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Beef Cattle Research in Texas

CAPITAL
FARM CREDIT

ADMINISTERING THE MATERNAL APPEASING SUBSTANCE IMPROVES OVERALL PRODUCTIVITY AND HEALTH IN HIGH-RISK CATTLE DURING A 60-D FEEDLOT RECEIVING PERIOD

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Summary

Beef cattle are exposed to several stressors during the initial days in the feedlot, which impair their immunity and lead to bovine respiratory disease (**BRD**). Strategies to mitigate stress upon feedlot arrival are warranted, including administration of the maternal bovine appeasing substance (**mBAS**). The mBAS is a mixture of fatty acids that replicate the composition of the original bovine appeasing pheromone, and shown to alleviate the physiological consequences elicited by stressful management procedures in beef cattle. In this study, male beef calves were purchased from a commercial auction yard soon after weaning, transported, and processed within a 48-h period. Calves were castrated and received a metaphylactic antibiotic treatment during initial processing, which are relevant management practices in US feedyards. In general, mBAS administration at initial processing and a booster 14 days later decreased physiological stress markers, improved immunity parameters, and reduced mortality by 83% during a 60-day feedlot receiving period. Calf growth and BRD incidence were not affected, but the reduced mortality from mBAS administration increased total liveweight production by the end of the experiment. Therefore, this study provides additional evidence of the benefits from administering mBAS to beef cattle upon feedlot arrival.

Introduction

Beef cattle are exposed to many stress and health challenges upon feedlot receiving which can lead to immunosuppression and increased occurrences of bovine respiratory disease (**BRD**) (Cooke, 2017). The industry has historically evaluated novel methods to mitigate stress and alleviate subsequent consequences to immunity and performance. Recent research has analyzed the utilization of administering the maternal bovine appeasing substance (mBAS) (Gaylean et al., 2022). The mBAS includes a mixture of fatty acids that replicate the composition of the original bovine appeasing pheromone. Previous research has demonstrated the application of the mBAS in the mitigation of stress induced consequences to performance and immunity in beef cattle (Cappellozza and Cooke, 2022). Additional research is needed to further investigate the mBAS use during additional management practices standard to the fed cattle industry. We hypothesize administration of the mBAS will improve immunity and productivity of lightweight, high-risk cattle castrated and receiving metaphylaxis at the time of feedlot receiving. To test this hypothesis, this experiment evaluated growth, physiological, and health responses of lightweight, high-risk cattle administered mBAS during a 60-d feedlot receiving period.

Experimental Procedures

This experiment was conducted at Texas A&M University – Beef Cattle Systems Research Facility. Angus-influenced (n = 120) recently weaned, non-castrated male calves were purchased from a commercial auction yard in southwestern Tennessee. On the day of purchase (d -2) cattle were transported 435 miles (12 h) to the research facility. Upon arrival, cattle were unloaded, immediately weighed (initial shrunk body weight [**BW**] = 439 ± 2.2 lb), and maintained as a single group for 24 h with *ad libitum* access to bermudagrass hay, water, and commercial mineral + vitamin mix. On d 0, cattle were allocated by shrunk BW to 1 of 2 treatments: mBAS (Ferappease®; FERA Diagnostics and Biologicals; College Station, TX; n = 60) or placebo (mineral oil; CON; n = 60). The mBAS active ingredient is based on a proprietary mixture of fatty acids added at 10% of the excipient and estimated to remain in treated animals for 15 d. Calves were separated into treatment groups with CON cattle processed first to avoid cross-contamination during application. Treatments (10 mL) were applied topically to the nuchal skin area (behind the poll; 5 mL) and above the muzzle (5 mL).

Immediately after treatment application on d 0, cattle were vaccinated against *Clostridium* (Covexin 8; Merck Animal Health), *Mannheimia haemolytica*, *bovine respiratory syncytial virus* (**BRSV**), bovine herpesvirus-1 (**BHV-1**), *bovine viral diarrhea virus* (**BVD**) 1 and 2, and *parainfluenza-3 virus* (**PI3**; Vista Once SQ; Merck Animal Health), anthelmintic (Safe-Guard, Merck Animal Health), growth-promoting implant (Synovex Choice®; Zoetis), tulathromycin (Draxxin; Zoetis), and band-castration (Callicrate Pro-BanderTM; No-Bull Enterprises, LLC). Cattle were ranked by shrunk BW within treatment and assigned to 1 of 10 drylot pens (12 calves/pen; 5 pens/treatment) balanced for equivalent BW. Pens were arranged in rows (5 pens/row) assigned to either mBAS or CON to preserve distance between treatments. From day 0 – 60, calves had free-choice access to water and a total-mixed ration (TMR) offered once daily in a manner to yield 10% residual orts for intake assessment. On d 14, calves were re-vaccinated for respiratory pathogens (Vista 5; Merck Animal Health) and received another 10 mL of assigned treatment.

Calf BW was recorded on d 0, 14, 28, 42, and 60 before daily feeding and shrunk BW was recorded on d 61 for average daily gain (**ADG**) calculation. Feed intake was evaluated daily from each pen by collecting and weighing offered and non-consumed feed then divided by the number of calves in the pen. Calves were observed daily for BRD symptoms according to the DART system (Zoetis) beginning after the d 7 postmetaphylactic interval. Briefly, cattle deemed necessary to receive antibiotic treatment were first administered Zactran (Boehringer Ingelheim), followed by a 7-day moratorium, then subsequently Nuflor (Merck Animal Health): 3-day moratorium, Excede (Zoetis): 5-day moratorium, and Bio-Mycin 200: removal from experiment.

Blood samples were collected on d 0, 14, 28, 42, and 60. Samples were analyzed for haptoglobin from all animals and BRD associated antibodies from animals not diagnosed with BRD illness. Additionally, 20 calves representative of average (2 calves/pen) were selected for blood collection at 2 and 4 h after initial processing to analyze cortisol and substance P concentrations. Hair samples were collected from the tail switch from each calf at the time of blood collection. Hair samples were analyzed for cortisol concentrations. Concurrently with hair and blood collections on d 0, 14 and 28, nasal swabs were collected from each animal for DNA extraction and 16S rRNA gene amplicon sequencing as in Pickett et al. (2023).

Results and Discussion

This experiment exposed newly weaned lightweight cattle to the stress of transport, commingling, initial processing, band castration, and a new environment within a 48-h period. Therefore, calves were considered high-risk to develop BRD illness (Wilson et al., 2017). While metaphylatic treatment is a useful industry method to manage BRD in high-risk calves (NAHMS, 2013), BRD incidence is difficult to completely eliminate. Therefore, management interventions such as mBAS have shown to improve first-treatment success rate.

Per experimental design, initial shrunk BW was similar (P = 0.92) between treatments. No treatment effects were detected (P = 0.40) for calf ADG during the experiment resulting in similar (P = 0.46) final shrunk BW. Feed intake and G:F were not affected ($P \geq 0.20$) by treatments. No treatment effects were detected ($P \geq 0.97$) for overall incidence of BRD signs nor timing of BRD incidence during the experiment. Although a greater proportion (P = 0.04) of mBAS calves diagnosed with BRD symptoms required one therapeutic antimicrobial treatment to regain health compared with CON calves. Colombo et al. (2020) attributed mBAS treatment to the earlier detection of BRD signs and lessened disease recurrence upon first therapeutic antimicrobial treatment in young cattle. Although in this experiment, metaphylatic treatment may have prevented early detection of BRD, nonetheless, mBAS calves had an increased proportion regaining health after a single therapeutic antimicrobial treatment. The proportion of calves excluded from the experiment (mortality + removals) was less in mBAS vs. CON when comparing all calves or only those with BRD signs. Furthermore, a greater ($P \geq 0.05$) proportion of mBAS calves completed the 60-d receiving period compared to CON (96.7 vs. 88.4% of all calves; 94.1 vs. 79.4% of calves diagnosed with BRD). This favorable decrease in mortality and removals suggest enhanced response to metaphylaxis and subsequent antimicrobial interventions.

Change in total liveweight per pen during the experiment and final total liveweight per pen were greater ($P \leq 0.04$) for mBAS vs. CON pens. This difference is a result of decreased removal rate of mBAS calves throughout the experimental period. The increased number of calves remaining in the experiment for the duration lead to increased feed cost for mBAS pens. Additionally, estimated medication costs did not change according to treatment despite increased efficacy of first antimicrobial use in mBAS calves. Accordingly, estimated final pen-based value profit were both increased by mBAS administration. The pen-based assessment provides evidence of the economic benefits of mBAS to receiving yards; however, it should be interpreted and extrapolated with caution as values used for cattle, feed, and medications vary according to time and location.

No treatment differences were detected (*P* = 0.97) for serum concentrations of substance P following castration on d 0. However, serum concentrations of cortisol after castration were reduced (*P* < 0.01) in mBAS compared to CON calves. Substance P is commonly used as a pain biomarker in cattle after castration, whereas cortisol concentrations are utilized as a biomarker for acute stress in cattle (Coetzee et al., 2008; Carroll and Forsberg, 2007). These results indicate mBAS administration did not alleviate pain but lessened the physiological stress reaction perceived from the pain of castration. Additionally, calves receiving mBAS treatment had less hair cortisol concentrations on d 14 (*P* = 0.08) and d 28 (*P* = 0.01) compared to CON calves. Cortisol concentrations from tail switch hair is a proven biomarker of chronic stress as cortisol is gradually accumulated in the emerging tail hair (Moya et al., 2013). Thus, mBAS administration lessened chronic stress during the period in which mBAS remains active (Cappellozza and Cooke, 2022). No treatment effects were detected for serum concentrations of haptoglobin (*P* = 0.51). Stressors associated with feedlot arrival stimulate an acute-phase response and subsequently elevate circulating haptoglobin. Previous studies have found peak circulating haptoglobin can be detected within 10 days of feedlot arrival (Cooke, 2017; Sousa et al., 2019) whereas this experiment sampled cattle on d 14, which may have limited mBAS effect on circulating haptoglobin concentrations. Serum concentrations of PI3 antibodies were greater (*P* ≤ 0.03) for mBAS compared to CON calves on d 42 and 60. Antibodies against BVDV and BHV-1 had no detected differences (*P* ≥ 0.81). The benefits of mBAS to vaccine efficacy can be attributed to alleviated stress during receiving, which is observed in serum and hair cortisol concentrations.

Although the bovine respiratory tract involves a variety of microorganisms that coexist in a harmonious state, stress can disrupt the microflora balance and increase immunosuppression leading to BRD (Bosch et al., 2013). Individual nasal swabs analyzed for bacteria from 29 different phyla and 864 different genera with the 5 most prevalent phylum and 10 most prevalent genus reported. Within phylum, calves administered mBAS had decreased (*P* = 0.04) mean prevalence of Tenericutes on d 14 and 28, with no other differences (*P* ≥ 0.34) for phylum compared with CON calves. Similarly, mBAS administration decreased (*P* = 0.04) mean prevalence of the genera *Mycoplasma* in swabs collected on d 14 and 28, with no other genera differences (*P* ≥ 0.18) detected compared to CON treatment. Tenericutes are one of the most prevalent bacterial phyla present in the nasopharynx and trachea of feedlot cattle (Timset et al., 2018). Within this phylum, the genus *Mycoplasma* is found, which is a major pathogen associated with BRD (Caswell and Archambault, 2007). The reduction in *Mycoplasma* did not alter BRD signs or timing of symptoms although did result in improved response to therapeutic antimicrobial treatment and decreased mortality. Nonetheless, this relationship warrants further investigation as the results are novel but support immune benefits of mBAS use during feedlot receiving.

Conclusions

High-risk calves were castrated and received metaphylaxis upon arrival, both relevant practices in US feedyards. Administration of the mBAS during the experiment decreased physiological stress markers, improved immunocompetence parameters and reduced mortality during a 60-d receiving period. Although calf performance and BRD incidence was not affected by mBAS treatment, an observed decrease in mortality resulted in greater pen-based liveweight change and final liveweight by the end of the 60-d receiving period. This experiment provides additional evidence of the benefits for mBAS administration on overall performance and health responses in receiving yards.

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Tables and Figures

Table 1. Performance parameters during a 60-d feedlot receiving period of beef calves administered the maternal bovine appeasing substance (mBAS; n = 5) or mineral oil as placebo (CON; n = 5).

Item	CON	mBAS	SEM	*P-value*
Initial body weight (d -1),[2] kg	439.6	440.0	4.0	0.92
Final body weight (d 61),[2] kg	568.4	559.5	8.4	0.46
Average daily gain, kg/d	2.08	1.93	0.12	0.40
Feed intake,[3] kg/d	10.54	10.54	0.20	0.99
Gain to feed,[4] kg/kg	0.395	0.366	0.013	0.20

Table 2. Morbidity and mortality parameters during a 60-d feedlot receiving period of beef calves administered the maternal bovine appeasing substance (mBAS; n = 5) or mineral oil as placebo (CON; n = 5).

Item	CON	mBAS	SEM	*P-value*
Steers treated for respiratory disease, %	56.7	56.7	6.4	0.99
One treatment required	47.0	70.6	8.3	0.03
Two treatments required	26.5	20.6	7.3	0.59
Three treatments required	5.88	2.94	3.56	0.56
Four treatments required (removals)	2.94	2.94	2.91	0.99
Overall mortality, %	10.0	1.66	3.00	0.04
Steers treated for respiratory disease	17.6	2.94	5.13	0.03
Overall mortality + removals, %	11.6	3.33	3.38	0.05
Steers treated for respiratory disease	20.6	5.88	5.75	0.04

Table 3. Physiological responses of beef calves administered the maternal bovine appeasing substance (**mBAS**; n = 5) or mineral oil as placebo (**CON**; n = 5).

Item	CON	mBAS	SEM	*P-value*
Responses during the day of initial processing				
Serum cortisol after castration, ng/mL	36.6	25.6	2.1	< 0.01
Serum substance P after castration, pg/mL	1856	1849	138	0.97
Responses during the 60-d receiving period				
Serum haptoglobin concentrations, mg/mL	0.693	0.771	0.080	0.51
Serum antibodies against BVDV types I and II, S:P	1.51	1.50	0.07	0.91
Serum antibodies against BHV-1, S:P	2.29	2.26	0.10	0.81

Table 4. Productive and economical responses during a 60-d feedlot receiving period of pens containing beef calves administered the maternal bovine appeasing substance (mBAS; n = 5) or mineral oil as placebo (CON; n = 5).

Item	**CON**	**mBAS**	**SEM**	***P-value***
Productive responses				
Initial liveweight (shrunk),[2] lb/pen	4795	4802	4	0.47
Final liveweight (shrunk),[2] lb/pen	5476	5900	143	0.04
Liveweight gain, lb/pen	681	1098	143	0.04
Total feed intake,[3] lb/pen	6841	7363	216	0.09
Gain to feed,[4] lb/lb per pen	0.214	0.326	0.033	0.04
Economical assessment[5]				
Initial value, $/pen	14,185	14,202	15	0.47
Final value, $/pen	15,350	16,534	418	0.04
Feed cost, $/pen	1,194	1,286	30	0.09
Medication cost, $/pen	265	229	30	0.53
Profit, $/pen	-294	816	408	0.04

Table 6. Bacterial composition (relative abundance, %) and diversity (Shannon diversity [SD index]) in the nasal cavity of beef steers administered the maternal bovine appeasing substance (**mBAS**; n = 5) or mineral oil as placebo (**CON**; n = 5).

Item	**CON**	**mBAS**	**SEM**	***P-value***
Bacterial phyla				
Tenericutes	34.2	27.0	2.3	0.04
Proteobacteria	26.9	30.3	2.4	0.34
Firmicutes	19.2	21.2	1.7	0.42
Actinobacteria	13.0	12.9	1.4	0.95
SD index	1.25	1.28	0.03	0.45
Bacterial genera				
Mycoplasma	34.7	27.4	2.3	0.04
Mannheimia	16.8	19.3	3.0	0.57
Corynebacterium	5.20	5.65	0.75	0.68
Salinicoccus	2.41	2.69	0.37	0.61
Cellulomonas	1.43	1.01	0.43	0.50
Pedobacter	1.70	2.91	0.60	0.18
Dietzia	1.06	1.25	0.15	0.39
Clostridium	1.24	1.24	0.10	0.97
Butyrivibrio	1.76	2.04	0.24	0.42
Blautia	1.08	1.67	0.30	0.18
SD index	2.56	2.73	0.12	0.37

ADMINISTERING A MATERNAL APPEASING SUBSTANCE BEFORE SLAUGHTER TO IMPROVE CARCASS CHARACTERISTICS OF FINISHING CATTLE

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Summary

Feedlot cattle are exposed to several stressors during processing for slaughter that directly impact their carcass and meat quality traits. Therefore, strategies to reduce stress in feedlot cattle prior to and during slaughter are needed. Maternal bovine appeasing substance (**mBAS**) is a solution that replicates the natural pheromone, and has shown to alleviate negative symptoms of stressful management. Two experiments evaluated carcass characteristics of finishing steers administered mBAS for 7 days prior to slaughter, using oilers. Experiment 1 evaluated finishing steers in a large-pen commercial feedlot, whereas experiment 2 was conducted in a small-pen research feedyard. Administration of mBAS increased carcass dressing by 1.7% and 1.0% in Experiments 1 and 2, respectively. Steers that received mBAS in experiment 2 also had lower blood cortisol concentrations at slaughter. Hence, mBAS administration to finishing cattle is a potential alternative to improve carcass dressing by alleviating the stress elicited by the process of slaughter.

Introduction

Feedlot cattle are exposed to several stressors during processing for slaughter that directly impact their carcass and meat quality traits (Kumar et al., 2023). Stress has been associated with several negative traits on beef carcasses (Grandin, 1980; Cheng and Sun, 2008); therefore, management strategies to minimize stress in feedlot cattle prior to and during slaughter are needed.

Maternal bovine appeasing substance (**mBAS**) is a solution that replicates the natural pheromone, and has shown to alleviate negative effects of stressful management procedures (Cappellozza and Cooke, 2022). Previous research has suggested potential for mBAS application during the last week of feeding to mitigate stress caused by handling cattle for truck loading (Scanga et al., 1998).

Oilers are already in use in feedlots and can also be used to deliver mBAS to cattle prior to slaughter (Barker et al., 2017). Therefore, we hypothesized that mBAS administration using oilers will reduce the stress caused by handling, transporting, and processing cattle for slaughter, resulting in improved carcass traits.

Experimental Procedures

Experiment 1

Experiment 1 was conducted at Pride Feeders in Adams, OK. A total of 954 Angus-influenced finishing steers were implanted and housed in 6 original pens. Table 1 describes the number of steers per pen, days on feed (**DOF**), body weight (**BW**), and days before slaughter, before treatments started. Immediately before the start of treatments, the six pens were split into two with each having the same number of steers and a similar average body weight. An oiler containing **mBAS** (Ferappease® Finish Cattle 5%; FERA Diagnostics and Biologicals; College Station, TX) was added to one pen 7 days prior to slaughter, while the other pen did not receive an oiler (**CON**). The oiler was designed to deliver 120 ml of mBAS per steer during a 7-day period.

All steers were slaughtered on the same day at National Beef Packing Company in Liberal, KS. Steers from the CON pen were weighed and loaded into livestock trailers in the morning (up to 36 steers/trailer). Immediately after the CON steers were loaded, steers from the mBAS pens were loaded the same way. Trailers traveled together for 30 miles to the packing plant where the CON steers were unloaded first. In the packing plant, the CON and the mBAS pens were maintained in separate, distant pens, and steers were slaughtered within 6 hours after arrival. Hot carcass weight (**HCW**), carcass quality grading, and incidence of dark cutters were recorded by the packing plant, and HCW was used to calculate carcass dressing according to the final BWs.

Experiment 2

Experiment 2 was conducted at the Texas A&M - McGregor Research Center in McGregor, TX. A total of 80 Angus-influenced finishing steers, averaging 1320 lbs., were assigned to this experiment. Steers were also implanted, and were housed in 16 pens (5 steers/pen). Each pen received one oiler (Prairie Phoenix Cattle Care System) containing **mBAS** (Ferappease® Finish Cattle 5%) or mineral oil (placebo; **CON+**) 7 days prior to slaughter. Half of the pens received mBAS and half received mineral oil. The oilers were designed to deliver 120 ml of mBAS or mineral oil per steer during a 7-day period.

Steer BWs were recorded 7 day prior to slaughter and at the time of loading to the packing plant (Tyson Foods in Amarillo, TX). As in Experiment 1, steers from CON+ pens were loaded into livestock trailers (20 steers/trailer) followed by mBAS pens (20 steers/trailer). All trailers traveled together to the packing plant where CON+ steers were unloaded first. Afterward, CON+ and mBAS pens were maintained in separate, distant pens. All steers were slaughtered within 6 hours after arrival. Upon slaughter, blood samples were collected during harvest into blood collection tubes with an anticoagulant for plasma collection. Hot carcass weight (**HCW**) was recorded soon after. Plasma samples were analyzed for concentrations of cortisol. After a 24-h chill, trained personnel assessed carcass characteristics including backfat thickness at the 12th-rib, marbling, and *Longissimus muscle* (**LM**) area.

Results and Discussion

Experiment 1

Initial BW was not different between CON and mBAS, as designed. Body weight gain and final BW were also similar between treatments (Table 2). Despite the benefits of mBAS to growth of weaned and feedlot receiving cattle (Cappellozza et al., 2020; Schubach et al., 2020; Colombo et al. 2020), BW gain was not expected to differ because of the short length of mBAS administration and the lack of major stressors during the final 7 days on feed. No differences were observed for proportion of carcasses that graded Choice or Prime (Table 2), as mBAS was also not expected to affect marbling during the last week on feed.

Carcass dressing was greater by 1.7% in mBAS steers (Table 2), which could be associated with reduced body tissue breakdown and less muscle glycogen depletion. One of the primary stress responses is to consume muscle glycogen stores and breakdown liver, muscle, and fat tissues to provide nutrients for restoration of normal bodily function (Nelson and Cox, 2005; Carroll and Forsberg, 2007). Muscle glycogen content directly impacts water holding capacity (**WHC**), as glycogen molecules bind up to 4 times their weight in water (Olsson and Saltin, 1970). It seems possible that mBAS administration increased carcass dressing by alleviating the stress associated with the slaughter process, thus reducing body tissue breakdown and increasing WHC of muscle cells. Nonetheless, treatment effects on carcass dressing did not affect HCW (Table 2).

Muscle glycogen is responsible for the formation of dark-cutting meat, as glycogen content is negatively associated with post-harvest meat pH (Apple et al., 2005). No treatment differences were noted for proportion of carcasses classified as dark cutters (Table 2). The incidence of dark cutters in this experiment averaged 1.8% which matched values reported by the 2016 National Beef Quality Audit (1.9%; Boykin et al., 2017).

Experiment 2

No treatment effects were detected for BW parameters, as well as carcass marbling score, backfat thickness, LM area, yield grade, and proportion of carcasses that graded Choice or Prime (Table 3). As in Experiment 1, mBAS was not expected to affect BW gain, muscle development, or marbling during the final 7 days on feed. Carcass dressing was greater by 1.0% in mBAS steers (Table 3), but there was still no effect on steer HCW (Table 3). Steers from this experiment were transported for 447 miles to the packing plant. Carcass dressing was calculated based on steer BW at loading and HCW. Hence, dressing calculation included the BW shrink caused by the long transport, resulting in carcass dressing values lower than in Experiment 1 (65%) and the industry average (63%; Davis et al., 2024). If a 4% pencil shrink is added to final BW to adjust for transport (González et al., 2012), the dressing percentage remains greater in mBAS compared with CON+ (63.2 vs. 62.2%, respectively).

Blood plasma concentration of cortisol upon slaughter was decreased by 44% in mBAS steers compared to CON+ (Table 3). This outcome supports our hypothesis and provides evidence that mBAS administration alleviated the stress associated with processing for slaughter (Cappellozza and Cooke, 2022). Cortisol plays a key role in the stress response (Sapolsky et al., 2000), and directly stimulates glycogen and muscle tissue breakdown (Nelson and Cox, 2005). Hence, the increase in carcass dressing in both experiments could be associated with less body tissue breakdown and increased WHC of muscle cells in mBAS steers. However, additional research is warranted to prove this rationale, including post-harvest glycogen breakdown potenetial and raw and cooked meat quality traits from cattle administered mBAS prior to slaughter (Wulf et al., 2002). No differences were noted for proportion of carcasses classified as dark cutters (Table 3). The incidence of dark cutters in this experiment (3.75%) was above industry average (1.9%; Boykin et al., 2017) and values from Experiment 1 (1.8%), which can also be associated with the long transport to the packing plant (Warren et al. 2010).

Conclusions

Administering mBAS to finishing cattle using oilers during the last 7 days on feed alleviated the stress associated with the process of slaughter, and resulted in increased carcass dressing. mBAS and CON steers were exposed to stressful conditions after they were removed from the pens, which could limit the potential impacts of oilers on results from Experiment 1. Other factors such as transport distance, small-pen vs. large-pen management, feedlot location, and packing plant procedures are also likely to have contributed to differences between experiments (Edwards-Callaway et al., 2020). Therefore, additional research is warranted to further characterize the benefits of mBAS administration to finishing cattle prior to slaughter.

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Table 1. Number of steers, days on feed (**DOF**), average body weight (**BW**), and days prior slaughter when 6 original pens were split into a pair of experimental pens and enrolled in Experiment 1.[1]

Item	Heads, n	DOF	BW	Days prior to slaughter, d
Pen 1	144	189	662	13
Pen 2	208	260	608	16
Pen 3	147	206	627	23
Pen 4	189	169	627	14
Pen 5	128	214	648	9
Pen 6	138	226	647	11
Mean ± SE	159 ± 13	210 ± 13	636 ± 8	14.3 ± 2.0

[1] Steers within each original pen were weighed and placed into two pens in a manner that number of steers and average pen BW were similar.

Table 2. Experiment 1 - Body weight (**BW**) and carcass characteristics of steers assigned to pens that contained or not (**CON;** n = 6 pens, 477 steers) an oiler that delivered the maternal bovine appeasing substance (**mBAS**; n = 6 pens, 477 steers) during the last 7 days prior to slaughter.[1,2]

Item	CON	mBAS	SEM	*P =*
Initial BW, lbs	1403	1397	18	0.75
Final BW, lbs	1439	1423	15	0.48
Average daily gain, lbs/d	2.35	1.83	0.55	0.51
Hot carcass weight, lbs	924	9393	9	0.29
Carcass dressing, %	64.2	65.9	0.5	**0.02**
Carcasses classified as dark cutters, %	2.83	0.87	1.10	0.23
Carcasses graded Choice or Prime, %	81.1	78.5	5.2	0.73

[1] The oiler (Prairie Phoenix Cattle Care System; Whitehorse, SD) containing mBAS (Ferappease® Finish Cattle 5%; FERA Diagnostics and Biologicals; College Station, TX) was designed to deliver 120 ml of mBAS per steer during a 7-day period. Oilers were checked daily and mBAS was replenished according to dosage when necessary.
[2] Initial BW was recorded when steers were assigned to experimental pens (mBAS or CON; 14.3 ± 2.0 d prior to slaughter), and final BW was recorded when steers were loaded for transport (30 mi) to the packing plant (National Beef Packing Company; Liberal, KS). Carcass characteristics were reported by the packing plant, and carcass dressing was calculated according to final BW and hot carcass weight.

Table 3. Experiment 2 - Body weight (**BW**) parameters, carcass characteristics, and plasma cortisol concentrations upon slaughter in steers assigned to pens that contained an oiler that delivered the maternal bovine appeasing substance (**mBAS**; n = 8 pens, 40 steers) or mineral oil (**CON**; n = 8 pens, 40 steers) during the last 7 days prior to slaughter.[1,2]

Item	**CON**	**FERA**	**SEM**	***P =***
BW parameters				
Initial BW, lbs	1322	1318	33	0.82
Final BW, lbs	1364	1320	13	0.79
Average daily gain, lbs/d	0.29	0.28	0.47	0.98
Carcass characteristics				
Hot carcass weight, lbs	790	801	9	0.47
Carcass dressing, %	59.6	60.6	0.3	**0.02**
Marbling score	396	401	11	0.78
Backfat, in	0.42	0.41	0.02	0.55
Longissimus muscle area, in^2	14.5	14.8	0.17	0.20
Yield grade	2.31	2.21	0.08	0.35
Carcasses classified as dark cutters, %	5.13	2.44	2.95	0.53
Carcasses graded Choice or Prime, %	46.1	51.2	7.9	0.65
Plasma cortisol upon slaughter, ng/mL	20.8	11.7	1.6	**< 0.01**

[1] Oilers (Prairie Phoenix Cattle Care System; Whitehorse, SD) containing mBAS (Ferappease® Finish Cattle 5%; FERA Diagnostics and Biologicals; College Station, TX) or mineral oil were designed to deliver 120 ml of mBAS per steer during a 7-day period. Oilers were checked daily and mBAS was replenished according to dosage when necessary.
[2] Steer initial BW was recorded 7 d prior to slaughter, and final BW was recorded when steers were loaded for transport (447 mi) to the packing plant (Tyson; Amarillo, TX). Upon slaughter, a blood sample was collected during harvest into a blood collection tubes containing an anticoagulant. Hot carcass weight was recorded soon after. Carcass dressing was calculated according to final BW and hot carcass weight. Trained personnel assessed carcass characteristics after a 24-hour chill. Backfat thickness was measured at the 12^{th} rib; marbling score: 300 = $Slight^{00}$, 400 = $Small^{00}$; yield grade calculated according to USDA (1997).

INNOVATIVE TECHNOLOGIES IN LIVESTOCK PHENOTYPING: THE INTEGRATION OF BOLUSES AND GPS COLLARS AT TEXAS A&M AGRILIFE RESEARCH-BEEVILLE STATION

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Summary

Two sensor systems were implemented, Smaxtec and Smart Paddock, on 60 multi-breed Brahman-influenced cows. They monitor internal body temperature, rumination, drinking behavior, location and movement. Based on Brahman breed percentage, two cow groups were formed (0-15% BR and 20-75% BR). Changes in average body temperature over time were investigated using linear regression and moving averages. Hotspot analysis for GPS data was performed. Results showed that 0-15% BR, during hot season, had a higher average body temperature (0.24 °F; $P < 0.05$). Body temperature was highly correlated with THI, and it increased by 0.05 °F per unit THI ($P < 0.001$). In conclusion, integrating boluses and GPS collars enabled monitoring of animal health, movement, and grazing behavior. Real-time big data from these systems aids in understanding cattle grazing behavior in subtropical environment. The THI index proves to be a reliable measure of environmental changes experienced by animals.

Introduction

Phenotyping technologies represent a transformative opportunity in modern agriculture. With advancements in sensor technologies, such as Boluses and GPS collars, coupled with the capabilities of big data analytics, cattle phenotyping has evolved dramatically. These technologies enable continuous and real-time monitoring of cattle health, productivity, and environmental interactions. At Texas A&M AgriLife Research-Beeville Station, we adopted these two technologies to monitor animal's internal body temperature, rumination, drinking behavior, movement, and location. These systems were deployed on 60 mixed-breed cows of the heat tolerant part of the USDA-ARS Meat and Animal Research Center, Clay Center, NE (**USMARC**) Germplasm Evaluation Project (**GPE**). The long-term goal of this project is to enhance our understanding of fitness traits of cattle grazing in a subtropical environment. This study aims to provide an overview of current research at the Beeville station and present initial findings from integrating boluses and GPS collars.

Experimental Procedures

Animals. The beef cattle herd at Texas A&M AgriLife Research-Beeville Station comprises 120 multi-breed Brahman-influenced females, including 60 bred cows and 60 2-year-old heifers. These cattle were sourced, January 2023, from the USMARC GPE project. The main breeds in this genetically diverse herd are Brahman, Beefmaster, Santa Gertrudis, Brangus, Hereford, Red Angus, and Charolais.

Data. Alongside the standard data collection of production and reproduction traits, we implemented two sensor systems: Smaxtec (https://smaxtec.com/us/) and Smart Paddock (https://www.smartpaddock.com/). These systems were deployed on 60 mature cows. The Smaxtec system uses boluses (SmaXtec Classic Bolus SX.2 US) that are orally administered and reside in the reticulum to monitor various parameters critical to animal health and performance. These parameters include internal body temperature, rumination, activity, and drinking behavior, recorded every 10 minutes. The Smart Paddock system uses GPS collars and tags to monitor an animal's location every 20 minutes and movement through an accelerometer. These two systems are employed to measure cows' responses to environmental changes (e.g., heat stress) as well as forage utilization and how these factors affect their grazing behavior, movement, water drinking, and body temperature.

A weather station (https://www.davisinstruments.com/) was installed on site to systematically collect meteorological data at 5-minute intervals. Data on ambient temperature, relative humidity, wind speed, and solar radiation provides insights into environmental conditions affecting animals. These measurements were combined to calculate various indices that represent the "feels-like temperature" experienced by animals.

Analysis of bolus data. Internal body temperature data (10-minutes intervals; from 3/22/2024 to 6/22/2024) collected from boluses were combined with its corresponding weather data from (5/7/2024 to 6/22/2024). Besides ambient temperature (**AT**), various heat stress indices were calculated (Python Software Foundation, 2023). These indices were Temperature-Humidity Index (**THI**; Thom, 1959), Adjusted Temperature-Humidity Index (***adj.*** **THI**; Mader et al., 2006), Heat Load Index (**HLI**; Gaughan et al., 2008), and Comprehensive Climate Index (**CCI**; Mader et al., 2010). Brahman breed percentage were used to classify cows into 2 groups (0-15% BR "heat sensitive" and 20-75% BR "heat tolerant"). Based on data, two seasons were defined as cool (March-April) and hot (May-June). For each season, summary statistics of daily average body temperature by group were calculated and boxplots were generated. Further, the daily average body temperature was regressed (R Core Team, 2024) on group (0-15% BR and 20-75% BR), hide color (Black, Red, and Gray), and HLI. To identify the best index and underlying trends for body temperature over time, moving averages (**MA**; 1 to 480-Hours) for body temperature and AT, THI, adj. THI, HLI, and CCI were calculated and correlated

Analysis of GPS data. Collar and ear tag GPS data collected from 2/19/2024 to 3/19/2024 were used to monitor animal movement and to identify areas of the pasture where animals showed most activity (e.g., shade, water source, feeder, forage utilization). Hotspot analysis (Python Software Foundation, 2023) was used to identify these areas of interest. Heatmaps obtained from this analysis help us understand the grazing behavior of animals.

Results and Discussion

Summary statistics and distribution of daily average body temperature, by group within season, are presented in Table 1 and Fig. 1. During cool season both groups have nearly similar distribution for body temperature. Here, the group 20-75% BR on average showed slightly higher body temperature (within 0.02 °F difference). However, during the hot season both groups showed more pronounced fluctuations and higher variation in body temperature where SD increased by 69 and 32% for 0-15% BR and 20-75% BR, respectively (Table 1 and Fig. 1). The heat sensitive group (0-15% BR) was on average higher by 0.2 °F.

Figure 2 depicts 8-hour, daily, and 10-day moving averages of the mean body temperature for the two groups of cattle. The 8-hour MA shows a lot of fluctuation and doesn't clearly show the underline trend of body temperature over time (Fig. 2A). As a wider window is used (daily and 10-Day MA; Fig. 2B and Fig. 2C, respectively), the trend becomes more pronounced and evident. In Figure 2C, the 10-Day MA of the two groups moved close to each other during the cool season, however, the heat sensitive group showed more variation and higher increase than the heat tolerant group. Differences in the daily MA between groups are depicted in Fig. 3, which showed that differences between groups increased as animals experienced more heat stress.

Correlations between equal-window MA for body temperature and various Indices are represented in Fig. 4. Estimated correlations between body temperature and THI were consistently higher than those with other indices. For all indices, correlations with body temperature had the highest value at 10-Day MA (Table 2 and Fig 4). The 10-Day correlations were 0.95, 0.94, 0.92, 0.91, and 0.72 for THI, CCI, AT, HLI, and *adj.* THI, respectively. Even though CCI, HLI, and *adj.* THI, in their calculations, account for wind speed and solar radiation, an interesting result was that THI outperformed them. These results showed that THI is a good predictor of environmental changes.

Figure 5 shows correlations between (24, 72, 168, 240, 360, and 480-Hour) MA for body temperature and (1 to 480-Hour) MA for THI. Maximum correlations ranged from 0.69 to 0.95. The 24-Hour MA for body temperature had the highest correlation with 24-Hour MA for THI (r = 0.69). The highest correlation (r = 0.95) was between 240-Hour MA (10 days) for body temperature and 240-Hour MA (10 days) for THI.

Based on correlations from Fig. 5, the standardized 10-Day MA for Body Temperature by group (0-15% and 20-75% BR) were plotted against standardized 10-Day MA for THI (Fig. 6). The standardized 10-Day MA for Body Temperature for the heat sensitive group (0-15% BR) was mirroring the movement of THI, which infers a very high association (i.e., MA of group 0-15% BR was almost a function of THI MA). For the heat tolerant group, it also followed the movement of THI; however, changes in its body temperature were minimal (Fig. 6).

Table 3 presents the regression coefficients (Estimates ± SE) for the daily average body temperature in relation to THI, hide color, and Brahman-influenced group. The intercept is estimated at 99.05 ± 0.24 ($P < 0.001$). The slope for THI was 0.05 ± 0.003 °F/*unit* THI ($P < 0.001$), suggesting that for each unit increase in THI, the body temperature increases by 0.05 °F. Hide color was not significant ($P > 0.05$). Additionally, the heat tolerant cattle group (20-75% BR) showed a lower body temperature (-0.24 ± 0.021 °F; $P < 0.05$) compared to the heat sensitive cattle.

Figure 7 shows hotspot analysis of GPS data collected from February 19 to March 19, 2024. This data was collected on two breeding groups during the breeding season (group in pastures 1 and 2, and the other group in pasture 20). The hotspots in this heatmap correspond to locations that had the most GPS fixes (i.e., most movement). These hotspots relate to locations of water source, feeders, and shade.

Conclusions

In conclusion, the Integration of Boluses and GPS Collars at Texas A&M AgriLife Research-Beeville Station facilitated monitoring animal health (e.g., body temperature), movement, and grazing behavior. To reach the long-term goal of better understanding fitness traits of cattle grazing in a subtropical environment, real-time big data collected using these systems can provide valuable information on animals under this environment. The Temperature-Humidity index was proven to be a reliable measure of environmental changes experienced by animals.

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Table 1. Summary statistics for body temperature (0-15% BR vs. 20-75% BR) during cool and hot season

Season		Group	N	Mean	SD	Minimum	Maximum	Difference
Cool	(March-April)	0-15% BR	112,608	102.31	0.43	100.4	105.1	-0.02
		20-75% BR	105,984	102.33	0.46	100	105.9	
Hot	(May-June)	0-15% BR	114,563	102.85	0.73	100.3	107.4	0.2
		20-75% BR	107,824	102.66	0.61	100.4	106.6	

Table 2. Correlations between body temperature 10-day moving average (MA) and various indices[1] 10-day MA

	THI	CCI	AT	HLI	*adj.* THI
Body temperature	0.95	0.94	0.92	0.91	0.72

[1]HLI = Heat Load Index, THI = Temperature-Humidity Index, AT = Ambient temperature, *adj.* THI = Adjusted Temperature-Humidity Index, and CCI = Comprehensive Clime Index.

Table 3. Regression coefficients (Estimates[1] ± SE) for daily average body temperature (F) on THI[2], Hide color, and Brahman-Influenced group.

	Estimate	SE
Intercept	99.05***	0.24
THI	0.050***	0.003
Hide color		
Red	-0.10	0.11
Gray	-0.24	0.16
Group		
20-75% Brahman	-0.24*	0.09

[1]*: $P < 0.05$; ***: $P < 0.001$

[2]THI = Temperature-Humidity Index.

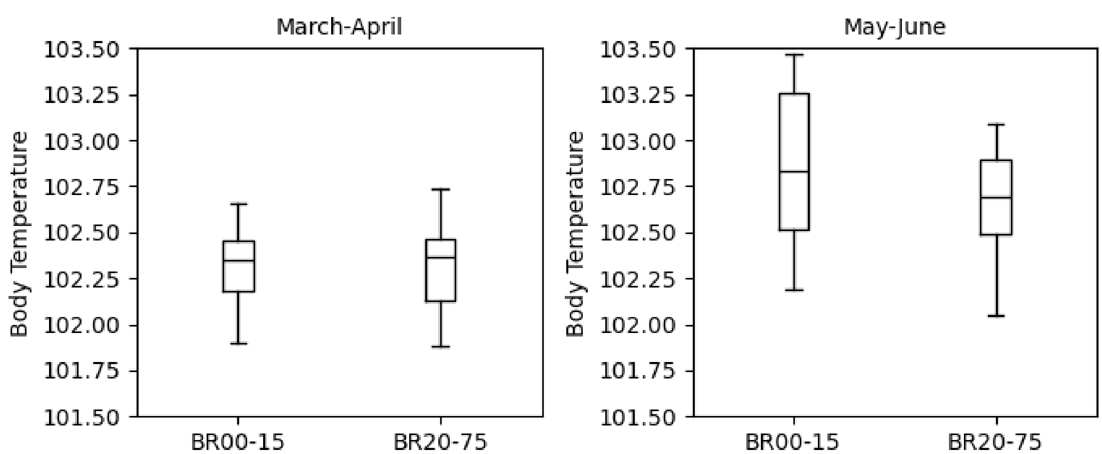

Figure 1: Boxplot of average body temperature (0-15% BR vs. 20-75% BR) during cool and hot season.

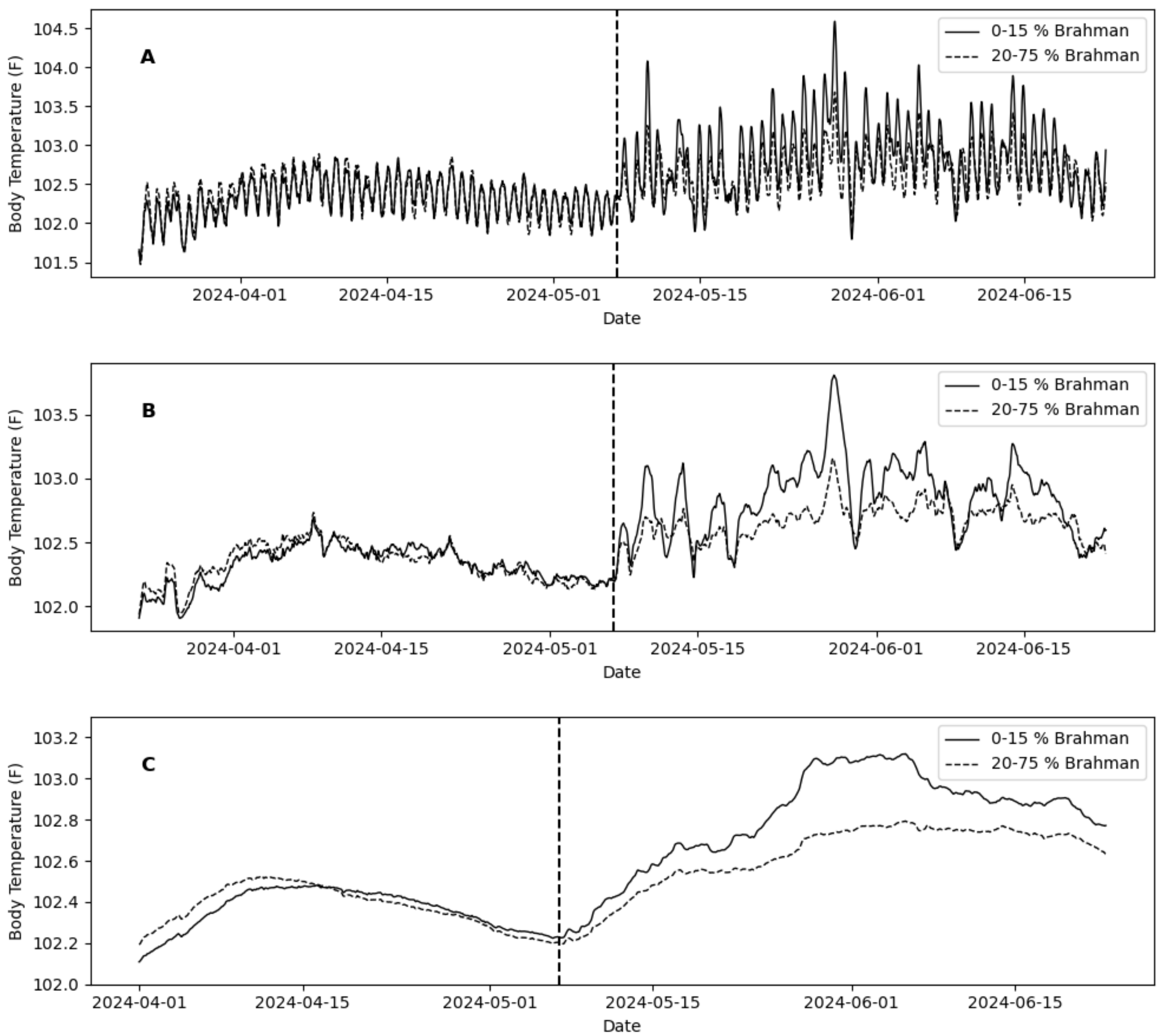

Figure 2: Moving Averages (**A**: 8-hour, **B**: Daily, and **C**: 10-day) of Mean Body Temperature for 0-15 % Brahman vs. 20-75 % Brahman.

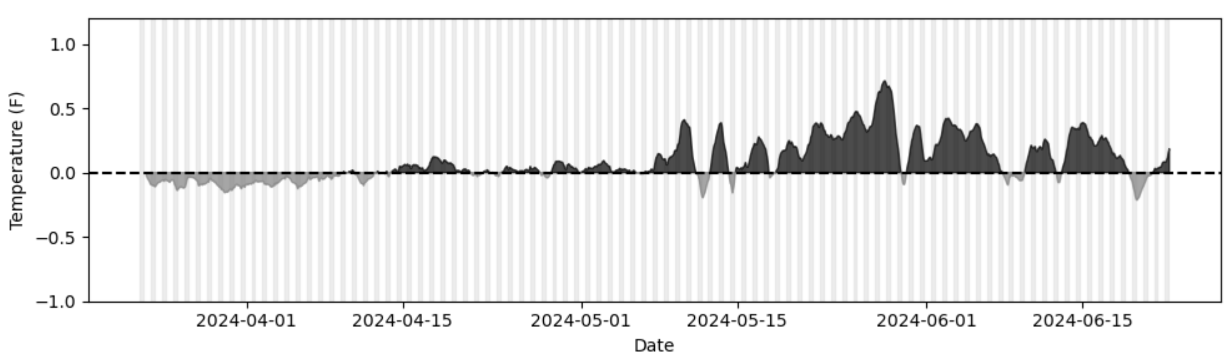

Figure 3: Difference in daily moving average for body temperature (Difference = 0-15% Brahman - 20-75% Brahman)

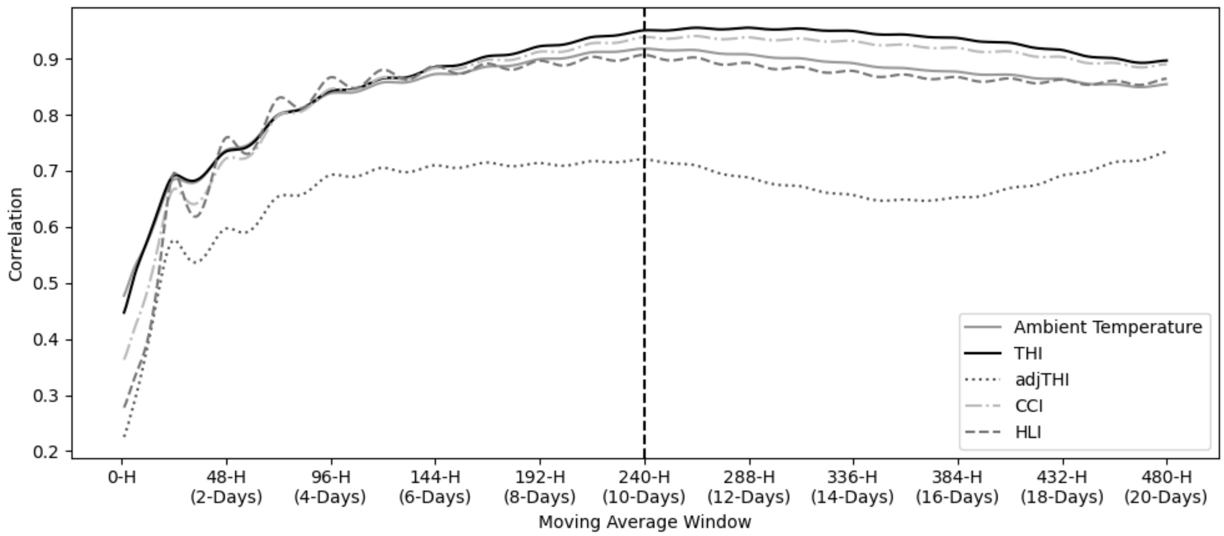

Figure 4: Correlations between equal-window moving averages for body temperature and various Indices (THI: Temperature-Humidity Index, *adj*THI: Adjusted Temperature-Humidity Index, CCI: Comprehensive Climate Index, HLI: Heat Load Index, and Ambient Temperature)

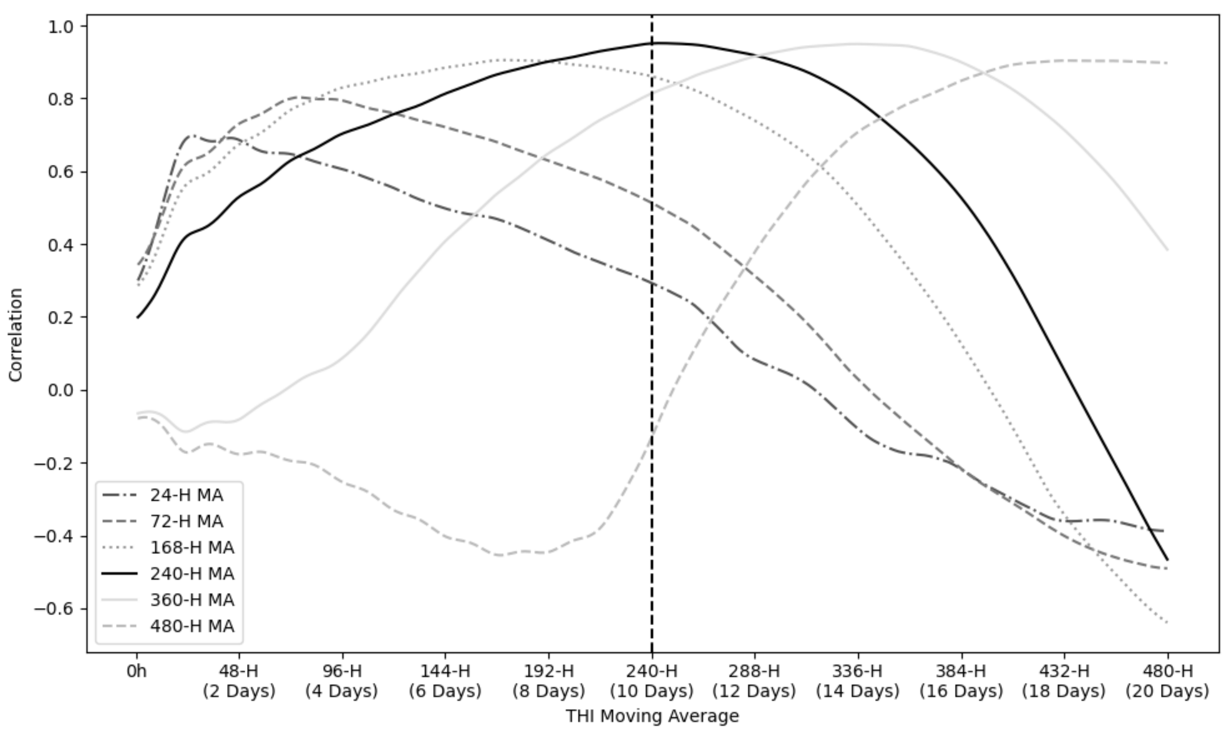

Figure 5: Correlations between moving averages for body temperature (24, 72, 168, 240, 360, and 480 Hours) and moving averages (1-480 hours) for Temperature-Humidity Index (THI).

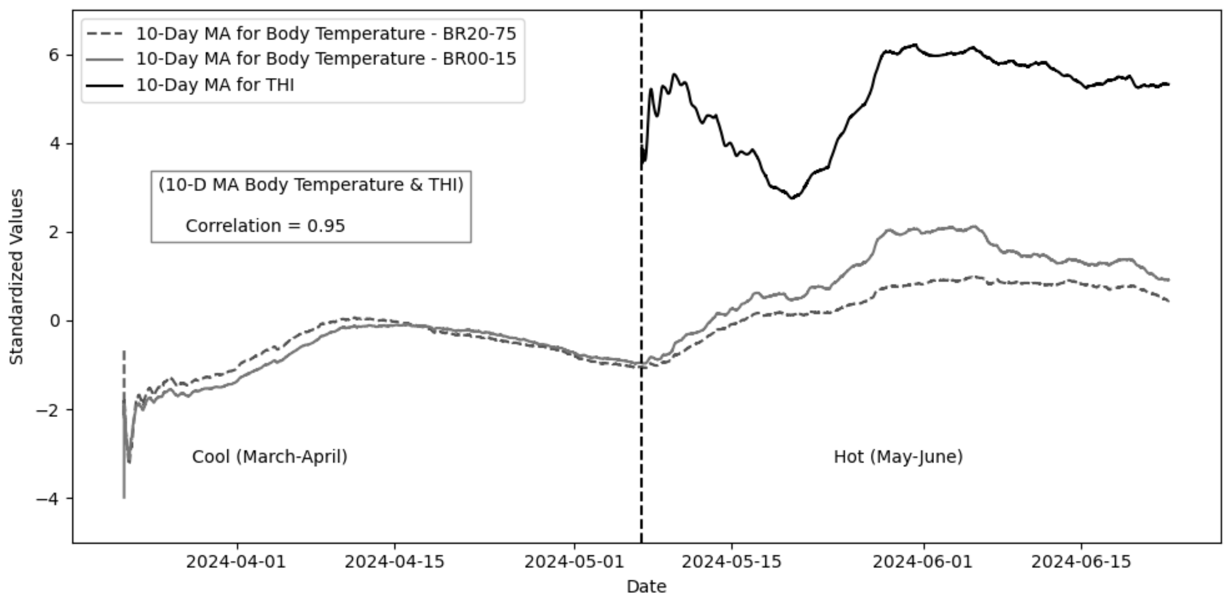

Figure 6: 10-Day moving average (MA) for Body Temperature by group (0-15% and 20-75% BR) vs. 10-Day MA for Temperature-Humidity Index (THI)

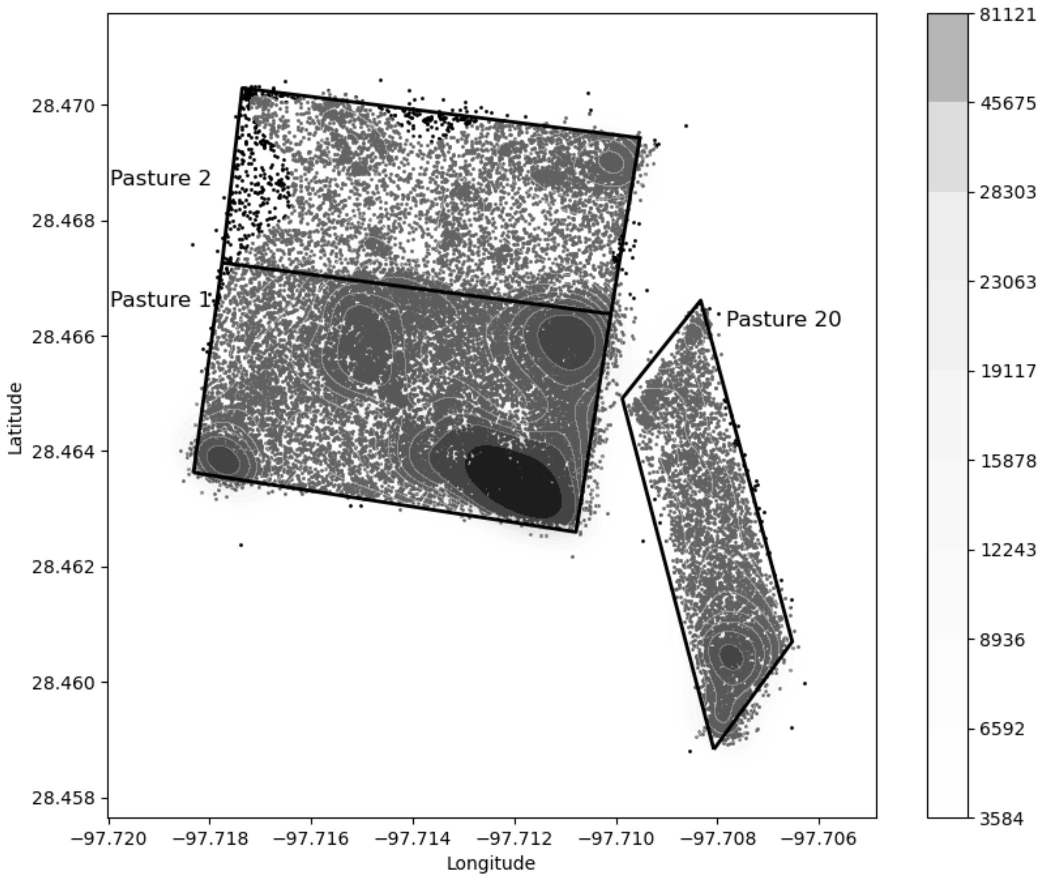

Figure 7: Hotspot analysis of GPS data (February 19 to March 19, 2024).

HEAT TOLERANT CATTLE PERFORMANCE AND GRAZING TRAIT ANALYSIS AT THE TEXAS A&M AGRILIFE RESEARCH BEEVILLE STATION

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Summary

In January of 2023, cattle arrived at the Texas A&M AgriLife Research Station in Beeville, Texas. These cattle are a part of the Germplasm Evaluation (GPE) Program at the U.S. Meat Animal Research Center (USMARC) in Clay Center, Nebraska. The GPE continuously evaluates the 18 most used breeds in the U.S. to better understand and quantify genetic differences amongst them. The cattle in the Beeville project are crossbreds consisting primarily of the four heat tolerant breeds within the GPE, these breeds being Brahman, Beefmaster, Brangus, and Santa Gertrudis. The Beeville project has two main objectives: to better understand environmental influence on breeds and cattle performance and to develop and evaluate new grazing traits.

Introduction

Cattle in the southeast region of the U.S. face unique challenges given the subtropical type of environments, characterized by high temperatures coupled with high humidity. The southeast faces other unique environmental challenges such as forage quality and parasites. Many cattle in this region have some proportion Brahman influence (*Bos indicus*) due to the Brahman's unique adaptability to these difficult conditions. Brahman cattle have unique characteristics such as slick hair, loose skin, and the ability to sweat, all of which aid in their ability to withstand extreme temperatures (ABBA). Many southeast producers utilize crossbreeding systems to capitalize on the performance increase seen when *Bos indicus* and *Bos taurus* are crossed, this added performance is due to heterosis also known as hybrid vigor which is when crossbred individuals outperform both of their parents. With agricultural land being a finite resource, it is important that cattle use the land they have as efficiently as possible. Not much is currently understood about how the genetics of cattle impact their grazing behavior.

Experimental Procedures

The Beeville Station is around 1300 acres and is currently home to 60 cows, 60 heifers, 7 bulls, and 58 calves. Cows and bulls in the project range from 3 to 8 years of age, heifers are all approximately 2 years of age. These cattle vary in breed composition; cows are at least half of the breeds Brangus, Beefmaster, Santa Gertrudis, and Brahman since their sires were purebreds of their perspective breed. Heifers in the project are all varying in composition of the same above-mentioned breeds. The cattle on this project are typically kept with their contemporary groups in pastures. These pastures once consisted of 'Coastal' bermudagrass, kleingrass, or buffelgrass, planted in the early 1980s. However, in the last 15 years, many of the pastures at the Beeville Station have been overtaken by yellow bluestem, so that is the most abundant forage source for the cattle. Due to the tough winter conditions, they received additional feed to supplement during that season. This project is in coordination with the USMARC GPE project, and they have internal genotyping procedures that are run for every animal in the project. Blood samples were collected for genotyping using low-pass sequencing techniques. The results of these sequences are like that which would be obtained from an Illumina sequencer. The cattle are bred to AI sires following the USMARC breeding strategies. Bull calves born in this project are castrated near birth and will then be grazed until it is appropriate to send them to a feedlot. Females in the study will be retained as replacements, and any extras will be marketed at a local sale barn. Cattle on the project are weighed approximately every 56 days, at that time hair shedding score and body condition score are also evaluated. Cattle got Smart Paddock GPS collars or ear tags placed in January 2024. The Smart Paddock, Pty Ltd (Moorabbin, Victoria, Australia) collars and tags offer GPS as well as accelerometer data to be analyzed. At the same time 60 smaXtec (Madison, WI, USA) boluses were placed. These boluses can detect water drinking events, internal temperature, and movement. There are some of these heat tolerant composites still at the USMARC in Clay Center, Nebraska. By pairing genomic and performance data from both locations, genome by environment interaction will be investigated. The genome by environment portion of the study will be conducted in the future as there is more data recorded on these animals. Studies investigating grazing traits will be performed using the technology mentioned above paired with the genomic data as sequenced by USMARC. There are plans to collaborate on the studies surrounding grazing trait development (Bailey et al., 2021), likely with the Deep Well Ranch in Arizona on a herd of primarily Corriente cattle. This collaborative effort will provide useful insights on cattle performance in the two environments, one being extremely humid heat and the other being equally as hot but drier.

Discussion

This study is still in the very early stages. However, some ways in which the data will be analyzed in the future and some of the implications are as follows. This combination of South Texas Plains data with Nebraska Great Plains data will help to improve accuracy of the across breed expected progeny difference (EPD) (Kuehn and Thallman, 2024) table by adjusting for environmental effects such as those seen in the subtropical environment of Beeville. The genomic values and breed compositions provided will also give the opportunity to estimate heterosis effects. The Beeville Station has a historic National Weather Service weather station with data going back to the 1890s. These data will be beneficial as the project aims to quantify the environmental impact on the animal's performance. This weather data will also be useful when developing trait analysis for grazing traits. This may be done by pairing the data from the technology with the weather data to characterize behavior as it relates to weather trends. Things such as time spent in shade and number of drinking events can be observed using the technology implemented in this study. Long term the new grazing trait development aims to increase sustainability within the industry as it seeks to identify which animals use their pasture resources the best.

Some preliminary figures have been created to investigate traits such as hair shedding score, percent Brahman, and average daily gain. As seen in Figure 1 there was an observed inverse relationship between cattle weights and average hair shedding scores within the period of April to November of 2023. It should also be noted that these data were collected on the group of 60 heifers which were still growing at this time. Hair shedding scores range from 1 being slick hair to 5 being long winter coat. In another preliminary analysis shown in Figure 2, a simple regression analysis was run to observe any possible relationship between genomic percent Brahman (pBr) and average daily gain (ADG), this analysis revealed an R-squared value of 0.13 which can be interpreted as approximately 13% of the variation in average daily gain can be explained by percentage Brahman, using the best-fit regression line. While these results are preliminary, more data collection over time will provide stronger evidence for relationships which may exist within the dataset. Figures 3 and 4 present examples of information generated by the technology being used in the project. Figure 3 is from the smaXtec database and shows critical information such as internal temperature and water drinking events. The data is collected from these devices every 10 minutes and automatically uploaded into this database. The database provides insightful graphics such as the visual seen in Figure 3 as well as the ability to manipulate the data i in computer software to analyze and characterize patterns within the large dataset. As seen in Figure 4, the Smart Paddock software also offers graphic representations of the data in the form of maps which show live cattle location, as well as excel format data which holds complete records of individual animal movements and accelerometer data. With the ability to use satellite mapping technology, markers can be added to the maps to indicate shade areas as well as water troughs. This data will allow for investigations such as how much time cattle are spending in the shade and how it relates to their genomic breed composition. It will also allow for investigation into time spent at or around water troughs and how that relates to breed composition. The GPS collars and tags also offer accelerometer data which will provide insight into which cattle are moving the most throughout the day.

Conclusion

The project at Beeville Station is utilizing exciting new technology and seeks to provide useful insight for producers in climates such as south Texas. The project will allow for future genome by environment interaction studies as contemporary groups in Nebraska and Texas are able to be compared and contrasted. The implementation of technology such as GPS collars and boluses will allow for in depth studies into grazing behaviors of the cattle. The collaboration with USMARC will provide genome sequence data on all project animals for genetic characterization and identification of opportunities for improvement programs.

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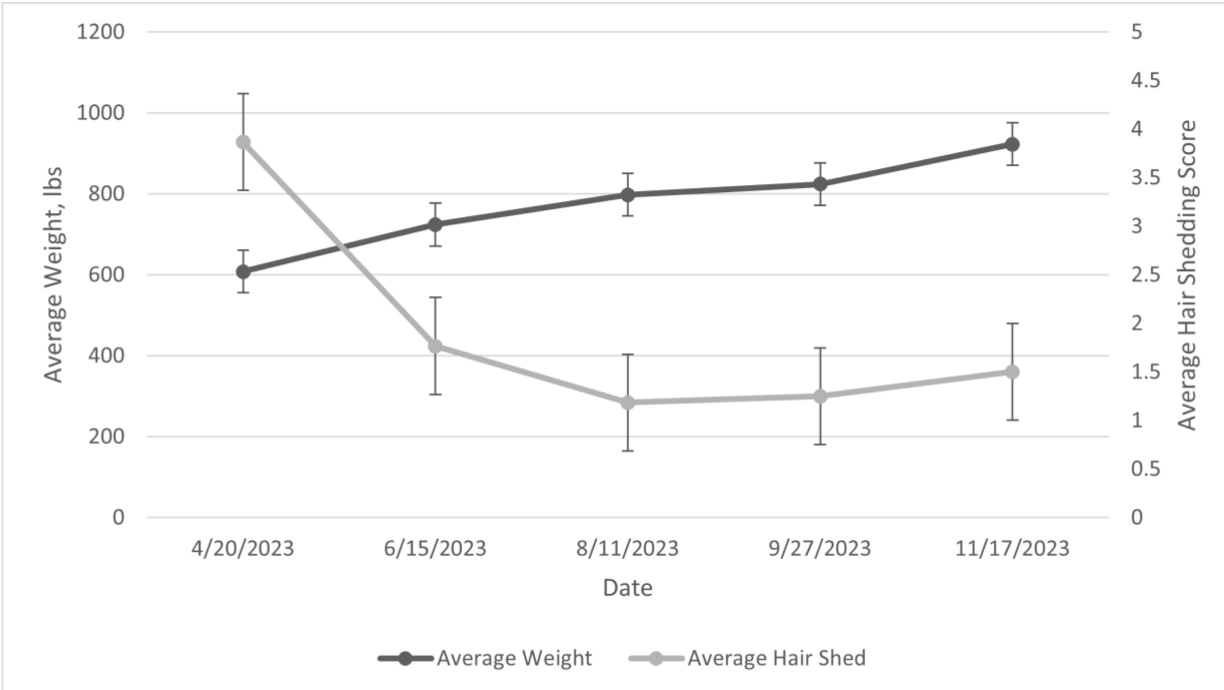

Figure 1. Weight and hair shedding scores of growing heifers over time.

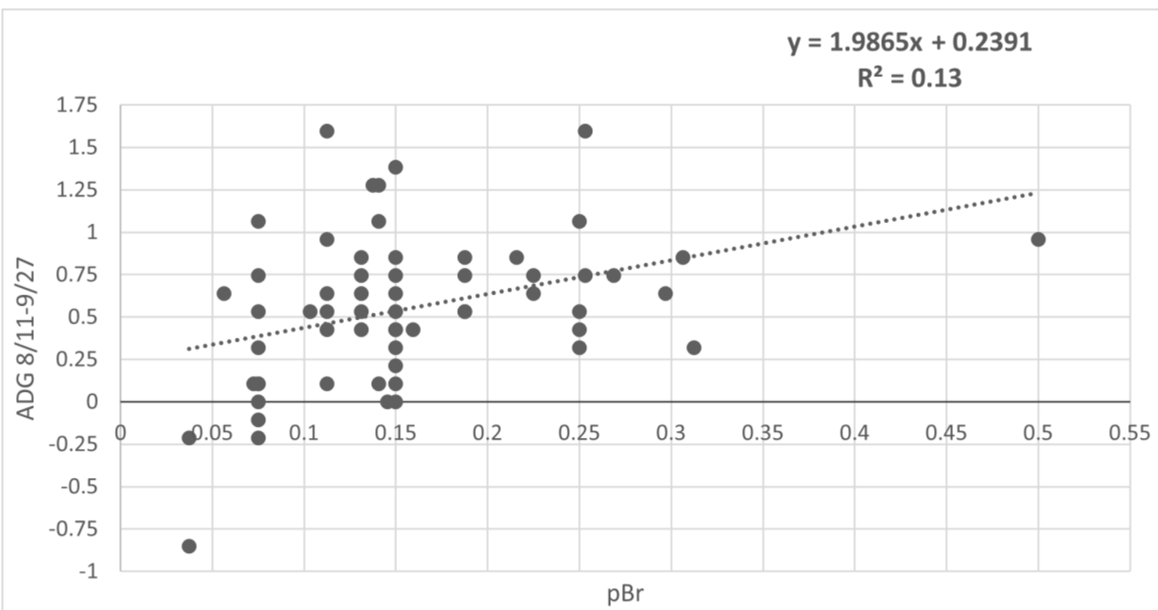

Figure 2. Average daily gain (ADG) by percent Brahman (pBr).

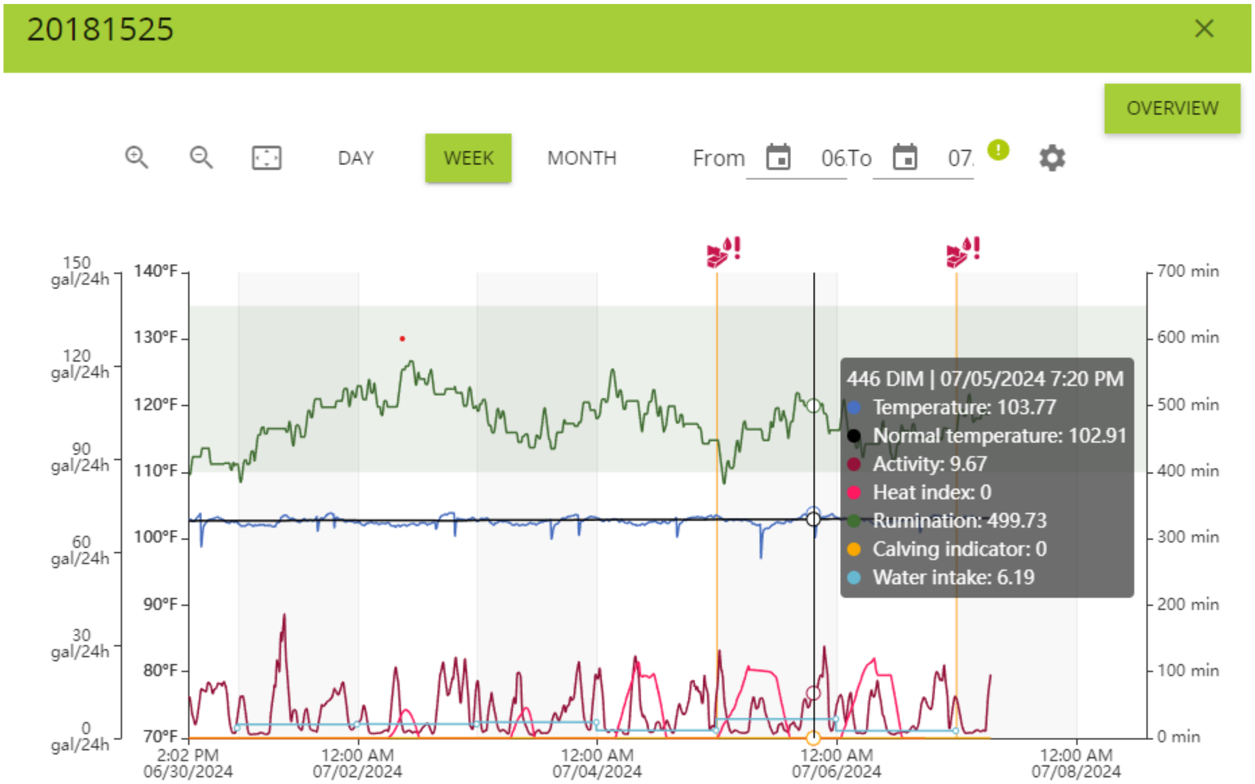

Figure 3: SmaXtec software image displaying metrics such as body temerapure and rumination

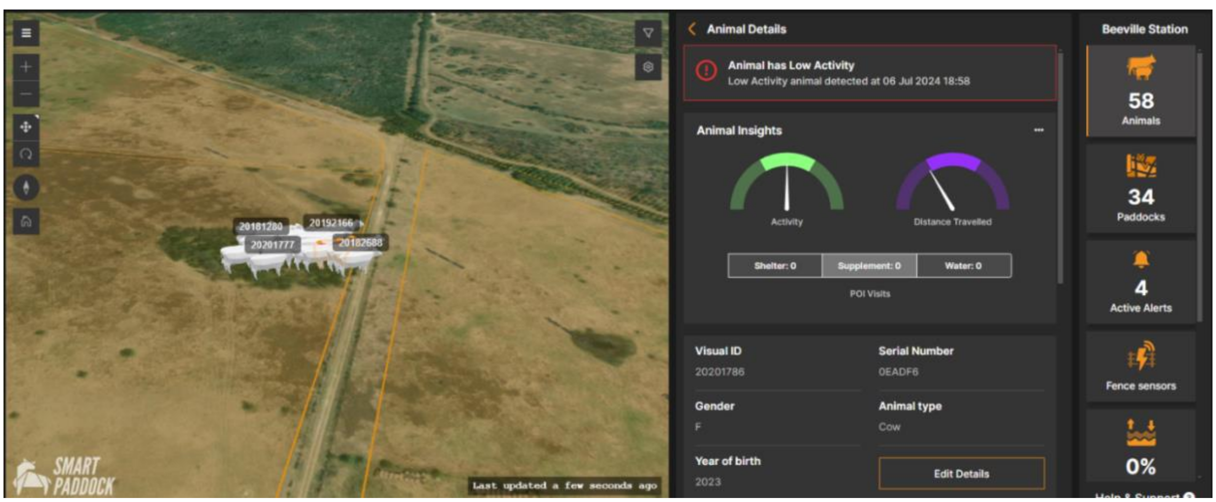

Figure 4: Image from Smart Paddock software displaying cattle location and activity levels

CONSIDERATIONS OF RECIPROCAL EFFECTS AMONG *BOS INDICUS-BOS TAURUS* CROSSES FOR GLOBAL BEEF VALUE CHAINS

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Summary

Increasing reports of "non-traditional" aspects of inheritance, many times referred to as "epigenetics," have been reported in mammalian species. Many epigenetic influences hold large potential implications for human health. Similarly, increasing reports of potential epigenetic influences on food animal production efficiency have been documented, and recent articles have emphasized the need to recognize the broad area of epigenetics and epigenomics for future research and consideration in livestock production systems. For many years, and in many environments, "unusual" aspects of cattle growth have been documented in *Bos indicus-Bos taurus* crosses. The purpose of this review is to summarize some of these research findings in *Bos indicus-Bos taurus* crosses for production traits. We propose that these phenomena in *Bos indicus-Bos taurus* crosses warrant further study for improved food animal production efficiency in many areas of the world and provide additional biological research models.

Introduction

Domestic cattle are broadly classified into two subspecies of *Bos taurus* and *Bos indicus*, and domestic cattle populations around the world are believed to be descendants and/or mixtures of these two groups. These subspecies of cattle are quite distinct phenotypically and genetically; *Bos taurus males* have a sub-metacentric Y chromosome, while *Bos indicus* males have an acrocentric Y (Keiffer and Cartwright, 1968; Frisch and O'Neill, 1998) due to an inversion or transposition of the centromere that changes the location of the pseudoautosomal region and male determining region in the subspecies (Di Meo et al., 2005). Major differences in mitochondrial (MacHugh et al., 1997; Achilli et al., 2008) and genomic DNA sequence (Bovine Genome Sequencing and Analysis Consortium, 2009; MacEachern et al., 2009) are also documented. *Bos indicus* cattle are utilized throughout tropical and subtropical global regions due to adaptation and resulting tolerances for heat index, parasites and low-quality forage. Several "unusual" aspects pertaining to performance differences in multiple traits among *Bos indicus-Bos taurus* cattle appear to have a non-traditional mode of inheritance, and examples of unique phenotypic variation in *Bos indicus-Bos taurus* beef cattle crosses that can impact breeding programs and production systems are discussed below. We propose that these influences involving *Bos indicus-Bos taurus* crosses may result in previously unaccounted variation within production systems and warrant detailed investigation.

Calf size and growth traits

Reciprocal differences among Brahman and Hereford crosses for calf birth weight were first reported by Cartwright et al. (1964). Data from reciprocal crosses of several studies are summarized in Table 1. Across 20 years of data, Roberson et al. (1986) reported calves that had the largest birth weights were sired by Brahman sires mated to Hereford cows, followed closely by those sired by F_1 bulls mated to Hereford cows. Conversely, the smallest calves were produced from sires mated to Brahman cows and were very similar regardless of the sire type (Brahman, F_1 or Hereford). In the F_1 and backcrosses, when there was more Brahman content in the sire compared to that in the dam, all crosses produced larger birth weight calves as compared to the reciprocal cross, and this trend has been reported in many independent studies. Among reciprocal Angus and Brahman F_1 crosses, Reynolds et al. (1980) reported that Brahman-sired calves were 12 lb heavier at birth weight compared to Angus-sired calves; Brown et al. (1993) reported that Brahman-sired calves were 23 lb heavier than Angus-sired calves. Riley et al. (2007) observed the same trend for reciprocal F_1 differences among Brahman-Angus and Brahman-Romosinuano crosses. Thallman et al. (1993) first postulated multiple potential influences such as mitochondrial inheritance, genomic imprinting, X-linked inheritance with non-random X-chromosome inactivation, Y-linked inheritance, maternal transmission of non-genetic ova cytoplasmic components, and maternal effect of ovary, oviduct and uterus of donor cow prior to day 7 of gestation might impact reciprocal differences in these crosses.

Several exaggerated sex differences have been reported when *Bos indicus* sires were mated to *Bos taurus* dams; male calves have been reported to be much heavier (5 to 12 kg) than female calves when compared to calves within a pure breed or among straightbred *Bos taurus*, straightbred *Bos indicus* or *Bos indicus x Bos taurus inter se* crosses (Notter et al., 1978; Lemos et al., 1984; Paschal et al., 1991; Brown et al., 1993; Herring et al., 2005; Amen et al., 2007). Furthermore, there have been several reports of non-significant differences in birth weight between male and female calves when pure *Bos indicus* dams were mated to *Bos taurus* sires (Brown et al., 1993; Browning et al., 1995; Riley et al., 2007;). Among some interspecies mouse crosses, varying amounts of body size in males *versus* females have been reported, with larger placental weights in crosses that yielded more pronounced size dimorphism between the sexes (Vrana et al., 2000). Although investigation of reciprocal F_2 differences is rare, Boenig (2011) reported simple means of reciprocal cross F_2 Brahman-Hereford calves where the sex difference in birth weight was substantially larger in calves sired by Brahman-sired F_1 (BH) bulls as compared to those sired by Hereford-sired F_1 (HB) bulls, and Mickey et al. (2022) reported similar findings among Nellore-Angus crosses. Data from several of these cattle studies where sex differences were reported among reciprocal crosses are summarized in Table 2.

In recent years, detailed studies of fetal development have been initiated in *Bos indicus-Bos taurus* crosses. Fitzsimmons et al. (2008) reported divergence in fetal size as well as uterine and placental size in reciprocal Angus-Brahman F_1 calves, at day 153 of gestation, which follows the same pattern in birth weight differences that has been observed among these types of crosses. Burns et al. (2010) reported that placental characteristics seemed to explain variation in birth weight more than early fetal size measurements in Droughtmaster calves (a stabilized 50% Brahman, 50% Shorthorn composite). Liu et al. (2021) reported more than 6500 differentially expressed genes in mid-gestation Angus, Brahman and reciprocal F_1 fetuses, and 110 genes that were differentially expressed in all five tissues investigated. Expression of 5% of the differentially expressed genes in each tissue were consistent with parent-of-origin (imprinting) effects. A more in-depth study of the uterus-calf genotype interaction to better understand prenatal development in *Bos indicus-Bos taurus* crosses is needed. Evidence from several rodent studies suggests that placentation effects in cattle also need to be studied further, including interactions between dam, sire-derived genes in the placenta (Wang et al., 2013), and calf genotypes. Traditional thought was that some type of maternal uterine effect (difference in *Bos indicus* vs. *Bos taurus* dams) was likely responsible for these developmental differences.

Birth weight and gestation length are known to be related, but there are fewer reports for breed and cross comparisons for gestation length than for birth weight because the precise date of conception is not known in many instances. *Bos indicus* breeds are known to have a longer gestation length of approximately 7 days as compared to *Bos taurus* breeds. In reciprocal F_1 cross calves, Reynolds et al. (1980) observed a 2.6 day longer gestation period in Brahman-sired calves (BA) as compared to Angus-sired (AB) calves. In natural service and AI matings, the genotype of the calf is naturally confounded with the genotype of the cow. However, this phenomenon has also been observed in reciprocal F_1 embryo transfer calves (Thallman et al., 1993) and reciprocal backcross embryo transfer calves (Amen et al., 2007; Table 3). Baker et al. (1989) produced embryo transfer purebred and reciprocal F_1 cross calves using Hereford and Brahman breeds, where both Hereford and Brahman recipient females were also evaluated (Table 3). There was a trend for longer gestation length in calves carried in Brahman *versus* Hereford recipients, regardless of the breeding of the calf. However, there was no associated increase in birth weight with increased gestation length. In addition, Amen et al. (2007) differentiated among F_1 parents if they were Angus-sired or *Bos indicus*-sired (AB *versus* BA), and a trend existed where a BA parent produced a longer gestation length than the AB parent even when F_1 sires were used on straight Angus or *Bos indicus* dams.

In the 1980s and 1990s, much interest and effort was devoted to cloning of cattle by nuclear transfer. In several instances, extreme variation was associated with birth weight in these clones resulting in a large offspring (fetal overgrowth) syndrome and extreme variation was also possible within clone-mates (Young et al., 1998; Wilson et al., 1995). This phenomenon has also been reported in calves produced through *in vitro* fertilization, and variability in methylation patterns is at least associated with the fetal over growth syndrome in cattle (Hiendleder et al., 2004a). Additionally, Hiendleder et al. (2004b) reported that fetal cells of somatic cell clones showed increased growth rates (higher skin, heart and liver), increased umbilical cord length, and increased placental weight when *Bos indicus* cytoplasm was used *versus Bos taurus* cytoplasm (source of nuclear cells were *Bos taurus,* as were recipient dams). Long and Cai (2007) demonstrated that DNA methylation was disrupted at a known imprinted gene (IGF2-R) in cloned Holstein cattle; de Montera et al. (2010) demonstrated large variation in methylation within genotype of cloned cattle, and much larger variability within genotypes than across genotypes. The interaction among the nuclear cell source and culture media and/or cytoplasmic sources in *in vitro* fertilization and cloned cattle may be a related phenomenon to prenatal development when producing *Bos indicus x Bos taurus* crossbred cattle under "normal" mating circumstances, although the mechanisms are not clear. It is also not known whether more subtle variation might be occurring within genomic regions or even individual genes among *Bos indicus-Bos taurus* crosses (or other types of cattle) in reciprocal F_1 and backcrosses, or in a stabilized composite.

Hybrid vigor (heterosis) associated with female fertility

Another phenomenon that is also perplexing is that of the small number of studies that have evaluated retention of heterosis (past the F_1 generation) in *Bos indicus-Bos taurus* crosses, very mixed results have been documented. The dominance model proposed by Falconer (1990) where heterosis is caused by dominance effects summed across multiple loci, and therefore heterosis retention should be proportional to the degree of breed heterozygosity (F_1 crosses of two breeds are 100% heterozygous and F_2 crosses are 50% heterozygous, etc.) has been used to model retention of heterosis in advanced generations of *Bos taurus* composites and is widely accepted. Williams et al. (1990) reported heterosis results in rotational crosses involving Brahman and *Bos taurus* breeds appeared to correspond to the dominance model. However, some reports of *Bos indicus-Bos taurus inter se* matings do not correspond well to expected breed heterozygosity levels. Early reports of a crossbreeding project at the CSIRO Belmont Station in Queensland, Australia showed very low reproductive rates in a F_2 generation of a Brahman composite population (Seebeck, 1973; Seifert and Kennedy, 1972). Subsequently, Rendel (1980) reported very low (60.7%) calving rates in F_2 Brahman (B)-British (Hereford-Shorthorn) (referred to as BX) *versus* F_1 BX cows (81.2%); later evaluations from this study (MacKinnon et al., 1989) found heterosis estimates from groups of F_1, F_2, and F_n (F_3 and greater) BX cows to be 16.4%, 5.2%, and 1.6%, respectively.

Key (2004) evaluated retention of heterosis in F_2 Brahman-Angus and F_2 Brahman-Hereford cows in Texas, USA and found less heterosis retained in Brahman-Angus crosses as predicted by heterozygosity estimates and more heterosis retained in Brahman-Hereford crosses than predicted by heterozygosity estimates. In this study, the F_1 Brahman-Angus bulls were exclusively Brahman-sired (BA) and were mated to both types of F_1 cows (BA and AB), whereas both types of F_1 Brahman-Hereford bulls and cows (BH and HB) were used to produce all four reciprocal F_2 animals. Among Brahman-Hereford F_2 cows, those sired by Brahman-sired F_1 bulls (BH bulls) had lower reproductive performance (Boenig, 2011); among Brahman-Angus F_2 cows, those from BA F_1 dams had reduced reproductive longevity vs. those from AB F_1 dams (Bohac et al., 2015). A report by Post and Reich (1980) from the Belmont station in Queensland, Australia reported potential differences in age of puberty for reciprocal F_2 Africander/British cross-Brahman/British cross matings (AXBX) where heifers from Africander-British (AX)-sired bulls had earlier puberty onset than cows from BX-sired bulls. It has been conveyed to the authors that F_1 BX females produced at the Belmont Research Station were also Brahman-sired (J.E. Frisch, personal communication), and this may relate to a broadscale pattern in regard to fertility in these types of populations.

Historical perspective

Many research projects have produced reciprocal F_1 cross cattle; however, in most of these reports the reciprocals were pooled to estimate heterosis of the crossbred generation and were assumed to be equal based on Mendelian assumptions. Moreover, very few studies have evaluated the differences of reciprocally produced F_2 *Bos indicus-Bos taurus* females, or their male counterparts. It may be possible that some historical datasets from earlier studies still exist, and these would be useful to evaluate reciprocal F_1 and F_2 crosses that were pooled in previous analyses. As a result, conflicting reports on retention of heterosis observed in the F_1 to the F_2 generation in *Bos indicus-Bos taurus* crosses and the reciprocal differences among F_1 and F_2 individuals could in fact be related to epigenetic mechanisms and should therefore be thoroughly investigated. Texas A&M University and the Texas Agricultural Experiment Station/Texas A&M AgriLife Research programs have investigated various aspects of productivity regarding *Bos indicus-Bos taurus* crossbred cattle for over 70 years and conducted the foundational work that described reciprocal differences for calf birth weight and gestation length, including sexual dimorphism that cannot be simply attributed to maternal/uterine effects. We have recently developed a strategic relationship with scientists at the USDA-ARS Meat Animal Research Center to more comprehensively study these phenomena.

Calf sex ratio

We have begun to assess this aspect, but have recently recognized a discrepancy in calf sex distribution among these crossbred populations that we believe warrant additional study (Table 4). This is based on reported numbers of calves in the historical literature and was first known to be reported by Mickey et al. (2022). We believe non-traditional inheritance patterns that may involve genomic imprinting, and potential non-random crossing over and/or interactions involving sex chromosomes may contribute to many of the unusual results associated with *Bos indicus-Bos taurus* crosses.

Conclusions

Many instances have been documented suggesting potential non-Mendelian effects may influence performance in *Bos indicus-Bos taurus* crosses. Specific phenomena from many independent trials highlighted in this review include: (1) substantial differences in calf fetal size, birth weight and gestation length among reciprocal crosses, (2) the long-standing recognition that *Bos indicus*-sired calves from *Bos taurus* dams have an exaggerated sex difference for birth weight with males much heavier than females (3) high heterosis levels in F_1 *Bos indicus-Bos taurus* crosses, but inconsistent (sometimes non-significant) heterosis in the F_2 or later generations, and (4) potential alterations among calf sex ratios at birth. The Mendelian genetic model has been applied successfully to breeding programs focused on both quantitatively and qualitatively inherited traits in livestock production systems, and utilization of *Bos indicus* cattle and their crosses will continue to be instrumental in meeting global dietary protein demands in and from tropical and subtropical regions. Improved knowledge of non-Mendelian influences in *Bos indicus-Bos taurus* crosses could hold potential for improved food animal production efficiency as well as contribution to basic biology knowledge in areas related to fetal growth, neonatal development and fertility in cattle and possibly multiple mammalian species.

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Table 1. Birth weight and weaning weight in *Bos indicus-Bos taurus* cross calves produced by natural service

Sire[1]	Dam[1]	Calf	Birth weight (lb)	Weaning weight (lb)	Reference and location
Brahman	Hereford	F_1 BH	83.3	409.2	Cartwright et al. (1964) Texas, USA
Hereford	Brahman	F_1 HB	64.2	427.8	
Hereford	F_1	3/4H1/4B	68.1	437.7	
Brahman	F_1	3/4B1/4H	72.1	420.1	
F_1	Hereford	3/4H1/4B	80.9	390.9	
F_1	Brahman	3/4B1/4H	63.1	398.4	
Angus	Brahman	F_1AB	60.6	429.1	Reynolds et al. (1980, 1982) Louisiana
Brahman	Angus	F_1BA	71.7	428.2	
Hereford	Brahman	F1HB	67.0	364.3	Roberson et al. (1986) preweaning ADG, Texas
Brahman	Hereford	F1HB	82.5	318.0	
F_1	Hereford	3/4H1/4B	82.0	307.6	
Hereford	F_1	3/4H1/4B	70.8	370.7	
F_1	Brahman	3/4B1/4H	65.7	330.3	
Brahman	F_1	3/4B1/4H	76.7	353.5	
Simmental	Brahman	F_1SB	68.1	551.9	Comerford et al., (1987, 1988) Georgia
Brahman	Simmental	F_1BS	84.5	550.1	
Limousin	Brahman	F_1LB	65.3	532.3	
Brahman	Limousin	F_1BL	86.4	511.6	
Hereford	Brahman	F_1HB	64.6	522.6	
Brahman	Hereford	F_1BH	86.0	475.2	
HS	Brahman	F_1HSB	68.4	420.7	Frisch and O'Neill (1998) QLD Australia
Brahman	HS	F_1BHS	80.9	384.1	
AfX	Brahman	F_1AXB	70.3	437.9	
Brahman	AfX	F_1BAX	85.6	431.3	

A = Angus, B = Brahman, H = Hereford, HS = Hereford-Shorthorn, L = Limousin, S = Simmental, AfX = Africander cross

Table 2. Combinations of mating type and calf sex for birth weight and weaning weight in *Bos indicus*-*Bos taurus* non-embryo transfer calves

			Birth weight (lb)		Weaning weight (lb)		
Sire	Dam	No.	Male	Female	Male	Female	Reference, location
Holstein	1/2Ho1/2Gyr	81	71.4	70.3	--	--	Lemos et al. (1984) Minas
Holstein	Gyr	72	63.1	65.0	--	--	Gerais, São Paulo, Rio de
Gyr	1/2Ho1/2Gyr	88	76.3	65.9	--	--	Janeiro, Espírito Brazil
HS	Brahman	63	69.0	68.1	434.4	406.8	Frisch and O'Neill (1998)
Brahman	HS	62	82.7	78.9	382.8	385.4	Queensland Australia
AfX	Brahman	65	71.7	68.6	454.0	421.6	
Brahman	AfX	73	91.7	79.4	451.1	411.5	
BX	Brahman	52	66.6	63.5	420.9	394.7	
Brahman	BX	52	80.7	68.4	439.7	380.4	
Type of pasture resource[2]							
Angus	Brahman	Bermuda	68.4	69.0	501.2	461.7	Brown et al. (1993) Arkansas
Angus	Brahman	Fescue	73.2	67.7	460.6	429.5	
Brahman	Angus	Bermuda	100.1	83.8	523.7	490.2	
Brahman	Angus	Fescue	102.1	85.3	467.5	445.6	
Romosinuano	Brahman	58	64.6	66.4	531.6	517.7	Riley et al. (2007) Florida
Brahman	Romosinuano	88	84.5	74.3	534.1	495.9	
Brahman	Angus	60	86.2	73.6	518.6	480.2	
Angus	Brahman	58	67.9	69.7	569.1	544.4	
Reciprocal F_2 crosses							
BH	BH	≤ 25	80.9	70.3	415.0	384.6	Boenig (2011) Texas,
BH	HB	≤ 25	79.8	69.5	424.0	364.5	preweaning gain
HB	BH	≤ 25	73.2	74.7	415.2	396.0	
HB	HB	≤ 25	71.7	77.6	394.0	397.1	
NA	NA	139	75.9	67.3	468.1	444.1	Mickey et al. (2022) Texas
NA	AN	80	73.4	69.2	434.8	453.3	
AN	NA	158	70.1	67.5	454.7	430.2	
AN	AN	68	71.7	71.4	438.1	447.4	

[1]A = Angus, B = Brahman, H = Hereford, Ho = Holstein, HS = Hereford-Shorthorn, R = Romosinuano, AfX = Africander cross, BX = Brahman cross, BH = Brahman-sired F_1, HB = Hereford-sired F_1, NA = Nellore-sired F_1, AN = Angus-sired F_1

[2]Bermudagrass (*Cynodon dactylon*), Fescue = endophyte-infested tall fescue (*Festuca arundinacea*)

Table 3. Gestation length, birth weight and weaning weight in *Bos indicus*-*Bos taurus* calves produced through embryo transfer

Sire breed[1]	Dam breed[1]	Calf breed[1] (n)	Recipient dam breed	Gestation length (d)	Birth weight (lb)	Weaning weight (lb)	Authors and location
Brahman	Brahman	BB (6)	Brahman	293	70.6	--	Baker et al.
Brahman	Brahman	BB (11)	Hereford	291	72.8	--	(1989)
Brahman	Hereford	F_1BH (3)	Brahman	297	93.1	--	McGregor,
Brahman	Hereford	F_1BH (5)	Hereford	292	108.7	--	Texas
Hereford	Brahman	F_1HB (8)	Brahman	287	76.7	--	
Hereford	Brahman	F_1HB (9)	Hereford	284	82.5	--	
Hereford	Hereford	HH (3)	Brahman	289	86.4	--	
Hereford	Hereford	HH (8)	Hereford	284	81.8	--	
Brahman	Simmental	F_1BS (M, 40)	Mainly Holstein, plus	291	52.0	305	Thallman et al.
		F_1BS (F, 40)	some	289	46.0	270	(1993)
Simmental	Brahman	F_1SB (M, 270)	crossbred beef	289	38.0	262	Wheelock,
		F_1SB (F, 270)		287	38.0	250	Texas
Angus	F_1 AB	3/4A1/4B (75)	½ Brahman ½ British	281.5	78.3 (M) 74.3 (F)	506.3	Amen et al. (2007)
Angus	F_1 BA	3/4A1/4B (62)		283.9	76.3 (M) 73.6 (F)	505.8	Angleton, Texas
F_1 AB	Angus	3/4A1/4B (68)		283.5	96.4 (M) 77.6 (F)	530.1	
F_1 BA	Angus	3/4A 1/4B (59)		285.8	82.7 (M) 79.4 (F)	507.8	
Brahman	F_1 AB	3/4B 1/4A (83)		289.0	89.7 (M) 80.9 (F)	527.9	
Brahman	F_1 BA	3/4B 1/4A (58)		292.6	88.6 (M) 79.8 (F)	505.4	
F_1 AB	Brahman	3/4B 1/4A (48)		284.2	75.0 (M) 71.7 (F)	503.2	
F_1 BA	Brahman	3/4B 1/4A (56)		286.6	74.2 (M) 73.2 (F)	499.7	

[1]BH = Brahman-sired F_1, HB = Hereford-sired F_1, BS = Brahman-sired F_1, SB = Simmental-sired F_1, BA = Brahman-sired F_1, AB = Angus-sired F_1.

Table 4. Observations where sex ratio at birth appears skewed[1] among *Bos indicus-Bos taurus* crosses

Cross/population description[2]	Percentage males (%)	Number of male calves	Source
Male surplus			
McGregor Cycle 1 - F_2 from NA x NA	57.2	273	Mickey (2021)
McGregor Cycle 2 – F_2 calves, NA sires	59.7	179	
McGregor Cycle 2 – F_2 calves, AN dams	59.4	120	
H-1936 F2 calves - multiple *Bos taurus* breeds crossed with Brahman	57.3	126	Original data
McGregor Heterosis Retention – F_2 crosses from HB dams	63.6	21	Boenig (2011)
McGregor Heterosis Retention – F_2 crosses from HB sires	58.2	39	
Angleton Angus x AB backcrosses	60.5	46	Amen et al. (2007
Angleton Brahman x AB backcrosses	56.6	47	
QLD BX x Brahman	61.5	32	Frisch & O'Neill (1998)
3/8 B 5/8 S x 3/8 B 5/8 S	55.7	320	Dillon et al. (2015)
½ B ½ S x ¾ S ¼ B	58.9	241	
Female surplus			
¾ B ¼ S x Simmental	43.3	100	Dillon et al. (2015)
Angleton Brahman x BA backcrosses	37.9	22	Amen et al. (2007)
McGregor Cycle 3 - F_3 calves from Cycle 1 (NA x NA) parents	43.9	301	Mickey (2021)
QLD Brahman x HS	38.7	24	Frisch & O'Neill (1998)
Progeny of Cycle 2 F_2 females – NA-sired cows	43.4	95	Mickey (2021)
Progeny of Cycle 2 F_2 females – NA x NA cows	41.0	59	

[1]Only sources that appear to have at least 5% sex ratio deviation (> 55%, < 45%) are referenced.
[2]Breed abbreviations: A = Angus, B = Brahman, H = Hereford, N = Nellore, S = Simmental, HS = Hereford-Shorthorn, NA = Nellore-sired F_1, AN = Angus-sired F_1, BX = Brahman cross.