 0.76% (J. Bartoshewski, personal communication, Lilydale, Wynyard, SK), so the last three journeys had higher than average death losses.

Deaths occurred throughout the trailer. The number of dead birds found in each module ranged from 0 to 7, 0 to 11 and 0 to 4 birds for the first three journeys, respectively. Due to complications at the plant, mortality distribution was not available and post-mortems were not performed for the last trip. It was suggested by plant personnel that during winter transportation, elevated levels of bird mortality occurred in the bottom three modules at the back of the trailer (modules X, Y and Z). If mortality for each journey were evenly distributed in all 26 modules, 3.85% of the expected death loss would occur in each module; therefore, the expected mortality in modules X, Y and Z would be 11.5% combined. Twenty-six percent of dead birds were found in this location following Journey 2. However, only 10% of bird mortality was in modules X, Y and Z after Journey 1, and no mortality was recorded in this area upon completion of Journey 3.

Ascites was identified in 64 and 57% of dead birds for the first and second trips, respectively. Birds with no visible lesions accounted for 14 and 10% of mortality for the same respective journeys.

Before completing Journey 3, the need to distinguish between birds dying in transit and birds that died whilst awaiting slaughter became evident. Bird mortality from the transportation period of the third trip was 0.4%, whereas the total number of birds dying between departure of the production site and slaughter was 0.9%. Mortality losses for Journeys 1, 2 and 4 did not include this distinction.

Of the 0.4% of birds arriving dead after Journey 3, ascites was recognized in 79% of the population and 3% had no visible lesions. Necropsy results were not available for Journey 4 but wet birds were observed at the farm prior to transportation.

Table 9. Regression equations for relationships between change in rectal temperature or core body temperature and ambient temperature, crate temperature or journey length

		r^2	P
Change in rectal temp.			
Ambient temp.	$y = 1.421468 + 0.199539x + 0.005065x^2$	0.1474	0.0003
Crate temp.	$y = -0.991014 + 0.057516x$	0.3300	<0.0001
Journey length	$y = -0.077301 - 0.030806x + 0.000165x^2$	0.1504	0.0122
Core body temp.			
Ambient temp.	$y = 43.401490 + 0.328406x + 0.008730x^2$	0.3787	0.0077
Crate temp.	$y = 41.088120 - 0.073252x + 0.003173x^2$	0.2256	0.1027
Journey length	$y = 40.513107 - 0.014482x$	0.3336	0.0090

DISCUSSION

Environment Canada (2009) indicated the maximum and minimum average daily temperatures in January for Saskatoon, located in central Saskatchewan, from 1892 to 2000 were −11.8 and −22.3°C, with high and low extremes of 10.0 and −48.9°C, respectively. Winter conditions in the United Kingdom are not as severe as in Saskatchewan. The maximum and minimum average daily temperatures in January for the United Kingdom from 1971 to 2000 were 6.1°C and 0.7°C, respectively, with a low extreme of −27.2°C (Met Office 2009). Although the journeys monitored in Saskatchewan for this study occurred under ambient temperatures colder than those experienced in the United Kingdom, temperature trends throughout the trailer were similar to those previously recorded on broiler carriers in warmer ambient temperatures (Kettlewell et al. 1993). Because air inlets and outlets were not clearly defined, the airflow distribution pattern in the broiler transportation vehicles was complex. The small opening on the top headboard vent and the spaces between the curtains and tailboard of the trailer where the tarp remained unfastened are both examples of unintentional air inlets created by the pressure distribution on the trailer. Thermal heterogeneity developed as the air moved from the back to the front of the trailer, creating cold spots in areas of air entry and thermal loads at the front, centre region of the trailers.

Not only were temperature gradients established along the trailer, but gradients also developed across the trailer. Observations of wet birds and frost accumulation on the crates and modules positioned closest to the tarpaulins, as well as the reduced crate temperatures recorded from locations near the curtains suggested birds outside the trailer core were subjected to colder temperatures. Previous data recorded from broiler carriers have been from the centre of the trailers (Kettlewell et al. 1993) but observations from the present study indicate during cold weather transportation, conditions outside the trailer core may be drastically different and therefore worth monitoring. In Journey 4, loggers attached to the top of the modules recorded comparatively lower temperatures than the loggers positioned in crates just beneath the module covers. These data indicate the thin sheet metal covering the modules is a benefit during cold weather transportation. However, this metal module covering may be detrimental under warmer transport conditions. The heterogeneous distributions of ventilation and thus temperature and total thermal loads within broiler transport vehicles may impose thermal stress by the creation of hot spots and cold spots which may be correlated with the occurrence of mortalities (Hunter et al. 2001).

The validity of the rectal temperature data may have been limited by delays during the sampling procedure as some rectal temperature measurements were not completed until 45 min after unloading the modules. However, the increases and decreases in average rectal temperatures taken from broilers before and after transportation revealed interesting tendencies. Journey 1 was conducted when the ambient temperature was -7.1°C and the average rectal temperatures taken from all four crate locations increased. Rectal temperatures from broilers located in modules A and F were significantly higher after transportation, despite the fact that the average crate temperature was warmer in module U. Mitchell et al. (1997) reported that birds could maintain body temperature in external temperatures as low as -4°C, and data from Journey 1 supported that finding. During the colder weather in Journeys 2 and 3 (-27.1 and -28.2, respectively), crate temperatures diminished along with the average rectal temperatures from birds located in the back half of the trailer. Kettlewell et al. (2000) found that excessive airflow around the birds resulted in reduced rectal temperatures after transportation. Birds in Journeys 2, 3 and 4, especially those located near air inlets, would have been exposed to cold air entering the trailer that would lower the effective environmental temperature thereby causing a reduction in rectal temperature. In Journey 4, average rectal temperatures in all locations were lower, including those taken from the thermal core. Although this reduction in rectal temperatures was only significant in I2 and Q2, the data imply that due to the short transportation distance and reduced time in transit, the trailer had not developed a thermal load comparable to previous journeys. Because conditions in the trailer were colder, the birds exhibited lower rectal temperatures from all four locations. These data also suggest that concentrating on the beginning and end points of the journey, and the journey means, underestimates low temperature stress conditions. Change in rectal temperature was correlated to ambient temperature, crate temperature and journey length. These positive relationships were likely due to the birds being located in the trailer core. Journey length was the only parameter with a positive relationship to core body temperature; however, the r^2 values are similar to the values for changes in rectal temperature and may have been significant with a larger sample size. Overall, the relatively low r^2 values are likely due to the complex transportation environment and its influence on bird body temperature.

Mortality values for all four journeys were high compared with national and provincial averages. In 1999, Saskatchewan and Canadian average mortality losses for all poultry classifications were 0.50 and 0.56%, respectively (Canadian Food Inspection Agency). In this study mortality ranged from 0.7 to 1.4%, and ascites, a condition common to fast-growing broilers and influenced significantly by farm management (Baghbanzadeh and Decuypere 2008), was the predominant cause of death. Bird mortality from the transportation period of Journey 3 was 0.4%, whereas the total number of birds dying between departure of the production site and slaughter was 0.9%. Therefore, 0.5% of the birds died in lairage prior to slaughter, indicating that lairage impacts the level of mortality reported. Though the distinction between bird losses associated with transportation and lairage can be categorized, many deaths during the lairage period may be a delayed consequence of the stresses occurring during transport; therefore, a casual distinction may be difficult to clarify. Mortality losses for Journeys 1, 2 and 4 did not distinguish between dead on arrival and dead on shackling birds.

Although necropsy results were not available for Journey 4, observations of wet birds at the farm indicated barn conditions could influence bird mortality, even when the journey time is relatively short. Birds with wet feathers have reduced insulating capacity and will experience a lower effective environmental temperature, which would be exacerbated when exposed to cold temperatures and air movement. It should be noted that exposure to both heat and cold stress in slaughter birds has profound and detrimental effects on meat quality in individual birds that do not succumb to thermal stress mortality (Mitchell 1999, 2008; Mitchell et al. 2007). This constitutes a major production problem due to downgrading, and probably reflects an important accompanying welfare concern as the surviving birds have been exposed to hostile thermal environments that will impose stress upon their thermoregulatory capacity, may involve marked changes in deep body temperature and will have depleted both energy and water reserves of the stressed birds (Mitchell and Kettlewell 2004; Mitchell 2006, 2008). Thermal stress in transit constitutes a major threat to the welfare and production efficiency of broiler chickens and the provision of sound strategies for the prevention or alleviation of these problems in commercial practice is of paramount importance (Mitchell 2006; Mitchell and Kettlewell 2008).

In summary, cold weather transportation resulted in compromising transport conditions for the broilers. The use of the trailer curtains reduced airflow around the step in the trailer frame and produced a thermal core capable of causing heat stress for birds in that location. Unplanned sites of air entry and the potential for cold stress near these air inlets were also noted. Consequently, a comprehensive investigation of the temperature gradients that develop across the trailer during transportation is required under cold ambient temperatures. Furthermore, mortality occurring during transportation and the lairage period should be separated to determine the impact that each of these periods has on bird losses.

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