

Effects of postpartum energy balance, body condition score, and insemination time on conception rates of Bonsmara cows bred using timed artificial insemination

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Abstract

Fertility management of extensively farmed beef cattle in South Africa is essential to ensure the economic viability of such production systems. However, the success of timed artificial insemination (TAI) programmes varies, affecting cattle farmers' adoption of this reproductive technique. This study investigated the effects of postpartum energy balance (ΔM), body condition score (BCS), time of artificial insemination (morning or afternoon), and any interactions on the conception rates of Bonsmara cows ($N = 72$, second to ninth parity, $BCS \geq 2.25$) in the Limpopo Province of South Africa. The cows were synchronised in the morning or afternoon using the seven-day CO-Synch synchronisation protocol. Cow live weight and BCS were recorded at synchronisation, TAI, and pregnancy determination, and the data were used to calculate the ΔM . Cows that did not conceive from TAI were naturally mated, and the number of cows that did not conceive was recorded. The average conception rate of cows bred by both TAI and natural mating was $76.7 \pm 5.60\%$. The ΔM and time of artificial insemination did not influence the conception rate. The BCS and duration of the postpartum period influenced the conception rates of cows bred by TAI and cows bred by combined TAI and natural mating. Cows that conceived from TAI tended to have higher estimated breeding values for fertility than those that conceived from natural mating or did not conceive. Cows with a BCS of 3.00–3.75 had the highest conception rates, followed by those with a BCS >3.75 , with cows with a BCS <2.75 having the lowest rates.

Keywords: beef cattle, conception rate, energy balance, extensive systems, timed artificial insemination

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Introduction

Sustainable food production is becoming increasingly critical to meet the food demands of growing world populations (United Nations, 2019), with this being particularly important in developing countries with limited natural resources (Webb & Erasmus, 2013). Beef production can contribute to food production if the reproductive potential of cows is managed optimally. Large parts of the Limpopo Province of South Africa are characterised by high environmental temperatures, poor veld quality, prevalent poisonous plants, and disease problems associated with external parasites (McCordle *et al.*, 2019). In this province, beef cattle production has declined because of these environmental constraints, leading to a noticeable shift towards game farming. The remaining commercial and small-scale farmers in the area are concerned about poor fertility in their cattle herds, which ultimately affects cost-efficient beef production.

The economic viability of beef production systems is influenced mainly by reproductive efficiency (Bearden *et al.*, 2006). Fertility has a low heritability, but the components of fertility (such as scrotal circumference, semen quality, and conception rate) have a higher heritability than reproduction overall (Fontes *et al.*, 2020). Most extensive beef production systems breed cows using natural mating with bulls, rather than using artificial insemination (AI), because conception rates are often variable in extensive beef AI programmes (Burrow & Prayaga, 2004). The use of AI in the beef industry is not as common as in the dairy industry, because of the extensive nature of beef cattle farming, low conception rates, high cost, the laborious task of detecting oestrus, and the required skills for artificially inseminating cows. Consequently, approximately 92% of cases where AI is used in South Africa are in the dairy industry (Dean, 2019; Washaya *et al.*, 2019). Timed artificial insemination (TAI) is an approach that could potentially overcome the laborious task of observing and detecting oestrus in cows in extensive beef production systems. It involves the use of different TAI protocols, intravaginal release devices, and hormonal treatments to maximise conception rates (Busch *et al.*, 2008).

The number of days postpartum includes the anoestrus period and the time required for uterine involution, histological repair, and resumption of regular hormonal activity (Macmillan, 2002). Many farmers and scientists have debated the optimal length of this involution period. A decrease in the number of days between parturition and conception will yield a higher income from the cow herd. However, the number of inseminations required may increase, and the ultimate conception rate may be compromised by shortening the cows' postpartum recovery period. The postpartum recovery period and the timing of AI are influenced by breed type, which is often overlooked when farmers, technicians, or veterinarians make decisions about breeding protocols for cattle (Byerley *et al.*, 1987; Funston, 2014; Perry, 2016).

This study aimed to determine the effects of body condition score (BCS), change in cow live weight postpartum, duration of the postpartum recovery period, and the time of day of AI (08:30 versus 14:00) on the conception rate of Bonsmara cows extensively farmed in the Limpopo Province of South Africa and bred by TAI.

Materials and methods

Ethical approval for this research was obtained from the Faculty of Natural and Agricultural Sciences Ethics Committee at the University of Pretoria, with ethical approval reference NAS313/2020.

The study was conducted at a commercial beef cattle farm near Modimolle in the Limpopo Province of South Africa. The study used nonpregnant Bonsmara cows selected based on parity (second to ninth) and BCS (scored on a scale of 1–5), and involved the use of TAI employing the seven-day CO-Synch breeding programme, with cows inseminated 48 hours after synchronisation of oestrus at either 08:30 or 14:00.

The beef herd was kept on natural pasture in the savanna biome (Tainton, 2003), with a veld quality of *ca.* 6%–12% crude protein and 8–10 MJ metabolisable energy/kg dry matter, and an average rainfall during the study period of 478 mm. The cow herd was managed based on a rotational grazing model with a stocking density of six cows/ha. The cow herd was supplemented with a salt-phosphate lick (100–200 g/cow/day, containing 240 g calcium/kg and 120 g phosphorus/kg; Voermol Rumevite P12) during spring and summer. All cattle had *ad libitum* access to water and mineral licks. The cow herd was frequently handled and weighed for data collection. The health programme included recommended vaccinations for botulism, black quarter, anthrax, brucellosis (S19), paratyphoid, Rift Valley fever, vibriosis, and *Pasteurella*.

A group of 72 nonpregnant cows was selected from the Bonsmara cow herd by blocking for BCS and parity. Cows in their second parity or greater and with BCSs >2.25 were included. Body condition score was recorded on a 5-point scale, with 1 representing very thin and 5 representing very fat (Rasby, 2007). The BCS of each cow was also categorised as follows: $2.50 \leq A < 2.75$, $2.75 \leq B < 3.00$, $3.00 < C < 3.50$, and $3.50 \leq D < 4.00$. Cows with a BCS of less than 2.25 were not included in the study since it is not economically viable to AI cows in poor condition because of their inadequate energy reserves (Esposito *et al.*, 2014). The 72 selected cows were then randomly allocated to the CO-Synch morning and afternoon groups. The live weights of the cows were recorded at their previous parturition and at synchronisation to determine their energy balance (ΔM). The days from parturition to TAI and from parturition to conception were recorded for all the cows in the study. The postpartum recovery period exceeded the minimum recommended period of 45 days, to allow for involution and recovery in all cows in the study (Byerley *et al.*, 1987; Funston, 2014; Perry, 2016).

The following data were obtained from the Logix Database of the SA Stud Book: cow identification number, previous calving records, age, inter-calving period, last calving date, live weight, number of calves per cow, and the estimated breeding value (EBV) for cow fertility. Each cow's fertility EBV was estimated using the first three inter-calving periods of the cow and her relatives, providing an indication of the expected performance of her offspring. These EBVs were used to test the effects of genetic influences on each cow in the study; for example, a heifer's EBV reflects the genetic merit for age at first calving. The EBVs were also used to determine the inclusion of cows in the study and their allocation to experimental groups. Cows with EBV values of below 90 or above 120 were regarded as outliers and were excluded from the study.

The dates on which the controlled internal drug release (CIDR) devices were inserted and removed, as well as the times and dates of AI, were recorded. An intra-vaginal progesterone-releasing device (CIDR[®]B; 1.9 g progesterone; Zoetis, South Africa) was inserted on day 0, and Estrumate[®] (1 mL cloprostenol; MSD Animal Health, South Africa) and oestradiol benzoate (2 mL oestradiol benzoate; compounded by V-Tech) were administered to each cow via intramuscular injection. Half of the cows were synchronised at 08:30 and the other half at 14:00. On day 7, the CIDR devices were removed according to the cows' TAI time-of-AI group (i.e. at 08:30 or 14:00), so that all AI occurred 48 hours after CIDR device removal. After CIDR device removal, all the cows were injected intramuscularly with 2 mL oestradiol cypionate (sodium cloprostenol; compounded by V-Tech).

Timed AI occurred on day 9, either in the morning or the afternoon. Before TAI commenced, the researcher and AI-technician observed previously described oestrus behaviours in the cows (mounting and standing oestrus; Bearden *et al.*, 2006). Straws of semen from the same bull and batch were thawed by a qualified AI technician using the conventional method: 0.25 mL straws thawed for 25 seconds at 35 °C using a thermostatically controlled electric heater (IAEA, 2005; Bearden *et al.*, 2006). Three bulls were introduced into the herd three days after TAI to cover non-pregnant cows during the remainder of the three-month breeding season. Pregnancy was diagnosed by rectal palpation by a qualified veterinarian at around 90 days after TAI. The pregnancy status of the cows was recorded as either in-calf or not-in-calf, and the stage of gestation in months was recorded. An additional pregnancy diagnosis was performed five months later to confirm conception from TAI or natural mating, and to identify non-pregnant cows.

Data were captured in Microsoft Excel, followed by the calculation of frequencies and descriptive statistics. Initial analyses of the effects of ΔM , BCS, and time-of-TAI on conception rates from TAI, pooled conception rates from TAI and natural mating, and other variables were analysed using multifactorial general linear analysis of variance in SAS version 13, and by a multinomial generalised logistic regression function (Rasby, 2007; Washaya *et al.*, 2019). As slight (non-significant) differences in cow age were observed between the BCS categories, the statistical models included cow age as a covariate. Differences between means were tested using Bonferroni's multiple range test at a 95% significance level ($P \leq 0.05$), which accommodates the unbalanced data due to missing values. Conception rates over the breeding season (including TAI and natural service by bulls) were also analysed using survival analysis of the number of days postpartum (from previous calving to TAI), as influenced by BCS and breeding outcome (conception by TAI or natural mating, or not pregnant), as previously described by Escrivao *et al.* (2012) and Short *et al.* (1990).

Results

The characteristics and conception data of the cows that conceived from TAI or natural mating or that did not conceive are presented in Table 1.

Table 1 The reproductive parameters and conception rates (means \pm standard deviation) of Bonsmara cows bred using timed artificial insemination (TAI) or natural mating with bulls

Characteristics (n = 72)	Breeding response		
	Conceived from TAI	Conceived from bulls	Not pregnant
Age of cows (years)	7.6 \pm 1.694	7.74 \pm 1.874	8.41 \pm 2.185
Parity	5.0 \pm 1.88	4.58 \pm 1.90	5.63 \pm 2.39
Body condition score	2.9 ^a \pm 0.17	3.0 ^a \pm 0.21	2.7 ^b \pm 0.21
Δ M (energy balance, kg) ¹	26.9 \pm 50.51	15.1 \pm 41.38	11.0 \pm 68.81
Days to conception ²	72.1 ^a \pm 11.94	101.1 ^b \pm 26.40	n/a
Age at first calving	911.6 \pm 141.49	961.5 \pm 164.13	866.8 \pm 116.03
Inter-calving period ³	350.4 \pm 16.89	390.0 \pm 104.38	382.5 \pm 64.42
Heifer EBV	103.9 ^a \pm 11.67	97.7 ^b \pm 10.60	95.5 ^b \pm 15.66

¹ Difference in cow mass from calving to TAI-breeding. ² Days from last calving date to conception by TAI or natural mating. ³ Inter-calving period for previous calf. ^{ab} Means in the same row with different superscript letters differ ($P \leq 0.05$). EBV: estimated breeding value, n/a: not applicable.

The pooled conception rate of the Bonsmara cows from both TAI and follow-up natural mating for the three-month breeding season was 76.7 \pm 0.05%. The BCSs of the cows that conceived from TAI and follow-up natural mating were higher ($P \leq 0.05$) than those of the cows that did not conceive. The Δ M values of the cows that conceived were not statistically higher than those of cows that did not conceive from TAI. The ages and parities of cows with different pregnancy statuses did not differ.

Overall, 47.9 \pm 0.08% of cows conceived from TAI, 28.8 \pm 0.09% conceived from the follow-up bulls, and 23.2 \pm 0.10% did not conceive. The number of days taken for cows to conceive from TAI was less ($P \leq 0.05$) than that taken for cows to conceive from the follow-up natural mating. Heifers that conceived from TAI had a higher ($P \leq 0.05$) EBV for fertility than those that did not conceive, which supports the importance of breeding values in improving the fertility of beef cows. In this study, the time-of-AI did not affect the cows' conception rates ($P = 0.61$), so similar conception rates were achieved from the morning and afternoon TAIs.

The effects of BCS on the reproductive characteristics of Bonsmara cows are presented in Table 2 and Figure 1. Body condition score had a positive impact ($P \leq 0.05$) on the conception rate, with conception rates increasing with an increase in BCS. The ages of the cows with different BCSs did not differ significantly, but cows with higher BCSs were chronologically older (Table 2). The preceding inter-calving period was also longer in cows with a D-category BCS (mildly over-conditioned). Neither the Δ M nor the EBVs of the cows differed between the BCS categories. A total of 79.4% of cows were in acceptable condition (categories B and C), while 12.3% were mildly over-conditioned (category D), and 8.2% were below the recommended BCS for breeding (category A). A higher proportion ($P \leq 0.05$) of cows in BCS categories B and C conceived than cows in BCS category A.

Body condition score also influenced the number of days required for cows to conceive ($P \leq 0.05$). Cows with a low BCS (2.25–2.75) required significantly longer to conceive than those with a BCS of 3.00 or higher. This emphasises the importance of postpartum involution and the recovery of breeding cows. Although not significant, cows with a better BCS that conceived had a numerical increase (19.6 to 28.9 kg) in body mass from parturition to breeding, while cows with a BCS ≤ 2.75 lost about 24 kg during this period (Table 2).

The survival analysis of the effect of BCS on the days to conception of the cows bred by TAI and by follow-up natural mating (Figure 2) illustrates the differences in the conception rates presented in Figure 1. Overall, cows with a BCS exceeding 2.75 conceived earlier in the breeding season ($P \leq 0.05$) than those with a BCS less than this threshold value. This stresses the importance of an acceptable BCS to achieve breeding success in extensively farmed beef cows.

Table 2 Effects of body condition score (BCS) on the reproduction parameters (means \pm standard deviation) of extensively managed Bonsmara cows bred by timed artificial insemination (TAI) and follow-up natural mating in the semi-arid bushveld of South Africa

Description (n = 72)	2.5 < BCS \leq 2.75 A	2.75 < BCS \leq 3.00 B	3.0 < BCS \leq 3.25 C	3.25 < BCS < 4.00 D
Cow characteristics:				
Age	6.33 \pm 2.86	6.12 \pm 2.46	6.48 \pm 2.20	8.09 \pm 1.72
Inter-calving period	363.7 ^{ab} \pm 19.22	353.1 ^a \pm 14.07	380.7 ^{ab} \pm 69.23	427.9 ^b \pm 136.56
Days to conception ¹	140.2 ^a \pm 69.87	113.4 ^{ab} \pm 55.78	97.9 ^b \pm 42.78	98.4 ^b \pm 43.74
Δ M (energy balance, kg) ²	-24.3 \pm 55.37	19.6 \pm 45.16	28.9 \pm 48.87	11.6 \pm 56.10
EBV (cow)	111.7 \pm 4.73	104.4 \pm 7.99	101.5 \pm 25.35	112.8 \pm 9.74
Breeding response:				
% of cows bred	8.2	39.7	39.7	12.3
% of cows conceived (TAI)	1.4 ^a	21.9 ^b	20.5 ^b	4.1 ^a
% of cows conceived (TAI + natural mating)	2.7 ^a	28.7 ^b	34.2 ^b	10.9 ^{ab}

¹ Days from last calving date to conception by TAI or natural mating. ² Difference in cow mass from calving to TAI-breeding. ^{ab} Different superscripts in rows indicate significant differences ($P \leq 0.05$). EBV: estimated breeding value.

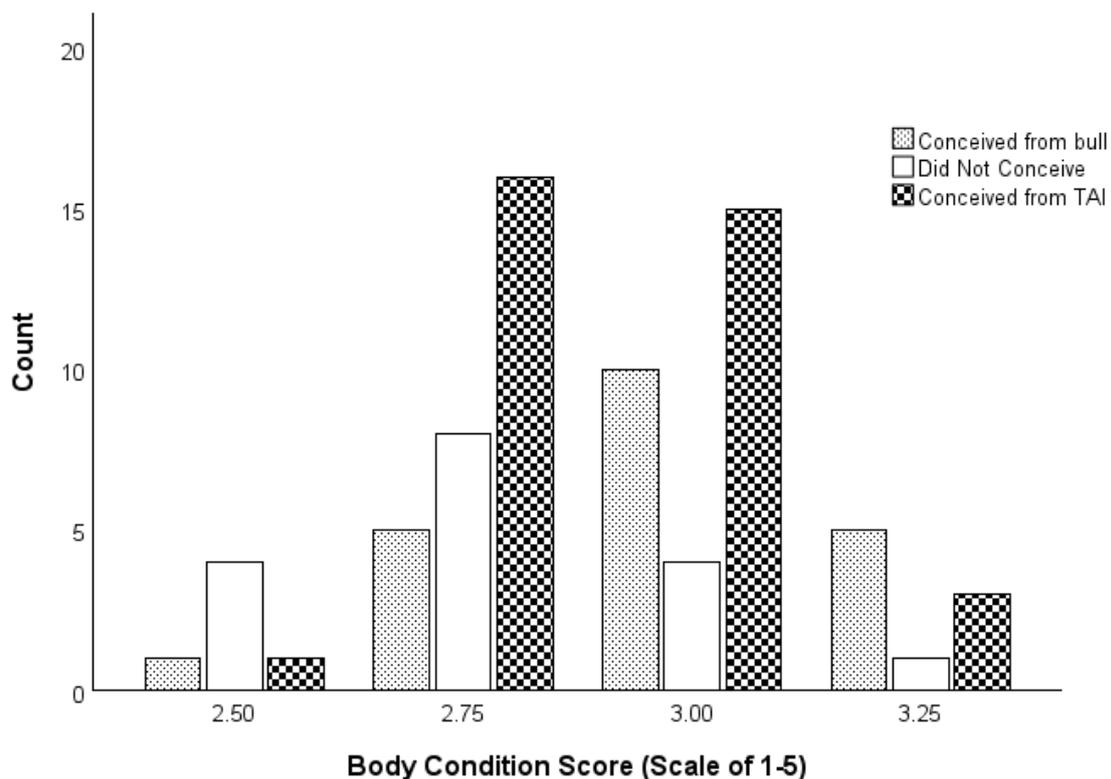


Figure 1 Effect of body condition score on the number of extensively managed Bonsmara cows that conceived from timed artificial insemination (TAI) or follow-up natural mating, or that did not conceive.

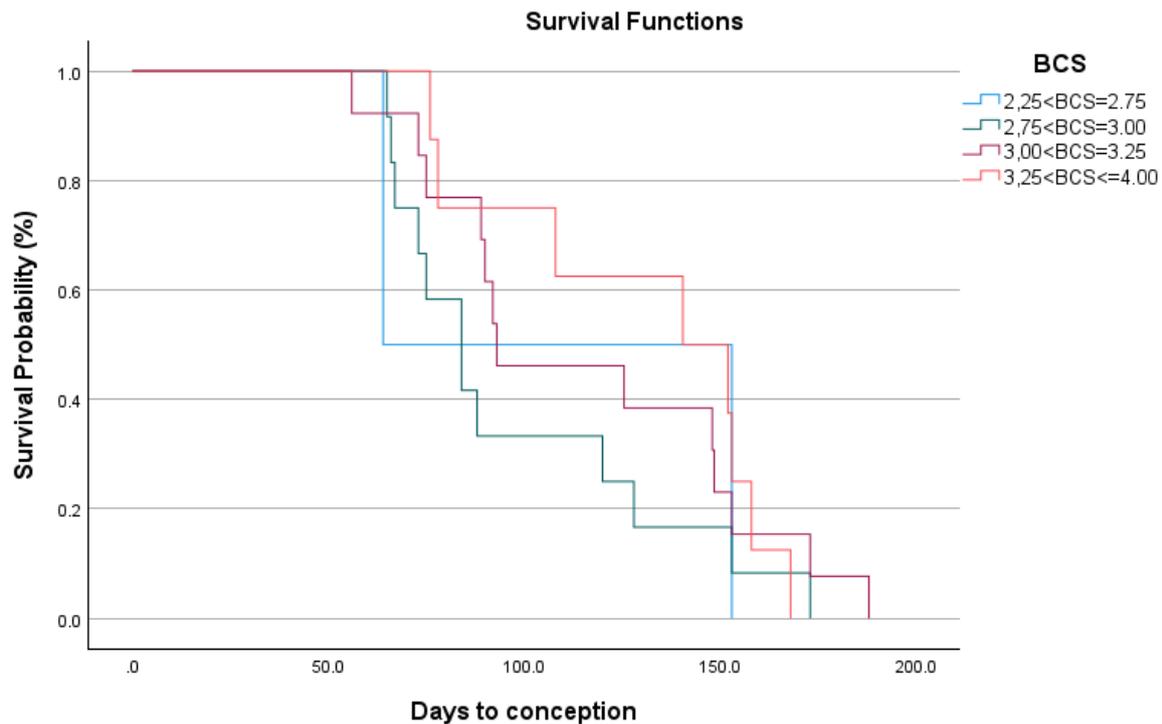


Figure 2 Survival analysis for the effect of body condition score (BCS) on days to conception in extensively managed Bonsmara cows bred using timed artificial insemination and follow-up natural mating.

Discussion

The results of this study indicate that BCS affects the conception rates of Bonsmara cows in the Limpopo Province of South Africa when they are bred using a combination of TAI and follow-up natural mating with bulls. This is significant as it shows that an acceptable BCS is important for breeding cows, even if the cows are synchronised in oestrus and inseminated at the recommended time post-synchronisation. Cow BCS had a more significant effect than ΔM , as ΔM had a numerical but not statistically significant impact on conception rates. These findings generally agree with those of Esposito *et al.* (2014) for dairy cows, and highlight the importance of maintaining the preferred BCSs of 3.0 to 4.0 to achieve the best conception rates in extensively managed beef cows. Cows with higher BCSs had a greater probability of conception until a threshold BCS of approximately 4.0, after which conception rates decreased. This confirms that nutrition, especially the accumulation of energy reserves during the periparturient period, influences the reconception of extensively managed beef cows. Heifer EBVs were higher for cows that conceived from TAI than for those that conceived from follow-up natural mating or that did not conceive at all.

The resumption of oestrus cyclicity is the last priority of cows with low energy reserves (Pereira *et al.*, 2006). For this reason, a positive energy balance (Esposito *et al.*, 2014) and nutrient partitioning that supports the resumption of a normal oestrous cycle (Pereira *et al.*, 2006) are essential for normal reproduction. Previous findings (Short *et al.*, 1990) indicate that BCS influences the ovarian cyclic activity of beef cows and that a BCS of 2.5 was the lowest score required for successful synchronisation of oestrus (Pereira *et al.*, 2006). In the current study, a BCS score of 2.25 was used as the minimum for synchronisation; however, several cows with a BCS of less than 2.5 failed to conceive from TAI and took longer to conceive from natural mating after the TAI programme. According to Crowe (2008), such cows take longer to respond to increased postpartum nutrients and therefore gain weight more slowly. The BCSs of cows can be improved by supplemental energy and protein feeding in as short a period as two months prepartum (Pereira *et al.*, 2006). This agrees with studies on the effects of BCS at calving on ovarian cyclic activity (Bennington & Thayne, 1994; Dongen *et al.*, 2004; Pereira *et al.*, 2006), confirming that a nutrient restriction results in a low luteinising hormone concentration. Follicle development occurs because of the influence of follicle stimulating hormone, but with atretic follicles due

to the lack of luteinising hormone. Similarly, the study by Rice (1991) showed that cows that improved their BCS during the dry period had a higher probability of first conception.

Fat reserves are associated with the production of the metabolic hormone leptin, which regulates body fatness. Cows that have excessive body fat (BCS >3.75) produce more leptin, resulting in reduced feed intake (Ayres *et al.*, 2014). These cows still conceive, although typically only later in the breeding season. However, if they are in a negative energy balance, it may adversely affect the energy available during pregnancy and lactation. A negative energy balance may extend the anoestrus period, which explains the observation in the current study that some cows with a BCS >3.75 required a longer period to conceive. This may be partly due to the restricting effects of a negative energy balance on the gonadotrophic axis, luteinising hormone pulses, and follicular development (Humbolt *et al.*, 2009). In addition, over-conditioned cows may suffer from ketosis, liver disease, endocrine imbalances, and reduced fertility, which causes a decrease in insulin-like growth factor-1 concentrations, lowers gonadotropin-releasing hormone pulses, and reduces follicular development (Filho *et al.*, 2009).

It follows that managing the cows' BCS and the number of days from parturition to rebreeding is critical to maximise reproductive efficiency. These results show that the optimal BCS for achieving the best conception rates from TAI varies between 2.75 and 3.75 for extensively managed Bonsmara cows, with scores below or above this range increasing the number of days to conceive. A study on postpartum involution (Samadi *et al.*, 2013) showed that the first follicle to approach ovulation after calving develops into a dominant follicle but often undergoes atresia, and ovulation does not occur (Murphy *et al.*, 1990). In the current study, the number of postpartum days to TAI influenced the conception rates of cows, which may explain why some cows in an acceptable body condition did not conceive from TAI, as this may have been caused by insufficient involution. The cows that had more than 60 days of recovery and still did not conceive were mainly poorly- or over-conditioned.

Some of the first reports on the effects of nutrition on conception rates in beef cows indicate that feeding a high-energy diet during the peripartum period improves the conception rates of both beef and dairy cows (Wiltbank *et al.*, 1962; VanRaden *et al.*, 2004; Esposito *et al.*, 2016). Although ΔM did not affect conception rates in the present study, it was observed that cows in a poor condition lost body mass, while those that conceived invariably gained 20–30 kg from parturition to the next breeding season. This observation aligns with previous studies that have demonstrated a positive effect of the change in live weight from the last calving to rebreeding on conception rates in cows (Wiltbank *et al.*, 1962; Agyemang *et al.*, 1991; VanRaden *et al.*, 2004; Esposito *et al.*, 2014).

Conclusions

Body condition score and the duration of the postpartum period influenced the conception rates of Bonsmara cows bred using TAI and follow-up natural mating in the Limpopo Province of South Africa. Ideal BCSs for conception in this study varied between 2.75 and 3.75, resulting in postpartum reconception periods of between 97 and 113 days. An increase in postpartum cow mass (positive ΔM) did not influence conception rates. Cows with higher heifer EBVs had higher conception rates, which confirms the use of EBVs to select replacement heifers to improve herd fertility. The time of day that AI was performed did not influence conception rates. It can be concluded that the conception rates of beef cows in TAI programmes could be improved by managing factors such as the BCS and ensuring adequate time for involution and postpartum recovery.

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Authors' contributions

Conceptualisation: E.C.W.; methodology: E.C.W. and K.J.D.; formal analysis: E.C.W. and K.J.D.; investigation: E.C.W. and K.J.D.; resource acquisition: M.R., H.E.T., and E.C.W.; data curation: K.J.D.; writing (original draft preparation): K.J.D.; writing (review and editing): E.C.W. and M.R.; visualisation: K.J.D. and E.C.W.; supervision: E.C.W.; project administration: E.C.W.; funding acquisition: E.C.W. All the authors have read and agreed to the published version of the manuscript.

Conflicts of interest declaration

The authors declare no conflicts of interest.

Data availability statement

The data can be obtained from the University Data repository, with permission from Embryo Plus and SA Studbook.

References

- Agyemang, K., Little, D.A., Bah, M.L., & Dwinger, R.H., 1991. Effects of postpartum body weight changes on subsequent reproductive performance in N'Dama cattle maintained under traditional husbandry systems. *Animal Reproduction Science*, 26:51–59. DOI: [https://doi.org/10.1016/0378-4320\(91\)90065-8](https://doi.org/10.1016/0378-4320(91)90065-8)
- Ayres, H., Ferreira, R.M., Torres-Júnior, J.R.S., Demétrio, C.G.B., Sá Filho, M.F., Gimenes, L.U., Penteado, L., D'Occhio, M.J., & Baruselli, P.S., 2014. Inferences of body energy reserves on conception rate of suckled Zebu beef cows subjected to timed artificial insemination followed by natural mating. *Theriogenology*, 82:529–536. DOI: <https://doi.org/10.1016/j.theriogenology.2014.04.026>
- Baruselli, P.S., Reis, E.L., Marques, M.O., Nasser, L.F., & Bó, G.A., 2004a. The use of hormonal treatments to improve reproductive performance of anestrus beef cattle in tropical climates. *Animal Reproduction Science*, 82–83:479–486. DOI: <https://doi.org/10.1016/j.anireprosci.2004.04.025>
- Bearden, H.J., Fuquay, J.W., & Willard, S.T., 2006. Applied Animal Reproduction, Sixth Edition, Prentice Hall.
- Bennington, C.C., Thayne, W.V., & Thayne, W.V., 1994. Use and misuse of mixed model analysis of variance in ecological studies. *Ecology*, 75:717–722.
- Burrow, H.M. & Prayaga, K.C., 2004. Correlated responses in productive and adaptive traits and temperament following selection for growth and heat resistance in tropical beef cattle. *Livestock Production Science*, 86:143–161. DOI: <https://doi.org/10.1016/j.livprodsci.2003.06.001>
- Busch, D.C., Schafer, D.J., Wilson, D.J., Mallory, D.A., Leitman, N.R., Haden, J.K., Ellersieck, M.R., Smith, M.F., & Patterson, D.J., 2008. Timing of artificial insemination in postpartum beef cows following administration of the h + controlled internal drug-release protocol. *Journal of Animal Science*, 86:1519–1525. DOI: <https://doi.org/10.2527/jas.2008-0925>
- Byerley, D.J., Staigmiller, R.B., Berardinelli, J.G., & Short, R.E., 1987. Pregnancy rates of beef heifers bred either on puberal or third estrus. *Journal of Animal Science*, 65:645–650. DOI: <https://doi.org/10.2527/jas1987.653645x>
- Crowe, M.A., 2008. Resumption of ovarian cyclicity in post-partum beef and dairy cows. *Reproduction in Domestic Animals*, 43:20–28. DOI: <https://doi.org/10.1111/j.1439-0531.2008.01210.x>
- Dean, S., 2019. Extending artificial insemination to beef cattle. *Farmer's Weekly*, 19 May.
- D'Occhio, M.J., Baruselli, P.S., & Campanile, G., 2019. Influence of nutrition, body condition, and metabolic status on reproduction in female beef cattle: A review. *Theriogenology*, 125:277–284. DOI: <https://doi.org/10.1016/j.theriogenology.2018.11.010>
- Escrivao, R.J.A., Webb, E.C., Garces, A.P.J.T., & Grimbeek, R.J., 2012. Effects of 48-hour calf withdrawal on conception rates of *Bos indicus* cows and calf weaning weights in extensive production systems. *Tropical Animal Health and Production*, 44:1779–1782.
- Esposito, G., Irons, P.C., Webb, E.C., & Chapwanya, A., 2014. Interactions between negative energy balance, metabolic diseases, uterine health and immune response in transition dairy cows. *Animal Reproduction Science*, 144:60–71.
- Filho, O.G.S., Meneghetti, M., Peres, R.F.G., Lamb, G.C., & Vasconcelos, J.L.M., 2009. Fixed-time artificial insemination with estradiol and progesterone for *Bos indicus* cows II: Strategies and factors affecting fertility. *Theriogenology*, 72:210–218. DOI: <https://doi.org/10.1016/j.theriogenology.2009.02.008>
- Fontes, P.L.P., Oosthuizen, N., & Cliff Lamb, G., 2020. Reproductive management of beef cattle. Mississippi State University Extension, Elsevier. pp. 57–73.
- Funston, R.N. & Deutscher, G.H., 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. *Journal of Animal Science*, 82:3094–3099. DOI: <https://doi.org/10.2527/2004.82103094x>
- Hall, J.B. & Benjamin, R.D., 2005. Timing of insemination of beef heifers. In: Proceedings of Applied Reproductive Strategies in Beef Cattle. pp.195–202.
- Humblot, P., Grimard, B., & Ponsart, C., 2009. Impact of energy balance on metabolic changes and reproductive tissues; consequences on fertility in dairy and beef cattle. *Cattle Practice*, 17(1):5–6.
- IAEA, 2005. Improving artificial breeding of cattle in Africa, Guidelines and recommendations. Animal Production and Health Section, International Atomic Energy Agency, Vienna, Austria, IAEA-TECDOC-1437. www-pub.iaea.org/MTCD/Publications/PDF/te_1437_web.pdf
- Macmillan, K.L., 2002. Advances in bovine theriogenology in New Zealand. 1. Pregnancy, parturition and the postpartum period. *New Zealand Veterinary Journal*, 50:67–73. DOI: <https://doi.org/10.1080/00480169.2002.36272>

- McCrinkle, C.M.E., Masethe, J.M., Botha, E.A., Webb, E.C., & Smuts, M.P., 2019. Scrotal tick damage as a cause of infertility in communal bulls in Moretele, South Africa. *Journal of the South African Veterinary Association*, 90:a1966. DOI: <https://doi.org/10.4102/jsava.v90i0.1966>
- Murphy, M.G., Boland, M.P., & Roche, J.F., 1990. Activity in post-partum beef suckler cows. *Journals of Reproduction and Fertility*, 90:523–533.
- Perry, G.A., 2016. Factors affecting puberty in replacement beef heifers. *Theriogenology*, 86:373–378. DOI: <https://doi.org/10.1016/j.theriogenology.2016.04.051>
- Pereira, E., De Oliveira, H.N., Eler, J.P., Silva, J.A.I.I.D.V., & Van Melis, M.H., 2006. Use of survival analysis as a tool for the genetic improvement of age at first conception in Nelore cattle. *Journal of Animal Breeding and Genetics*, 123:64–71. DOI: <https://doi.org/10.1111/j.1439-0388.2006.00567.x>
- Samadi, F., Phillips, N.J., Blache, D., Martin, G.B., & D'Occhio, M.J., 2013. Interrelationships of nutrition, metabolic hormones and resumption of ovulation in multiparous suckled beef cows on subtropical pastures. *Animal Reproduction Science*, 137(3–4):137–144.
- Rasby, R.J., Stalker, A., & Funston, R.N., 2014. Body Condition Scoring Beef Cows: A Tool for Managing the Nutrition Program for Beef Herds. University of Nebraska-Lincoln Extension, NE, USA. pp. 1–7.
- Rice, L.E., 1991. The effects of nutrition on reproductive performance of beef cattle. *The Veterinary Clinics of North America. Food Animal Practice*, 7:1–26. DOI: [https://doi.org/10.1016/S0749-0720\(15\)30807-0](https://doi.org/10.1016/S0749-0720(15)30807-0)
- Renquist, B.J., Oltjen, J.W., Sainz, R.D., & Calvert, C.C., 2006. Effects of age on body condition and production parameters of multiparous beef cows. *Journal of Animal Science*, 84:1890–1895. DOI: <https://doi.org/10.2527/jas.2005-733>
- Short, R.E., Bellows, R.A., Staigmiller, R.B., Custer, E.E., Ballewos, A., Staigmiller, R.B., & Berardinelli, J.G., 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. *Journal of Animal Science*, 68:799–816. DOI: <https://doi.org/10.2527/1990.683799x>
- Tainton, N., 2003. Veld management in South Africa. University of KwaZulu Natal Press, KZN, RSA. ISBN 978 0869809488.
- Taponen, J., 2009. Fixed-time artificial insemination in beef cattle. *Acta Veterinaria Scandinavica*, 51:48. DOI: <https://doi.org/10.1186/1751-0147-51-48>
- United Nations, 2019. World Population Prospects 2019, Volume II: Demographic Profiles. United Nations Department of Economic and Social Affairs.
- Van Dongen, H.P.A., Olofsen, E., Dinges, D.F., & Maislin, G., 2004. Mixed-model regression analysis and dealing with interindividual differences. *Methods in Enzymology*, 384:139–171. DOI: [https://doi.org/10.1016/S0076-6879\(04\)84010-2](https://doi.org/10.1016/S0076-6879(04)84010-2)
- VanRaden, P.M., Sanders, A.H., Tooker, M.E., Miller, R.H., Norman, H.O., Kuhn, M.T., & Wiggans, G.R., 2004. Development of a national genetic evaluation for cow fertility. *Journal of Dairy Science*, 87:2285–2292. DOI: [https://doi.org/10.3168/jds.S0022-0302\(04\)70049-1](https://doi.org/10.3168/jds.S0022-0302(04)70049-1)
- Washaya, S., Tavirimirwa, B., Dube, S., Sisito, G., Tambo, G., Ncube, S., & Zhakata, X., 2019. Reproductive efficiency in naturally serviced and artificially inseminated beef cows. *Tropical Animal Health and Production*, 51:1963–1968. DOI: <https://doi.org/10.1007/s11250-019-01889-z>
- Webb, E.C. & Erasmus, L.J., 2013. The effect of production system and management practices on the quality of meat products from ruminant livestock. *South African Journal of Animal Science*, 43(3):413–423. DOI: <http://dx.doi.org/10.4314/sajas.v43i3.11>
- Wiltbank, J.N., Rowden, W.W., Ingalls, J.E., Geegoey, K.E., & Koch, R.M., 1962. Effect of energy level on reproductive phenomena of mature Hereford cows. *Journal of Animal Science*, 21:219–225. DOI: <https://doi.org/10.2527/jas1962.212219x>