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Article

Minor stall modifications and outdoor access can help improve dairy cow welfare in tie-stalls

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Abstract

Tie-stalls are the most confining method of housing for dairy cows and remain commonly used to house cows in many countries. Finding methods to improve animal welfare through housing modifications and alternative management strategies are of increasing importance. Twelve tie-stall dairy farms in Ontario and Quebec, Canada were visited four times in a 12 month period. Visits were spread to observe the effects of pasture (visit 1), short-term effects of stall modifications (visit 2), effects of winter confinement (visit 3), and final measures after 1 year (visit 4). Lameness, injuries, cow cleanliness, lying and rising behaviors, and production parameters were assessed at each visit. Outdoor access had the largest effect: cows with access to pasture had a lower prevalence of various outcome measures throughout all four visits. Also, cows in modified stalls had a higher prevalence of dirty udders compared to cows in unmodified stalls, but only on farms that provided outdoor access. Although applying minor stall modifications to tie-stalls can help improve aspects of animal welfare, providing year-round outdoor access may represent a more effective method; the continued provision of time outside the stall helps maintain the positive impact of outdoor/pasture access on the welfare of tie-stall dairy cows.

Key words: tie-stall, dairy cow, outdoor access, animal welfare

Résumé

La stabulation entravée est la méthode de logement des vaches laitières qui confine le plus les animaux, mais elle demeure communément utilisée pour leur logement dans de nombreux pays. Il devient ainsi de plus en plus important de trouver des méthodes pour améliorer le bien-être animal, par l'entremise de modifications au logement et/ou via des stratégies alternatives de gestion. Douze fermes laitières à stabulation entravée de l'Ontario et du Québec (Canada) ont été visitées 4 fois sur une période de 12 mois. Les visites ont été étalées afin d'observer les effets du pâturage (visite 1), les effets à court terme de modifications apportées aux stalles (visite 2), les effets du confinement hivernal (visite 3), et les résultats finaux après 1 an (visite 4). Boiterie, blessures, propreté des vaches, comportements de lever et de coucher, et paramètres de production ont été évalués à chaque visite. L'impact de l'accès à l'extérieur était le plus important, les vaches ayant accès au pâturage obtenaient de meilleurs résultats pour la plupart des indicateurs de bien-être évalués lors des 4 visites. Chez les fermes offrant un accès à l'extérieur, la prévalence de pis sales était plus élevée chez les vaches dans des stalles modifiées que chez les vaches dans des stalles non modifiées . Si appliquer des modifications mineures aux stalles en stabulation entravée pourrait aider à améliorer des aspects du bien-être animal, offrir un accès à l'extérieur toute l'année pourrait représenter une méthode plus efficace; continuer d'offrir du temps à l'extérieur des stalles aide à maintenir l'impact positif de l'accès à l'extérieur/aux pâturages sur le bien-être des vaches laitières en stabulation entravée.

Mots-clés : stabulation entravée, vache laitière, accès à l'extérieur, bien-être animal

Introduction

Animal welfare concerns from consumers and, processors and retailers are now an important aspect of the food production industry. The main concern raised by consumers in the U.S. when asked what issues they found important for an ideal dairy farm was animal welfare (Cardoso et al. 2016). With confinement being at the forefront of animal welfare concerns by consumers (Fraser 2008) (e.g., banning of gestation crates for pigs, battery cages for poultry, and crates for veal), methods to mitigate the effects of confinement of the animals are an important concern for producers to address. Tie-stall dairies represent a large portion of the housing facilities in North America with 49% of U.S. farms (USDA 2017) and 73% of Canadian farms based on farms on a milk recording program (CDIC 2021) housing their lactating cows in tie-stalls. A majority of tie-stall dairy producers in Ontario and Quebec, Canada do not house their cows in stalls adequate for their size (Bouffard et al. 2017). Inadequate stall configurations have been associated with lameness, hock, knee, and neck injuries (Nash et al. 2016; Bouffard et al. 2017). Additionally, inadequate stall configurations may prevent the cows from performing behaviors in a natural manner; an example of this is coming into contact with the stall when rising (Veissier et al. 2004). Rebuilding the barn to provide cows with larger stalls or switching to a group-housing system represent a high investment in terms of time and money, with a minimum estimated cost of $2500 USD per stall (University of Wisconsin - Extension Dairy Team 2015). Alternative strategies would be to make minor and affordable modifications to the existing tie-stalls and (or) provide cows with exercise year-round.

Providing cows with outdoor access through pasture or a paddock yard may be a good strategy to both minimize cow confinement and improve welfare outcomes (i.e., injuries, BCS, lameness, cow cleanliness, ability to perform more natural behaviours) (Gustafson 1993; Regula et al. 2004; Popescu et al. 2013), and may also allow them to perform a wider range of behaviours. Although it has been shown that cows benefit from regular outdoor access year-round (Regula et al. 2004; Seo et al. 2007), this may not always be the case. Severe and cold winters, such as those found in the northern United States and Canada, may affect how much cows choose to utilize this outdoor access or the quality of the outdoor environment (e.g., walking surface could be icy) and thus, potentially affect the outcome measures of welfare. Recent studies have shown Canadian dairy cows do not suffer severe production or other physiological side effects from summer pasture access (Palacio et al. 2015). Further when experienced, cows will choose to spend time outside in Canadian summers (Shepley et al. 2016*b*) and winters (Shepley et al. 2016*a*). To our knowledge, the long-term effects of access to the outdoors on Canadian dairy cows in a commercial situation has not been measured.

Our objectives were to assess whether minor stall modifications, requiring little monetary and time investment by producers, could improve the welfare outcomes of cows on Canadian tie-stall dairies. Additionally, we wanted to assess whether year-long outdoor access could also be a useful and perhaps an alternative method to making physical housing changes to improve dairy cow welfare on Canadian tie-stalls.

Materials and methods

Ethical statement

All methods used in the study were approved by the Research Ethics Board of the University of Guelph for research involving human participants (REB # 14AP020) and by the University of Guelph's Animal Care Committee for data collection conducted on animals (AUP # 3133) according to the guidelines of the Canadian Council of Animal Care.

Herd selection

Holstein dairy herds were recruited in Ontario and Quebec, Canada through the help of field advisors in both provinces. Advisers were asked to provide contact information of producers they believed would be opened to participating in the study and adopting stall modifications recommended to them. All farms were required to meet the study criteria of having a minimum of 40 lactating cows, house lactating cows in tie-stalls, be open to make housing improvements, and be willing to take part in the study for 12 months. Eighteen farms were contacted, nine farms were certified organic and nine were conventional tie-stall farms. Of these 18 farms, 11 provided outdoor access as a pasture area during the grazing season and the same plots of land outside of the grazing season. Out of these 18 farms originally visited, 12 farms were visited four times throughout the 12 month duration of the experiment. Two farms dropped out due to the inability to make the necessary modifications to the housing environment, one farm due to lack of time, and the remaining three farms dropped out due to personal circumstances. Of the 12 farms left, 8 farms provided outdoor access, 4 were in Ontario, and 6 were certified organic. Average herd size was 55 (range: 37–101) cows, which is close to the average herd size for tie-stall farms in Ontario (59 cows) and Quebec (57 cows; CDIC 2015). Annual average milk production in the herds was 8887 kg/cow with an average days in milk (DIM) of 150 and average parity of 2.5.

Farm participation was voluntary with no financial compensation provided and producers could remove themselves from the study at any point. Farms were first contacted by phone to ensure they met all the criteria and were willing to participate. During the first visit, producers signed a consent form informing them of the details of the study.

Stall Modifications treatment

During the first visit, a dairy cattle comfort expert from Valacta Inc. (Sainte-Anne-de-Bellevue, Quebec) conducted an animal welfare assessment and in concertation with the producer, determined what stall modifications would be applied to the treatment stalls. Eight farms adjusted the tie-rail position, six farms increased the chain length, three farms adjusted the trainer positions, and one farm switched from tie-rail to tie-chains (Table 1). To assess the possible effects housing modification had on the welfare measures of the cows, housing modification measures were compared to the recommended housing measures (adapted from Valacta 2014 and Dairy Farmers of Canada 2017) (plus a 5% margin of error) based on cow size (Table 1). Within farms, cows on the control treatment were housed in stalls with no modifications.

Table 1. Percentage of cows on each farm that fit in their stalls based on their body dimension and recommendations relative to the specific stall configuration aspect that was targeted for modification.

		Unmodified rows		Modified rows	
		Visit 1‡	Visit 4	Visit 1	Visit 4§
	Nb* of farms†	Percentage of cows that fit (range)	Percentage of cows that fit (range)	Percentage of cows that fit (range)	Percentage of cows that fit (range)
Rail height	8	30 (0–100)	33.33 (0–100)	33.33 (0–100)	40 (0–100)
Rail forward	8	0 (0–0)	14.29 (0–100)	0 (0–0)	40 (0–100)
Chain length	6	0 (0–0)	14.29 (0–25)	0 (0–11)	20 (0–100)
Stall width	1	100	0	100	100
Bed length	1	0	100	100	100

*Nb represents number.
†On a total of 12 individual farms, 2 farms applied only one modification, 10 applied multiple modifications.
‡Visit 1 represents stalls before modifications were applied on both unmodified and (future) modified rows.
§Visit 4 represents the same stalls after modifications were applied to the targeted stalls (modified rows).

Outdoor Access treatment

Eight of the 12 farms provided outdoor access to the cows by providing access to a pasture area during the grazing season and the same plots of land outside of the grazing season to varying degrees. Grazing season lasted on average 145 days (range: 92–170 days), from early May to early November. Cows were outside for an average of 17.8 h/day (range: 5.3–22.0 h/day). Provision of winter outdoor access (outside of grazing season) varied amongst farms. Some farms extended outdoor access (8 h/day) after the end of the pasture season for an average of 33.6 days (range: 14–90 days). On the other hand, some farms provided weekly outdoor access during the whole winter season (i.e., remainder of the days or 186 days) where cows received 2–3 h of outdoor access 2–3 days/week. Farms on the control treatment did not provide outdoor access.

Animal selection

Twenty cows per farm were selected representing on average 36% (range: 20%–54%) of the herd, where 10 cows would be kept in stalls with modifications and 10 cows in stalls without modifications. Cow selection was based on DIM starting after 10 DIM (average of 157 $\pm$ 5.9 days) and parity (average of 2.6 $\pm$ 0.10). Within each farm, the 20 cows were paired based on parity and DIM and randomly assigned to one of the two treatments: unmodified stall or modified stall.

The total number of cows varied across the 12 month study. Cows were removed from the study if they were switched from the assigned stalls (modified vs. unmodified) from the point of the observed switch (69 total cows throughout the four visits). A total of 43 cows were culled (i.e., removed from the herd) within the duration of the study and 40 cows were not recorded at one of the four visits due to being dry at the time of the visit and (or) housed outside or in a different barn.

Farm visits

Farms were followed for 1 year with a total of four visits throughout where an on-farm assessment was conducted in each visit. Visit 1 was conducted towards the end of the pasture season of 2014 (October–November). Visit 2 was conducted 9–30 days after the modifications were applied to the stalls (November–March) to assess the possible short-term effects of the stall modifications applied. Visit 3 was performed towards the end of the winter season of 2015 (April–early May) to observe the effects the stall modifications had when the cows had been confined for the longest time (winter), and to observe the possible impacts of winter outdoor access. Visit 4 was conducted towards the end of the pasture season of 2015 (October–November) to observe the long-term effects of stall modifications as well as the possible effects of the stall modifications when the cows have access to pasture.

On-farm assessment

Animal-based measures

All scoring methods followed (Vasseur et al. 2015) and the corresponding standard operation procedures (SOPs) used to record said measures are described on the Canadian Dairy Research Portal (https://www.dairyresearch.ca/cow-comfort.php#self). Observers' repeatability was assessed for outcome measures multiple times throughout the project and overall κ averages for outcome measures are reported in the text in their respective sections. Further details on repeatability (i.e., number of observer, frequency, repeatability min. and max., etc.) can be found in Supplemental Table S1. Cows were scored live using visual numerical scoring charts for cleanliness, where leg below the hock, back portion of the udders, and the right flank were observed. These body areas were scored on a scale of 0–4 and categorized as clean (score 0–1) or dirty (score 2–3). Hock and knee injuries were assessed using a scale of 0–3 and categorized as noninjured (score 0–1) and injured (2–3), while neck injuries were assessed on a scale of 0–2 and categorized as noninjured (score 0–1) or injured (score 2). A cow was determined to be injured or not for each respective area (hock or knee) based on the more severe of the two possible scores (i.e., left or right leg) per area per cow. Body condition score (BCS) was assessed using a scoring system from <2 to 5 with increments of 0.25, where a score of 2 or below categorized the cow as severely underconditioned and a score above 2 categorized the cow as adequately conditioned. Body dimensions (cow height at the rump and hook bone width)

Table 2. Rising behaviours observed to determine the ease of rising of a dairy cow in a tie-stall.

Criteria	Rating	Explanation
Duration of rising motion	mm:ss (beginning) to mm:ss (end)	Beginning of rising motion: the cow is in sternal position to propel herselfEnd of rising motion: the cow gathers her forelimb side by side behind the feed bunk(Nb*: does not take into account hind legs nor stretching movements)
Head or neck contact	Yes or no	The cow propels herself forward (both knees on the ground) and her head or neck touches the tie-rail (shock, impact)
Knee adjustment	Yes or no	Before or after propelling herself (to avoid the tie-rail)†
Delayed rising	Yes or no	Resting on carpal joints for more than 10 s‡
Overall restricted rising	Yes or no	An observation of one or more of the above behaviours observed

*Nb represents number.
†Adapted from Wechsler et al. (2000).
‡Adapted from Regula et al. (2004).

of the cows were also recorded. Cleanliness, injuries, and BCS were scored by the same trained observer on all farms. Intraobserver repeatability (overall κ average = 0.74) and interobserver repeatability (overall κ average = 0.62) for outcome measures were assessed several times throughout the year using both live scoring and photos.

Rising behaviour was recorded in the stall and later scored by one observer. Video recording of rising was performed by one individual (Technician 1) while a second team member (Technician 2) stood behind that cow and vocally encouraged her to rise in a stern but low voice. If the cow did not respond to the vocal command, the individual would tap the cow near the spine or hook bones with increasing pressure until cow had risen. As soon as the rising motion began, technician 2 moved behind technician 1 to encourage the cow to rise facing the direction of the camera. For the scoring of rising videos, a single observer scored the behaviours presented in Table 2. Each cow was observed for the presence of the behaviours and restricted rising was determined if the cow displayed any of the three behaviours in Table 2. Intraobserver reliability (overall κ average = 0.70) was assessed multiple times throughout the scoring period, and interobserver reliability was assessed at the start of the scoring period (overall κ average = 0.81) using video recordings.

Lameness was scored by three trained observers when the cows were in their stalls through video stall lameness scoring following Gibbons et al. (2014) and Palacio et al. (2017). All training followed an intensive procedure (up to 2 weeks) where SOPs were learned by all observers to ensure results were consistent within and between observers. Periodic assessments were conducted on the observers to ensure that intraobserver (overall κ average = 0.84) and interobserver (overall κ average = 0.75) repeatability during the data collection period were maintained. Cows were observed while standing in their stalls from three angles for 10 s at a time where the observer looked for (1) weight shift: regular, repeated shifting of weight from one hoof to another, defined as lifting each hind hoof completely off the ground at least twice and landing in the same location, (2) stand on edge: the cow places one hoof or both at the edge of the stall while standing, (3) uneven weight: the cow repeatedly rests one foot more than the other, indicated by raising a part or the entire hoof off the ground. The cow was then encouraged to move from side to side in her stall in which the fourth behaviour was observed, and (4) uneven movement: uneven weight bearing between the left and right feet when the cow moves from side to side. A cow was considered lame when two or more of these behaviours were observed.

Lying time was automatically recorded using leg-mounted activity loggers (Hobo Pendant G Acceleration Data Logger, Onset Computer Corp., Bourne, MA.), as validated by Ledgerwood et al. (2010), on one of the hind legs using Vet-Wrap (CoFlex, Andover Coated Products Inc., Salisbury, MA) and removed by a researcher in a follow-up visit a week later. Duration of total lying time, average number of lying bouts, and average duration of lying bouts were computed using Excel macros (Microsoft Corp., Redmond, WA) for each visit (4 day period).

Stall configuration

Different measures of the cow's housing environment were recorded on the day of the visit (Fig. 1); detailed descriptions on the measures are found in Table 3 (following Vasseur et al. 2015). Stall width, chain length, lunge space, trainer position, and access to water were measured in all stalls housing the focal cows (i.e., cows under study). For stall length and tie-rail forward position, stalls at both ends of a row were measured and the measures of each stall in between was calculated based on the incremental change per stall in each row.

Production parameters

Milk production variables (i.e., milk yield, milk fat yield, milk protein yield, and milk somatic cell count (SCC)) were obtained from dairy herd improvement service providers used. In Ontario these data were provided by CanWest DHI (Guelph, Ontario, Canada) and in Quebec by Valacta Inc. (Sainte-Anne-de-Bellevue, Quebec, Canada).

Data handling and statistical analysis

Data were entered into Microsoft Excel 2010 (Microsoft Corp.). Cow parity was categorized as 1, 2, and ≥3. DIM were categorized as early (10–100 DIM), mid (101–200 DIM), and late (201+ DIM). Outcome measures of cow health and behaviour and stall configuration measures were analyzed at

Fig. 1. Adapted from Valacta (2014), tie-stall housing measures. (A) Stall length, (B) bed length, (C) tie-rail height, (D) chain length, and (E) brisket board height.

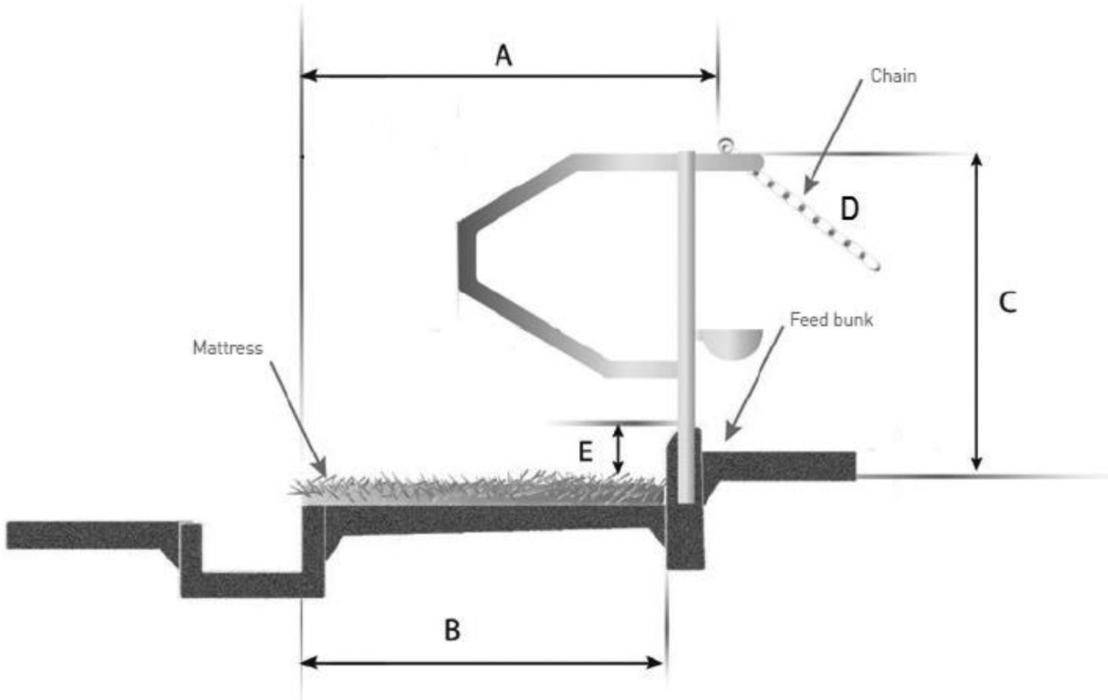


Table 3. Tie-stall housing measures definitions*.

Stall dimensions	Definition
Stall width	Measure distance from center-to-center of stall divider placement
Stall length	Measure distance from stall rear curb to the rear of the tie-rail
Bed length	Measure distance from the rear curb to manger wall
Tie-rail forward position	Stall length minus bed length
Manger wall height	Measure vertical distance from top of manger wall to stall surface
Lunge space	Measure if forward and side space obstruction for 76 cm from top of brisket board. If no brisket board, measure horizontally below neck rail but 10 cm above stall surface. If no neck rail, measure 127 cm from curb and 10 cmabove stall surface. If no obstruction in lunge space, indicate YES (1) and if obstruction in lunge space indicate NO (2)
Tie-rail height	Measure vertical distance from bellow the tie-rail to the stall surface (bedding surface)
Chain length	Measure length of tie-chain from tie-rail to neck of the cow
Trainer position	Check if trainer was in contact with the cow during a normal stance in the center of the stall. Indicate if contact was observed or not
Water access	Check functionality of water bowls by releasing water for 5 s. Record if water flow observed or not
Bedding quantity	Rake bedding evenly throughout stall. Check if bedding depth is $\leq$2 or $>$2 cm
Bedding quality	Use two selected spots (center of stall and rear of stall). Fold single square paper towel in four, use paper towel to kneel on one knee on selected spot in the stall (repeat for second spot). If paper towel is wet, score based on how far wetness permeated through towel†

*Adapted from Vasseur et al. (2015).
†Detailed SOP can be found at https://www.dairyresearch.ca/animal-comfort-tool.php.

the cow level for each of the four visits separately. For all categorical data (injuries, cow cleanliness, lameness, BCS) scores were determined to be acceptable (e.g., hock injuries: 0 or 1), or unacceptable (e.g., hock injuries: 2 or 3), and reported as the prevalence of cows per farm observed to have unacceptable levels of the outcome measure. Rising behaviours were scored as binary variables (presence/absence of a behaviour) and were reported as the prevalence of cows observed performing each abnormal rising behaviour. Continuous data (i.e., total rising time, lying time, number of lying bouts, lying bout duration, milk yield, milk fat, milk protein, and milk SCC) are reported as cow averages.

All data were analyzed using SAS 9.4 (SAS Institute Inc., Cary, NC). The sample unit was the cow. Outdoor Access and Stall Modification treatments and their interactions were considered fixed effects. Parity and DIM were considered as potential confounding variables and were considered as fixed effects. Each visit was analyzed separately, and separate

Table 4. Differences in average (± standard error (SE)) of category of parity and days in milk (DIM) between cows with or without outdoor access and housed in unmodified or modified stalls for all four visits.

			Parity[‡] (#)		DIM* (#)		*P* value[†]	
Visit	Treatment	N	Average	SE	Average	SE	Parity	DIM
1	No Outdoor Access	80	1.8[b]	0.08	1.9	2.67	0.009	0.371
	Outdoor Access	140	2.1[a]	0.06	2.0	3.15		
	Modification	109	1.9	0.07	2.0	2.92	0.254	0.656
	No Modification	111	2.0	0.07	2.0	2.92		
2	No Outdoor Access	71	1.7[b]	0.09	1.8	2.40	0.002	0.078
	Outdoor Access	132	2.1[a]	0.06	2.0	3.08		
	No Modification	105	1.9	0.07	1.9	2.96	0.920	0.788
	Modification	98	1.9	0.08	2.0	2.62		
3	No Outdoor Access	69	1.7[b]	0.09	1.8	2.51	0.010	0.135
	Outdoor Access	118	2.0[a]	0.06	2.0	3.08		
	No Modification	110	1.9	0.07	1.9	3.00	0.583	0.363
	Modification	77	1.9	0.09	2.0	2.61		
4	No Outdoor Access	60	1.8	0.10	1.9	2.45	0.099	0.055
	Outdoor Access	104	2.0	0.07	2.1	2.86		
	No Modification	97	1.9	0.07	2.0	2.93	0.739	0.403
	Modification	67	1.9	0.09	2.1	2.40		

[‡]Treatment averages (within each visit) with different superscripts (a,b) differ ($P \geq 0.05$). *DIM was computed as categories where 1 = early (10–100 DIM), 2 = mid (101–200 DIM), and 3 = late (201+ DIM). Value reported above is the calculated average DIM categories.
[†]Kruskal–Wallis test significant at $P \leq 0.05$.

models were built for all dependent variables under analysis. A generalized linear mixed model with logistic link function using Proc GLIMMIX was built for all variables analyzed in a binomial distribution (i.e., all injuries, lameness, BCS, cow cleanliness, and the binary rising behaviours). For variables where the GLIMMIX procedure did not converge a MIXED procedure was used. For continuous variables (i.e., rising time, lying time, number of lying bouts, lying bout duration, 24 h milk production, 24 h milk fat and protein yield, and SCC) normality was checked through a Shapiro–Wilk test and visual inspection of histograms and Q–Q plots, duration of lying was log transformed to fit a normal distribution and a mixed linear model was used to analyze these variables. A Kenwood–Rogers adjustment was used for the denominator degrees of freedom (dDF) to account for multiple comparisons. Random effects included in the model were the farm nested within the Outdoor Access treatment as the provision of outdoor access was based on the farm the cows belonged to. Pairing of the cows to balance out the treatments (i.e., group) was nested within the Stall Modification treatment, the farm they were in and if they had outdoor access or not.

Wilcoxon's signed-rank test and Kruskal–Wallis analysis of variance test were used to assess if category of parity and category of DIM varied between the experimental treatments (i.e., outdoor access and housed in modified stalls) at each visit.

On visit 1, although no modifications of the stalls had occurred at that time (i.e., modifications occurred before visit 2), differences between treatment groups were tested for all welfare outcome measures for Stall Modification treatment and Outdoor Access treatment. This was done to test for possible differences between treatment groups that could not be controlled for at the time of treatment allocation.

Between farms and therefore for the Outdoor Access treatment, DIM and parity could not be controlled for (i.e., different management strategies leading to different herd longevity). Average category of parity and DIM for both Stall Modification and Outdoor Access treatment for all the four visits can be found in Table 4 showing that Outdoor Access farms have higher parity than No Outdoor Access farms (differences found in visits 1, 2, 3, and 4 (tendency); Kruskal–Wallis test $P < 0.05$). DIM was not detected to be different among treatments.

Results

Parity and DIM

Parity categories during visits 1, 2, and 3 were higher for farms that provided outdoor access compared to farms that did not (Table 4), while category of DIM did not differ in any of the treatment groups throughout all four visits. Therefore, for each outcome measure where Outdoor Access treatment was significant, the effect of parity was also evaluated for significance as it may contribute to the observed effect of outdoor access on the outcome measure and reported as necessary.

Visit 1

Although during visit 1 no stall modifications had occurred, cows were grouped into their corresponding treatments to acquire a baseline for all outcome measures for all possible treatments. Among all variables assessed in visit 1

(Table 5), prevalence of knee and neck injuries were affected by access to the outdoors. Cows with access to the outdoors had (difference in least square mean ± standard error mean) 14.1 ± 5.48% and 33.4 ± 13.51% less knee and neck injuries, respectively, compared to cows without outdoor access.

Visit 2

On visit 2, cows without outdoor access had a prevalence of neck injuries 2.3 times higher compared to cows with outdoor access (Table 6). Similarly, cows housed in unmodified stalls had a 1.9 times higher prevalence of neck injuries compared to cows housed in modified stalls. Cows with outdoor access and kept in modified stalls were observed to have a prevalence of dirty udders five times higher than cows that also had outdoor access but were kept in unmodified stalls (Fig. 2). Head or neck contact when rising and overall restricted rising were 2.2 and 1.6 times less prevalent, respectively, for cows kept in modified stalls compared to cows kept in unmodified stalls. Rising time was 1.5 ± 1.07 s longer for cows without outdoor access compared to cows with outdoor access. Parity category was also observed to affect rising time ($P = 0.034$) with older cows taking longer to rise than younger cows. Parity category was observed to interact with Outdoor Access treatments, where cows without outdoor access being in a lower parity category.

Twenty-four-hour milk fat yield (kg/day) was observed to differ between the Outdoor Access treatments, with cows without outdoor access producing an extra 0.3 ± 0.02 kg of fat per day compared to cows with outdoor access.

Visit 3

On visit 3 (Table 7), no effects of the Stall Modification treatment were observed. However, access to the outdoors during the winter was observed to affect several measured outcomes. Cows without outdoor access had a higher prevalence of hock and knee injuries compared to cows with outdoor access (1.4 and 1.9 times higher, respectively). Prevalence of lameness was also 2.5 times higher for cows without outdoor access compared to cows with outdoor access. Total rising time was 1.4 times higher for cows without outdoor access compared to cows with outdoor access. Similarly, to visit 2, rising time was also affected by parity category ($P = 0.029$) with older cows taking longer to rise than younger cows.

Visit 4

On visit 4 (Table 8), cows without outdoor access had a prevalence of hock injuries 2.1 times higher than cows with outdoor access and rising took 1.3 times longer.

Discussion

Parity and outdoor access

Farms providing outdoor access to their cows had a higher parity category (i.e., older cows) during visits 1, 2, and 3 and had a statistical tendency in the same direction on visit 4. Similar observations were found on organic herds (Bennedsgaard et al. 2003, 2010; Ahlman et al. 2011), which are required to provide pasture and exercise, when compared to non-organic herds.

A possible reason behind higher parity categories on farms providing outdoor access may be the use of different herd management strategies by the producers in those herds. With this may come different objectives to have less cow turnover leading to more resistant cows and of higher parities. It is important to point out that this possible management strategy difference between farms that provide outdoor access and those that do not causes a confounding effect between outdoor access and parity category in the present experiment. Although we cannot definitely say that providing outdoor access increased the productive longevity of the cows, our results showed that providing outdoor access does yield improved outcome measures (specifically body injuries, rising behaviour, and lameness), which may help improve or maintain the health and welfare of the cow and thus its productive lifespan.

Visit 1: Outdoor access effect before modifications

Hock and knee injuries were lower than those reported by Bouffard et al. (2017) (58% and 44%, respectively) and Nash et al. (2016) (56% and 43%, respectively) for other tie-stall farms in Canada. However, prevalence of neck injuries for cows housed in tie-stalls and without outdoor access was similar to that recorded by Bouffard et al. (2017) (33%). Lameness prevalence was also similar to that recorded by Bouffard et al. (2017) (25%) and Cook (2003) (22%) in tie-stall herds.

In the present study, cows with outdoor access started with fewer lesions and swelling compared to cows without outdoor access. This is in line with Corazzin et al. (2010), who reported that the injury levels of cows housed in tie-stalls at the end of the pasture season were lower compared to cows without access to pasture. This suggests that providing outdoor access to dairy cows can help decrease multiple body injuries. Some body injuries are likely a consequence of constant contacts with the confinement of the stalls. While provided with outdoor access, cows have an opportunity to leave their stalls, which in many cases do not properly fit their body dimensions. Previous epidemiological studies conducted in Canada showed that as many as 90% of tie-stall farms did not meet the recommended stall configurations for their cows (Zurbrigg et al. 2005*a*). More recently Bouffard et al. (2017) found that the percentage of farms that met the different recommended aspects of stall configuration ranged from 2% to 62%, indicating that a large portion of farms are still not meeting recommendations. This was also observed in our sample (Table 1). The opportunity for cows to leave their tie-stall can give them the ability to rest in more diverse positions allowing areas of the body that are usually in contact with the stall when lying to heal.

Visit 2: Effects of access to the outdoors measured after the grazing season and short-term effects of stall modifications

On visit 2, cows with outdoor access maintained a lower prevalence of neck injuries than cows without outdoor

Table 5. Least square means (LSM) ± standard error mean (SEM) of all possible outcome measures affected by the experimental treatments (i.e., outdoor access vs. no outdoor access and modified vs. unmodified stalls) and their interactions during visit 1*.

		LSM (SEM)§				*P* value		
Outcome measures†	N	No outdoor	Outdoor	No modification	Modification	Outdoor	Mods‖	Outdoor × Mods
Injured hock (%)	194	34.7 (18.09)	7.7 (5.18)	19.6 (9.04)	15.40 (7.57)	0.129	0.469	0.417
Injured knee (%)	220	21.4 (4.96)[b]	7.4 (2.34)[a]	11.1 (3.35)	14.9 (3.70)	**0.005**	0.431	0.448
Injured neck (%)	220	38.0 (13.27)[b]	4.6 (2.54)[a]	16.9 (6.09)	12.6 (5.44)	**0.018**	0.440	0.089
Low BCS (≤2.0)‡ (%)	220	1.8 (2.14)	3.8 (1.64)	4.1 (1.89)	1.6 (1.90)	0.446	0.332	0.364
Lame (%)	217	19.4 (6.58)	8.1 (2.98)	11.2 (3.87)	14.3 (4.38)	0.108	0.543	0.077
Dirty leg (%)	220	6.2 (5.32)	11.3 (6.57)	7.0 (4.12)	10.1 (5.39)	0.569	0.418	0.655
Dirty flank (%)	220	19.7 (17.31)	32.9 (18.30)	23.4 (12.86)	28.3 (14.42)	0.622	0.506	0.691
Dirty udder (%)	220	7.1 (4.45)	16.9 (6.40)	7.5 (3.50)	16.1 (5.91)	0.245	0.062	0.994
Head/neck contact (%)	157	17.7 (12.06)	18.0 (9.37)	18.8 (8.68)	17.0 (8.28)	0.987	0.798	0.292
Knee adjustment (%)	157	16.7 (7.58)	15.5 (6.05)	18.9 (6.19)	13.7 (5.40)	0.899	0.407	0.859
Delayed rising‡ (%)	157	6.6 (3.80)	7.7 (3.22)	10.3 (3.06)	4.1 (3.17)	0.835	0.089	0.151
Restricted rising (%)	157	40.2 (20.10)	37.7 (14.72)	43.8 (13.65)	34.2 (12.87)	0.922	0.322	0.883
Total rising time (s)	157	8.4 (1.10)	8.5 (1.08)	7.6 (1.08)	7.5 (1.08)	0.111	0.906	0.722
Average total lying time (min/day)	212	720.8 (32.26)	648.7 (24.42)	687.2 (21.96)	682.3 (22.09)	0.107	0.772	0.998
Average number of lying bout/day	212	11.1 (0.59)	10.1 (0.45)	10.5 (0.43)	10.7 (0.44)	0.190	0.565	0.242
Average lying bout duration (min)	212	71.4 (4.76)	70.1 (3.61)	71.7 (3.38)	69.8 (3.40)	0.837	0.535	0.422
24 h milk (kg)	558	31.1 (2.23)	28.8 (1.69)	29.7 (1.44)	30.1 (1.44)	0.407	0.483	0.749
24 h milk fat yield (kg/day)	555	1.2 (0.08)	1.1 (0.06)	1.2 (0.05)	1.2 (0.05)	0.250	0.510	0.417
24 h milk protein yield (kg/day)	555	1.0 (0.07)	0.9 (0.05)	1.0 (0.05)	1.0 (0.05)	0.202	0.389	0.789
Somatic cell count (100 000)	423	163.7 (34.71)	135.2 (37.20)	189.9 (36.11)	109.0 (37.41)	0.575	0.110	0.654

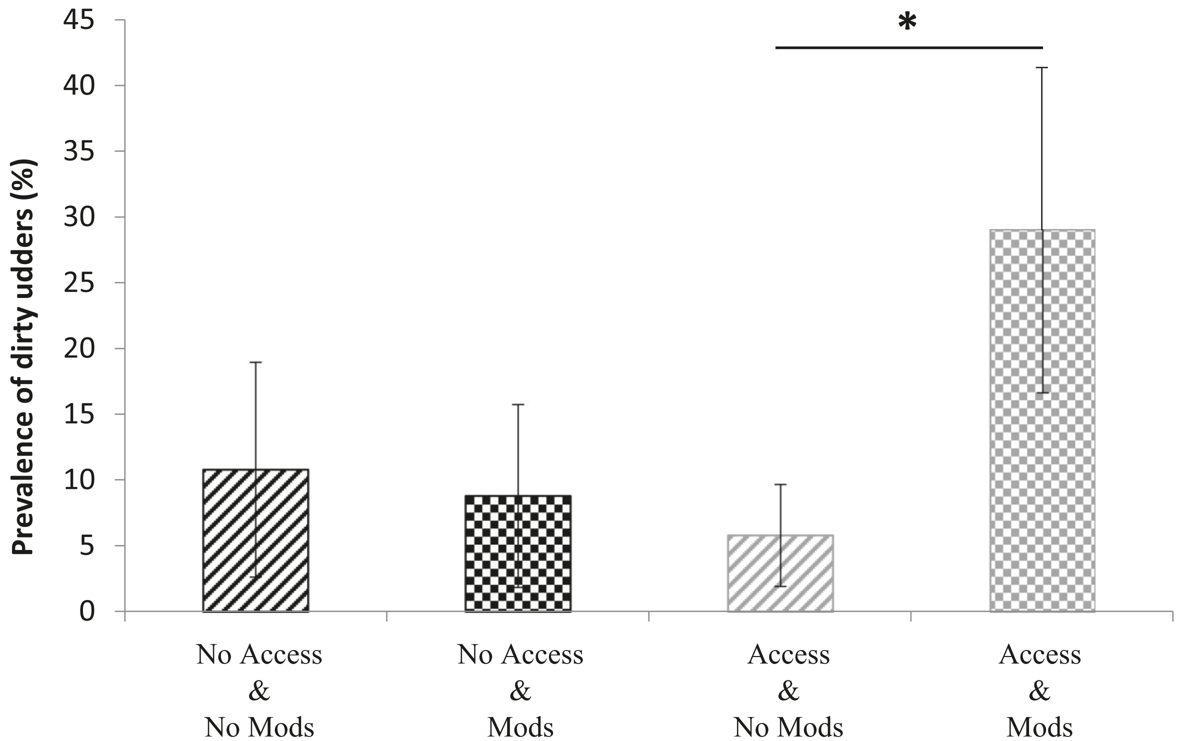
*During visit 1 cows were separated into cows in modified and unmodified stalls, however, no stall modifications were applied until several days before visit 2. Reason for grouping in visit 1 was to have individual baseline measures of all outcome measures for all groups (i.e., outdoor access or not and modified stalls or not).
†Presented as prevalence of cows, unless specified otherwise.
‡Mixed models results presented because the GLIMMIX model did not converge.
§LSM (SEM) with different superscripts (a, b) differ ($P \leq 0.05$).
¶*P*-values denoting statistically significant differences ($P \leq 0.05$) are bolded. ‖Mods represents Modification.

Table 6. Least square means (LSM) ± standard error mean (SEM) of all possible outcome measures affected by the experimental treatments (i.e., outdoor access vs. no outdoor access and modified vs. unmodified stalls) and their interactions during visit 2.

		LSM (SEM)†				*P* value¶		
Outcome measures*	N	No outdoor	Outdoor	No modification	Modification	Outdoor	Mods§	Outdoor × Mods
Injured hock (%)	191	28.1 (8.52)	19.4 (5.27)	22.7 (5.78)	24.3 (6.05)	0.392	0.810	0.368
Injured knee (%)	202	11.5(5.66)	5.0 (2.39)	5.5 (2.73)	10.5 (4.33)	0.181	0.160	0.988
Injured neck (%)	202	23.5 (6.37)[b]	10.2 (2.96)[a]	21.7 (5.02)[b]	11.2 (3.48)[a]	**0.047**	**0.049**	0.644
Low BCS (≤2.0)‡ (%)	202	–	–	–	–	–‡	–	–
Lame (%)	200	42.7 (12.02)	20.2 (6.24)	28.8 (7.40)	31.7 (7.87)	0.120	0.711	0.923
Dirty leg (%)	202	10.6 (1.27)	11.0 (6.89)	2.9 (2.26)	4.2 (3.14)	0.098	0.545	0.487
Dirty flank (%)	202	9.8 (10.03)	31.5 (17.81)	13.7 (8.76)	24.0 (13.23)	0.334	0.102	0.829
Dirty udder (%)	202	9.7 (6.90)	13.7 (7.04)	7.9 (4.12)	16.6 (7.34)	0.702	0.060	**0.017**
Head/neck contact (%)	164	24.3 (13.20)	17.8 (8.24)	30.4 (10.34)[b]	13.7 (6.35)[a]	0.676	**0.036**	0.388
Knee adjustment (%)	165	21.0 (9.70)	19.8 (6.73)	22.0 (7.01)	18.8 (6.79)	0.924	0.670	0.229
Delayed rising‡ (%)	165	–	–	–	–	–	–	–
Restricted rising (%)	165	49.2 (17.25)	43.7 (12.46)	57.9 (11.37)[b]	35.4 (11.07)[a]	0.803	**0.027**	0.654
Total rising time (s)	165	7.3 (1.06)[b]	5.8 (1.05)[a]	6.7 (1.05)	6.3 (1.05)	**0.014**	0.326	0.248
Average total lying time (min/day)	184	751.1 (18.85)	742.9 (14.25)	750.4 (14.45)	743.5 (14.86)	0.734	0.688	0.431
Average number of lying bout/day	184	10.7 (0.51)	10.3 (0.39)	10.6 (0.39)	10.5 (0.40)	0.542	0.936	0.271
Average lying bout duration (min)	184	76.8 (4.53)	79.2 (3.42)	78.6 (3.27)	77.4 (3.36)	0.681	0.725	0.127
24 h milk (kg)	343	32.3 (2.16)	27.7 (1.68)	29.6 (1.47)	30.4 (1.44)	0.125	0.362	0.761
24 h milk fat yield (kg/day)	342	1.4 (0.08)[a]	1.1 (0.06)[b]	1.3 (0.06)	1.3 (0.06)	**0.041**	0.972	0.531
24 h milk protein yield (kg/day)	342	1.1 (0.07)	0.9 (0.06)	1.0 (0.05)	0.9 (0.05)	0.097	0.406	0.758
Somatic cell count (100 000)	239	463.0 (64.33)	300.0 (69.03)	412.2 (66.71)	350.8 (62.01)	0.094	0.431	0.390

*Presented as prevalence of cows, unless specified otherwise.
†LSM (SEM) with different superscripts (a, b) differ ($P \leq 0.05$).
¶*P*-values denoting statistically significant differences ($P \leq 0.05$) are bolded. ‡Data not available because the model did not converge.
§Mods represents Modification.

Fig. 2. Average prevalence of dirty udders observed for the four possible combinations of cows with or without outdoor access (Access) and housed in unmodified or modified stalls (Mods) during visit 2. *Significance of $P \leq 0.05$.



access. At the time of the visit, cows with outdoor access were still permitted to access the outdoors on a daily basis, which may have prevented them from developing injuries caused by recurrent contacts with the tie-rail and chain. Other studies have also indicated that contact with the tie-rail is likely to lead to neck lesions. Zurbrigg et al. (2005*b*) found that improper placement of the tie-rail was linked to more observed neck lesions.

Cows with outdoor access had a shorter rising time compared to cows without outdoor access, which is in agreement with Corazzin et al. (2010), who observed shorter rising times after the grazing season compared to before, on cows housed in tie-stalls. Rising time was also reported by Shepley et al. (2019) to be numerically shorter for cows housed in a loose pen for 8 weeks during the dry period as opposed to tie-stall-housed cows with less movement opportunity. We also found that older cows had a longer rising time than younger cows, which to our knowledge, has not been measured before. However, Chaplin and Munksgaard (2001) reported that for cows in tie-stalls, time to lie down, and rising score were higher (where a higher score represents more difficulty/abnormal rising) for older cows, perhaps due to the animals being heavier and (or) their legs being in worse condition (e.g., swelling, stiffness of articulations) due to aging . If the effect of parity on rising time was expected to partially explain the effect of outdoor access on rising time, the expected outcome would have been that cows with outdoor access should have longer rising times as the Outdoor Access treatment had older cows; we found the opposite. It is possible that as cows age (i.e., increase in parity) they become less physically fit, and the outdoor access allowed them to maintain and improve their physical fitness, something that has been reported by others (Davidson and Beede 2003, 2009).

Additionally, short-term effects of stall modifications were also observed, where cows kept in modified stalls had a lower prevalence of neck injuries compared to cows kept in unmodified stalls. As most of the stall modifications focused around adjusting the front of the stall, either adjusting the tie-rail position or chain length (Table 1), it was expected that improvement of neck condition would occur. Moving the tie-rail forward to meet recommendations is likely to result in a decrease in neck injuries as the cow will not have to come into contact with the tie-rail when rising or have to press against it when eating (Bouffard et al. 2017). In fact, our rising behaviour analyses shows that cows kept in modified stalls had a lower prevalence of head or neck contact with the stall when rising and a lower prevalence of restricted rising. This indicates that modifications to the tie-rail placement (both height and forward positions) and chain length may allow the cows more freedom of movement in their tie-stalls and decrease neck injuries. However, Bouffard et al. (2017) found that increasing the height of the tie-rail increased the risk of neck injuries, while Zurbrigg et al. (2005*b*) found that neck injuries were lowest when the height of the tie-rail was at the extremes (i.e., either very low or high). Moreover, in a study where different combinations of tie-rail height and forward position were investigated, it was observed that the position of neck injuries shifted based on the tie-rail positioning, showing that cows are still limited in their ability to move without coming into contact with the confines of

Table 7. Least square means (LSM) ± standard error mean (SEM) of all possible outcome measures affected by the experimental treatments (i.e., outdoor access vs. winter no outdoor access and modified vs. unmodified stalls) and their interactions during visit 3.

		LSM (SEM)‡				*P* value¶		
Outcome measures*	N	No outdoor	Outdoor	No modification	Modification	Outdoor	Mods‖	Outdoor × Mods
Injured hock (%)	183	68.8 (6.25)^{b}	50.3 (5.33)^{a}	62.7 (5.63)	57.1 (6.45)	**0.030**	0.502	0.237
Injured knee (%)	184	37.5 (6.79)^{b}	19.6 (4.21)^{a}	25.0 (4.90)	30.4 (6.11)	**0.023**	0.477	0.066
Injured neck (%)	186	24.8 (6.33)	4.9 (2.57)	23.2 (4.94)	5.4 (2.94)	0.210	0.228	0.989
Low BCS (≤2.0)† (%)	187	4.7 (3.64)	4.2 (2.62)	4.1 (2.44)	4.8 (3.45)	0.810	0.845	0.059
Lame (%)	186	42.1 (9.41)^{b}	16.7 (4.85)^{a}	28.7 (6.13)	26.6 (6.67)	**0.040**	0.780	0.175
Dirty leg (%)	187	–	–	–	–	–§	–	–
Dirty flank (%)	187	10.7 (9.02)	12.0 (7.77)	10.5 (5.92)	12.2 (7.01)	0.915	0.712	0.090
Dirty udder (%)	187	4.2 (4.37)	5.4 (4.10)	4.2 (2.95)	5.4 (3.85)	0.852	0.683	0.112
Head/neck contact† (%)	116	9.8 (11.88)	29.5 (8.39)	24.8 (7.87)	14.5 (8.85)	0.201	0.205	0.918
Knee adjustment (%)	116	21.7 (7.94)	15.4 (4.63)	17.0 (5.41)	19.7 (7.05)	0.456	0.750	0.424
Delayed rising† (%)	116	5.7 (3.68)	2.3 (2.49)	4.7 (2.78)	3.3 (3.46)	0.437	0.744	0.192
Restricted rising (%)	116	34.0 (15.05)	43.0 (11.43)	41.0 (10.89)	35.8 (11.55)	0.650	0.648	0.351
Total rising time (s)	116	8.1 (1.08)^{b}	5.6 (1.05)^{a}	6.7 (1.06)	6.7 (1.07)	**<0.0001**	0.971	0.285
Average total lying time (min/day)	187	720.6 (20.96)	721.1 (16.27)	718.7 (16.45)	723.0 (17.59)	0.985	0.836	0.954
Average number of lying bout/day	187	10.9 (0.70)	10.7 (0.54)	10.9 (0.49)	10.8 (0.51)	0.900	0.832	0.908
Average lying bout duration (min)	187	73.0 (4.56)	73.2 (3.49)	74.0 (3.21)	72.2 (3.37)	0.960	0.567	0.504
24 h milk (kg)	360	32.2 (1.90)	28.9 (1.54)	30.4 (1.36)	30.6 (1.38)	0.231	0.812	0.252
24 h milk fat yield (kg/day)	353	1.3 (0.07)	1.2 (0.06)	1.2 (0.06)	1.3 (0.05)	0.165	0.857	0.096
24 h milk protein yield (kg/day)	353	1.0 (0.06)	0.9 (0.05)	1.0 (0.04)	1.0 (0.04)	0.183	0.689	0.122
Somatic cell count (100 000)	279	355.1 (99.57)	265.5 (110.93)	381.1 (98.20)	239.5 (102.69)	0.504	0.274	0.974

*Presented as prevalence of cows, unless specified otherwise.
†Mixed models results presented because the GLIMMIX model did not converge.
‡LSM (SEM) with different superscripts (a, b) differ ($P \leq 0.05$).
¶*P*-values denoting statistically significant differences ($P \leq 0.05$) are bolded. §Data not available because the model did not converge.
‖Mods represents Modification.

their stalls (St John et al. 2021). This suggests that current recommendations regarding tie-rail height may need to be re-visited. Further research is needed to determine the best tie-rail position or alternative (i.e., chain, no tie-rail) to favour freedom of movement and improve welfare outcomes.

Cows with outdoor access and kept in modified stalls had a higher prevalence of dirty udders compared to cows with outdoor access and kept in unmodified stalls. This is in agreement with Bouffard et al. (2017) who reported that moving the tie-rail forward increased the risk of dirty udders. A combination of management practices of producers who provide outdoor access and the increased risk of dirty udders for cows with a modified tie-rail position may explain our results. Since for a large portion of the year, cows provided with outdoor access were housed outdoors, producers as part of their routine may infrequently visit their barn resulting in a possible lower frequency of stall scraping. Combined with the increased possibility of the cow defecating within the stall in modified stalls (Bouffard et al. 2017), the odds of dirty udders would likely be higher for cows kept in modified stalls on farms that provide outdoor access compared to farms that do not provide outdoor access. Additionally, producers providing outdoor access may have different priorities and management strategies and may be more willing to compromise some cow cleanliness to mitigate other potential welfare issues (e.g., body injuries or lameness) as outdoor access was shown to help decrease the prevalence of neck injuries by 2.5 times and rising times of the cows by 1.5 s.

Milk fat yield was 0.3 ± 0.1 kg higher for cows without outdoor access compared to cows with outdoor access. On visit 2, cows with outdoor access were receiving an average of 8 h/day of daily outdoor access. During this time, they were not receiving, nor did they have access to their feed and some may have been foraging on the low-quality pasture left over at the end of the season. Conversely, cows without outdoor access were receiving and had access to their formulated feed for longer periods of time and more frequently than cows with outdoor access. Woolpert et al. (2017) found that when farms delivered feed twice a day, there was a higher de novo fatty acid concentrations in bulk tank milk compared to farms that only delivered feed once a day. Additionally lower levels of feed sorting, which decreases when more frequent meals are provided (DeVries et al. 2005), leads to higher milk fat as more fiber is consumed, thus increasing the rumen pH and making rumen conditions optimal for milk fat synthesis (DeVries et al. 2008).

Visit 3: Effects of winter confinement with and without outdoor access

On visit 3, cows with access to outdoors had fewer hock and knee injuries compared to cows in complete confinement.

Table 8. Least square means (LSM) ± standard error mean (SEM) of all possible outcome measures affected by the experimental treatments (i.e., outdoor access vs. no outdoor access and modified vs. unmodified stalls) and their interactions during visit 4.

		LSM (SEM)‡				P value‖		
Outcome measure*	N	No outdoor	Outdoor	No modification	Modification	Outdoor	Mods§	Outdoor × Mods
Injured hock (%)	160	77.2 (8.88)[b]	36.4 (8.85)[a]	61.0 (8.98)	55.39 (9.46)	**0.019**	0.578	0.7883
Injured knee (%)	162	22.5 (11.15)	14.5 (6.69)	19.8 (7.47)	16.6 (6.96)	0.539	0.656	0.544
Injured neck (%)	162	24.4 (8.47)	10.5 (4.23)	20.4 (5.97)	12.9 (5.07)	0.141	0.263	0.709
Low BCS (≤2.0) (%)	163	6.5 (3.36)	9.0 (3.33)	7.5 (3.25)	7.8 (3.47)	0.593	0.945	0.699
Lame (%)	162	39.1 (7.52)	24.0 (4.99)	30.5 (5.81)	31.6 (6.57)	0.119	0.891	0.556
Dirty leg† (%)	163	1.6 (3.45)	7.8 (2.78)	6.2 (2.97)	3.1 (3.24)	0.154	0.471	0.125
Dirty flank (%)	163	13.0 (11.44)	13.1 (8.95)	10.6 (6.62)	15.9 (9.18)	0.996	0.355	0.732
Dirty udder (%)	163	5.4 (4.86)	8.8 (5.27)	3.6 (2.68)	12.7 (6.65)	0.660	0.061	0.915
Head/neck contact (%)	106	7.2 (6.15)	20.1 (10.40)	11.1 (6.73)	13.4 (7.31)	0.312	0.729	0.360
Knee adjustment (%)	106	26.4 (11.87)	21.9 (8.61)	19.9 (7.58)	28.8 (9.75)	0.769	0.357	0.122
Delayed rising† (%)	106	6.9 (3.95)	6.1 (3.21)	6.1 (3.41)	6.9 (3.71)	0.862	0.873	0.213
Restricted rising (%)	106	32.5 (13.10)	50.7 (11.58)	38.9 (10.29)	43.8 (11.04)	0.349	0.659	0.242
Total rising time (s)	106	8.4 (1.08)[b]	6.7 (1.06)[a]	7.5 (1.07)	7.5 (1.07)	**0.023**	0.951	0.131
Average total lying time (min/day)	160	742.8 (36.43)	662.1 (28.03)	693.9 (25.15)	711.0 (25.85)	0.112	0.432	0.320
Average number of lying bout/day	160	10.0 (0.60)	9.8 (0.47)	9.5 (0.44)	10.2 (0.46)	0.814	0.143	0.119
Average lying bout duration (min)	160	82.4 (5.74)	73.9 (4.43)	79.7 (4.22)	76.6 (4.36)	0.263	0.493	0.137
24 h milk (kg)	250	30.1 (3.24)	28.6 (2.66)	28.1 (2.23)	30.6 (2.33)	0.709	0.063	0.760
24 h milk fat yield (kg/day)	247	1.3 (0.09)	1.1 (0.08)	1.2 (0.07)	1.2 (0.08)	0.115	0.983	0.912
24 h milk protein yield (kg/day)	247	1.0 (0.09)	0.9 (0.08)	0.9 (0.06)	1.0 (0.07)	0.494	0.155	0.736
Somatic cell count (100 000)	169	183.4 (69.65)	105.6 (105.99)	190.1 (74.38)	98.8 (101.08)	0.450	0.360	0.493

*Presented as prevalence of cows, unless specified otherwise.
†Mixed models results presented when the GLIMMIX model did not converge.
‡LSM (SEM) with different superscripts (a, b) differ ($P \leq 0.05$). ‖P-values denoting statistically significant differences ($P \leq 0.05$) are bolded.
§Mods represents Modification.

Even when winter confinement only allowed cows access to the outdoors for several hours a week, this may have allowed change in resting positions relieving some pressure from the areas with injuries, allowing them to heal. These results agree with those found by Popescu et al. (2013) where cows housed in tie-stalls and given outdoor access during Romanian winters had lower levels of hock lesions and hairless patches at their hocks and neck. Keil et al. (2006) also found that, on Swiss dairy farms, access to outdoor exercise year-round for cows housed in tie-stalls also reduced the prevalence of hock injuries (scabs and wounds).

Lameness, which is regarded as one of the most important issues of dairy cow welfare (Whay et al. 2003; von Keyserlingk et al. 2009), was lower on visit 3 for cows provided with outdoor access, than for the cows without outdoor access. These results are in agreement with past research where cows in different housing systems showed lower levels of lameness when provided outdoor access (Regula et al. 2004; Bielfeldt et al. 2005; Popescu et al. 2013). Providing cows with pasture is believed to give the cows a more comfortable lying surface (Hernandez-Mendo et al. 2007), which may give them the opportunity to lie for longer and spend less time on their feet. Despite the harsh Canadian winters, when given the opportunities to access outdoors, cows have been observed to lie down outside (Shepley et al. 2016*a*). Outdoor access also gives the cows the opportunity to walk, which increases blood flow to the claw and may help improve the horn producing area of the claw, thus creating healthier feet (Bielfeldt et al. 2005).

Similarly, to the fall season (visit 2), rising time was also shorter for cows with outdoor access compared to cows without outdoor access at the end of winter and was also affected by the parity of the cows, with older cows taking longer to rise. This may indicate that continued outdoor access during the winter season may allow the cows to maintain a higher physical dexterity than that of cows without outdoor access. This agrees with findings in a study by Shepley and Vasseur (2021) comparing differences in gait attributes before and after cows spent their 8 weeks long dry period either in a loose pen or in a tie-stall, wherein joint flexion improved over time for cows in the loose pen and worsen over time for cows in the tie-stall. Further research would be necessary to investigate this topic.

Visit 4: Year follow through

On visit 4, hock injuries were lower for cows with outdoor access, a difference maintained from visit 3. Total rising time was also lower for cows with outdoor access compared to cows without outdoor access, a difference maintained through visit 2 and 3. This indicates that providing the cows with outdoor access during the pasture season may be an alternative to modifying the cows housing to improve outcome measures of welfare and help maintain the physical fitness of the cows throughout the year.

Challenges and opportunities

The methodology used in the design of the study was meant to minimize biases; however, there were limitations that should be taken into consideration. One relates to the nature of the study itself, being a living lab study in which constraints were important. For instance, the study involved the producers directly and made them responsible for modifications, giving us no control over treatment application. This yielded a variety of different modifications applied at the farm level, which complicates the statistical analysis and interpretation of results. Also, neither the conditions cows were subjected to during winter outdoor access, nor the type of grazing system were under our control, and these were not documented in the current study, limiting the scope of the interpretation of results. Moreover, the study was dependent upon the level of the information provided by the producers on their practices after 1 year of study; this implies a potential variability in the detail and reliability of the information collected and may have led to overstating or understating of results. The study required a large involvement on the producers' behalf, however only one producer left the study before its end, which, despite the initial sample size being relatively small, is positive. Nonetheless, despite the challenges a living lab study such as this one involves, this design also provides many opportunities such as the follow-up of the evolution of a treatment's implementation in real-life conditions; this is an opportunity to ease the transfer of knowledge to other producers, something not as easily done when in a controlled research environment. The work done with the participating producers to establish modifications and to take part in the decision-making processes on which ones to apply or not resemble the work of professional advisors, again helping with the development of knowledge transfer strategies aimed towards commercial farms.

Conclusions

Our results show there are housing and management options available to address some of the key animal welfare concerns in tie-stalls, especially since a majority of the stalls in many tie-stall farms were not built to accommodate the larger modern dairy cow. Modifying stalls to more closely resemble recommended stall configurations found in the Canadian Dairy Code of Practice (DFC-NFACC 2009) can help reduce body injuries and allow the cows more room to freely perform behaviours such as rising without various parts of the stall obstructing their movements. However, there is only so much that can be done to improve the housing with minimal time and money investments or due to physical constraints in existing barns. One alternative is to provide tie-stall dairy cows with some time out of the stall, which is most easily provided through outdoor access. Such access should be granted not only during the grazing season, but also extended to a winter outdoor access which can help to improve some welfare outcomes (e.g., rising and lying behaviours, injuries, and lameness). We found that providing outdoor/pasture access to tie-stall dairy cows helps to improve their condition, an effect maintained by continuous access. Hence, tie-stall dairy cows in Canada would also benefit from outdoor access or time out of the stalls year round, similarly to practices adopted in other countries.

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Competing interests

The authors have no competing interests to declare.

Supplementary material

Supplementary data are available with the article at https://doi.org/10.1139/CJAS-2022-0038.

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