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IMPACT OF PROPORTION OF *BOS INDICUS* GENETICS ON PRODUCTIVITY OF CROSSBRED COWS

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Introduction

Over half of the world's cattle population is raised in tropical environmental conditions (Food and Agricultural Organization [FAO], 2009), marked by hot temperatures, high humidity, and heavy precipitation. In the United States, approximately 40% of the beef cows are in hot, humid or arid environmental conditions of the Southeast and Southwest, respectively (Cundiff et al., 2012). The enhanced thermotolerance ability of *Bos indicus* cattle breeds (e.g., Brahman) (Hansen, 2004; Recha, 1987) make them more adaptable to the harsh environmental conditions of hot climate than *Bos taurus* cattle breeds (e.g., Angus). They are also more tolerant to other hot and humid related environmental stressors, such as incidence of parasitic and parasite-transmitted disease, than *Bos taurus* cattle (Burrow, 2015). Thus, it is common to find purebred or *Bos indicus* crossbred cattle in tropical and subtropical regions. Despite more resilient, *Bos indicus* cattle have suboptimal productive traits when compared to *Bos taurus* (Hruska et al., 1993; Casas et al., 2011; Cooke et al., 2020), therefore crossbreeding is an important and frequently used strategy to increase productivity in tropical and subtropical environments (Lamy et al., 2012). The benefits for productivity include improvements in weaning weight, reproduction, and feed performance (Syrstad, 1985; Casas et al., 2011) due to the combination of traits from complementary breeds through gene additive effect and heterosis (Elzo and Wakeman, 1998; Leal et al., 2018). However, the impact of *Bos indicus* genetics on reproductive and productive performance of crossbred cows it is not well described. Such analysis is difficult because of the challenge of finding beef herds with crossbred cows with different proportions of *B. indicus* genetics raised contemporaneously. This information would help producers make better management and breeding decisions. The present article therefore focuses on exploring the relationship between the proportion of *B. indicus* genetics in Brahman-Angus cows and their performance during the breeding and calving seasons. The article is based on the results of two published manuscripts (Martins et al., 2022; Martins et al., 2024). The database used in both studies originated from the University of Florida Brahman-Angus multibreed herd between 1989 and 2020 (31 years of accumulated data). Brahman-Angus cows were produced that differed by approximately 3-percentage points of Brahman genetics (0 to 100%) and divided into six breed groups according to the proportions of Brahman: G0–19%, G21–34%, G38% (Brangus), G41–59%, G63–78%, and G81–100%. Cows were at research stations located in North-Central Florida in the city of Gainesville and managed contemporaneously under grazing conditions to meet or exceed nutritional maintenance requirements. Breeding events occurred between February and August (late winter and throughout spring) and calving events between November and March (late fall and throughout winter). All cows were exposed to an estrus synchronization program, followed by artificial insemination (AI) based on estrus expression. Cows not detected in estrus were inseminated by timed AI (TAI). The herd was constructed and was perpetuated through a diallel crossbreeding scheme, that is, the six sire groups were reciprocally mated with the six dam groups during AI and natural services. The breeding seasons lasted approximately 90 days.

Pregnancy per AI (P/AI) and estrous response due to estrous synchronization

The proportion of Brahman genetics in Brahman-Angus crossbred cows was negatively related to P/AI (Table 1) in conventional estrous synchronization programs. Crossbred cows with 63-78% or 81-100% of Brahman genetics had the lowest P/AI, regardless of parity category (2-yr-old nulliparous, 3-yr-old primiparous, 4-yr-old secundiparous, or pluriparous). Despite impairing P/AI, overall pregnancy rates (i.e. AI + natural service) were similar after the end of the 90-d breeding seasons.

Table 1. Association between the proportion of Brahman genetics of cows and pregnancy per AI (P/AI) at first AI and pregnancy at the end of the breeding season. **Source:** (Martins et al., 2022)

Item	**Proportion of Brahman genetics**						***P*-value**		
	0-19%	21-34%	38% (Brangus)	41-59%	63-78%	81-100%	Breed	Parity	Breed x parity
P/AI[1], % (n/n)	51.6 [a] (631/1201)	44.3 [b,c] (489/1071)	44.7 [b,c] (405/893)	46.3 [a,b] (655/1415)	39.5 [c,d] (349/855)	37.4[d] (362/969)	< 0.0001	0.24	0.82
P/AI+NS[2], % (n/n)	89.2 (1056/1216)	88.6 (935/1085)	88.7 (773/900)	88.6 (1229/1435)	88.5 (749/868)	88.2 (855/1000)	0.99	0.006	0.84

Parity = 2-years-old nulliparous, 3-year-old primiparous, 4-year-old secundiparous, or pluriparous.

[a,b,c,d] Values without a common superscript differed between breed groups ($P < 0.05$) by applying Tukey test for multiple comparisons.

[1]P/AI: Proportion of cows receiving AI, after estrous synchronization, that were pregnant to this insemination. Every cow submitted to the estrous synchronization was inseminated based on estrus expression or following TAI.
[2]P/AI+NS: Proportion of cows pregnant at the end of breeding season as result of AI or natural service.

At the beginning of the breeding season only 1.7% of the crossbred cows presented body condition score lower than 4.0 (scale 1 to 9). The multibreed herd was mostly managed to maintain an adequate body condition score (5 to 6) throughout the year. Thus, there was no evidence that the crossbred cows with greater proportion of Brahman genetics were nutritionally disadvantaged in relation to the crossbred cows with smaller proportion of Brahman genetics. This is important because it is common to attribute lower P/AI (i.e., < 40%) to nutritional restriction to which *Bos indicus* cattle are exposed in tropical and subtropical climates due to low-quality tropical roughage (Baruselli et al., 2004). Nutritional restriction is associated with prolonged anestrus postpartum and delayed puberty attainment (D'Occhio et al., 2018). These reproductive physiological conditions have been referred as two of the main causes of poor P/AI when *B. indicus* cattle reared in the tropics are submitted to estrous synchronization programs (Baruselli et al., 2004; Nogueira, 2004). Additionally, the proportion of cycling cows (66%) at the beginning of the estrous synchronization program was similar across the six breed groups when we scanned the ovaries of a subgroup of pluriparous crossbred cows (n = 251) (Martins et al., 2022). Thus, in this study, a prevalence of anestrus due to nutritional restriction did not seem the cause of suboptimal P/AI among cows with a greater proportion of Brahman genetics.

Crossbred cows with a greater proportion of Brahman genetics had a reduction in estrous response to the synchronization program by up to 27.9% (Fig. 1), regardless of parity category. These results refer specifically to the Select Synch + CIDR & TAI program. Estrus response is a key fertility marker in estrous synchronization programs (Richardson et al., 2016). In our study, P/AI of cows inseminated in estrus was 2.3-fold greater than those non-estrus cows submitted to TAI (Martins et al., 2022).

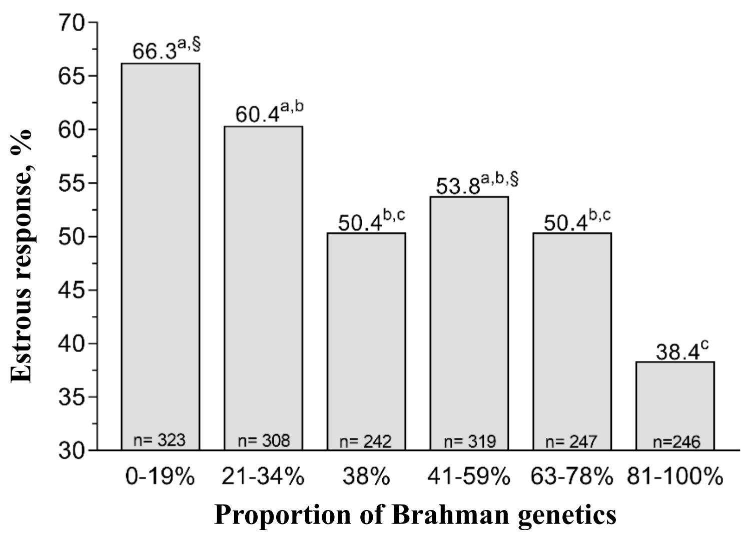

Figure 1. Estrous response to Select Synch + CIDR & TAI program according to the proportion of Brahman genetics of Brahman-Angus crossbred cows ($P < 0.0001$). Means without a common superscript were different ($P < 0.05$) or with the same symbol tended to differ ($P = 0.07$) by applying Tukey test for multiple comparisons. Estrous response was reduced according to the increase in proportion of Brahman genetics of crossbred cows. **Source:** Martins et al., 2022

The conventional estrous synchronization programs recommended for *B. taurus* cattle in the United States (Lamb and Mercadante, 2016) do not seem to efficiently induce estrus in *B. indicus* crossbred cows, generally yielding inconsistent and disappointingly low P/AI (< 45%) (Yelich and Bridges, 2012). Two indicative parameters of successful estrous synchronization programs are the recruitment of a new follicular wave and a presence of large dominant follicle at the end of an estrous synchronization programs (Atkins et al., 2010a; Atkins et al., 2010b). Purebred and crossbred *Bos indicus* cattle do not respond efficiently to the first gonadotropin-releasing hormone (GnRH) ovulatory stimulus of the U.S. estrous synchronization programs, resulting in more failures to recruit a new follicular wave (Saldarriaga et al., 2007; Baruselli et al., 2012). The low ovulatory response to first GnRH stimulus has been related with the incidence of anestrus (Saldarriaga et al., 2007; Baruselli et al., 2012) and decreased luteinizing hormone (LH) response to a GnRH challenge among *Bos indicus*-influenced cattle (Portillo et al., 2008). *Bos indicus*-influenced cattle also present reduced follicular growth when submitted to estrous synchronization programs, which increases the incidence of small follicles at the end of program. The reduced follicular growth is partially explained by the elevated circulating progesterone concentration when *Bos indicus*-influenced cattle are synchronized using progesterone-based estrous synchronization programs (Carvalho et al., 2008; Sartori et al., 2016; Batista et al., 2020). The elevated circulating progesterone concentration leads to suppression of dominant follicle growth, estrus response, and ovulation, being especially relevant among cycling animals because of the additional source of progesterone coming endogenously from the corpus luteum (Carvalho et al., 2008). *Bos indicus*-influenced cattle have different production and clearance rates of steroid hormones, in which *B. taurus* breeds seem to have lesser production and greater metabolism than *B. indicus* breeds (Sartori et al., 2016; Batista et al., 2020). In fact, steroid hormone concentrations are greater in *B. indicus* than in *B. taurus* cattle, whereas ovarian structures are smaller (Sartori et al., 2016). In our results, we verified that at the end of the estrous synchronization program, follicles were up to 22% smaller in diameter among Brahman-Angus crossbred cows (n= 256) with greater proportion of Brahman genetics (Martins et al., 2022). Collectively, unsatisfactory P/AI (~50%) in *Bos indicus*-influenced cattle is a consequence of the inadequacy of conventional U.S. estrous synchronization programs to address the physiological particularities of these cattle.

Strategies that stimulate follicular growth during estrous synchronization programs have improved estrous response and, consequently, P/AI of *Bos indicus* cattle. The most common strategies consist of: **(i)** reducing circulating levels of progesterone concentrations during estrous synchronization such as inserting previously used intravaginal progesterone devices and/or advancing the injection of prostaglandin analogues (Dias et al., 2009; Peres et al., 2009; Martins et al., 2014; Williams and Stanko, 2020), **(ii)** using exogenous estradiol instead of GnRH to induce recruitment of a new follicular wave at the beginning of the estrous synchronization program (Baruselli et al., 2004), **(iii)** using exogenous estradiol at the end of estrous synchronization program to induce ovulation and estrous response (Sá Filho et al., 2011; Martins et al., 2017), and **(iv)** administering equine chorionic gonadotropin (eCG) or adopting 48-h temporary calf removal in the end of synchronization protocol as a LH-support to stimulate follicular growth (Baruselli et al., 2004; Filho et al., 2009). It is important to highlight that estradiol and eCG do not constitute alternatives in the United States as they are not FDA-approved drugs to synchronize estrus. Williams and Stanko (2020) developed an estrous synchronization for *Bos indicus* cows by treating cows with prostaglandin analogue at the beginning of a 5d-CIDR estrous synchronization program. The physiological basis underlying this strategy is to reduce the endogenous concentration of progesterone, inducing luteolysis of any preexisting corpus luteum, which increases LH pulsatile frequency to better support follicular growth. The authors reported satisfactory P/AI (~50%) when injecting prostaglandin upfront. Greater P/AI results were nevertheless described among cows with more than 65 days postpartum (Williams and Stanko, 2020), probably because more cows were cycling at this advanced stage of postpartum. The new developed estrous synchronization program for *Bos indicus*-influenced cattle is recommended by the Beef Reproduction Task Force under the name *Bos indicus* PG 5-day + CIDR (https://beefrepro.org/wp-content/uploads/2023/11/Cow-2024-BRTF_Protocol-sheets-2024_FINAL_for-print-1.pdf).

Impact of Brahman genetics on productivity of crossbred cows at weaning

Brahman-Angus crossbred cows with 81% to 100% of Brahman genetics weaned the lightest calves (Table 2). The impaired P/AI among crossbred cows delayed the time to conception in the breeding season and consequently the time to calving in the calving season. Crossbred cows that conceive later during the breeding season indeed wean younger, lighter calves (Rodgers et al., 2012; Cushman et al., 2013). Crossbred cows with 81% to 100% of Brahman genetics continued to wean the lightest calves even after adjusting weaning weights to 205-d. Thus, indicating that genetics itself contributed to the compromised performance of this group of crossbred cows.

Table 2. Association between the proportion of Brahman genetics of Brahman-Angus cows and weight of calves. Source: (Martins et al., 2024)

Item[1]	**Proportion of Brahman genetics**						SEM	***P*-value**
	0-19%	21-34%	38% (Brangus)	41-59%	63-78%	81-100%		
BW, kg	33.1^{b}	33.9^{a}	33.9^{a}	$33.4^{a,b}$	31.8^{c}	31.8^{c}	0.29	< 0.0001
WW, Kg	245.2^{b}	250.2^{a}	$247.9^{a,b,Y}$	$252.5^{a,X}$	245.2^{b}	220.6^{c}	2.80	< 0.0001
205-day WW, Kg	215.3^{b}	223.6^{a}	$221.5^{a,Y}$	$225.0^{a,X}$	222.5^{a}	208.9^{c}	2.35	< 0.0001

Values without a common lowercase (^{a,b,c,d}) or uppercase (^{X,Y}) superscript in the row differ (P < 0.05) or tend to differ (P < 0.10), respectively, after applying the Tukey test for multiple comparisons.

[1]BW = birth weight; WW = weaning weight; 205-day WW = weaning weight adjusted to 205-day of age.

Crossbred cows with 0 to 19% of Brahman genetics also weaned lighter calves despite having the greatest P/AI (Table 1). The lack of hybrid vigor among a few calves from the crossbred cows with 0% to 19% and 81% to 100% of Brahman genetics likely contributed to these results, as heterosis favors the productivity of crossbred cows over purebred cows in the tropics (Dominguez-Castaño et al., 2021; Trail et al. 1985). The nurturing ability of crossbred cows may have varied according to the proportion of Brahman genetics. For example, *Bos indicus* purebred cows produced less milk than *Bos taurus* purebred cows (Syrstad, 1985; Galukande et al., 2013). Thus, crossbred cows with 81% to 100% of Brahman genetics could have produced less milk, limiting the daily body weight gain of calves. Crossbred cows with 0% to 19% of Brahman genetics as well as their calves may have suffered with heat-stress, compromising the performance of cow–calf pairs. An earlier study demonstrated that the 2-yr-old Brahman–Angus heifers with 0% proportion of Brahman genetics had the lowest heat-stress resilience during summer days while on pasture in Florida (Mateescu et al., 2020). Heifers with 75% to 100% and 25% to 50% of Brahman genetics had superior to intermediate heat-stress resilience, respectively. Thus, in general, crossbred cows with somewhat moderate to slightly high proportion of Brahman genetics (21% to 78%) weaned heavier calves than cows with very low (0% to 19%) or high (81% to 100%) proportion of Brahman genetics.

We defined weaning productivity as kilograms of calf weaned divided by the number of crossbred cows submitted to reproduction. Productivity was, therefore, a compound result of losses due to failure to become pregnant, failure to calve, stillbirth, deaths of cows or calves, and the weaning weight of calves (Martins et al., 2024). The proportion of crossbred cows exposed to reproduction that calved during the calving season was similar across the six breed groups (Table 3). Thus, the preweaning losses and weaning weight components played an important role on determining the productivity of the crossbred cows. Crossbred cows with 81% to 100% of Brahman genetics weaned light calves and lost more calves, being the least productive cows (Table 3).

Table 3. Association between the proportion of Brahman genetics and productive traits. **Source:** (Martins et al., 2024)

Item	**Proportion of Brahman genetics**						***P*-value**
	0-19%	21-34%	38% (Brangus)	41-59%	63-78%	81-100%	
Preg. loss[1], % (no./no.)	0.6 (6/1020)	0.3 (3/889)	1.3 (10/749)	0.7 (8/1189)	0.6 (4/729)	1.2 (10/829)	.
Calving[2], % (no./no.)	85.9 (1014/1180)	85.3 (886/1039)	84.4 (739/876)	84.7 (1181/1395)	85.5 (725/848)	84.1 (819/974)	.
Stillbirth [3], % (no./no.)	0.04 (19/1014)	0.03 (9/886)	0.06 (17/739)	0.04 (18/1181)	0.04 (13/725)	0.05 (17/819)	0.57
Calf mortality[4],% (no./no.)	4.3^{b} (54/1014)	4.3^{b} (44/886)	$5.7^{a,b,Y}$ (50/739)	5.8^{b} (85/1181)	$7.0^{a,b}$ (59/725)	$9.2^{a,X}$ (90/819)	<0.0001
Weaning[5], % (no./no.)	95.7^{a} (960/1180)	95.7^{a} (842/1039)	$94.3^{a,b,X}$ (689/876)	94.2^{a} (1096/1395)	$93.0^{a,b}$ (666/848)	$90.8^{b,Y}$ (729/974)	<0.0001
Non-adjusted Productivity[6], kg/cow	$233.2^{a,b,X} \pm 3.9$	$238.6^{a} \pm 4.0$	$232.4^{a,b} \pm 4.0$	$236.1^{a} \pm 3.9$	$222.4^{b,Y} \pm 4.0$	$199.3^{c} \pm 3.9$	<0.0001
Adjusted Productivity[7], kg/cow	$191.1^{b,Y} \pm 2.3$	$197.0^{a} \pm 2.3$	$195.9^{a,b,X} \pm 2.3$	$199.7^{a} \pm 2.3$	$196.2^{a,b,X} \pm 2.3$	$181.8^{c} \pm 2.3$	<0.0001

[1]Pregnancy loss: proportion of cows that never calved in a given calving season out of the pregnant cows expected to calve.

[2]Calving: proportion of cows exposed to reproduction that calved during the calving season.

[3]Stillbirth: LSMEANS of proportion of stillbirth calves.

[4]Calf mortality: LSMEANS of proportion of calves that died between birth and weaning.

[5]Weaning rate: LSMEANS of proportion of cows weaning a calf.

[6] Non-adjusted productivity: LSMEANS of kilograms of calf weaned per cow exposed to reproduction non-adjusted for weaning rate nor age of calf at weaning.

[7]Adjusted productivity: LSMEANS of kilograms of calf weaned per cow exposed to reproduction adjusted for weaning rate and age of calf at weaning.

Values without a common lowercase (^{a,b,c}) or uppercase (^{X,Y,Z}) superscript in the row differ ($P < 0.01$) or tend to differ ($P < 0.10$), respectively, after applying the Tukey test for multiple comparisons.

As crossbred cows calved during the winter, calves with greater proportion of Brahman genetics may have suffered with cold stress, predisposing crossbred cows with 81% to 100% of

Brahman genetics to lose more calves. In the North-Central Florida, despite winter being mild, freezing temperatures are commonly observed. Newborn Brahman calves were indeed more susceptible to cold-stress than ½ Simmental × ¼ Brahman × ¼ Hereford calves (Godfrey et al., 1991). Brahman calves are also susceptible to weak calf syndrome (Roberson et al., 1986; Carstens, 1994). Newborn calves with this syndrome display muscular weakness, take longer to stand for the first time, and lack a strong suckle reflex. Even after adjusting for weaning rates and age of calf at weaning, crossbred cows with 81% to 100% of Brahman genetics remained among the least productive, indicating that genetics itself also undermined the production of these cows.

Crossbred cows with 0% to 19% of Brahman genetics were underproductive as they wean light calves. They also remained less productive after adjusting for weaning rates and age of calf at weaning. Thus, the association between proportion of Brahman genetics of crossbred cows and productivity resembled a quadratic relationship. A proportion of Brahman genetics somewhere between 21% and 78% ensured superior productivity of Brahman–Angus cows subjected to subtropical conditions.

Summary

Collectively, under subtropical conditions, Brahman-Angus cows with over 63% of Brahman genetics had poorer pregnancy per AI (<40%) than cows with smaller proportion of Brahman genetics (≥45%). The conventional estrous synchronization programs in the United States do not seem to address the reproductive physiology particularities of *Bos indicus* cattle, resulting in poor estrous response and consequently pregnancy per AI. After a 90-day breeding season, Brahman-Angus cows with different proportions of Brahman genetics had similar pregnancy rates though. Crossbred cows with 81% to 100% of Brahman genetics were the least productive because of more calves died before weaning and they weaned lighter calves. The susceptibility of Brahman calves to cold stress is one explanatory factor for the elevated incidence of preweaning calf mortality, as crossbred cows calved during winter months amidst freezing temperatures. On the other hand, crossbred cows with only 0% to 19% of Brahman genetics were also among the least productive because they weaned lighter calves. This group of cows seemed to be less able to cope with the harsh subtropical environmental conditions, such as heat stress, compromising their performance as dams. Overall, moderate to slightly high Brahman genetics (21% to 78%) ensured greater productivity of subtropical Brahman-Angus cows.

Bibliography

Atkins, J. A., M. F. Smith, K. J. Wells, and T. W. Geary. 2010a. Factors affecting preovulatory follicle diameter and ovulation rate after gonadotropin-releasing hormone in postpartum beef cows. Part II: Anestrous cows. *J. Anim. Sci.* 88:2311–2320. doi:10.2527/jas.2009-2532.

Atkins, J. A., M. F. Smith, K. J. Wells, and T. W. Geary. 2010b. Factors affecting preovulatory follicle diameter and ovulation rate after gonadotropin-releasing hormone in postpartum beef cows. Part I: Cycling cows. *J. Anim. Sci.* 88:2300–2310. doi:10.2527/jas.2009-2531.

Baruselli, P. S., E. L. Reis, M. O. Marques, L. F. Nasser, and G. A. Bó. 2004. The use of hormonal treatments to improve reproductive performance of anestrous beef cattle in tropical climates. *Anim. Reprod. Sci.* 82–83:479–486. doi:10.1016/j.anireprosci.2004.04.025.

Baruselli, P. S., J. N. S. Sales, R. V Sala, L. M. Vieira, and M. F. S. Filho. 2012. History, evolution and perspectives of timed artificial insemination programs in Brazil. *Anim. Reprod.* 9:139–152.

Batista, E. O. S., R. V. Sala, M. D. D. V. Ortolan, E. F. Jesus, T. A. Del Valle, F. P. Rennó, C. H. Macabelli, M. R. Chiaratti, A. H. Souza, and P. S. Baruselli. 2020. Hepatic mRNA expression of enzymes associated with progesterone metabolism and its impact on ovarian and endocrine responses in Nelore (*Bos indicus*) and Holstein (*Bos taurus*) heifers with differing feed intakes. *Theriogenology.* 143:113–122. doi:10.1016/j.theriogenology.2019.11.033.

Burrow, H. M. 2015. Genetic aspects of cattle adaptation in the tropics. 2014. In: Dorian J Garrick and Anatoly Ruvinsky, editors, The genetics of cattle. Wallingford, United Kingdom. p. 571-597

Carstens, G. E. 1994. Cold Thermoregulation in the Newborn Calf. *Vet. Clin. North Am. Food Anim.* 10:69–106. doi: 10.1016/S0749-0720(15)30590-9.

Carvalho, J. B. P., N. A. T. Carvalho, E. L. Reis, M. Nichi, A. H. Souza, and P. S. Baruselli. 2008. Effect of early luteolysis in progesterone-based timed AI protocols in *Bos indicus*, *Bos indicus* × *Bos taurus*, and *Bos taurus* heifers. *Theriogenology.* 69:167–175. doi:10.1016/j.theriogenology.2007.08.035.

Casas, E., R. M. Thallman, and L. V. Cundiff. 2011. Birth and weaning traits in crossbred cattle from Hereford, Angus, Brahman, Boran, Tuli, and Belgian Blue sires. *J. Anim. Sci.* 89:979–987. doi:10.2527/jas.2010-3142.

Cooke, R. F., C. L. Daigle, P. Moriel, S. B. Smith, L. O. Tedeschi, and J. M. B. Vendramini. 2020. Cattle adapted to tropical and subtropical environments: Social, nutritional, and carcass quality considerations. *J. Anim. Sci.* 98:1–20. doi:10.1093/jas/skaa014.

Cundiff, L. V, R. M. Thallman, and L. A. Kuehn. 2012. Impact of *Bos indicus* genetics on the global beef industry. In: Proc. of Beef Improvement Federation. Houston, TX, USA, April 18-21.

Cushman, R. A., L. K. Kill, R. N. Funston, E. M. Mousel, and G. A. Perry. 2013. Heifer calving date positively influences calf weaning weights through six parturitions1. *J. Anim. Sci.* 91:4486–4491. Available from: http://dx.doi.org/10.2527/jas.2013-6465

Dias, C. C., F. S. Wechsler, M. L. Day, and J. L. M. Vasconcelos. 2009. Progesterone concentrations, exogenous equine chorionic gonadotropin, and timing of prostaglandin F2α treatment affect fertility in postpuberal Nelore heifers. *Theriogenology.* 72:378–385. doi:10.1016/j.theriogenology.2009.03.006.

D'Occhio, M. J., P. S. Baruselli, and G. Campanile. 2018. Influence of nutrition, body condition, and metabolic status on reproduction in female beef cattle: A review. *Theriogenology.* 125:277–284. doi:10.1016/j.theriogenology.2018.11.010.

Dominguez-Castaño, P., A. M. Maiorano, M. H. V. de Oliveira, L. E. C. dos Santos Correia, and J. A. I. V. Silva. 2021. Genetic and environmental effects on weaning weight in crossbred beef cattle (Bos taurus × Bos indicus). *J. Agric. Sci*. 159:139–146. doi:10.1017/S0021859621000344.

Elzo, M. A., and D. L. Wakeman. 1998. Covariance components and prediction for additive and nonadditive preweaning growth genetic effects in an Angus-Brahman multibreed herd. *J. Anim. Sci.* 76:1290–1302. doi:10.2527/1998.7651290x.

Food and Agriculture Organization (FAO). 2009. How to feed the world in 2050. In: Proc. Expert Meeting on How to Feed the World in 2050. FAO Headquarters, Rome, Italy.

Filho, O. G. S., M. Meneghetti, R. F. G. Peres, G. C. Lamb, and J. L. M. Vasconcelos. 2009. Fixed-time artificial insemination with estradiol and progesterone for Bos indicus cows II: Strategies and factors affecting fertility. *Theriogenology.* 72:210–218. doi:10.1016/j.theriogenology.2009.02.008.

Godfrey, R. W., S. D. Smith, M. J. Guthrie, R. L. Stanko, D. A. Neuendorff, and R. D. Randel. 1991. Physiological responses of newborn *Bos indicus* and *Bos indicus* x *Bos taurus* calves after exposure to cold. *J. Anim. Sci.* 69:258–263. doi: 10.2527/1991.691258x.

Hansen, P. J. 2004. Physiological and cellular adaptations of zebu cattle to thermal stress. *Anim. Reprod. Sci.* 82–83:349–360. doi:10.1016/j.anireprosci.2004.04.011.

Hruska, R. L., R. M. Koch, J. D. Crouse, M. E. Dikeman, L. V Cundiff, K. E. Gregory, and R. M. Koch. 1993. Effect of marbling on variation and change in beef tenderness in *Bos taurus* and *Bos indicus* crosses. 1993. Roman L. Hruska U.S. Meat Anima Research Center. 127. https://digitalcommons.unl.edu/hruskareports/127

Lamb, G. C., and V. R. G. Mercadante. 2016. Synchronization and ar- tificial insemination strategies in beef cattle estrus synchronization artificial insemination beef cattle economics. *Vet. Clin. Food Anim.* 32:335–347. doi:10.1016/j.cvfa.2016.01.006

Lamy, E., S. Van Harten, E. Sales-Baptista, M. M. M. Guerra, and A. M. de Almeida. 2012. Factors influencing livestock productivity. In: Springer-Verlag, editor, Environmental Stress and Amelioration in Livestock Production. Heidelberg, Berlin. p. 19–51. doi: 10.1007/978-3-642-29205-7_2.

Leal, W. S., M. D. Macneil, H. G. Carvalho, R. Z. Vaz, and F. F. Cardoso. 2018. Direct and maternal breed additive and heterosis effects on growth traits of beef cattle raised in southern Brazil. *J. Anim. Sci.* 96:2536–2544. doi:10.1093/jas/sky160.

Martins, T., R. F. G. Peres, A. D. P. Rodrigues, K. G. Pohler, M. H. C. Pereira, M. L. Day, and J. L. M. Vasconcelos. 2014. Effect of progesterone concentrations, follicle diameter, timing of artificial insemination, and ovulatory stimulus on pregnancy rate to synchronized artificial insemination in postpubertal Nellore heifers. *Theriogenology.* 81. doi:10.1016/j.theriogenology.2013.10.020.

Martins, T., C. C. Rocha, J. D. Driver, O. Rae, M. A. Elzo, R. G. Mateescu, J. E. P. Santos, and M. Binelli. 2022. What a 31-year multibreed herd taught us about the influence of B. indicus genetics on reproductive performance of cows. *J. Anim. Sci.* doi:10.1093/jas/skac366.

Martins, T., C. C. Rocha, J. D. Driver, O. Rae, M. A. Elzo, R. G. Mateescu, J. E. P. Santos, and M. Binelli. 2024. Influence of proportion of Brahman genetics on productivity of Brahman–Angus cows at weaning. *Transl. Anim. Sci.* 8. doi:10.1093/tas/txae093.

Martins, T., J. P. Talamoni, M. Sponchiado, J. R. G. Maio, G. P. Nogueira, G. Pugliesi, and M. Binelli. 2017. Impact of estradiol cypionate prior to TAI and progesterone supplementation at initial diestrus on ovarian and fertility responses in beef cows. *Theriogenology.* 104. doi:10.1016/j.theriogenology.2017.08.017.

Mateescu, R. G., K. M. Sarlo-Davila, S. Dikmen, E. Rodriguez, and P. A. Oltenacu. 2020. The effect of Brahman genes on body temperature plasticity of heifers on pasture under heat stress. *J. Anim. Sci.* 98:1–9. doi:10.1093/jas/skaa126.

Nogueira, G. P. 2004. Puberty in South American Bos indicus (Zebu) cattle. *Anim. Reprod. Sci.* 82–83:361–372. doi:https://doi.org/10.1016/j.anireprosci.2004.04.007.

Peres, R. F. G., I. C. Júnior, O. G. S. Filho, G. P. Nogueira, and J. L. M. Vasconcelos. 2009. Strategies to improve fertility in Bos indicus postpubertal heifers and nonlactating cows submitted to fixed-time artificial insemination. *Theriogenology.* 72:681–689. doi:10.1016/j.theriogenology.2009.04.026.

Portillo, G. E., G. A. Bridges, J. W. de Araujo, M. K. V Shaw, F. N. Schrick, W. W. Thatcher, and J. V. Yelich. 2008. Response to GnRH on day 6 of the estrous cycle is diminished as the percentage of Bos indicus breeding increases in Angus, Brangus, and Brahman × Angus heifers. *Anim. Reprod. Sci.* 103:38–51. doi:10.1016/j.anireprosci.2006.12.008.

Rechav, Y. 1987. Resistance of Brahman and Hereford cattle to African ticks with reference to serum gamma globulin levels and blood composition. 1987. *Exp. Appl. Acarol*. 3: 219-232. doi: 10.1007/BF01270458.

Richardson, B. N., S. L. Hill, J. S. Stevenson, D. Gemechis, and G. A. Perry. 2016. Expression of estrus before fixed-time AI affects conception rates and factors that impact expression of estrus and the repeatability of expression of estrus in sequential breeding seasons. *Anim. Reprod. Sci.* 166:133–140. doi:10.1016/j.anireprosci.2016.01.013.

Roberson, R. L., J. O. Sanders, and T. C. Cartwright. 1986. Direct and Maternal Genetic Effects on Preweaning Characters of Brahman, Hereford and Brahman-Hereford Crossbred Cattle. *J. Anim. Sci.* 63:438–446. doi:10.2527/jas1986.632438x.

Rodgers, J. C., S. L. Bird, J. E. Larson, N. Dilorenzo, C. R. Dahlen, A. Dicostanzo, and G. C. Lamb. 2012. An economic evaluation of estrous synchronization and timed artificial insemination in suckled beef cows. *J. Anim. Sci.* 90:4055–4062. doi:10.2527/jas.2011-4836.

Sá Filho, M. F., J. E. P. Santos, R. M. Ferreira, J. N. S. Sales, and P. S. Baruselli. 2011. Importance of estrus on pregnancy per insemination in suckled Bos indicus cows submitted to estradiol/progesterone-based timed insemination protocols. *Theriogenology.* 76:455–463. doi:10.1016/j.theriogenology.2011.02.022.

Saldarriaga, J. P., D. A. Cooper, J. A. Cartmill, J. F. Zuluaga, R. L. Stanko, and G. L. Williams. 2007. Ovarian, hormonal, and reproductive events associated with synchronization of ovulation and timed appointment breeding of *Bos indicus*-influenced cattle using intravaginal progesterone, gonadotropin-releasing hormone, and prostaglandin F2α. *J. Anim. Sci.* 85:151–162. doi:10.2527/jas.2006-335. Available from: https://dx.doi.org/10.2527/jas.2006-335

Sartori, R., L. U. Gimenes, P. L. J. Monteiro, L. F. Melo, P. S. Baruselli, and M. R. Bastos. 2016. Theriogenology Metabolic and endocrine differences between Bos taurus and Bos indicus females that impact the interaction of nutrition with reproduction. *Theriogenology.* 86:32–40. doi:10.1016/j.theriogenology.2016.04.016.

Syrstad, O. 1985. Heterosis in *Bos taurus* x *Bos indicus* crosses. 1985. *Livest. Prod. Sci.* 12:299-307.

Trail, J. C. M., K. E. Gregory, H. J. S. Marples, and J. Kakonge. 1985. Comparison of *Bos taurus*-*Bos indicus* breed crosses with straightbred *Bos indicus* breeds of cattle for maternal and individual traits. *J. Anim. Sci.* 60:1181-1187. doi: 10.2527/jas1985.6051181x.

Williams, G. L., and R. L. Stanko. 2020. Theriogenology Pregnancy rates to fi xed-time AI in *Bos indicus*-influenced beef cows using PGF2α with (Bee Synch I) or without (Bee Synch II) GnRH at the onset of the 5-day CO-Synch + CIDR protocol. *Theriogenology.* 142:229–235. doi:10.1016/j.theriogenology.2019.09.047.

Yelich, J. V, and G. A. Bridges. 2012. Synchronization response: *Bos taurus* vs. *Bos indicus* cattle. In. Proc. of Beef Improvement Federation. Houston, TX, USA, April 18-21.