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Amelioration of heat stress in feedlot cattle by dietary means

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Abstract

One way to alleviate heat stress in feedlot cattle may be to change the processing method or grain type being fed such that the peak evolution of heat from metabolic processes in the animal does not coincide with maximum environmental heat load. In order to provide proof of this concept, two feedlot finisher diets that differed only in grain type were fed to Hereford cattle. The wheat-based diet was fermented rapidly in the rumen, while fermentation of the sorghum-based diet was relatively less rapid.

When environmental heat load was imposed on 16 steers over 3 days in a climate room, cattle fed the wheat diet showed greater thermal stress than the cattle fed the sorghum diet, but when animals were subjected to a second period of heat load, the result was equivocal.

Before the feedlot industry can benefit from this finding, there needs to be experimental clarification of the response, followed by formulation of feeding strategies compatible with feedlot operation.

Executive Summary

Nutritional strategies may reduce the incidence and/or minimise the effect of high environmental heat load (EHL) in feedlot cattle. One such strategy would be to increase the dissipation rate of body heat during the cooler night hours, preferably without compromising growth rates. This could be implemented by managing feeding times or by altering the composition or the processing method of the dietary grain, to promote an increase in the proportion of metabolic heat that is evolved at night.

The principle objective of this preliminary study was to determine if cattle fed a diet containing slowly-fermentable grain would exhibit less heat stress than when fed a rapidly-fermentable grain under conditions of a cyclical EHL. To maximise the chances of obtaining “proof of concept”, maximum EHL in the climate rooms was timed to coincide with peak fermentation of the rapidly-fermentable wheat-based feedlot diet. As a control, a group of cattle were fed a sorghum diet, characterised by slow fermentation and a more uniform dissipation of metabolic heat from the body after feeding. Both diets were sourced from a commercial feed supplier. Compared to levels in the sorghum diet, starch content of the wheat diet was 95%, and nitrogen content was 109%. Digestibility of starch and energy was about 15% higher in animals given wheat which resulted in 8% higher intake of digestible starch in these animals.

In order to ensure the desired synchrony between EHL and metabolic heat production from the morning meal of the wheat-based diet, several techniques were used to characterise dietary fermentation patterns. Firstly, results using the dacron bag technique and rate of evolution of gas during *in vitro* fermentation of the diets, suggested that there were substantial differences in rates of digestion and fermentation in the rumen. Secondly, *in vivo* assessment of patterns of aerobic and anaerobic heat production was made by measuring gas exchange of animals in respiration chambers. This indicated that metabolic rate, reflecting aerobic metabolism in cattle tissue, was 6% higher in wheat-fed animals over a 7-hour post feeding period, consistent with differences in intake of digestible starch. In addition, wheat-fed steers expired 14% ($P<0.01$) more methane than sorghum-fed steers, attributable to methane from previous days’ feeds plus a burst of methane from feed eaten in the chamber. The burst of methane from wheat-fed steers over 8.5 hours post feeding was calculated to be twice ($P<0.05$) that from steers fed sorghum.

Sixteen steers were subjected to the first cyclic exposure of EHL over 3 days, employing a cycle that was calculated to avoid carryover of accumulated heat load between days. Most (75%) of the diet was fed at 0700 h, and maximum heat stress coincided with maximum EHL at 1400 h. On the basis of panting scores, respiration rates, and rectal temperature measured hourly between 0800 and 1700 h, steers fed wheat exhibited significantly more heat stress than cattle fed sorghum. Between the second and third day of EHL, there was a significant increase in mean rectal temperature. Changes in blood biochemistry, in particular in the expression of heat shock protein in lymphocytes, also supported the conclusion that steers fed the wheat diet had been subjected to greater heat stress than steers fed the sorghum diet.

When 8 steers were subjected to a second exposure to EHL, there were no differences in respiration rates or panting score, but the degree of stress was less than in the first exposure. However, wheat-fed steers showed greater swings in rectal temperature than did sorghum-fed animals, when corrected for rectal temperature patterns of the same steers at thermoneutrality, during both first and second exposures to EHL.

The project was deemed to be successful in its main aim, to demonstrate differential responses to EHL associated with diet, but interpretation of this result was confounded by the greater intake of digestible starch by wheat-fed steers. The results highlighted further areas that require clarification through experimentation before the industry can benefit from this research. Following this clarification, protocols appropriate to feedlot operations and incorporating the information about the diet characteristics could be devised.

Contents

1 Background - Section

Nutritional strategies may reduce the incidence and/or minimise the effect of high environmental heat load (EHL) in feedlot cattle (Sparke et al. 2001; Kennedy and Cronje, 2005). One such strategy identified was to increase the dissipation of body heat during the cooler night hours, preferably without compromising growth rates. This could be implemented by managing feeding times to alter the peak timing and/or pattern of body temperature fluctuations. For example, Davis et al. (2003) fed a corn-based diet to cattle at either 0800 or 1600 h, and found that cattle fed in the afternoon had lower body temperature at night. Another strategy identified was to alter the diet composition or processing method in order to change the amount or pattern of heat evolved from metabolic sources. Alternatively, a combination of these strategies, requiring changes to diet and time of feeding, might be tailored to normal feedlot operations, and result in the desired pattern of metabolic heat production relative to EHL.

2 Project Objectives

The principle objective of this preliminary study was to determine if cattle fed a diet containing slowly-fermentable grain would exhibit less heat stress than when fed a rapidly-fermentable grain under conditions of a cyclical EHL. To optimise the demonstration of "proof of concept", it was desirable that the maximum EHL applied in the climate rooms would largely coincide with peak fermentation of the rapidly-fermentable diet. As a control, a second diet was needed, characterised by slow fermentation, leading to a more constant evolution of metabolic heat during the period of high EHL. In order to select a feeding time that would achieve the desired synchrony between EHL and metabolic heat evolved from the readily-fermentable diet, it was deemed desirable to:

- Determine the likely digestion patterns of diets in the rumen
- Characterise the patterns of aerobic energy production in (non-rumen) body tissues
- Establish an experimental protocol to achieve synchrony between EHL and peak metabolic load for one diet.

Then

- To measure the animal response to EHL for cattle fed 2 diets, using behavioural and physiological indices.

3 Methodology - Section

3.1 Trial location and oversight

Trials were conducted in the animal house and two climate rooms at the J M Rendel Laboratory, CSIRO Rockhampton, in Queensland. An oversight committee, appointed by the MLA, gave advice on diet composition, feeding level, and whether the experiment should be extended to a second phase. The experimental protocol was approved by the JM Rendel Laboratory Animal Ethics Committee (permit RH232-07).

3.2 Animals, diets and heat exposure conditions

3.2.1. Diets

The oversight committee advised that the diets be fed at a rate of 2.7% (as fed) of body weight, that the diets should differ only by grain type, specified as wheat or sorghum, both grains processed by dry-rolling, and diets should not contain growth promotants. Accordingly no attempt was made to balance the diets for protein or digestible starch content. Diets were sourced from Young Country Enterprises, Biloela, Queensland, and conformed to their proprietary formulation for feedlot finisher (which typically contains sorghum). Grain and urea comprised 78% and 1 % of the ration respectively. The starch, energy and protein contents of the two diets are shown in Table 1. The detailed composition was provided by the supplier under a confidentiality clause. According to the general specifications contained grain, cottonseed meal, bentonite, urea, ammonium sulphate, biofos, salt, 'Feedlot 802" (but omitting lasalocid), cotton hulls, calcium carbonate, and molasses.

Initially, suitability of the diets was investigated by characterising their digestion patterns diets by; (i) incubation in dacron bags in the rumen of Brahman steers fed a ration comprising a 1:1 mixture of the two grain-based diets plus wheat straw (ii) determining the time course of gas evolution *in vitro* (Pell and Schofield, 1992). Subsequent *in vivo* measurements of methane emission and metabolic rate were made to characterise patterns of fermentation and total heat production after feeding. Methane measurements were attempted twice throughout the experiments; firstly in closed circuit chambers and secondly after conversion of these chambers to open circuit, but before establishment of their full capability to measure metabolic rate. With the chambers in closed circuit mode, steers were fed in pens, then removed to chambers where gas exchange measurement was interrupted at 30 minute intervals to allow for flushing of air. In contrast, during open-circuit measurements, uninterrupted methane emissions were made from steers consuming feed in the chambers over 9 hours.

3.2.2. Animals.

Twenty *Bos taurus* (Hereford) steers, mean weight 307 kg (range 261 to 370 kg), were trucked from Roma, Queensland in July 2007, treated for external parasites with Cydectin© and fed lucerne hay for 4 weeks while being trained to experimental conditions. The steers were then introduced to a 1:1 mixture of the grain diets, fed *ad libitum* plus 1.5 kg/d of wheat straw for a further 4 weeks during which training continued. The lightest 4 steers were allocated as 'spares' and subsequently were used to establish the EHL protocol and to test equipment in the climate rooms but not used further in the experiment. Sixteen steers were allocated into 4 groups of 4 on the basis of live weight, with group 1 containing the heaviest steers and group 4 the lightest. This procedure was adopted in order to maximise the live weight of steers when they were exposed to EHL. At the time of allocation, mean live weight of the groups ranged from 266 to 342 kg. On entering the climate room, steers were bled and weighed. Mean live weights were: group 1, 370 (standard error of mean, SEM 11) kg; group 2, 355 (SEM 6) kg; group 3, 331 (SEM 13) kg; group 4, 326 (SEM 27) kg.

After a recovery period, 8 steers, designated group 5 sourced from groups 3 and 4 (7 steers) or group 2 (1 steer), were randomly assigned to diets and exposed to a second EHL, when their live weights were 420 (SEM 26). The animals had been fed sorghum (3 steers) or wheat (5 steers) when previously exposed to EHL -one steer from group 4 was not included because it had been the most highly the heat-stressed animal in groups 1-4.

The maximum degree of heat stress imposed in this experiment conformed to that approved by the JM Rendel Laboratory Animal Ethics Committee; that approval required that no more than 50% of the cattle were to be exposed to moderate heat load as indicated by panting score of 3 (see MLA, 2006) during the hottest 3 hours.

3.3 Experimental protocol

Twelve weeks after steers had arrived in the animal house, the 4 animals in group 1, which had been feeding on the mixed grain ration plus 1.5 kg wheat straw, were randomly allocated to the diets and fed at a daily rate of 2.7% (as fed) of live weight, plus 1 kg/d of wheat straw. The animals were fed 75% of their ration at 0700 h and the remainder at 1700 h. After 14 days, these steers were moved to a climate room. This procedure was followed for the successive 3 groups at intervals of 1 week, so that all steers had been eating their allocated ration at fixed intake for 21 days at the time of the first day of EHL.

Cattle in groups were exposed to EHL in climate rooms in which ambient temperature and relative humidity could be controlled, and feed intake of the grain based diet (but not straw) was automatically logged every 10 minutes. Measured values for relative humidity deviated by a maximum of 4 %units around the set point and temperature was maintained within 0.2^{o}C of set point once the selected temperature was achieved. Temperature was ramped from a minimum of 24.5^{o}C to a maximum of 35^{o}C for 3 hours (1100 to 1400 h) for groups 1-4, and for 4 hours (1100 to 1500) for group 5.

For groups 1-4, conditions in climate rooms were either thermoneutral (24 ^{o}C, 50% RH) in climate room 1, or 24 ^{o}C/ 75% RH or as depicted in Figure 1 in climate room 2. The diurnal temperature cycle adopted resulted in a cycle of THI (temperature-humidity index) which ranged between 73.6 to 89.8. THI was calculated from the equation:

$$THI = 0.8 * Temp + (Temp - 14.3) * RH/100 + 46.3.$$

THI was maintained below 86 for 3 h after the main feed event at 0700, in order to encourage feed consumption. This was followed by a rapid increase in THI to allow the maximum EHL to coincide with the maximum fermentation of the wheat-based diet.

Following recovery for 4-7 weeks at thermoneutral conditions when steers were fed the sorghum diet ad libitum plus 1.5 kg straw, animals in group 5 were simultaneously exposed to a second 3-day EHL with a protocol similar to that that used for earlier groups, but the maximum THI of 90 was extended by an additional hour to 1500 h on each day of EHL.

Using accumulated heat load units, calculated using as 77 and 86 THI as lower and upper limits for *Bos taurus* animals (see MLA, 2006), it was expected that steers in groups 1 to 4 would start reducing accumulated load by 2000 h and would regain thermoneutrality by 0200 h (see Figure 1).

After steers had been in climate room 1 for 7 days, rectal temperature (RT) probes (Dallas *Thermocron* iButton DS1921H/Z, see Lea et al. 2008) were inserted and secured with a bandage around the base of the tail, heart rate monitors (*Polar* equine transmitter) strapped on, and steers were returned to the second climate room. Feeding patterns were then measured for 6 days, the last 3 being during EHL. Thus each group was in a climate room for 13 days, comprising 10 days of thermoneutrality and 3 days of cyclical EHL. During the 3 EHL days, panting scores (PS) and respiration rates (RR, breaths per minute) were measured by observers with stopwatches, on the hour between 0800 and 1700 h.

Blood samples were taken before feeding from steers as they were moved to climate room 1, and when they exited the second climate room after EHL, when rectal temperature probes and heart rate monitors were removed and data downloaded.

For the first exposure to EHL, one group of 4 steers was subjected to heat load for 3 consecutive days, with a different group used in each of 4 successive weeks. After the final group had exited the climate rooms, all animals were fed the mixed (1:1) grain diet at 2.7% of body weight per day until 12 were transported to abbatoirs. The remaining steers were allocated to form group 5 as previously described and exposed to EHL for a second series of 3 days, commencing 7 weeks after group 4 had exited from climate rooms. Finally after a further 7 days, a balance trial on these 8 steers was conducted over 7 days in order to determine starch digestibility of the diets.

4 Results and Discussion

4.1 Extent and pattern of fermentation of diets

Initial assessment of diet suitability, employing the dacron bag technique (Figure 2) and by measuring gas evolution with time *in vitro* (Figure 3), indicated substantially faster digestion and fermentation in the rumen of the wheat diet when compared to the sorghum diet.

Diets were further characterised by gas exchange (*in vivo*) measurement using animals allowed to eat for 1 hour in pens before being moved into respiration chambers. Results indicated that cattle fed wheat had a higher (by 5.5%) metabolic rate over 7 hours after feeding (Figure 4), consistent with greater aerobic metabolism of metabolites from starch, than for sorghum animals. Patterns of methane emissions indicated a more rapid decline for animals fed wheat (Figure 4). A more satisfactory comparison of methane emissions was obtained after conversion of respiration chambers to open circuit (Figure 5). During the 9 hours of measurement, wheat-fed steers expired 14% ($P<0.01$) more methane, attributable to methane from previous days' feeds plus a burst of methane from 2.5 kg feed eaten in the chamber. The latter burst was calculated to be twice ($P<0.05$) that from steers fed wheat than in steers fed sorghum.

Starch content of the wheat diet was 95%, and nitrogen content was 109% that of the sorghum diet. Digestibility of starch and energy was about 15% higher in animals given wheat which resulted in 8% higher intake of digestible starch in animals fed the wheat diet, consistent with the metabolic rate estimates.

The emission of methane over 6 hours (Figure 5) after feeding was consistent with the ruminal digestion of 75% of the ingested wheat starch and 40% of sorghum starch during that time, assuming that 24 g methane is evolved per kg digestible starch (Hindichsen et al., 2005).

4.2 Response of animals to cyclical THI

4.2.1. Patterns of feed intake.

Steers in groups 1-4 fed the wheat diet tended to eat more slowly than steers on sorghum; 25% and 50% of the wheat ration was consumed by 1.8 and 5.2 hours respectively, compared to 1.2 and 4.5 hours for the sorghum ration. For group 5, respective values for steers fed wheat were 1.9 and 4.3 hours, and for sorghum were 1.0 and 5.1 hours. Eating rate was not well related to PS, RR or RT.

4.2.2. Behavioural and physiological indices of thermal stress.

The heart rate monitors were unreliable, yielding data sets with many missing values. Results were not analysed.

For data collected from 0800 to 1700 h, RT and PS for steers for second EHL exposure were lower ($P<0.001$) than for the first exposure (groups 1-4) as shown in Table 2. Furthermore there was a significant interaction of diet with exposure (first or second), indicating inconsistency in responses in the two periods. Accordingly, separate analyses were conducted for the two exposures to EHL. In all analyses, live weight was used as a covariate.

4.2.2.1. First EHL exposure (groups 1-4).

Maximum values of PS, RR and RT were obtained at 1400 h (Figure 6), and means of all indices were significantly higher on the third day of EHL compared to previous days. Three quarters of wheat-fed steers were observed to have a RR of above 120 bpm and PS of 2 or greater, whereas only half of the sorghum steers exceeded these levels. Wheat-fed animals had higher RR, PS and RT (see Table 3).

During the thermoneutral day preceding the first EHL day, wheat steers had higher mean RT than sorghum steers (39.2 vs 38.9 ^{o}C, $P<0.001$, see Figure 7). For the three EHL days, mean RT was; wheat, 38.9; sorghum 38.6 ($P<0.001$). The mean increase from thermoneutral values at equivalent times of day, was 0.35 vs. 0.18 ^{o}C ($P<0.001$) respectively. Half of the wheat steers had achieved a RT of 40 ^{o}C or greater during EHL, compared to only 25% of sorghum steers. During EHL exposure, the minimum RT for wheat- and sorghum- fed steers was 38.8 and 38.1 ^{o}C respectively ($P<0.05$), and the minimum did not increase with day of EHL, indicating lack of carryover of accumulated heat load. Mean minimum RT was recorded at 0540 h and 0400 h for wheat and sorghum steers. The mean diurnal increase in RT, corrected for the pattern for the thermoneutral day prior to the first EHL day, was greater ($P< 0.05$) for wheat steers than in sorghum steers (0.35 ^{o}C vs 0.18^{o}C, see Figure 8). Between 0800 and 2100, this difference was 0.62 vs. 0.39 ^{o}C.

4.2.2.2. Second EHL exposure (group 5).

For data taken between 0800 and 1700, for EHL days, three quarters of wheat-fed steers, and all sorghum steers were observed to have a RR of above 120 bpm. Half of wheat steers and a quarter of sorghum steers had PS of 2 or greater. Wheat-fed steers had lower RR (87.7 vs 92.29 $P<0.05$) than sorghum-fed steers, but similar PS (0.64) and RT (38.8^{o}C). A RT of 40.0^{o}C or greater was achieved by 1 sorghum-fed steer.

In respect to the 24-h measurements of RT, wheat animals had lower mean RT than sorghum animals (38.3 vs 38.4 ^{o}C, $P<0.001$) during the thermoneutral day, but for the three EHL days, mean RT was identical (38.6^{o}C) for the two diets. The mean diurnal increase in RT, corrected for the pattern for the thermoneutral day prior to the first EHL day, was greater ($P< 0.05$) for wheat steers than in sorghum steers (0.35 ^{o}C vs 0.20^{o}C, see Figure 8). Between 0800 and 2100, this difference was 0.72 vs. 0.43 ^{o}C.

4.2.4. Blood stress indicators.

Biochemical indicators of stress, including general haematological measures and lymphocyte heat shock proteins, were analysed by Dr Linda Agnew at the CSIRO Armidale laboratory as part of the MLA-funded project “Interactions between the neurophysiological and immune systems as objective measures of animal welfare”, project number B.AWW.0184, and will be reported/discussed in the final report of that project). In general, wheat-fed animals exhibited significantly higher values, and in particular for heat shock protein, which is synthesised in response to hyperthermia (Table 3).

4.2.5. General comments

When interpreting results, the confounding of diet type with intake of digestible starch (and energy) needs to recognised. Other dietary factors, e.g. pH changes and perhaps temporary acidotic conditions in the rumen during rapid fermentation of the wheat diet, may also have played a part in the responses of steers on that diet to EHL, but these were not measured in the current experiment. The lower stress response for steers for RR and PS, but not for RT during a second exposure to EHL occurred despite more severe EHL. This was unexpected.

5 Success in Achieving Objectives

- Selection of diets to produce contrasting patterns of digestion was successful.
- Evidence was obtained that metabolic rate and ruminal digestion was higher in wheat-fed animals for 6-8 h after feeding, than for sorghum-fed animals.
- Demonstration was achieved of the influence of dietary differences in the expression of heat stress under conditions of cyclical environmental heat load during the first, but not unequivocally confirmed during the second EHL exposure.
- It is considered that ‘proof of concept’ was achieved, with some reservations. Differences in grain type and fermentation characteristics of a feedlot ration were associated with degree of heat stress, measured using a range of physiological and biochemical indices. There is still uncertainty concerning the relative importance of intake of digestible starch, fermentation patterns and other factors associated with grain type, in this response.

6 Impact on Meat and Livestock Industry

The impact on the feedlot industry will come only after more experimentation to clarify the mechanisms and specific diet characteristics involved in the differential responses observed in these experiments. Following this clarification, protocols appropriate to feedlot operations and incorporating the information about the diet characteristics that lead to differential responses in animals subjected to EHL, could be devised.

7 Conclusions and Recommendations

Conclusions from this trial are that substitution of a slowly-fermentable grain such as sorghum, in lieu of a rapidly-fermentable grain such as wheat or barley, impacts on the amount and pattern of ruminal starch fermentation. This study clearly indicates a dietary association with indices of heat stress, particularly rectal temperature, but further research is required before the effect can be ascribed to fermentation pattern rather than to differences in digestible starch intake.

Such experimentation should aim to untangle the effects of amount of starch digested, the pattern and site nutrient digestion and metabolism, and other dietary influences which affect the response of cattle to EHL. This would be aided by detailed consideration and balancing of dietary ingredients. The role of rate of eating the ration should be considered, and also the reasons for the increase in rectal temperatures between day 2 and 3 of EHL.

To this end, an appropriate experiment might include different times of feeding of two diets, one readily-fermentable and one slowly fermentable, using an EHL protocol more severe than used in the present study.

8 Acknowledgments

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10 Appendices

10.1 Tables

Table 1. Dietary characteristics of the grain-based feedlot diets.

	Wheat-based ration	Sorghum-based ration
Starch (g/kg dry matter,DM)	441	465
Energy (MJ/kg DM)	17.5	17.2
Nitrogen (g/kg DM)	30.5	28.0
Starch digestibility (g/kg starch intake)	970	850
Energy digestibility (kJ/MJ intake)	770	660

Table 2: First and second EHL exposures. Influence of diet on panting score, respiration rate, and rectal temperatures (LS means, covariate adjusted for live weight) measured hourly between 0800 and 1700 h. Cattle were exposed to EHL on 3 consecutive days.

	Wheat	Sorghum	P^y of difference, diet	First EHL exposure	Second EHL exposure	P^y of difference exposure
Respiration rate (bpm)	83.6	81.2	NS	84.8	80.0	0.08
Panting score	0.69	0.55	*	0.76	0.48	**
Rectal temperature (°C)	38.9	38.8	**	39.3	38.4	***

Table 3. First EHL exposure. Influence of diet on panting score, respiration rate, and rectal temperatures (LS means covariate adjusted for live weight) measured hourly between 0800 and 1700 h on 3 days of EHL.

	Wheat	Sorghum	P^y of difference
Respiration rate (bpm)	83.4	76.0	**
Panting score	0.79	0.57	**
Rectal temperature (°C)	39.2	38.9	**

Table 4: Influence of diet on post-heat exposure haematology
(LS means of transformed values where appropriate). (Data of Dr Linda Agnew).

Parameter	Wheat	Sorghum	P^y of difference
Tγδ lymphocyte hsp70 (% cells expressing protein)	0.873	0.423	*
Haemoglobin (g/dl)	2.686	2.092	*
Haematocrit (%)	0.665	0.526	*
Platelets (10^3/µl)	6.259	5.148	*

10.2 Figures

Figure 1. Conditions of THI (temperature-humidity index) during cyclical EHL of cattle, together with the calculated accumulated heat load.

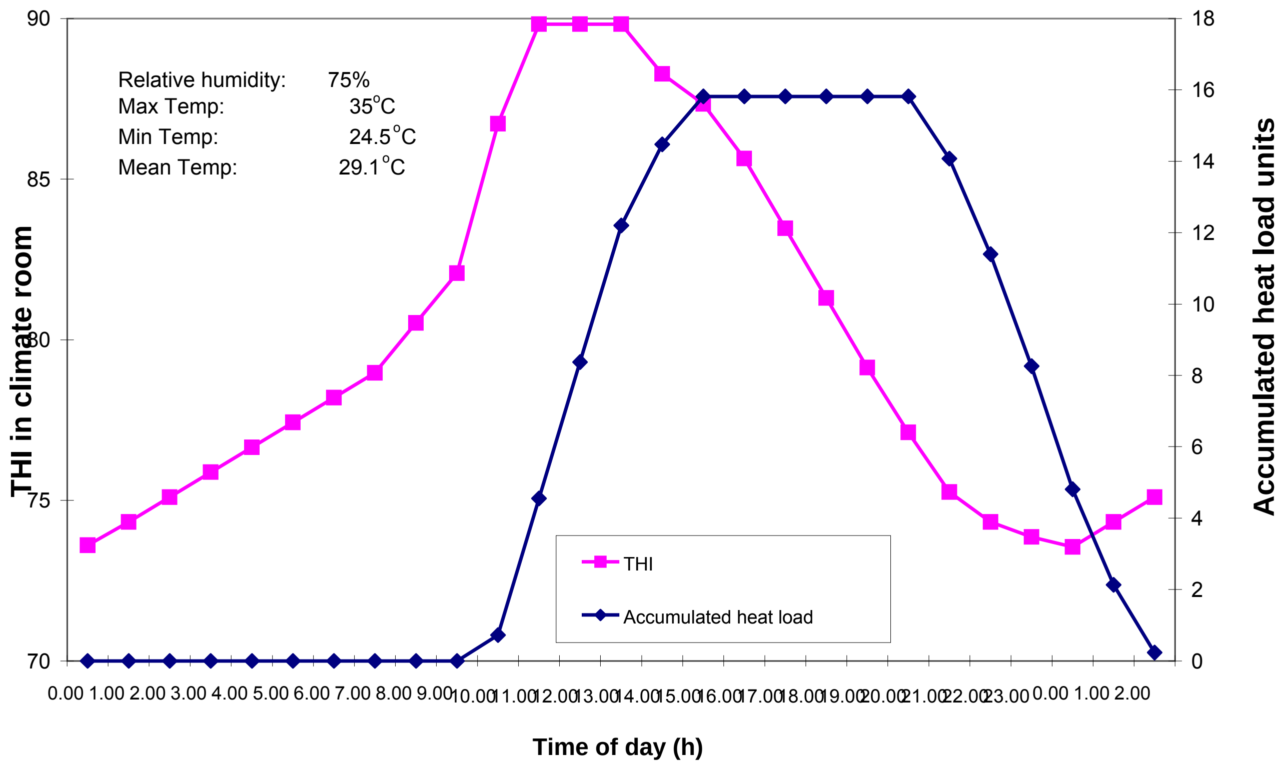


Figure 2. Disappearance of wheat- or sorghum-based diets from dacron bags incubated in the rumen

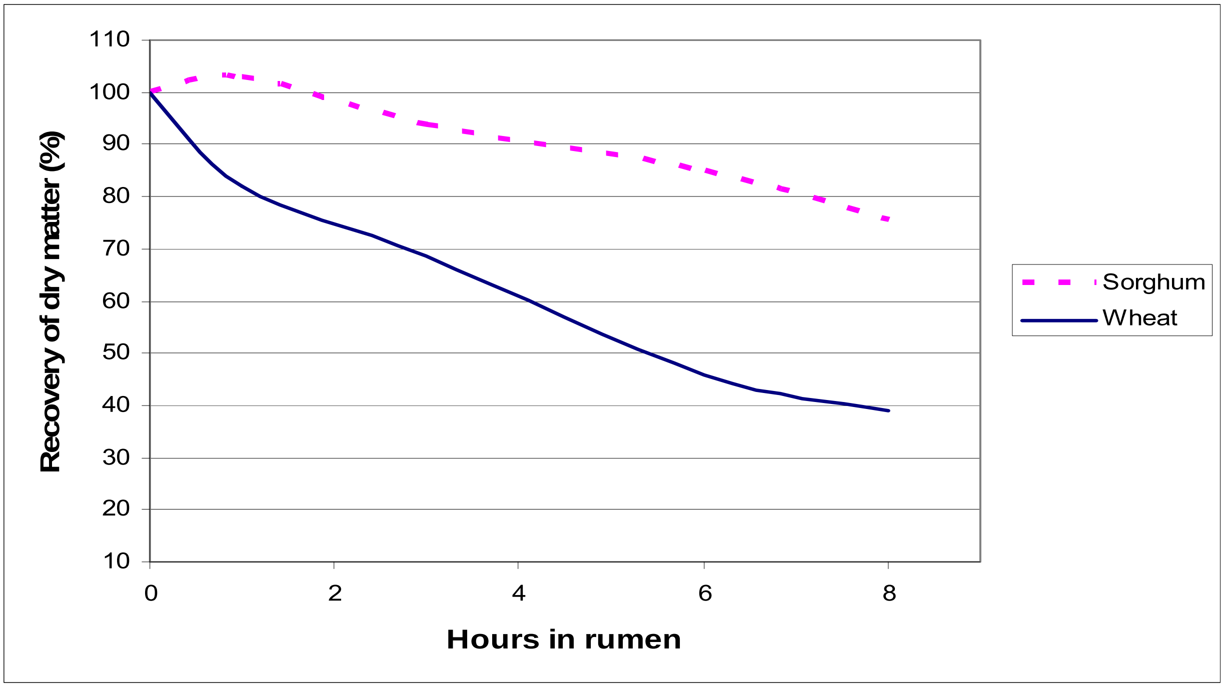


Figure 3. *In vitro* gas pressures during anaerobic fermentation of wheat- or sorghum-based diets.

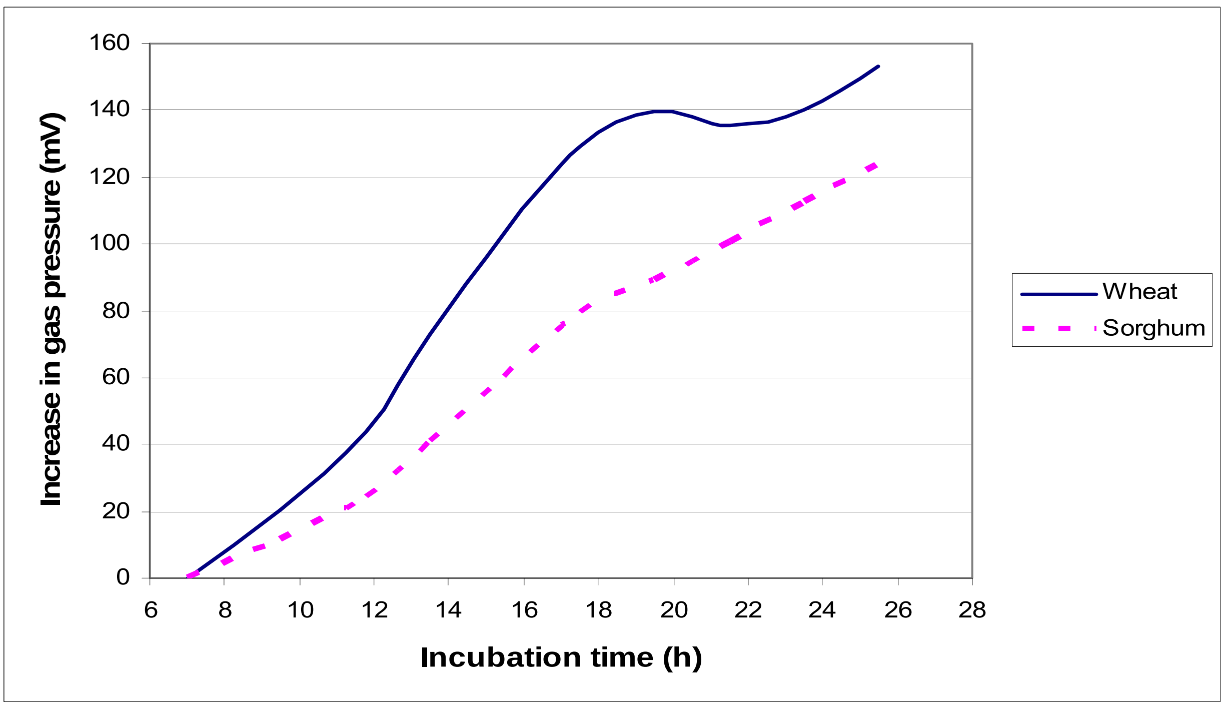
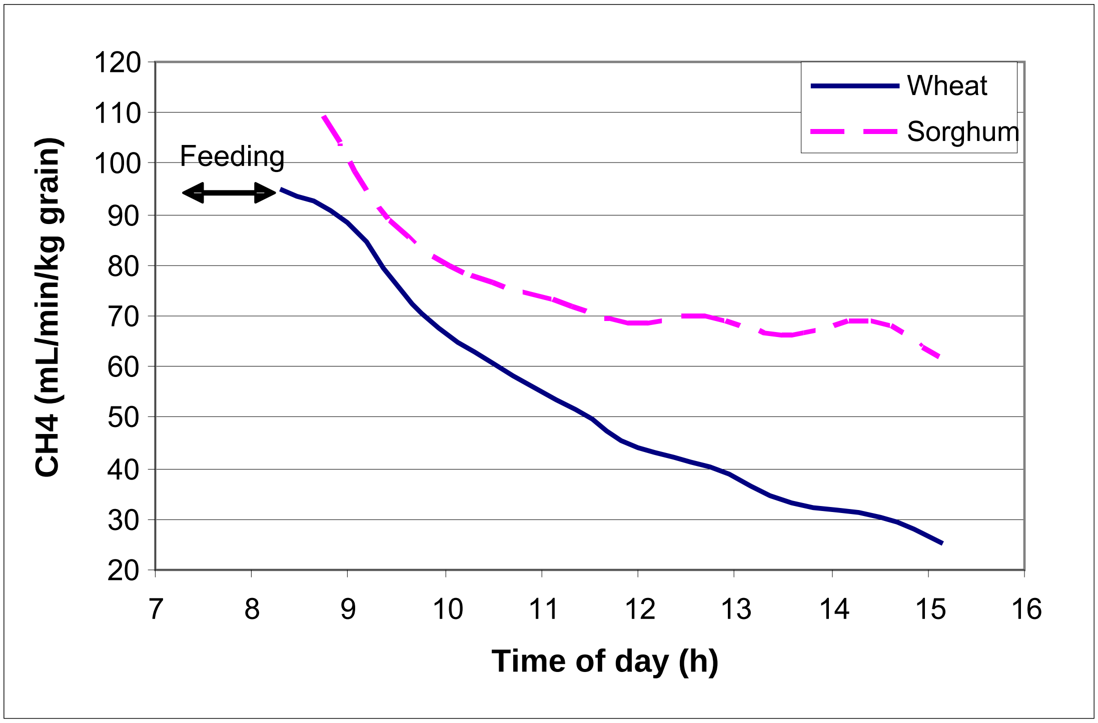
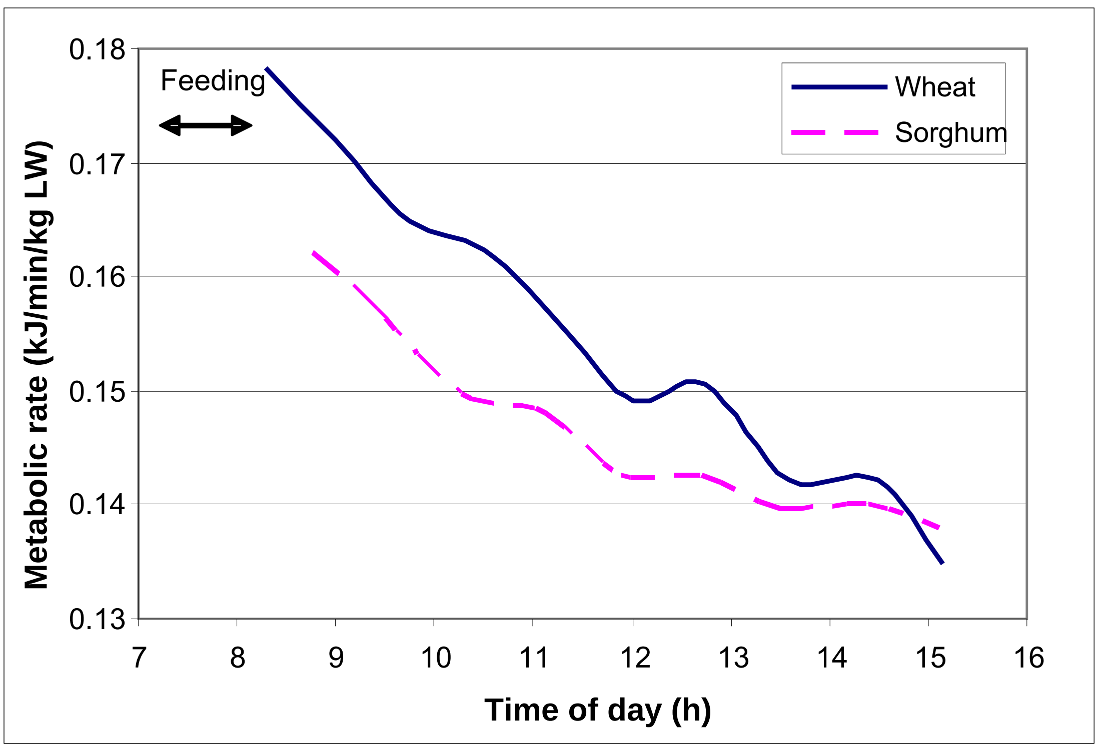


Figure 4. Methane production and metabolic rate of cattle after feeding either wheat or sorghum- based diets in respiration chambers.





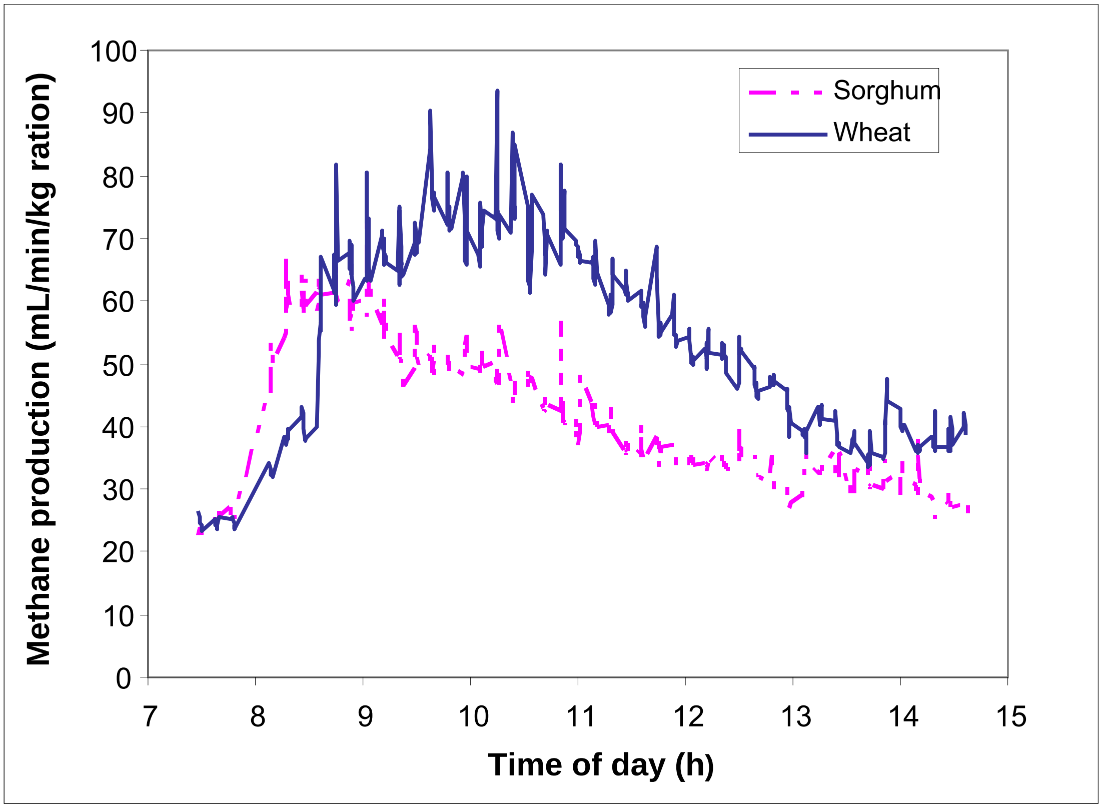


Figure 5.

Methane production, measured in open circuit chambers, from cattle fed 2.5 kg of wheat or sorghum-based diets in the chambers at 0800 h.

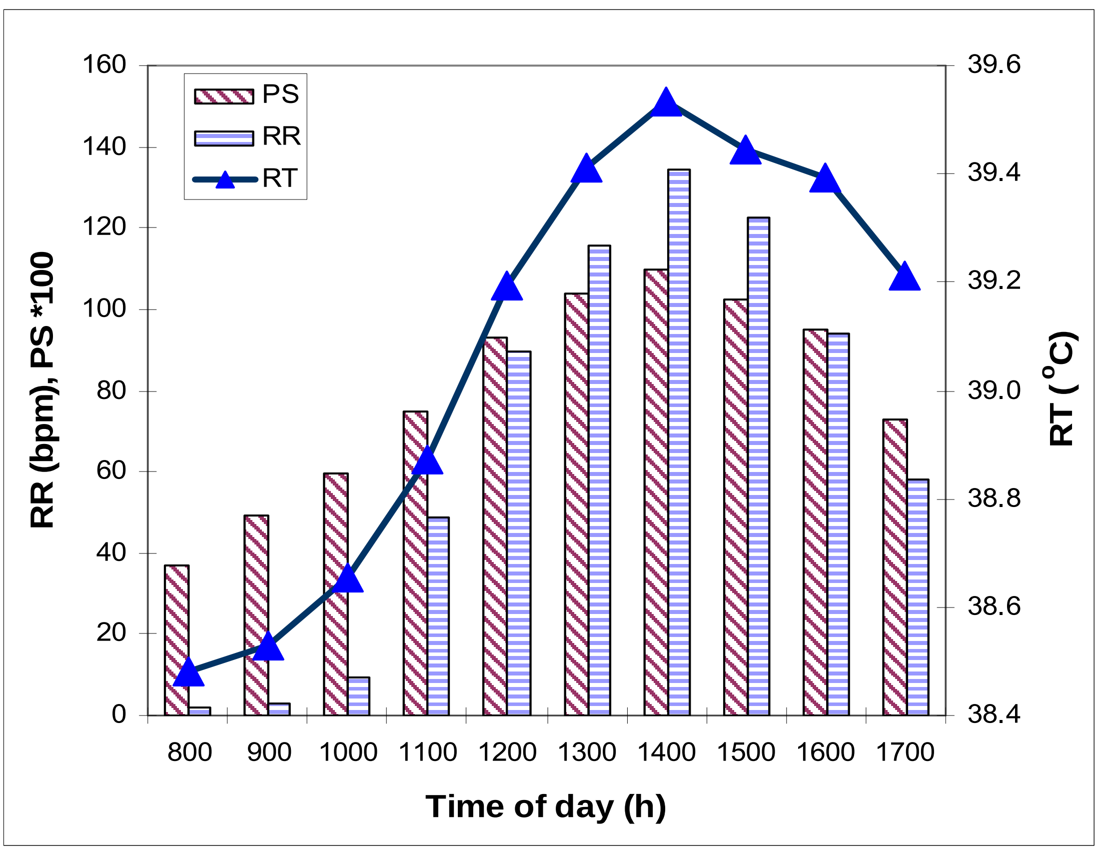


Figure 6.

Least squares means, (covariate corrected for live weight), for respiration rate, panting score *100, and rectal temperature versus time for groups 1-4 during environmental heat load.

Figure 7. First EHL exposure. Relationships with time of rectal temperatures (LS means, live weight as covariate) for steers fed wheat and sorghum-based diets for 4 consecutive days.
TN= thermoneutral, EHL= environmental heat load. Wheat-continuous line; sorghum, broken line.

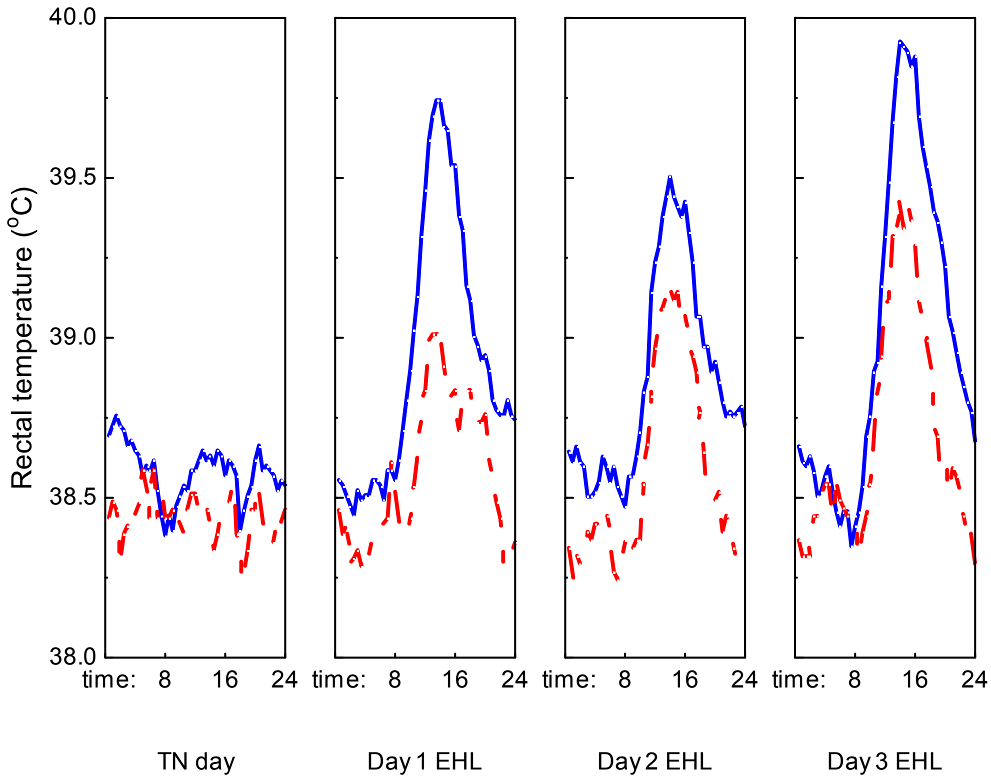


Figure 8. First and second EHL exposures. Diurnal cycle of rectal temperatures (LS means, live weight as covariate) corrected for rectal temperatures during thermoneutral day. Wheat-continuous line; sorghum, broken line.