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Feedlot pens with greenhouse roofs improve beef cattle performance in temperate weather

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ABSTRACT

Muddy pens can negatively affect welfare and performance of feedlot beef cattle. In some regions with temperate weather, plastic greenhouse covers, above the entire pens are used to fatten cattle in a clean and dry environment. The objective of this research was to investigate effects of greenhouse roofed pens on beef cattle feedlot performance in temperate weather. Data were collected from a feedlot located in Central Mexico between 2016 and 2019. The study included 1,062 closeouts of pens with 68,305 crossbred bulls fed in pens with or without a greenhouse roof. Feeding ranged from 82 to 210 d, depending on the initial weight of cattle, which ranged from 255 to 511 kg. For each pen, average daily dry matter intake (DMI; kg of DMI·animal^{-1}·d^{-1}), average daily gain (ADG, kg·animal^{-1}·d^{-1}), and feed efficiency (G:F, ADG/DMI) were measured. Factorial analyses were performed to test the interaction and main effects of initial weight grouping (light, medium, and heavy), roof, and season as fixed effects, and year as a random effect. None of the three-way interactions were significant ($P > 0.51$). There was no initial weight grouping × roof interactions for DMI and ADG ($P > 0.31$). There was ($P = 0.03$) an initial weight grouping × roof interaction for G:F, as pens of all initial weight groups had greater ($P < 0.01$) G:F in pens with greenhouse roof than its counterpart in pens without greenhouse roof, but the advantage was greater for pens with light cattle (0.178 vs. 0.166; $P < 0.01$). There was no initial weight grouping × season interactions for all variables ($P > 0.39$). There was no roof × season interaction for DMI ($P = 0.47$), but there were interactions for ADG and G:F ($P < 0.01$). The ADG was not different ($P > 0.13$) during summer and autumn based on the roofing system, but pens with greenhouse roofs had greater ADG during spring (1.70 vs. 1.61) and winter (1.68 vs. 1.64; $P \leq 0.01$). The G:F was greater ($P < 0.01$) in all seasons for pens with a greenhouse roof, with the most prominent advantage during spring (0.173 vs. 0.160). There were main effects for cattle initial weight grouping and roof for all variables ($P < 0.01$). Season affected DMI and G:F ($P < 0.01$). Pens with greenhouse roofs had decreased DMI (9.70 vs. 9.86), greater ADG (1.67 vs. 1.63), and increased G:F (0.173 vs. 0.166) compared to pens without greenhouse roofs ($P < 0.01$). Pens with greenhouse roofs in feedlots located in temperate regions positively affect beef cattle performance.

Key words: beef cattle, greenhouse roof, muddy pens, performance

INTRODUCTION

Environmental conditions (e.g., temperature, rain, wind speed and humidity, snow, and solar radiation) substantially impact livestock health status, growth, and reproductive performance. Use of open outdoor feedlots for housing cattle is increasing around the globe (Grandin, 2016). These facilities face performance challenges, including muddy conditions, keeping cattle clean, and avoiding extreme weather conditions. These threats are crucial for productivity and animal welfare; therefore, it is vital to identify strategies to address them (Mader, 2014). Heat stress affects cattle in production systems located in hot weather regions, for example, arid, tropical, and subtropical areas with temperatures above 25 °C. In contrast, cold stress has a more significant impact on cattle situated in cold regions with temperatures below 0 °C (Graunke et al., 2011). In heat or cold stress cattle increase their energy needs, which also leads to decreased body weight gain and feed efficiency (Fox et al., 1988)

Rain, which can also exacerbate cold stress (Van Laer et al., 2014), represents a considerable limitation of outdoor feedlots because it creates a muddy environment with negative consequences for cattle (Grandin, 2016; Valadez-Noriega et al., 2019). Rain and muddy conditions increase the maintenance energy requirements of beef cattle for regulating its core temperature because when an animals' hair coat gets wet, its insulation value decreases, increasing evaporation heat losses (Van Laer et al., 2014). External insulation is determined by the combined effect of the hair coat and the layer of air surrounding the animal's body. The effectiveness of a hair coat depends on hair depth and is also affected by wind, rain, mud, and hide thickness. External insulation decreases by 20% with some mud on the lower body, 50% with mud on the lower body and sides, and 80% when the animal is severely covered with mud (NASEM, 2016). Therefore, under cold weather conditions, maintenance energy requirements can double for animals with wet and muddy hair coats, especially in windy areas (Mader, 2014).

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Mud in pens harms dry matter intake (DMI) of beef cattle, Fox and Tylutki (1998) estimated a DMI reduction of 1% for every centimeter of mud depth in the pen. Thus, muddy conditions negatively impact average daily gain (ADG) and feed efficiency (G:F; Tedeschi and Fox, 2018). Additionally, navigating a muddy environment constitutes additional energy required for the animal when it moves through the mud. Smith (1971) reported cattle in open feedlots with deep mud increased energy expenditure by 30%. Valadez-Noriega et al. (2019) found cattle immersed in mud have increased morbidity for bovine respiratory disease as another negative consequence of muddy pens. Rain and mud can also cause variation in feed consumption, which increases bunk management time and the risk of metabolic problems (NRC, 1981). Finally, another primary welfare concern associated with open outdoor feedlots and muddy conditions is keeping cattle clean (Grandin, 2016).

If the annual rainfall exceeds 51 cm, it becomes increasingly difficult to keep the pen surface dry (Grandin, 2016); therefore, maintaining clean and dry pens to provide cattle optimal environment is time-consuming and increases labor costs. Central Mexico has primarily temperate weather. Therefore, heat or cold stress are not significant problems in this region; however, rain can create muddy pens in feedlots due to annual rainfall exceeding 51 cm. Data used in this research study were collected at a feedlot located at Belem, Estado de Mexico, in central Mexico. The altitude is 2,491 m, the weather is classified as temperate (Cwb), and temperatures range from 5 to 25 °C. Temperatures under or above this range are uncommon, and annual average temperature is 13 °C. The rainy season extends from May to October, with a yearly rainfall of 64 cm (SMN, 2020). In this region, 75% of annual rainfall concentrates in 4 months (June to September), hindering pen cleaning and creating muddy pens if no strategies to mitigate this issue are undertaken by the producers.

To provide comfortable conditions for feedlot cattle, producers employ intensive protocols for cleaning pens, especially from June to September when rainfall is increased; however, as mentioned above, this activity is labor and time-consuming. Furthermore, cleaning pens requires moving cattle to another pen, and this movement harms DMI, ADG, and G:F stability. Thus, beef cattle producers in central Mexico have adopted greenhouse roofs that provide shade (avoiding direct solar radiation) and rain protection for the whole pen to avoid muddy pens and provide more comfortable conditions for cattle over the feeding period. Furthermore, pens are only cleaned with this infrastructure once the feeding period is over, saving labor and upkeep costs.

Figure 1a shows a general view of the design of the pens without (left) and with (right) the greenhouse roof. Figure 1b shows a general view of the conditions of the pens during the rainy season (June to September). General specifications of the design were outlined by Valadez-Noriega et al. (2019); however, the design can have minor changes from one feedlot to another. We hypothesized pens constructed with a greenhouse roof will improve feedlot cattle performance when feedlots are located in regions with temperate weather providing a more comfortable environment and maintaining cattle clean and dry. Therefore, the objective of this research study was to investigate effects of pens with greenhouse roofs in a feedlot located in a region with temperate weather on finished beef cattle performance.

MATERIALS AND METHODS

Since data were obtained from preexisting databases, approval of the Animal Care and Use Committee was not needed.

Data

A total of 1,062 pen closeouts, consisting of 68,305 crossbred bulls (25% *Bos taurus* – 75% *Bos indicus*) penned by initial weight grouping (light, <300 kg; medium, ≥300 kg; and <360 kg; heavy, ≥360 kg), collected over four years (2016 to 2019) from a feedlot located in Central Mexico (Belem, Estado de Mexico, Mexico) were analyzed. Performance measurements: DMI (kg of DMI·animal^{-1}·d^{-1}), ADG (kg/d; calculated based on full initial and final weights), and G:F (ADG/DMI) were recorded per pen. There was an average number of 64.3 ± 7.3 bulls per pen with average starting and finishing weights of 278 ± 7 and 570 ± 22 (light cattle), 339 ± 6 and 580 ± 20 (medium cattle), and 414 ± 16 and 621 ± 23 (heavy cattle) kg per animal. Fattening cycles commenced all year round and ranged from 82 to 210 d, depending on the initial weight grouping of the cattle; the average days on feed were 184 ± 9, 143 ± 9, and 125 ± 11 d for light, medium, and heavy cattle, respectively.

Closeouts of pens were classified according to the year's season in which the fattening cycle started. As an illustration, consider the case of medium cattle with an average fattening cycle of 143 d; if the fattening cycle began in April, the closeout pertained to spring, meaning that cattle were fed from April to August (the months with the highest rainfall). Therefore, this group of cattle ended the feeding phase in summer. This classification is essential for adequate interpretation of results, and it is emphasized in the Discussion section.

The feedlot had 151 pens in the same location, grouped according to the roof cover (with [90] or without a greenhouse roof [61]). The height of the greenhouse roof was 7 m in the bunk side, and it was 5 m in the opposite extreme to facilitate air movement. For a complete description of the design of pens with greenhouse roof see Valadez-Noriega et al. (2019). Bunks were covered in all pens; in pens with the greenhouse roof, it also covered the bunk (Figure 1). In pens without the greenhouse roof, the bunk was covered by galvanized metal sheets providing 10 m of shade with approximately 5 m of height (Figure 1). Flooring was solid in all the pens without greenhouse roof, whereas pens with greenhouse roof had dirt flooring (Figure 1) with 2 m of concrete floor around the waterers and feed bunks. In all pens, the stocking density was 10 m^2·bull^{-1}, the feed bunk space was 40 cm·bull^{-1}, and automatic waterers (two per pen) had potable and freshwater. It is important to highlight that the pens differed mainly on the availability of the greenhouse roof and the flooring system. The greenhouse roof provides shade and protection from rain and direct sun over the whole pen; however, it is different from an enclosure.

Upon arrival at the feedlot, bulls were weighed (to estimate the reduction of weight due to the trip), blocked by initial weight (based on weight in origin, i.e., the full initial weight; bulls were also weighed at origin), and randomly allocated to different pens (either with or without a greenhouse roof). The cattle were initiated on the feeding program on the same day of arrival. Bulls were fed with alfalfa hay for the first three days in feed. After that, bulls were gradually adapted over a 4-wk period to a high-energy diet based on steam-flaked corn.

Figure 1. (a) General view of the design of pens without and with the greenhouse roof. (b) General view of the conditions of the pens without and with the greenhouse roof during the rainy season (June to September). Pens with greenhouse roofs are covered, and they stay dry even in the rainy season. Pens without the greenhouse roof only have covered the bunk area and are muddy during the rainy season, demanding frequent cleaning.

Three diets were used during the adaptation period, and each was provided to the bulls by approximately 10 d. All diets were formulated to fulfill or exceed NRC (2000) energy, protein, minerals, and vitamins guidelines. The $NE_m(NE_g)$ of the finishing diet was 1.98(1.30) Mcal·kg^{-1}, it contained 35 ppm of monensin (Rumensin, Elanco Animal Health, Inc., Greenfield, IN, USA), 500 ppb of chromium propionate (Phi-Chrome 10x, Phibro Animal Health Corporation, Guadalajara, JA 44130, Mexico), and 500 ppm of virginiamycin (Stafac 500, Phibro Animal Health Corporation, Guadalajara, JA 44130, Mexico). The complete mixed diets were delivered two times per day. The first feed service provided 30% of the daily allotment, from 07:00 to 09:00 h. The second feed service provided 70% of the daily allotment, from 16:00 to 18:00 h. Slick feed bunk feeding strategy used was and feed bunk scores were evaluated visually and recorded every day from 06:00 to 07:00 h.

After 24 h of arrival at the feedlot, bulls received a vaccine for IBR, BVD Types 1 and 2, BRSV, PI^3, and *Mannheimia haemolytica* (Bovi-Shield Gold One Shot, Zoetis, Florham Park, NJ, USA); an intranasal vaccine for IBR and PI^3 (TSV-2, Zoetis, Florham Park, NJ, USA), and a vaccine for *Clostridium chauvoei*, *septicum*, *novyi*, *sordellii*, *perfringens* Types C & D plus *Haemophilus somnus* (Ultrabac 7/Somubac, Zoetis, Florham Park, NJ, USA). Cattle were also treated for internal and external parasites (Baymec prolong, Elanco Animal Health, Inc., Greenfield, IN, USA), injected with A, D, and E vitamins (Vigantol ADE, Elanco Animal Health, Inc., Greenfield, IN, USA) and implanted (Synovex, Zoetis, Florham Park, NJ, USA). Cattle were reimplanted at d 60 on feed (light, medium, and heavy cattle), and at d 120 on feed (only light cattle; Revalor, Merck & Co., Inc., Kenilworth, NJ, USA), that is, medium, and heavy cattle received two implants, and light cattle received three implants during the whole fattening cycle. Descriptive statistics of analyzed variables are reported in Table 1.

To investigate and describe the climatic variables and their potential effect on cattle performance, climate data with measurements collected every 10 min from January of 2016 to December of 2019 were obtained from a meteorological station (Davis Vantage Pro2 Wireless) at the International Maize and Wheat Improvement Center (El Batan, Texcoco, Mexico). This meteorological station is located 19.5 km from the feedlot and shares the same environmental conditions. Therefore, the temperature humidity index (THI) was calculated based on the formula proposed by Mader et al. (2006) as follows:

Table 1. Descriptive statistics of closeouts data included in the analysis

Variable	Minimum	Maximum	Mean	SD	CV
Length of the feeding cycle, d	82.0	210.0	135.7	22.0	16.2
Dry matter intake, kg/animal/d	7.9	13.0	10.0	0.7	7.1
Daily gain, kg/animal/d	1.1	2.1	1.7	0.1	6.6
Feed efficiency	0.10	0.22	0.17	0.01	7.2
Initial weight, kg/animal	255.0	511.0	372.3	49.1	13.2
Final weight, kg/animal	524.0	707.0	601.0	31.3	5.2
Pen size, animals/pen	41.0	84.0	64.3	7.3	11.3

SD, standard deviation; CV, coefficient of variation (%).

$$\mathrm{THI} = 0.8 * \mathrm{Tdb} + \left[\frac{\mathrm{RH}}{100} * (\mathrm{Tdb} - 14.4)\right] + 46.4$$

where, Tdb is the dry bulb temperature (°C), and RH is relative humidity (%).

The categories for THI were defined as: THI < 75 = normal; 75 ≥ THI ≤ 78 = alert; 78 > THI ≤ 83 = danger, and THI > 83 = emergency.

The THI is a single value that represents the combined effects of air temperature and relative humidity. Limitations to this index are that there is no reference to air movement or solar radiation; also, it does not consider management and animal factors. Heat load index (HLI) was developed by Gaughan et al. (2008), and considered the factors mentioned above. This index was calculated as follows:

The HLI calculation requires the black globe temperature (BGT) in °C, inferred from temperature and solar radiation measurements:

$$\mathrm{BGT} = 1.33 * \mathrm{Tdb} - 2.65 * \sqrt{\mathrm{Tdb}} + 3.21 * \log(\mathrm{SR} + 1)\, 3.5$$

where, Tdb is defined as above, log is the logarithm function (base 10), and SR is solar radiation in Wm^{-2}. Then, if:

$$\mathrm{BGT} = \begin{cases} < 25, & \mathrm{HLI}_{\mathrm{low}} = 1.3 * \mathrm{BGT} + 0.28 * \mathrm{RH} - \mathrm{WS} + 10.66 \\ \geq 25, & \mathrm{HLI}_{\mathrm{high}} = 1.55 * \mathrm{BGT} + 0.38 * \mathrm{RH} - 0.5 * \mathrm{WS} \\ & + \exp(2.4 - \mathrm{WS}) + 8.62 \end{cases}$$

where, RH is defined as above, and WS is the wind speed in ms^{-1}. A blending function S(BGT) is needed to compute the final HLI:

$$\mathrm{S(BGT)} = \frac{1}{1 + \exp\left(-\frac{\mathrm{BGT} - 25}{2.25}\right)}$$

$$\mathrm{HLI} = \mathrm{S}(\mathrm{BGT}) * \mathrm{HLI}_{\mathrm{high}} + (1 - \mathrm{S}(\mathrm{BGT})) * \mathrm{HLI}_{\mathrm{low}}$$

Finally, HLI values smaller than 50 were set to 50. Whether cattle recover or become stressed depends on the value of certain thresholds. The first threshold occurs at an HLI value of 77. For HLI values below 77, the cattle cool down and recover. The second or upper threshold depends on the type and condition of the cattle and their pen environment; its value ranges from about 80 for unacclimatized (and possibly compromised) black Angus cattle to about 95 for acclimatized Brahman cattle. The range of HLI values between 77 and the upper threshold is called the thermoneutral zone. For this zone, cattle neither recover nor become stressed. In the current research study, an upper threshold of 86 (for unshaded black *B. taurus*) as the basis was established based on Gaughan et al. (2008) and adjusted +4 for genotype (25% *B. taurus* – 75% *Bos indicus*); thus, the upper threshold was set at 90. Based on that: HLI < 77 = cooling; 77 ≥ HLI ≤ 90 = thermoneutral; and HLI > 90 = danger.

Statistical Analysis

Data were analyzed as a randomized incomplete block design with a 3 × 2 × 4 factorial arrangement utilizing pen as the experimental unit and year as the block. Data were analyzed with the MIXED procedure of SAS(SAS Institute Inc. 2020), with cattle initial weight grouping, greenhouse roof use, season as fixed effects, and year as a random effect. Pairwise comparisons between the least square means were computed using the pairwise differences (PDIFF) option of the least squares means (LSMEANS) statement. Differences were considered statistically significant at $P < 0.05$. The following statistical model was fitted to the three response variables analyzed:

$$y_{ijklm} = \mu + W_i + R_j + S_k + Y_l + (WR)_{ij} + (WS)_{ik} + (RS)_{jk} + (WRS)_{ijk} + e_{ijklm}$$

where:

y_{ijklm}: each of the response variables analyzed (DMI, ADG, and G:F);

μ: Overall mean;

W_i: Fixed effect of the *ith* initial weight grouping (i = light, medium, heavy);

R_j: Fixed effect of the *jth* roof condition category on the feedlot (j = with, without greenhouse roof);

S_k: Fixed effect of the *kth* season of the year at the start of the fattening cycle (k = spring, summer, fall, winter);

Y_l: Random effect of the *lth* year at the start of the fattening cycle (l = 2016, 2017, 2018, 2019) ~normally, identically and independently distributed data (NIID) $(0, \sigma_Y^2)$;

$(WR)_{ij}$: Interaction of the *ith* initial weight grouping with the *jth* roof condition

$(WS)_{ik}$: Interaction of the *ith* initial weight grouping with the *kth* season of the year

$(RS)_{jk}$: Interaction of the *jth* roof condition with the *kth* season of the year

$(WRS)_{ijk}$: Interaction of the *ith* initial weight grouping with the *jth* roof condition, and with the k^{th} season of the year

e_{ijklm}: residual ~NIID $(0, \sigma_e^2)$

There were 24 treatment combinations (3 × 2 × 4) and 1,062 total observations (closeouts of pens). The number on observations per year of data collection was 283, 280, 250, and 249 for 2016, 2017, 2018, and 2019, respectively. On average, the number of replications per treatment combination was ~11; however, the number of replications was unequal with greater number of replications for medium and heavy cattle than for light cattle.

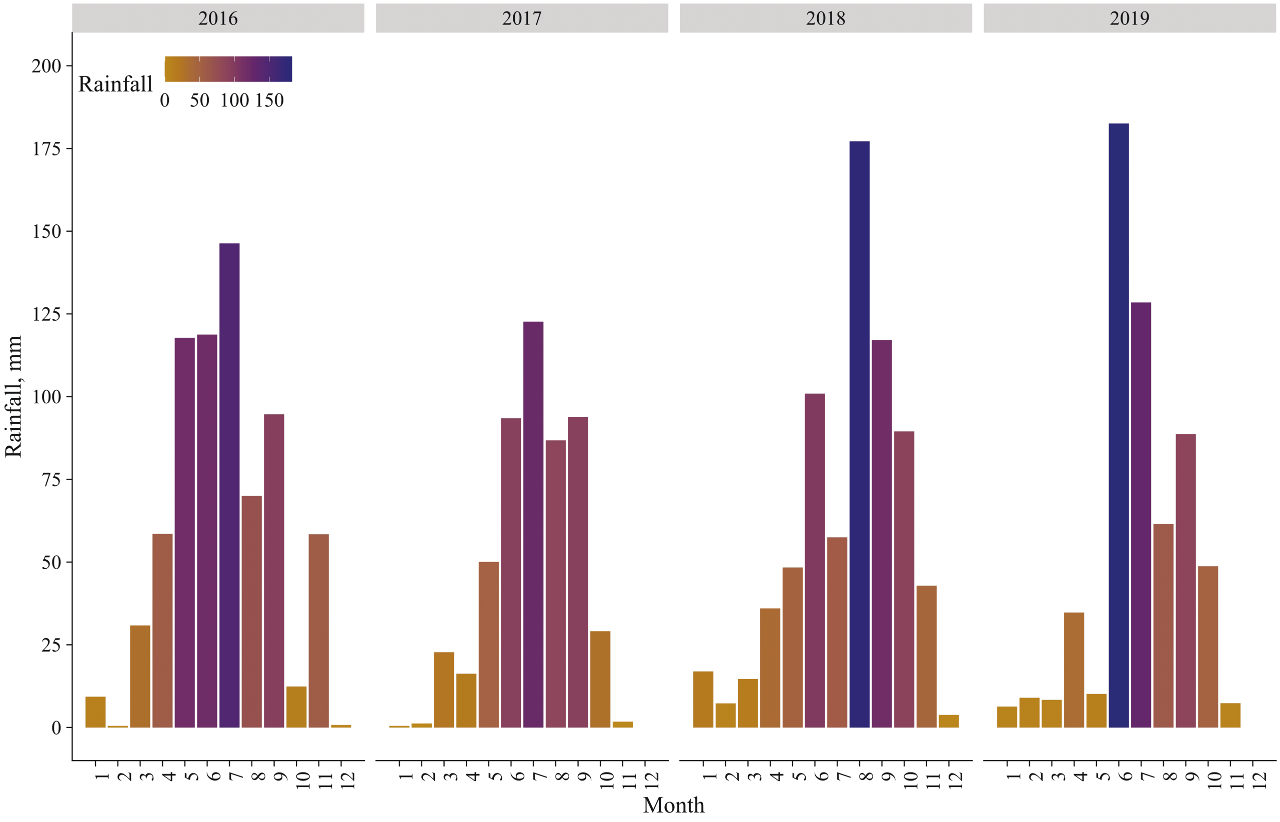

Figure 2. Distribution of rainfall from January of 2016 to December of 2019 in Belem, Estado de Mexico, Mexico. Rainfall concentrates from June to September. The annual rainfall ranged from 51.8 to 71.8 cm, with an average of 63.4 cm.

RESULTS

Figure 2 shows rainfall distribution from January 2016 to December 2019 in the region where the feedlot is located. In general, rain falls in this region from June to September. Across the years considered in the study, the annual rainfall ranged from 51.8 to 71.8 cm, with an average of 63.4 cm. Table 2 presents the yearly and monthly averages of temperature, relative humidity, solar radiation, wind speed, THI, and HLI. Average temperature by month ranged from 10.7 to 19.9 °C, with an average of 15.9 °C. Average relative humidity by month ranged from 45.2% to 80.2%, with an average of 64.1%. Average wind speed by month ranged from 0.6 to 6.9 m·s^{-1} with an average of 3.4 m·s^{-1}. Finally, average solar radiation by month ranged from 174.4 to 271.4 W·m^{-2} with an average of 224.9 W·m^{-2}.

Average THI by month ranged from 51.5 to 63.8, and the average across years considered in the study was 59.1, whereas average HLI by month ranged from 51.7 to 62.1 and the average across the years of the study was 56.7 (Table 2). Figure 3 shows estimates of THI (Figure 3a) and HLI (Figure 3b) every 10 min from January 2016 to December 2019. Looking into detail at the measurements every 10 min of 207,444 estimates of THI and HLI, only 30 and 21 of the estimates were classified into the alert and danger categories for THI and HLI, respectively.

The significance of interactions and main effects on the analyzed variables are reported in Table 3, and the least square means are presented in Table 4. There were cattle initial weight grouping and roof main effects for all variables ($P < 0.01$). Differences in DMI and ADG across all cattle initial weight groups comparisons were statistically significant ($P \leq 0.01$); as expected, closeouts of heavy cattle had the greatest DMI (10.41 ± 0.06 kg·anima^{-1}·d^{-1}) and ADG (1.70 ± 0.01 kg·d^{-1}); closeouts of light cattle had the lowest DMI (9.21 ± 0.08 kg·animal^{-1}·d^{-1}) and ADG (1.58 ± 0.01 kg·d^{-1}); and the closeouts of medium cattle had an intermediate DMI (9.72 ± 0.06 kg·animal^{-1}•d^{-1}) and ADG (1.68 ± 0.01 kg·d^{-1}). The G:F did not differ ($P = 0.34$) for closeouts of light and medium cattle (0.172 ± 0.001 vs. 0.173 ± 0.001), which had greater ($P < 0.01$) G:F than closeouts of heavy cattle (0.164 ± 0.001).

Pens with greenhouse roofs had an important positive effect on the performance of beef cattle: closeouts of pens with greenhouse roof had decreased DMI (9.70 ± 0.06 vs. 9.86 ± 0.06 kg·animal^{-1}·d^{-1}), greater ADG (1.67 ± 0.01 vs. 1.63 ± 0.01 kg·d^{-1}), and increased G:F (0.173 ± 0.001 vs. 0.166 ± 0.001) compared to closeouts of pens without the greenhouse roof ($P < 0.01$). Season of the year had a significant effect on DMI and G:F ($P < 0.01$). The highest DMI (10.02 ± 0.07 kg·animal^{-1}·d^{-1}) was recorded for spring closeouts, and it was statistically different ($P < 0.01$) from closeouts of the remaining seasons of the year. DMI was not statistically different ($P = 0.22$) between autumn (9.60 ± 0.07 kg·animal^{-1}·d^{-1}) and summer (9.69 ± 0.08 kg·animal^{-1}·d^{-1}) closeouts, and those had the lowest values for DMI. Closeouts in winter had DMI (9.82 ± 0.06 kg·animal^{-1}·d^{-1}) not different from closeouts in summer ($P = 0.08$), but greater ($P < 0.01$) than closeouts in autumn, and lower ($P < 0.01$) than closeouts in spring. The G:F did not differ ($P \geq 0.09$) among summer, autumn, and winter closeouts (0.171 ± 0.001, 0.172 ± 0.001,

Table 2. Averages of meteorological variables from January of 2016 to December of 2019 in a feedlot located in Central Mexico (Belem, Estado de Mexico, Mexico)

Year/ Month	Temperature, °C	Relative humidity, %	Wind speed, ms^{-1}	Solar radiation, Wm^{-2}	THI	HLI
2016	15.73	65.23	2.20	218.45	58.94	57.43
1	12.21	55.16	1.49	175.28	53.92	52.64
2	13.46	48.33	1.36	219.44	55.34	54.12
3	15.69	53.09	2.22	229.84	58.42	55.17
4	18.20	47.45	6.36	247.34	61.43	55.47
5	18.89	61.81	1.37	266.24	63.20	60.90
6	17.06	75.55	0.93	233.89	61.52	61.23
7	16.77	76.61	0.91	237.80	61.04	61.20
8	17.04	77.09	0.65	231.73	61.44	62.01
9	16.54	77.46	0.61	203.77	60.62	60.77
10	15.45	70.77	2.98	209.65	58.58	56.71
11	13.50	74.52	3.01	174.42	55.63	54.60
12	13.89	64.29	4.49	191.58	55.96	54.05
2017	15.51	62.15	3.26	223.23	58.50	56.36
1	12.49	52.83	4.15	205.41	53.86	52.58
2	14.62	46.18	6.74	232.99	56.91	52.77
3	15.07	55.01	1.75	249.75	57.47	55.15
4	17.50	45.17	2.02	267.55	60.51	56.26
5	19.18	58.70	3.35	246.35	63.52	59.05
6	18.16	67.20	4.91	246.02	62.53	58.57
7	16.04	80.18	1.88	212.67	59.97	59.23
8	17.14	77.29	2.08	219.91	61.57	60.51
9	16.41	79.87	1.43	192.29	60.55	60.03
10	15.57	71.81	3.49	203.83	58.87	56.45
11	12.78	58.38	3.35	219.92	54.06	53.56
12	11.45	53.95	4.10	183.62	52.61	52.16
2018	15.81	66.24	4.33	225.86	59.04	56.18
1	10.66	59.30	4.70	188.27	51.49	51.70
2	14.88	59.26	4.78	220.55	57.45	54.11
3	16.92	49.27	6.07	261.44	59.90	54.77
4	17.58	54.09	5.87	256.32	61.14	55.62
5	18.29	54.63	5.98	271.38	61.97	56.45
6	17.69	70.09	5.36	236.88	62.18	57.78
7	16.83	70.10	3.80	245.46	60.73	57.72
8	16.13	79.82	2.58	218.68	60.17	58.75
9	16.58	79.99	1.95	217.42	60.86	59.87
10	16.11	77.48	3.61	196.88	59.99	57.48
11	13.88	72.84	3.52	190.69	56.05	54.75
12	12.73	69.03	3.31	188.35	54.28	53.68
2019	16.42	62.52	3.77	232.27	59.77	56.80
1	12.68	56.54	4.51	200.92	54.29	52.41
2	15.59	52.11	5.61	236.75	58.10	54.06
3	17.07	47.80	5.37	265.52	60.05	55.06
4	18.28	45.33	6.88	270.93	61.72	55.29
5	19.86	47.02	6.05	267.32	63.76	57.08
6	17.83	72.47	4.40	235.99	62.50	59.21
7	16.32	78.78	1.96	233.88	60.41	59.58
8	17.46	73.20	1.81	264.95	61.75	60.87
9	17.08	73.54	2.12	223.03	61.27	59.33
10	16.74	75.64	2.09	205.94	60.83	58.68
11	15.44	68.37	1.98	197.63	58.35	56.53
12	12.74	59.51	2.56	184.77	54.19	53.37
Total	15.87	64.02	3.38	224.93	59.06	56.70

THI, temperature and humidity index; HLI, heat load index.

and 0.170 ± 0.001), which had greater ($P < 0.01$) G:F than spring closeouts (0.166 ± 0.001).

The three-way interactions were not significant ($P > 0.51$; Table 3); however, some of the two-way interactions were significant. There was no cattle initial weight grouping × season interaction for all variables ($P > 0.39$). There was no cattle initial weight grouping × roof interaction for DMI and ADG ($P > 0.31$), but there was an interaction ($P = 0.03$) for G:F. Closeouts of light and medium cattle with greenhouse roofs did not differ in G:F (0.178 ± 0.001 vs. 0.176 ± 0.001; $P = 0.19$); however, they have greater ($P \leq 0.01$) G:F than all other combinations. Closeouts of heavy cattle with greenhouse roofs had greater ($P \leq 0.01$) G:F than closeouts of heavy cattle reared without roofs but did not differ ($P = 0.89$) from closeouts of light cattle raised without a greenhouse roof. Closeouts of the light, medium, and heavy cattle reared without roofs differed in G:F among them ($P \leq 0.03$), with medium cattle having the greatest, followed by light and then heavy cattle.

There was no roof × season interaction ($P = 0.47$) for DMI, but there were interactions for ADG and G:F ($P < 0.01$). Closeouts from cattle without greenhouse roofs did not differ in ADG ($P > 0.14$) across all seasons of the year among them. However, closeouts of spring with greenhouse roofs had greater ADG (1.70 ± 0.01 $kg\cdot d^{-1}$) than closeouts of all other seasons and roof combinations ($P < 0.03$). As an illustration, the closest value to the spring-greenhouse roof combination for ADG, yet statistically smaller, was for the combination winter-greenhouse roof (1.68 ± 0.01 $kg\cdot d^{-1}$), while the lowest value for ADG was for the combination spring-without greenhouse roof (1.61 ± 0.01 $kg\cdot d^{-1}$). Closeouts of summer and autumn, either with or without greenhouse roofs, had an intermediate performance and did not differ among them in ADG ($P > 0.09$). However, summer and autumn closeouts with greenhouse roofs presented greater ADG ($P < 0.02$) than spring closeouts without greenhouse roofs. Closeouts of winter with greenhouse roofs outperformed ($P < 0.02$) the ADG of most of the combinations but had lower ADG than spring closeouts with greenhouse roofs ($P < 0.03$) and did not differ in ADG compared to summer closeouts with greenhouse roofs ($P = 0.30$).

Closeouts of spring without greenhouse roofs had less G:F than closeouts of the other seasons without greenhouse roofs ($P < 0.01$), which did not differ among them ($P > 0.44$). Closeouts of cattle raised with greenhouse roofs on all the seasons of the year were more efficient than cattle without greenhouse roofs on all seasons of the year ($P < 0.04$), excepting the comparison of winter-greenhouse roof vs. summer-without greenhouse roof, which were not different ($P > 0.05$). Closeouts of spring and summer with greenhouse roofs did not differ ($P > 0.45$) in G:F from closeouts of winter with greenhouse roofs. Closeouts of cattle under greenhouse roofs in autumn had greater G:F

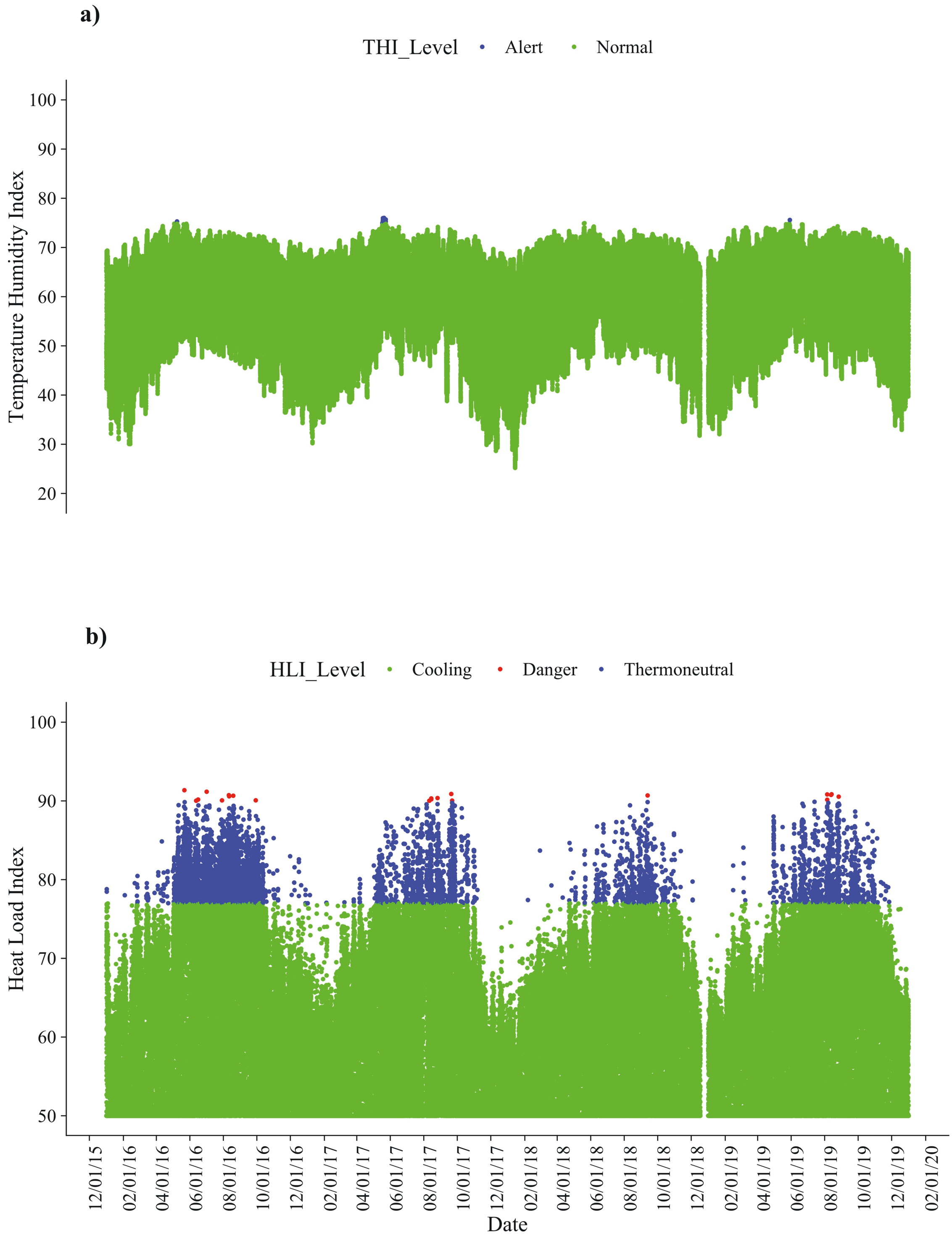

Figure 3. Distribution of (a) Temperature Humidity Index (THI), and (b) Heat Load Index (HLI) from January of 2016 to December of 2019 in the region of Belem, Estado de Mexico, Mexico. Most of the time, HLI and THI levels were below the alert and danger thresholds, respectively.

than closeouts of cattle from winter under greenhouse roofs ($P < 0.03$) but did not differ from spring and summer closeouts with greenhouse roofs ($P > 0.12$).

DISCUSSION

Based on the findings of THI and HLI in this research study, heat stress most likely is not a problem in the region where the feedlot subject of this research study is located. However, it is essential to highlight that the meteorological station was not located inside the feedlot, and because the feedlot can have a microclimate, this deserves future research. In contrast, it is imminent that the rainfall reached levels greater than 51 cm in that region and concentrated in only four months of the year, proving that muddy pens can be a problem if no actions are undertaken in this feedlot.

In regions with temperate weather, beef cattle in feedlots typically do not suffer heat or cold stress; however, rainy and windy conditions can create discomfort and reductions in performance. One of the main concerns of feedlots in central Mexico is the side effects of muddy pens, especially during the rainy season. Muddy pens can reduce productivity, increase morbidity and mortality, producing significant economic losses and animal welfare concerns. Using greenhouse roofs is a strategy to provide a more comfortable environment and avoid productivity losses. Beef cattle producers have adopted this innovation during the last decade in Central Mexico. Pens are constructed with greenhouse roofs covering the entire pen, protecting cattle from rain, wind, and direct solar radiation.

In addition to benefits mentioned above, a greenhouse roof has the following advantages: prefabricated light structures, easy transportation with a minimum time of installation, low cost of installation and maintenance, easy replacement of damaged parts, appropriate natural ventilation and lighting, safe, sanitary conditions, and easy cleaning (Nikita-Martzopoulou, 2007).

The flexibility of the greenhouse roofs has spread its use in feedlots even in hot environments where one can think its use can be counterproductive; however, in combination with technologies such as mechanical ventilation, they can benefit the performance of beef cattle. For example, Castro-Pérez et al. (2020) investigated effects of shade allocation and shade plus fan (mechanical ventilation) on growth performance, dietary energy utilization, and carcass characteristics. The latter study was done in a region with tropical weather and included limited shade, 1.2 or 2.4 $m^2 \cdot animal^{-1}$ provided with a galvanized metal sheet; and total shade, which was equivalent to 9 $m^2 \cdot animal^{-1}$ provided with greenhouse roofs (high-density polyethylene canvas) either with or without mechanical ventilation provided by fans (3 $fans \cdot pen^{-1}$) 24 h per day. Average daily THI was 80.9 ± 2.1 and increasing the shade allocation tended to linearly increase ADG (1.15, 1.19, and 1.20 $kg \cdot d^{-1}$ for 1.2, 2.4 or 9 $m^2 \cdot animal^{-1}$, respectively) and

Table 3. Level of significance (probability) of the fixed effects fitted to the model for the variables analyzed

Effect	Variables *P*-value		
	DMI	ADG	G:F
Initial weight grouping	<0.01	<0.01	<0.01
Roof	<0.01	<0.01	<0.01
Season	<0.01	0.47	<0.01
Initial weight grouping × Roof	0.31	0.48	0.03
Initial weight grouping × Season	0.70	0.69	0.39
Roof × Season	0.47	<0.01	<0.01
Initial weight grouping × Roof × Season	0.64	0.51	0.72

DMI, dry matter intake (kg/animal/d); ADG, average daily gain (kg/day); G:F, feed efficiency.

Table 4. Least square means (±S.E.) for the fixed effects fitted to the model for the variables analyzed[*]

		Variable					
Effect	Level	DMI	ADG	G:F	*n*	AIW	ADF
IWG	Light	9.21 ± 0.08^{c}	1.58 ± 0.01^{c}	0.172 ± 0.001^{a}	114	278	184
	Medium	9.72 ± 0.06^{b}	1.68 ± 0.01^{b}	0.173 ± 0.001^{a}	382	229	143
	Heavy	10.41 ± 0.06^{a}	1.70 ± 0.01^{a}	0.164 ± 0.001^{b}	566	414	125
Roof	With GR	9.70 ± 0.06^{b}	1.67 ± 0.01^{a}	0.173 ± 0.001^{a}	637	376	134
	Without GR	9.86 ± 0.06^{a}	1.63 ± 0.01^{b}	0.166 ± 0.001^{b}	425	375	141
Season	Spring	10.02 ± 0.07^{a}	1.66 ± 0.01^{a}	0.166 ± 0.001^{b}	320	363	139
	Summer	9.69 ± 0.08^{bc}	1.64 ± 0.01^{a}	0.171 ± 0.001^{a}	238	373	133
	Autumn	9.60 ± 0.07^{c}	1.66 ± 0.01^{a}	0.172 ± 0.001^{a}	281	377	137
	Winter	9.82 ± 0.06^{b}	1.65 ± 0.01^{a}	0.170 ± 0.001^{a}	223	379	132
IWG × roof	Light with GR	9.33 ± 0.10^{a}	1.55 ± 0.02^{a}	0.178 ± 0.002^{a}	54	278	185
	Medium with GR	9.09 ± 0.09^{a}	1.61 ± 0.01^{a}	0.176 ± 0.001^{a}	228	339	142
	Heavy with GR	9.75 ± 0.08^{a}	1.66 ± 0.01^{a}	0.167 ± 0.001^{c}	355	414	121
	Light without GR	9.68 ± 0.06^{a}	1.70 ± 0.01^{a}	0.166 ± 0.002^{c}	80	278	182
	Medium without GR	10.50 ± 0.07^{a}	1.68 ± 0.01^{a}	0.171 ± 0.001^{b}	155	338	143
	Heavy without GR	10.33 ± 0.06^{a}	1.72 ± 0.01^{a}	0.161 ± 0.001^{d}	190	412	122
Roof × Season	Spring with GR	9.86 ± 0.08^{a}	1.70 ± 0.01^{a}	0.173 ± 0.001^{ab}	198	368	137
	Summer with GR	9.71 ± 0.09^{a}	1.66 ± 0.01^{bc}	0.173 ± 0.002^{ab}	145	375	131
	Autumn with GR	10.12 ± 0.09^{a}	1.65 ± 0.01^{c}	0.175 ± 0.001^{a}	166	380	136
	Winter with GR	9.74 ± 0.10^{a}	1.68 ± 0.01^{b}	0.172 ± 0.001^{be}	128	383	131
	Spring without GR	9.78 ± 0.06^{a}	1.61 ± 0.01^{d}	0.160 ± 0.002^{d}	114	343	148
	Summer without GR	9.50 ± 0.07^{a}	1.64 ± 0.02^{cd}	0.169 ± 0.002^{ce}	91	365	139
	Autumn without GR	9.91 ± 0.07^{a}	1.63 ± 0.02^{cd}	0.168 ± 0.002^{c}	119	364	141
	Winter without GR	9.64 ± 0.08^{a}	1.64 ± 0.01^{cd}	0.167 ± 0.002^{c}	101	369	136

[*] Within attribute, effect and level, least square means with different superscript are different ($P < 0.05$; Tukey).

DMI, dry matter intake (kg/animal/d); ADG, average daily gain (kg/day); G:F, feed efficiency; AIW, average initial weight; ADF, average days on feed; IWG, initial weight grouping; GR, greenhouse roof.

had a quadratic effect on DMI (7.06, 7.59, and 7.49 kg·d^{-1} for 1.2, 2.4 or 9 m^2·animal^{-1}, respectively). Although, no significant effect ($P \geq 0.33$) of shade was observed on G:F. The use of mechanical ventilation improved ADG (1.20 vs. 1.32. kg·d^{-1}) and G:F (0.162 vs. 0.175), whereas it did not have a significant effect on DMI.

Muhamad et al. (1983) studied the effect of the starting season (summer vs. winter) and housing (an open lot with or without overhead shelter) on the performance of beef cattle in Iowa, US. These authors found no differences between summer and winter for DMI and efficiency (expressed as feed conversion ratio) in agreement with the current study's findings; however, ADG was greater for cattle placed on feed in summer (1.12 ± 0.05 kg·d^{-1}) than cattle placed on feed in winter (1.05 ± 0.05 kg·d^{-1}) that contrasts with the current study's results because ADG was not different across seasons in our study. Furthermore, in contrast to the current study's results, the Muhamad et al. (1983) housing system did not affect DMI, ADG, and feed efficiency.

Pusillo et al. (1991) studied the effect of starting month and housing (an open lot with or without overhead shelter) on beef cattle performance over five years in the Midwest of the US. The latter authors reported cattle started on feed in spring have 11% more DMI than cattle started on feed in autumn, which had the lowest DMI. In the current study, closeouts of cattle initiated on feed in spring had 4.4% more DMI than closeouts of cattle with the lowest DMI, started on feed in autumn; therefore, their results agree with the current study's results in the effect of the season, although with different magnitude. In contrast, Pusillo et al. (1991) reported cattle with access to overhead shelter had 2.6% greater DMI than cattle without overhead shelter. In the current study, closeouts of cattle raised with the greenhouse roofs had a 1.6% reduction in DMI compared to those of cattle reared without the greenhouse roofs, and ADG was not affected by the year's season; however, Pusillo et al. (1991) published an advantage for cattle started on fed in May versus November of 37%. Feed efficiency was better for closeouts of summer, autumn, and winter than for closeouts of spring in the current study. A different pattern was observed by Pusillo et al. (1991), as cattle were more efficient (feed efficiency expressed as feed conversion ratio) when placed on feed in spring and summer than in autumn and winter.

Concerning housing system, Pusillo et al. (1991) stated that across months, cattle with shelter had greater ADG (7%) and efficiency (4%–5%) than cattle without shelter ($P < 0.05$); these findings agree with the current study's results of cattle reared under greenhouse roofs had an increase of 2.4% in ADG and of 4.2% in G:F. Differences between Pusillo et al. (1991) and the study can be explained by differences in housing systems and weather conditions. For instance, the notable difference in ADG across months reported by these authors can be due to moderate-severe cold stress combined with rain and snow affecting the cattle started on feed in November in the US Midwest. In addition, a month × housing interaction existed in their study, suggesting shelter enhanced ADG and feed efficiency when cattle started the feeding in autumn or winter because of colder environmental conditions in that region. During spring and summer, ADG and feed efficiency were not improved due to the availability of overhead shelters.

Koknaroglu et al. (2005) investigated the effect of housing (an open lot with or without overhead shelter), the initial weight of cattle (the cattle classification by weights was similar to the one in the current study), and seasons, which were defined as in the current study. The data was collected from feedlots located in Iowa, USA. The annual average temperature was 8.3 °C, with a minimum of −26 °C in winter and a maximum of 38 °C in summer. The annual rainfall was 81.3 cm; thus, unpaved pens were very muddy during spring and autumn. Contrary to the current study, an interaction initial weight grouping × season existed for ADG, DMI, and feed efficiency, cattle placed on feed in spring and reared in pens with overhead shelter did not differ in ADG and feed efficiency from cattle raised in pens without overhead shelter. These discrepancies are most likely attributable to differences in the housing systems and more significant differences in weather across seasons. Though not measured, it is possible that cattle in Iowa experienced heat or cold stress. In parallel to our results, Koknaroglu et al. (2005) found cattle started on feed during spring and reared in pens with overhead shelter had greater ADG than cattle started on feed in autumn. Also, cattle were more efficient in pens with shelter than in pens without shelter independently of initial weight grouping.

In a study undertaken in an arid region in Mexico, also evaluating the effect of pens with greenhouse roofs on finishing performance of beef cattle, Valadez-Noriega et al. (2019) reported decreased DMI (13.4 ± 1.3 vs. 14.5 ± 0.8 kg·animal^{-1}·d^{-1}), greater ADG (1.9 ± 0.1 vs. 1.8 ± 0.1 kg·d^{-1}) and better feed efficiency expressed as feed conversion ratio (6.9 ± 0.9 vs. 7.9 ± 0.4) for pens constructed with greenhouse roofs in contrast with pens built without the greenhouse roofs. In the current study, the more prominent advantages (greater ADG and G:F) of using pens with greenhouse roofs were presented for spring closeouts, proving importance of keeping cattle comfortable, clean, and dry during the rainy season. Cattle that started the feeding cycle during spring were fed during spring and summer; thus, these cattle were fed during the month of increased rains.

According to Morrison et al. (1970), muddy pens can reduce ADG and feed efficiency by 35% and 25%. Rayburn and Fox (1990) estimated a reduction in cattle feed efficiency of approximately 8% for every 4 cm of accumulated mud. Thomas (2013) reported mud over 30 cm in pens decreased feed efficiency of beef cattle by 25% and Sweeten et al. (2014) stated 11 to 20 cm of mud decreased feed efficiency by 13%. In the current study, the increase in feed efficiency was 4.2% for pen closeouts with greenhouse roofs compared with closeouts of pens without greenhouse roofs; these differences could be explained because in the current study, mud level in the pens without a greenhouse roof never reached those accumulation levels due to the feedlot having a good cleaning calendar. Pens were cleaned as soon as they accumulate approximately 5 cm of mud; however, it is essential to highlight pens constructed with a greenhouse roof yielded benefits even with good management.

Across cattle initial weight groups, feed efficiency was improved in pens with greenhouse roofs, with the most significant advantage for light cattle; therefore, providing more comfortable conditions is even more crucial for light cattle, which are usually at greater risk than medium and heavy cattle. Furthermore, pens with greenhouse roofs provided more prominent advantages for ADG and G:F when cattle started the fattening cycle in spring, which means that pens with greenhouse roofs offer a much better environment than its counterpart during the months of greater rainfall in central Mexico, allowing maintaining clean and dry cattle.

Effects of the protection provided by greenhouse roofs in pens can be attributable to a better microclimate that favors animal welfare and performance. For example, in regions with temperate weather and annual rainfall over 51 cm, providing protection with greenhouse roofs in feedlots generates a microclimate that protects cattle against extreme temperature variation and the adverse effects of rain, such as mud, resulting in increased ADG and G:F; therefore, the feeding period could be shorter and profitability larger. It is also important to highlight that using cost-effective technologies as greenhouse roofs that improve feed efficiency can lead to more sustainable beef production in challenging environments.

CONCLUSIONS

The adoption of pens with greenhouse roofs in feedlots located in temperate weather favors the productivity and efficiency of beef cattle, providing an alternative for more sustainable production systems. At the same time, it advantages animal welfare due to a more comfortable environment for the animals. More substantial benefits are provided for light cattle and fattening cycles that are undertaken during months of increased rainfall.

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Conflict of interest statement

The authors declare no real or perceived conflicts of interest.

LITERATURE CITED

Castro-Pérez, B. I., A. Estrada-Angulo, F. G. Ríos-Rincón, V. H. Núñez-Benítez, C. R. Rivera-Méndez, J. D. Urías-Estrada, R. A. Zinn, A. Barreras, and A. Plascencia. 2020. The influence of shade allocation or total shade plus overhead fan on growth performance, efficiency of dietary energy utilization, and carcass characteristics of feedlot cattle under tropical ambient conditions. *Asian-Australas. J. Anim. Sci*. 33:1034–1041. doi:10.5713/ajas.19.0112.

Fox, D. G., and T. P. Tylutki. 1998. Accounting for the effects of environment on the nutrient requirements of dairy cattle. *J. Dairy Sci*. 81:3085–3095. doi:10.3168/jds.S0022-0302(98)75873-4.

Fox, D. G., C. J. Sniffen, and J. D. O'Connor. 1988. Adjusting nutrient requirements of beef cattle for animal and environmental variations. *J. Anim. Sci*. 66:1475–1495.

Gaughan, J. B., T. L. Mader, S. M. Holt, and A. Lisle. 2008. A new heat load index for feedlot cattle. *J. Anim. Sci*. 86:226–234. doi:10.2527/jas.2007-0305.

Grandin, T. 2016. Evaluation of the welfare of cattle housed in outdoor feedlot pens. *Vet. Anim. Sci*. 1:23–28. doi:10.1016/j.vas.2016.11.001.

Graunke, K. L., T. Schuster, and L. M. Lidfors. 2011. Influence of weather on the behavior of outdoor-wintered beef cattle in Scandinavia. *Livest. Sci*. 136:247–255. doi:10.1016/j.livsci.2010.09.018.

Koknaroglu, H., D. D. Loy, and M. P. Hoffman. 2005. Effect of housing, initial weight, and season on feedlot performance of steers in Iowa. *S. Afr. J. Anim. Sci*. 35:282–290. doi:10.4314/sajas.v35i4.3972.

Mader, T. L. 2014. Bill E. Kunkle Interdisciplinary BEEF Symposium: Animal welfare concerns for cattle exposed to adverse environmental conditions. *J. Anim. Sci*. 92:5319–5324. doi:10.2527/jas.2014-7950.

Mader, T. L., M. S. Davis, and T. Brown-Brandl. 2006. Environmental factors influencing heat stress in feedlot cattle. *J. Anim. Sci*. 84:712–719. doi:10.2527/2006.843712x.

Morrison, S., R. Givens, W. Garrett, and T. Bond. 1970. Effects of mud-wind-rain on beef cattle performance in feed lot. *Hilgardia* 24(8):6–7. doi:10.3733/ca.v024n08p6.

Muhamad, Y. B., M. P. Hoffman, and H. L. Self. 1983. Influence of different ratios of corn and corn silage, housing systems, and seasons on the performance of feedlot steers. *J. Anim. Sci*. 56:747–754. doi:10.2527/jas1983.564747x.

National Academies of Sciences, Engineering, and Medicine. 2016. *Nutrient requirements of beef cattle*. 8th revised ed. Washington (DC): The National Academies Press. doi:10.17226/19014.

National Research Council. 1981. *Effect of environment on nutrient requirements of domestic animals*. Washington (DC): The National Academies Press. doi:10.17226/4963.

National Research Council. 2000. *Nutrient requirements of beef cattle: 7th revised edition: update 2000*. Washington (DC): The National Academies Press. doi:10.17226/9791.

Nikitae-Martzopoulou, C. 2007. New trends in animal housing in Greece: greenhouse type livestock buildings. In CIGR Workshop. *Animal housing in hot climate*. Cairo, Egypt, April 1–4.

Pusillo, G. M., M. P. Hoffman, and H. L. Self. 1991. Effects of placing cattle on feed at two-month intervals and housing on feedlot performance and carcass grades. *J. Anim. Sci*. 68:443–450. doi:10.2527/1991.692443x.

Rayburn, E. B., and D. G. Fox. 1990. Predicting growth and performance of Holstein steers. *J. Anim. Sci*. 68:788–798. doi:10.2527/1990.683788x.

SAS Institute Inc. *SAS 9.4*. 2020. Cary (NC): SAS Institute Inc.

Servicio Metereológico Nacional (SMN). 2020. Normales Climatológicas por Estado [accessed 11 May 2020]. https://smn.conagua.gob.mx/es/informacion-climatologica-por-estado?estado=mex.

Smith, G. E. 1971. Nutrition. In: Church, D. C., editor. *Digestive physiology and nutrition of ruminants*. vol. 2. Corvallis (OR): O & B Books, Inc.

Sweeten, J., L. Lubinue, R. Durland, and B. Bruce. 2014. *Feedlot mounds, beef cattle handbook*. Madison (WI): Extension Beef Cattle Resource Committee, University of Wisconsin Extension.

Tedeschi, L. O., and D. G. Fox. 2018. *The ruminant nutrition system. And applied model for predicting nutrient requirements and feed utilization in ruminants*. Acton, MA (USA): XanEdu.

Thomas, H. S. 2013. Feedlot pen maintenance leads to optimal performance. https://www.progressivecattle.com/topics/facilities-equipment/feedlot-pen-maintenance-leads-to-optimal-performance#:~:text=Feedlot%20animals%20do%20best%20%E2%80%93%20with,can%20help%20minimize%20these%20problems.www.progressivecattle.com/topics/facilities-equipment/5784-fe

Valadez-Noriega, M., M. C. Méndez-Gómez-Humarán, A. A. Rayas-Amor, C. F. Sosa-Ferreyra, F. M. Galindo, and G. C. Miranda-De la Lama. 2019. Effects of greenhouse roofs on thermal comfort, behavior, health, and finishing performance of commercial zebu steers in cold arid environments. *J. Vet. Behav*. 35:54–61. doi:10.1016/j.jveb.2019.10.012.

Van Laer, E., C. P. Henri Moons, B. Sonck, and F. A. Maurice Tuytteens. 2014. Importance of outdoor shelter for cattle in temperate climates. *Livest. Sci*. 159:87–101. doi:10.1016/j.livsci.2013.11.003.