Effects of greenhouse roofs on thermal comfort, behaviour, health, and finishing performance of commercial Zebu steers in cold-arid environments

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Abstract

The aim of this study was to determine the effects of two housing systems (thermal plastic greenhouse roofs -PGR- vs without roof-PWR) on health, welfare and finishing performance of Zebu steers in cold-arid environments. A total of 880 animals were included in the study, these were divided in two independent studies. For the first study, 260 steers were used (effect on steers welfare) and 620 steers for the second study (effect on steers performance). Steers in the PWR treatment showed a trend of standing during 12:00 to 14:59 h, which was considered the hottest period of the day and the steers that were standing showed a trend for feed intake. On the other hand, the steers in the PGR treatment showed a trend of lying down ($P<0.001$) and ruminating ($P=0.031$) during the same period of the day; additionally, more steers were drinking in PGR than in PWR treatment. Survival analysis of physical health indicated that the number of healthy steers decreased as the number of days increased, more sick steers were observed in PWR treatment ($P<0.05$). Finally, steers in PGR achieved different ($P<0.001$) final body weight (599.7±46.4 kg), then steers in PWR treatment (569.0±31.6 kg). The steers in PWR showed higher feed intake ($P<0.001$); nonetheless, the steers in PGR treatment showed higher average daily gain ($P<0.001$) and higher feed conversion efficiency ($P<0.001$). Under the winter conditions were the temperatures fluctuated from a high of 33.9 °C to a low of -2.7 °C, the use of thermal plastic greenhouse roofs demonstrated an improvement of steers' welfare, health, the average daily gain and feed conversion efficiency.

Key words: Greenhouse-roofs; Thermal comfort; Health; Behaviour; Performance; Zebu steers.

1. Introduction

Cattle feedlot systems can be restrictive with respect to key resources such as shade, thermal comfort, feeding spaces, and dry and comfortable lying surfaces. As a consequence, competition for these resources can have high biological costs that relate to welfare, health and productivity (Miranda-de la Lama et al., 2013). The use of open outdoor feedlots on a soil surface for fattening large numbers of cattle is increasing in arid and semi-arid of the world. Along cold season in semiarid environments, cattle fattening at feedlots are exposed to cold, rainy and windy conditions (Grandin, 2016). This may cause discomfort due to the great formation and accumulation of mud, and if such conditions are extreme and/or persistent thermal stress responses (Webster et al., 2008).

Thermal stress events can, directly or indirectly, cause reduced performance, morbidity, and even mortality producing significant economic losses and animal welfare concerns (Fournel et al., 2017). In this context, the roof should normally buffer the extremes of climate conditions, create a micro-environment, which protects the cattle from stressful environment and allow efficiency of labour utilization (Kamal et al., 2013). A possible solution for the latter could be the implementation of thermal plastic greenhouse roofs, because they have the following advantages; prefabricated light structures, easily transported with minimum time of installation, low cost of installation and maintenance, easy replacement of spoiled parts, better natural ventilation and lighting, safe sanitary conditions; easy cleaning, esthetical asset and finally their installation do not require permission from the urban planning sector (Nikita–Martzopoulou, 2007).

Cattle production is one of the most important sectors of Mexican agribusiness because is the 7th largest producer of beef in the world (18 million heads; USDA, 2018), the exports of live cattle represents the fourth place worldwide and meat exports represent the fourteenth place (SIAP, 2017). In the country, the Zebu breeds (Brahman, Red Brahman, Nellore, Guzerat, Indubrazil, Gyr and Sardo Negro) are maintained as purebred animals but also as crossbred animals with European breeds in beef production systems and dual-purpose systems as well (Parra-Bracamonte et al., 2015). Beef calves are typically raised on extensive farms located in the southern region of Mexico and Central American countries and remain with their mothers for several months until, after weaning (7 to 12 months), they are transported to feedlots located in the semiarid regions of the country (usually cold/dry summers and cold winters), where the cattle is initiated into more intensively managed husbandry systems (Valadez-Noriega et al., 2018). Beef production practices in Mexico are changing as the demand for exportation of beef increases (Vazquez-Mendoza et al., 2017). Population growth, economic growth, and access to international markets have promoted changes that suggest that more beef suitable for the U.S. market will be produced in Mexico (Peel, et al., 2011). The increase in U.S. exports of feed and distiller's grain to Mexico, coupled with more domestic course grain use, suggests a shift to more cattle fed in feedlots in Mexico (Johnson and Hagerman, 2012).

More than one-third of North America can be considered arid and semiarid, where they are raised approximately 28 million beef cattle, normally in feedlots (Huntsinger and Starrs, 2006). Feedlots focus on the efficient growth and weight gain of the animals by providing a readily digestible, high-energy diet, reducing the amount of energy expended to find food and managing the cattle to minimize stress and health problems (Caruana, 2019). From this perspective, the establishment of modern feedlots is of paramount importance in developing countries for exporting and to develop a modern Mexican meat industry. A growing tendency in Mexican producers to install PGR at feedlots in arid environments is observed to protect animals of cold and windy conditions during winter and to minimize sun radiation during summer. Despite the importance of this shelter tendency and improvements on beef cattle, studies that actually offer a choice between different types of shelter are rather scarce (Van et al., 2015; Grandin, 2016). A cold and semiarid region of Mexico was chosen for this study because it represents the largest feedlot industry for meat production in the country and a growing tendency in Mexican producers to install thermal plastic greenhouse roof sat feedlots has been observed. In our study, we test the hypothesis that thermal plastic greenhouse roofs improve the welfare and performance of cattle at feedlots. Therefore, the aim of the study was to determine the effects of two housing systems (greenhouse roofs -PGR- vs without roof-PWR-) on thermal comfort, behaviour, health, and finishing performance of commercial Zebu steers in cold-arid environments.

2. Material and Methods

The study was carried out in a commercial feedlot located in the municipality of Ezequiel Montes (20°31′ N, 99°44′ W) in the Queretaro State (central Mexico) from October 2015 to February 2016 (fall-winter seasons). The municipality is located at 1978 m above sea level and a mean temperature of 18.5 °C (rage of -5 °C to 27 °C). The Köppen climate classification system describes the municipality as cold semiarid climate (BSk), with hot summers and cool winters and the majority of rainfall occurs in the cooler months (Markus et al., 2006). Long-term annual precipitation in the study area is 555 mm and the soils are mainly dark-brown with regozol and phaeozem. A total of 880 commercial Zebu steers (there-quarters Zebu mixed with some European breeds -Bos Taurus-, particularly Brown Swiss, Holstein and Simmental), were included in the study, these were divided in two independent studies. For the first study, 260 steers were used (effect of PGR on cattle welfare) and 620 steers for the second study (effect of PGR on steers' performance). All the steers came from grazing systems and the animals were transported in pot-belly trailers (same trucks and same drivers) for 16 hours (more details of Mexican cattle transportation in Valadez-Noriega et al., 2018). After the journey the animals were unloaded, weighed, dewormed, and received clostridial vaccine, and were then distributed in pens with 62 to 65 steers each.

2.1. Study 1: Impacts on thermal comfort, welfare, and health

A total of 260 entire commercial Zebu steers were used, 24-30-months old and an average live weight of 421.74 kg (±41.14). The steers were randomly allocated in two experimental groups according to two different treatments (Fig.1): pens without roof (PWR) and pens with greenhouse roofs (PGR), every treatment was replicated once (65 animals per pen). Each pen has an approximate size of 600 m^2 (9.5 m^2 per steer), besides being equipped with a water bowl, a lying area (bare soil) and a feeding area with concrete floor. In the case of the PGR pens, the roof covering the total of pen and was placed at 7.30 m height (Fig.2). Finishing diet was formulated according to NRC (2000) and contained (g/kg DM): maize straw (200), bakery waste (240), ground corn (430), soybean meal (80), bypass fat (10; Enervit, Zuavit SA de CV, Ecatepec, Mexico), mineral premix (15), buffer (5; containing (mg/kg DM) Na 182, 84 Mg) and 6.7 mg/kg of zilpaterol hydrochloride (Zilmax, Intervet; Merck and Co., Inc., Madison, NJ, USA). The chemical composition of the diet was; 132 g/kg DM of crude protein, 7 and 3 g/kg DM of calcium and phosphorus respectively, 1.9 and 1.29 Mcal/kg DM of net energy for maintenance and body weight gain, respectively. At the end of the trials the steers were transported to a commercial abattoir located at 250 km and they were slaughtered.

2.1.1. Thermal comfort

To evaluate the risk of heat stress on zebu steers, the air temperature (ºC) and relative humidity (%) were recorded hourly during a period of 11 hours per day (08:00 am to 19:00 pm) by means of automatic dataloggers (HOBO Pro v2).The HOBO loggers were placed in the centre of the pens in both treatments (1.20 m above ground level) to record the environmental conditions of the standing steers. The Temperature Humidity Index (THI) was calculated with the equation developed by Thom (1959): [(0.8 x air temperature) + (relative humidity/100) x (air temperature-14.4) + 46.4].The periods were considered thermo-neutral when average THI was lower than 70, minor heat stress was considered when THI fall in the range of 70 to 74, heat stress was considered when THI fall in the range of 74 to 77 and severe heat stress when THI was higher than 77 (Davis et al., 2003).The soil surface temperature (SST),skin temperature (ST) and respiration rate (RR) of steers were measured from 09:00 to 18:00 h daily for one week using a compact thermal imaging camera (FLIR i7, 140 x 140 IR, FLIR Systems®). The SST was measured hourly in five different points with in each pen, the ST was measured in 6 animals (3 with dark fur and 3 with light fur) within each pen, always in the rumen side. The RR was calculated by counting the movements of the flank per minute (breaths/ min). The steers that were used for ST recordings were used for the RR evaluation and the steers that presented some type of nasal discharge or respiratory difficulty during the clinical evaluation were excluded.

2.1.2. Behaviour measuring

All steers were individually identified with large cattle ear tag within each pen. Direct observations with scan sampling were carried out to collect information of individual behaviours. Binoculars were used to observe the cattle from a platform at 3.0 m above the ground. The steers were observed during three different periods of time (period 1= 08:00 am to 11:00 am, period 2= 12:00 pm to 15:00 pm and period 3= 16:00 pm to 19:00 pm) giving a total of 55 hours of observations (6 days per pen), always being observed by the same trained observer. Within each period of observation, the scan sampling was used every 15 min to count the number of steers that showed behaviours like: standing (body supported by four limbs), lying down (body on the ground), feeding (steers chewing with the head inside the feeder), ruminating (the steers showed chewing movements and they were distant from the feed) and drinking (the nose over the water source).

2.1.3. Health indicators

The presence or absence as well as the type of nasal discharge was used as indicator to assess physical health problems that could compromise the steers welfare. The nasal discharge was defined as a clear visible matter from the nostrils, often of thick consistency (Welfare Quality®, 2009). The nasal discharge was observed as a clear nasal discharge (CND) when it was transparent and turbid nasal discharge (TND) when it was yellow or green colour. The observer carried out these evaluations at morning, twice a week, during 10 weeks of the study and in all pens. These data were used to generate a survival analysis of Kaplan Meier.

2.2. Study 2: Impacts on performance

A total of 620 entire commercial Zebu steers were used, 24-27-months old and an average of 337.14 kg (±38.99) body weight. The steers were randomly allocated in two experimental groups according to two different treatments (Fig.1): pens without roof (PWR) and pens with greenhouse roofs (PGR), every treatment was replicated four (62 animals per pen). The diet and housing conditions were the same as described in study 1. The steers were weighed as a group at the beginning of the study (initial body weight -BW_i) and at the end (final body weight-BW_f); in this study, 134 days were considered for fattening. The steers had access *ad libitum* to the feed and feed refusals were quantified daily at 07:00 am by the same person; therefore, individual dry matter intake (DMI) was estimated. Feed conversion efficiency (FC) and average daily weight gain (ADG) were estimated at the end of the fattening period. The FC was calculated using the total kilograms gained per steer (FBW = final body weight- IBW = initial body weight) and divided by total feed intake (FI). The ADG was calculated using the total kilograms gained per steer and divided by 134 days. The net income per animal in the study was calculated considering; hired labour (one worker), initial investment of the steers, annual cost for the greenhouse roofs installation (20% depreciation and amortization rate), total feed and medicine expenses during the period of the study.

2.3 Statistical analysis

Most of the variables were not normally distributed, therefore nonparametric tests were used for independent samples. The median was used as measure of central tendency, the interquartile range (IQR) as measure of dispersion and the Kruskal-Wallis test was used to identified statistical differences (P<0.05) between the treatments and when differences (P<0.05) were observed the Mann-Whitney U test was applied (Field, 2009). For variables with normal distribution, the mean was used as measure of central tendency, the standard deviation (±SD) as measure of dispersion and the Student's t-test was used to identified statistical differences (P<0.05). A survival analysis of Kaplan Meier with a confidence level of 90% was performed to determine significant differences (P<0.05) among the steers that showed nasal discharges. All statistical analyses were carried out using the SPSS Statistics software (Version 22) of IBM®

3. Results

The feedlots were exposed in winter season to extreme temperatures fluctuated from a high of 33.9°C to a low of -2.7°C. Table 1 showed temperature indicators during the study and the temperature was significantly lower in the PWR treatment between 19:00 pm to 8:59 am.

3.1 Study 1: Impacts on thermal comfort, welfare, and health

The average temperature, the relative humidity and temperature-humidity index are shown in Table 2. The average temperature for PGR was 34.02°C and 37.67°C for PWR treatment, no significant differences were observed between treatments (P=0.276) during the period of fattening. The steers were under thermo-neutral zone (67% of the time during the evaluation period) and exposed to mild heat stress (25%), heat stress (7%) and severe heat stress (1%). Nevertheless, 72% of severe heat stress cases were observed in the PWR treatment. Soil surface temperature in both resting and feeding areas of PWR treatment (30.4±9.7°C and 29.8±8.3°C, respectively) were higher (P<0.006) than in PGR treatment (27.5±5.4°C and 25.8±5.0°C, respectively) and temperatures up to56.3°C were measured in the ground for the latter treatment (Fig. 3).The steers in the PWR treatment showed a trend of standing during period 2 (12:00 to 14:59 h), which was considered the hottest period of the day (Table 3) and the steers that were standing showed a trend for feed intake. On the other hand, the steers in the PGR treatment showed a trend of lying down(P<0.001) and ruminating (P=0.031) during the same period of the day; additionally, more steers were drinking water in PGR than in PWR treatment (Table 3). No significant differences (P=0.925) were observed between treatments in both skin temperature and RR variables; however, higher temperature and RR were recorded in dark fur (36.09±4.45 °C and 40.24±13.92 breath/min, respectively) than in light fur (34.75±3.2°C and 36.76±11.09 breath/min, respectively) and these were significantly different (P<0.003). Survival analysis of physical health indicated that the number of healthy steers decreased as the number of days increased, more sick steers were observed in PWR treatment (P<0.05) (Fig.4). No significant differences (P>0.05) were observed in turbid nasal discharges.

3.2. Study 2: Impacts on performance

The steers in PGR achieved higher (P<0.001) final body weight (590.60+36.80kg) than steers in PWR (582.06+21.97kg) although they had lower initial body weight (Table 4). The steers in PWR showed higher feed intake ($P<0.001$); nonetheless, the steers in PGR treatment showed higher average daily gain ($P<0.001$) and higher FC ($P<0.001$) (Table 4). In terms of economic return, higher profits were obtained in PGR (USD $17,797.10), than in PWR treatment.

4. Discussion

Our study has shown that the use of greenhouse roofs in feedlots in semi-arid areas has a beneficial effect on the health, welfare and productivity of Zebu cattle. However, it is important to note that these effects are due to the specific greenhouse roof shown in the figures 1c, 1d, and 2. It is possible that roofs of different design and at lower heights above the ground (5.2 m), will have different effects than those found in this study. Worldwide, the research has focused on the study of extreme temperature stress in dairy cattle due to a quick decrease in milk production has been observed (Hahn, 1999, West, 2003; Schütz et al., 2010a). In the United States of America, it has been observed that heat stress in livestock can be devastating, causing a decrease in yield and livestock death (Hubbard et al., 1999; Mader, 2014). Little has been studied about cold stress that also affects the health, welfare and production of animals. It is usually quantified by the Wind Chill Index (WCI), originally developed to assess the risk of hypothermia and freezing in humans (Environment Canada, 2013). For cattle, WCI has not yet been scientifically validated and it is only possible to compare the values of "lower critical temperatures" (LCT) and to get an approximation of the potential impact of low temperatures on the comfort and physiology of this species (Van et al., 2014). *Bos indicus* or zebu cattle are native to South and Southeast Asia, regions with a tropical climate. The main adaptive characteristics of these animals include the presence of hump, abundant and pleated skin, pigmentation and shorter and thinner hair compared to *Bos taurus* (Pérez O'Brien et al., 2015). In the case of zebu cattle, the same characteristics that give greater thermotolerance to heat stress, can result in a lower resistance to cold and dry environments. Therefore, our study is one of the first to analyse the effects of PGR treatment on thermal comfort, behaviour, health, and performance of zebu steers under commercial conditions during a cold season.

4.1 Study 1: Impacts on thermal comfort, welfare, and health

In general, it has been mentioned that cattle are more efficient and perform better when temperatures are kept within the thermal comfort zone between 5 and 20 °C (Hahn, 1999). In this study the minimum and maximum temperatures recorded were -2.63 and 35.05°C, respectively; which showed a remarkable variation with temperatures recorder 3 years ago and the recorded temperature during the study was outside of the thermal comfort range for cattle. Extreme temperature changes between day and night are common in cold semiarid climates, sometimes up to 20 °C or even more. The season in which the study was conducted (winter), could be related to the low number of steers with severe heat stress, moderate heat stress and heat stress according to the temperature and THI (Thom, 1959; Davis et al., 2003). No significant differences were observed between both treatments in terms of THI, however, the steers in PWR showed severe heat stress during longer time. The existence of steers with severe heat stress in winter suggests the possibility of an increase in these cases during the summer season, therefore some additional shelter that prevents direct solar radiation is advisable to improve the thermal comfort of steers (Brown-Brandl et al., 2005); example, a shade cloth mesh which is a very affordable way to protect from ultraviolet rays and offers a cooler environment (10 to 20º C lower).

In the SST measurements, the highest temperatures were recorded at the feeding and resting area in the PWR treatment during 12:00 pm to 14:59 pm. which could explain the behaviour of steers standing longer time (Table 3), Gu et al. (2016) reported a similar behaviour with buffalos and according to Curtis (1983), Rovira (2014) and Kendall et al. (2006) a greater number of standing steers could be due to their attempts to increase the body surface exposed to the environment, which would facilitate the regulation of their temperature through a greater flow of air over their body. The steers spent longer time lying down when the soil surface was protected by the PGR that reduced direct solar radiation on the ground and decreased the heat gain by conduction and radiation (Hansen, 2004). According to EFSA (2004), a microclimate is a term used to describe the "internal" climate that animals are experimenting during the day or night (heat, humidity, gas concentration and air quality). Due to the microclimate that generated the PGR, a greater thermal comfort was evident in the PGR treatment (greater number of steers laying down and ruminating) which resulted in higher FC efficiency in study 2.

During the study, it was observed that PGR in the feedlots had a positive effect because they worked as a barrier against the wind and minimised the temperature fluctuation between day and night. It is important to mention that farmers use the PGR because reduces the respiratory illnesses and livestock deaths. According to Schütz et al. (2010b) and Van et al. (2014) when heat loss by convection (wind chill) and exposure to precipitation are combined cold stress can arise, therefore the steers in the PGR treatment showed low nasal discharges. The number of animals with clear nasal discharge and turbid nasal discharge was evidently higher in PWR treatment which caused a greater investment in medicines and therefore lower utility per animal. It is possible that nasal discharges are related to Bovine Respiratory Disease (BRD). Beef cattle of all ages can be affected with these disease; however, they are most likely to be affected during the 40 days after entrance into the feedlot because they are exposed to a wide range of pathogens (due to commingling) concurrent with various stressors (e.g., transportation and social-mixing), which can suppress their immune system (Timsit et al., 2016). In this context, the PGR roofs of our study are an investment that can help to reduce the prevalence of respiratory diseases of calves during fattening. Additional to economic costs, outbreaks of BRD impair the welfare of the animal and extra expertise and labour are needed to treat and care for the infected animals.

The infrared thermography is a non-invasive diagnostic technique used as an indicator of thermal biometric variations in surface temperature of animals with precision without the need for physical contact with the animals (Lokesh-Babu et al., 2018). The skin surface is a highly efficient radiator, a fact that permits to detect infrared emissions of the skin and to map temperature distributions (Salles al., 2016). Under the conditions of this study we did not find differences between the treatments in both skin temperature and RR variables; however, higher temperature and RR were recorded in dark fur animals than in light fur and these were significantly different. It seems that the ceiling does not inhibit the levels of radiation that animals receive, although the effect of skin colour. In a study with Angus cattle, Mader et al. (2006), found an effect similar to that of our study, where black-haired animals had a higher skin surface temperature compared to red-haired animals. A possible explanation could be related to dark animals associated to solar radiation absorption by the dark pigment while light pigmented animals reflected more and absorbed less solar radiation (Katiyatiya et al., 2017).

4.2. Study 2: Impacts on performance

The steers in PGR treatment had low exposure to solar radiation and therefore stable temperatures throughout the fattening period could favour the ADG, similar results were obtained reported by

Rovira and Velazco (2011), however these steers showed lower DMI than steer in PWR treatment. Probably this could be explained by SST because it was higher in PWR treatment therefore the steers showed a high standing-eating behaviour and low ruminating behaviour. Although steer in PWR treatment had higher DMI, the ADG and FC efficiency was lower than steers in PGR treatment which could be explained by the THI because according to Hahn (1999) and EFSA (2004) the temperature range in which the animals do not need to spend additional energy to maintain body temperature and homeostasis is 0 to 28°C. In Mexico, economic development of the country affects the application of modern technologies and therefore, differences fattening systems exist in the country. On feedlots, high investment costs and lack of capital investment may delay the modernization of facilities (Van et al., 2015). Despite of subtracting the annual investment cost for the greenhouse roofs installation a profit of US$57.41 per steer in the PGR (a total of US$17,797.10), compared to the steers in PWR treatment was obtained. Nonetheless, other factors that were not evaluated in our study such as an "investment payback period" need to be included. To improve the conditions of welfare in which cattle are fattened at feedlots should be in principle ethical, however, it is clear that farmers will not put their income at risk. Our study has shown that it is possible to substantially improve housing and to provide better conditions for animals to be thermally protected, which in turn increases the efficiency and enhances the profitability of the farmer.

5. Conclusions

Under the winter conditions, the use of thermal plastic greenhouse roofs demonstrated an improvement of steers’ welfare, health, the average daily gain and feed conversion efficiency. As it was observed in this study, farmers in the area reported that providing shadow to the cattle reduced feed intake, however, the greenhouse roof in this study generated a microclimate that protected to the steers against cold, rain, wind, solar radiation and extreme temperature variation which offered greater comfort to the steers resulting in a superior average daily weight gain and feed conversion efficiency. The design and installation of these thermal plastic greenhouse roofs should be carefully planned for each feedlot and adapted to each terrain, because the height should allow the proper ventilation and to minimise the ammonia accumulation and excessive heat in the summer season, as well as damage to the structure caused by strong wind currents and hail.

Conflict of interests

The authors declared that they have no conflicts of interest with respect to their authorship and/or the publication of this article.

Ethical considerations

This study was approved by the Institutional Animal Ethics Committee for the Care and Animal Use (CICUAE) of the National Autonomous University of Mexico (UNAM).

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Fig. 1. The two treatments tested in the study: PWR treatment (a and b), and PGR animals (c and d).

a) b)

c) d)

PGR: pen with thermal plastic greenhouse roof. PWR: pen without thermal plastic greenhouse roof.

Fig. 2. Plastic greenhouse roof of feedlots located in a semiarid region in Mexico.

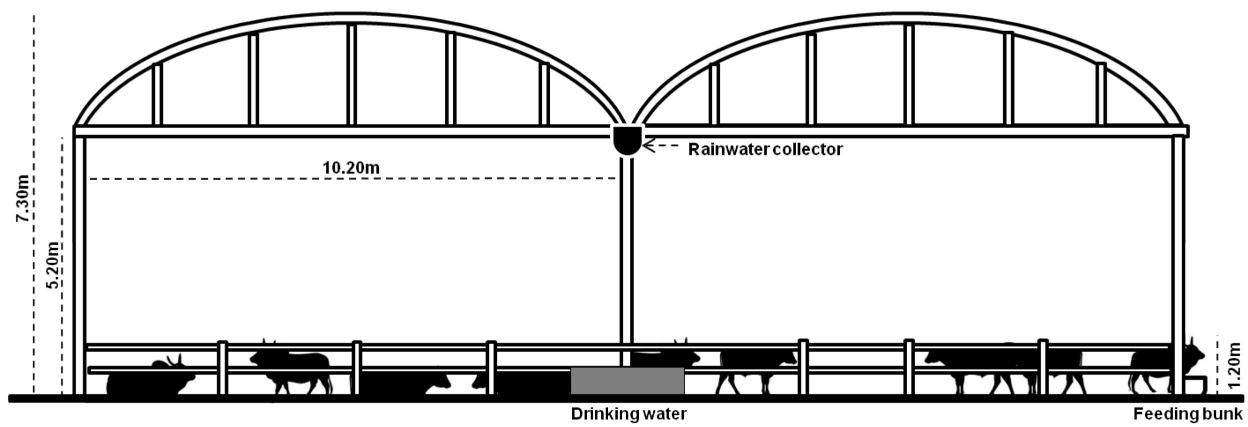
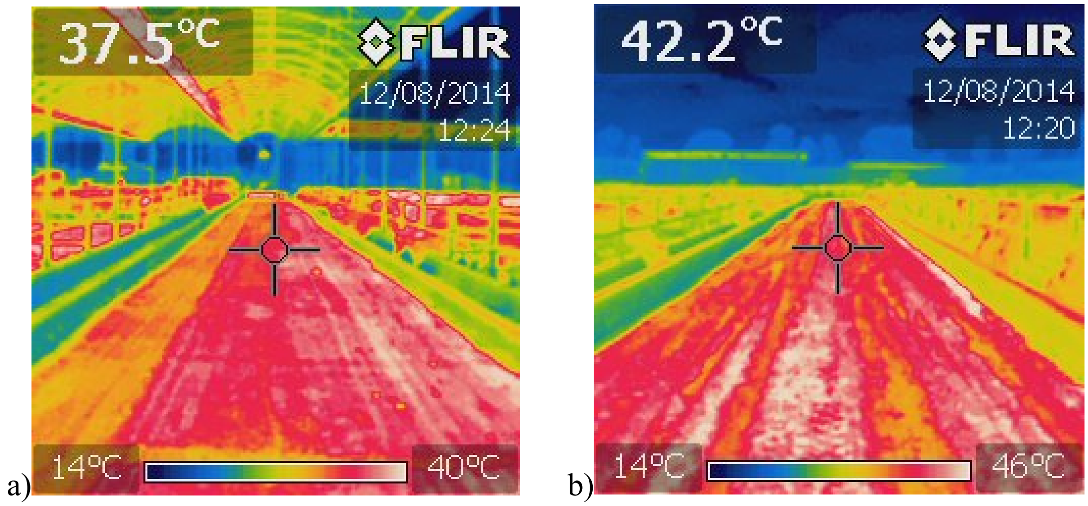
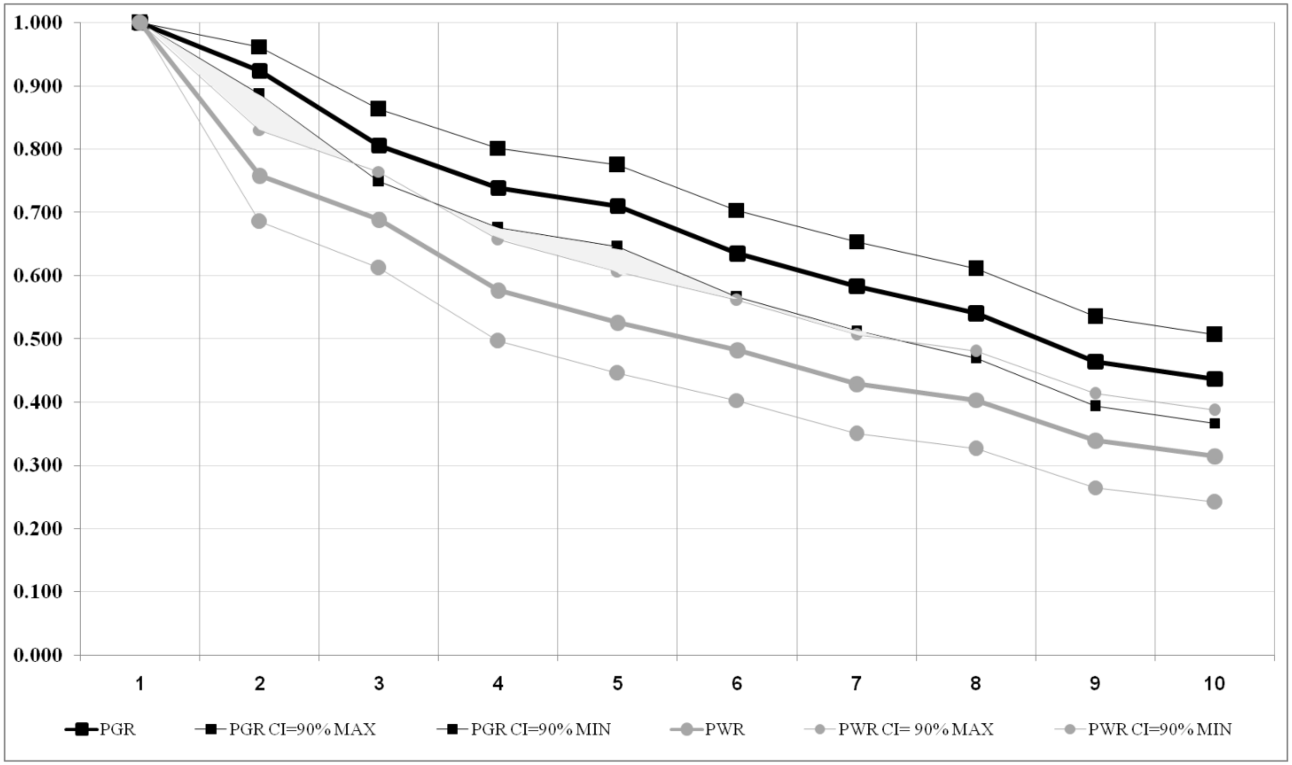


Fig. 3. Thermal image of surface temperature. (a) Soil temperature in PGR treatment, (b) Soil temperature in PWR treatment.



PGR: pen with thermal plastic greenhouse roof**;** PWR: pen without thermal plastic greenhouse roof

Fig. 4. Cumulative survival curve of Kaplan-Meier, steers with clear nasal discharge (CND) during ten weeks of fattening (CI= 90%) evaluated in PGR treatment and PWR treatment.



Gray shaded area indicates significant differences between treatments (P≤0.05).

Table 1. Recorded temperature in different periods of the day (n=3100 hours) along the fattening period.

Period	*Hour*	*PGR* *Median (IQR)*	*PWR* *Median (IQR)*	*P-value*
1	00:00 – 08:59	11.3 ^{a} (5.6)	9.9 ^{b} (5.7)	<0.001
2	09:00 – 09:59	11.5 ^{a} (6.7)	11.3 ^{a} (7.0)	NS
3	10:00 – 10:59	15.4 ^{a} (5.3)	16.3 ^{a} (6.1)	NS
4	11:00 – 11:59	19.8 ^{a} (4.3)	20.6 ^{b} (4.8)	0.036
5	12:00 – 12:59	22.7 ^{a} (4.3)	23.0 ^{a} (4.3)	NS
6	13:00 – 13:59	25.1 ^{a} (4.8)	24.6 ^{b} (4.5)	0.031
7	14:00 – 16:59	26.4 ^{a} (5.1)	25.9 ^{a} (5.4)	NS
8	17:00 – 17:59	24.6 ^{a} (5.2)	25.9 ^{b} (5.9)	0.040
9	18:00 – 18:59	23.6 ^{a} (4.7)	23.7 ^{a} (4.8)	NS
10	19:00 – 19:59	20.3 ^{a} (3.5)	19.5 ^{b} (4.1)	0.013
11	20:00 – 20:59	18.4 ^{a} (3.0)	17.0 ^{b} (3.9)	<0.001
12	21:00 – 21:59	16.7 ^{a} (3.6)	15.4 ^{b} (3.9)	<0.001
13	22:00 – 22:59	15.6 ^{a} (3.6)	13.9 ^{b} (4.0)	<0.001
14	23:00 – 23:59	14.3 ^{a} (4.4)	12.9 ^{b} (4.3)	<0.001

PGR: pens with thermal plastic greenhouse roof; PWR: pens without thermal plastic greenhouse roof; ^{ab}: Different letters at the same row indicate significant differences within treatments (P<0.05). IQR: Interquartile range; NS: no significant differences (P>0.05).

Table 2. Average and standard deviation (±SD) values for climatic conditions recorded during the fattening period (n=3100 hours).

Variable	*PGR* *Mean (±SD)*			*PWR* *Mean (±SD)*		
	Average	*Minimum*	*Maximum*	*Average*	*Minimum*	*Maximum*
Air temperature, °C	17.2±6.5	-1.4	32.7	16.4±7.1	-2.6	35.1
Relative Humidity, %	65.0±21	18.0	96.7	66.8±25	12.5	100
THI	60.7±8.7	32.1	78.0	59.4±9.7	28.2	82.8

THI (Temperature-Humidity Index) = [(0.8 x temperature) + (relative humidity/100) x temperature - 14.4) + 46.4]

Table 3. Percentage of animals showing a particular behaviour during three periods of observation.

Period	*Behaviour*	*PGR* Median (IQR)	*PWR* Median (IQR)	*P-value*
	Standing			
1	08:00 – 10:59	83.2 [a] (34.2)	60.0 [b] (47.0)	<0.001
2	12:00 – 14:59	38.7 [a] (15.6)	44.8 [b] (31.8)	<0.001
3	16:00 – 18:59	82.2 [a] (38.6)	81.8 [a] (26.7)	NS
	Lying down			
1	08:00 – 10:59	16.8 [a] (34.3)	40.0 [b] (47.0)	<0.001
2	12:00 – 14:59	61.3 [a] (15.5)	55.2 [b] (31.8)	<0.001
3	16:00 – 18:59	17.8 [a] (38.6)	24.7 [a] (9.7)	NS
	Feeding			
1	08:00 – 10:59	10.7 [a] (22.0)	11.40 [a] (8.5)	NS
2	12:00 – 14:59	14.8 [a] (9.4)	24.8 [b] (15.8)	<0.001
3	16:00 – 18:59	25.7 [a] (11.6)	24.7 [a] (9.7)	NS
	Ruminating			
1	08:00 – 10:59	10.0 [a] (10.6)	8.6 [a] (7.80)	NS
2	12:00 – 14:59	8.3 [a] (5.3)	6.6 [b] (5.6)	<0.031
3	16:00 – 18:59	4.4 [a] (7.0)	2.8 [a] (4.4)	NS
	Drinking			
1	08:00 – 10:59	1.8 [a] (1.6)	1.0 [b] (2.2)	<0.001
2	12:00 – 14:59	2.1 [a] (1.7)	1.4 [b] (2.3)	<0.002
3	16:00 – 18:59	1.5 [a] (1.5)	1.4 [b] (1.8)	<0.001

[ab]: Different letters at the same row indicate significant differences within treatments (P<0.05); IQR: Interquartile range; NS: no significant differences (P>0.05).

Table 4. Performance of the steers (n=620) during the fattening period (134 days).

Variable	*PGR* *Mean (±SD)*	*PWR* *Mean (±SD)*	*P-value**
BW_i (kg)	331.4 [a] ±48.7	334.9 [a] ±19.7	NS
BW_f(kg)	590.6 [a] ±36.8	582.1 [b] ±22.0	<0.001
ADG (kg)	1.9 [a] ±0.1	1.8 [b] ±0.1	<0.001
DMI (kg)	13.4 [a] ±1.3	14.5 [b] ±0.8	<0.001
FC	6.9 [a] ±0.9	7.9 [b] ±0.4	<0.001
Profit per steer (USD)	250.6 [a] ±56.1	193.2 [b] ±45.9	<0.001

*P values correspond to Student's t-test. [ab]: Different letters at the same row means significant difference of treatments (P<0.05). NS: no significant differences (P>0.05). BW_i: Initial body weight; BW_f: Final body weight; ADG: Average daily gain; DMI: Dry matter intake; FC: feed conversion efficiency; USD: American dollar.