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Strategies for Enhancing Reproductive Efficiency in Beef Cattle

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Abstract | Reproductive efficiency is of crucial significance inside the optimization of productivity and profitability in pork cattle manufacturing. In this research, numerous strategies of improving reproductive overall performance were analyzed, inclusive of herbal carrier, estrus synchronization, hormonal stimulation, and assisted reproductive era (ART) like synthetic insemination (AI) and embryo switch (ET). Comparisons of the primary reproductive developments including conception fee, being pregnant price, estrus reaction, delivery weight, and price effectiveness have been made. The findings confirmed that the ART institution (ARTG) had the very best theory price (91%) and pregnancy rate (89%) and drastically handed other agencies. Moreover, ART calves had heavier beginning weights (35.7 kg) and higher postnatal boom prices, resulting in delivered market price. Economic analysis recognized that ART, even though extra expensive to implement initially, gave the satisfactory return on investment (ROI of 350%), indicating that it became a sustainable method for livestock rearing. These outcomes emphasize the need to comprise superior reproductive technology into farm animals manufacturing packages to growth productivity, pleasant of genetics, and monetary profits. Adoption of ART, estrus synchronization, and optimized control practices are advocated by the studies for improving reproductive efficiency in red meat farm animals manufacturing.

Keywords | Reproductive efficiency, Beef cattle, Artificial insemination (AI), Embryo transfer (ET), Estrus synchronization, Hormonal stimulation, Genetic improvement, Conception rate, Pregnancy rate, Economic analysis

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INTRODUCTION

Reproductive efficiency is a fundamental driver of productivity and profitability in red meat livestock systems, particularly in beef cattle operations (Azizah and Rachmawati, 2024; Hsu *et al*., 2024; Govindarajan *et al*., 2023). It directly influences calving rates, herd replacement strategies, genetic progress, and the overall economic sustainability of cattle production (Baruselli *et al*., 2023; Kadham *et al*., 2023). Achieving maximum reproductive performance allows producers to maintain a continuous supply of high-quality calves, reduce the number of non-productive (open) cows, and ensure long-term herd viability (Bellows and Short, 2021; Karupusamy *et al*., 2023; Saadh *et al*., 2024).

Despite its importance, reproductive inefficiency remains a major challenge, driven by a combination of factors such as poor estrus detection, inadequate nutrition, environmental stress, disease pressures, and genetic limitations (Berry *et al*., 2014; Al-Saadi and Shwan, 2024; Ahmad *et al*., 2019). To address these issues, producers have increasingly turned to advanced reproductive strategies such as nutritional optimization, estrus synchronization, hormonal stimulation, and assisted reproductive technologies (ART), all of which have shown potential in improving conception rates, shortening calving intervals, and enhancing overall herd fertility (Bhat *et al*., 2021; Alhaqmuhamad *et al*., 2019; Zangana *et al*., 2022).

Importance of reproductive efficiency in beef cattle production

Reproductive performance underpins the success and economic viability of beef cattle operations (Brito *et al*., 2021; Noman and Ahmad, 2023; Ahmad and Noman, 2023). Effective breeding programs aim to optimize conception rates per breeding season, achieve favorable calving rates, and enhance herd genetic improvement through selective breeding (Burns *et al*., 2010; Ahmad *et al*., 2024; Ahmad, 2023). Improved reproductive efficiency reduces the proportion of open cows, shortens calving intervals, and enhances the uniformity and quality of calf crops (Cardoso *et al*., 2021; Laylani *et al*., 2024). Additionally, leveraging reproductive technologies contributes to the selection and propagation of desirable traits such as growth rate, feed efficiency, and disease resistance (de Sá Filho and Vasconcelos, 2011; Ahmad, 2025; Mohamad *et al*., 2025). Economically, enhanced reproductive performance increases return on investment by lowering maintenance costs on non-productive animals and producing additional marketable calves (Diskin and Kenny, 2016; Ramadhan *et al*., 2025; Saadoon *et al*., 2025). Conversely, reproductive inefficiency leads to severe financial losses due to prolonged calving intervals and reduced pregnancy rates, diminishing overall herd output (Emerenciano *et al*., 2022; Saed *et al*., 2024; Abdulateef *et al*., 2024).

Challenges affecting reproductive efficiency

Multiple factors influence reproductive outcomes in beef cattle:

Inadequate nutrition

Nutrition is a critical determinant of reproductive success. Deficiencies in energy, protein, vitamins, and minerals can lead to anestrus, poor conception rates, and increased embryonic mortality (Fernandez-Novo *et al*., 2021; Abed *et al*., 2024; Thabet and Alsalame, 2024). Low body condition scores are associated with delayed estrus cycles and decreased fertility, while excessive body fat disrupts reproductive hormone balance, causing irregular cycles (Gupta *et al*., 2022; Alsalame and Laylani, 2024; Abdulnabi *et al*., 2024).

Poor estrus detection and breeding management

Failure to accurately detect estrus remains one of the primary causes of missed breeding opportunities. Visual observation, the most common detection method, often falls short due to the subtlety or brevity of estrus signs (Heller *et al*., 2021; Alsalame, 2019, 2020). Ineffective estrus detection ultimately reduces pregnancy rates (Jiménez *et al*., 2022; Al-Aameli *et al*., 2019).

Environmental and stress factors

Environmental stressors like extreme heat or cold, poor handling practices, and transport stress negatively impact fertility, reduce estrus expression, lower conception rates, and increase early embryonic loss (Kenny *et al*., 2018; Keogh *et al*., 2021; Ahmad *et al*., 2019).

Disease and reproductive disorders

Infectious diseases such as brucellosis, leptospirosis, and bovine viral diarrhea (BVD) directly compromise reproductive performance by causing infertility, abortion, and reduced pregnancy rates (McDaneld *et al*., 2014; Alhaqmuhamad *et al*., 2019; Zangana *et al*., 2022). Additional reproductive challenges include cystic ovaries, uterine infections, and retained placentas. Annual health checks, vaccination programs, and strict biosecurity are critical to mitigate these risks (Noman and Ahmad, 2023; Ahmad and Noman, 2023).

Genetic limitations and inbreeding

Genetic factors inherently affect fertility, with some breeds predisposed to lower reproductive rates. Excessive inbreeding exacerbates these limitations, reducing overall herd reproductive capacity. Strategic breeding and genetic improvement programs targeting fertility traits are essential for sustainable improvement (Mincu *et al*., 2021; Ahmad *et al*., 2024; Ahmad, 2023).

Key strategies for enhancing reproductive efficiency

To remedy the problems associated with reproductive inefficiency, cattle producers have certain guidelines for enhancing fertility, shortening days to calving, and improving herd productivity per se.

Nutritional management

Nutrition represents an important element among contributors to reproductive efficiency (Olson *et al*., 2021). When breeding occurs, increased potential productivity of the herd exists. Without nutritional deficiencies, animals go into heat and come out more productively with less embryonic mortality. However, when nutritional deficiencies exist, breeding can be a disaster (Richardson, 2022). Animals do not go into heat or have erratic patterns; they do not get bred or get bred incorrectly, and sired offspring experience mortality.

Thus, energy and protein are required to maintain appropriate body condition scoring. Animals in good condition achieve proper estrus and breeding. For example, energy feeding maintains the integrity of reproductive abilities while protein encourages fetal development and milk production during parturition (Santa *et al*., 2022). The body requires a balance of energy and protein for metabolic needs and successful reproduction.

Similarly, supplementation of minerals and vitamins fosters successful breeding efforts because without these microscopic additions, animals can experience anestrus, fewer cycles per year, and unsuccessful breeding. For example, microminerals include phosphorus and calcium, which create bone function, and sodium, magnesium, iron, and cobalt help with hormonal and immune responses. Furthermore, vitamins A, D, and E provide functionality supportive of reproductive abilities and developments during the gestational process.

Pregnancy/lactation and post-calving nutrition. The need for scientific feeding occurs during gestation and beyond as there's a requirement for pregnant/lactating animals (Ullah *et al*., 2022). This ensures proper development when in utero and proper condition management after calving to maintain body condition scores and milk production, leading to proper increases in future gestation success rates.

Estrus synchronization

Estrus synchronization refers to manipulating the estrous cycle of a herd through hormonal procedures so that farmers can detect heat and breed cows more efficiently. It maximizes reproductive capabilities (Vandana *et al*., 2021).

The most advantageous aspect of estrus synchronization is the reduction in estrus detection, as synchronization allows for multiple cows to come into heat simultaneously, making it easier for farmers to breed cows and not waste potential when they could be breeding instead of waiting for detection. Increased conception rates with management efficiency are positive within a herd.

Increased breeding efficiency is an advantage since fixed-time artificial insemination (FTAI) is more feasible, as it allows for multiple breeding at the same time without strict monitoring for estrus cycles.

The final advantageous aspect of estrus synchronization is decreased calving intervals, which, in turn, means a more consistent aged calf crop within a herd (Vasconcelos *et al*., 2018). This increases herd efficiencies and allows for better management of resources, which effectively leads to profitability for many cattle producers. The most common hormone used in estrus synchronization is prostaglandins (PGF2α). Cows can be synchronized in estrus when they have a functional corpus luteum; thus, CIDR is a progesterone-based protocol for estrus cycling and subsequent synchronization. Finally, for ovulation regulation, gonadotropin-releasing hormone (GnRH) is injected.

Hormonal stimulation for improved fertility

Hormonal therapy is commonly applied to alleviate reproductive concerns attributed to anestrus and ovarian malfunction. This stabilizes reproductive hormones, supports detection of heat, and increases the potential for pregnancy.

Gonadotropins (FSH and LH) are routinely given to facilitate ovulation and follicle development. Follicle stimulating hormone (FSH) encourages the development of ovarian follicles, whereas luteinizing hormone (LH) encourages ovulation to enable proper breeding.

Prostaglandins (PGF2α) are used to induce estrus in cows with a functional corpus luteum. These hormones help stabilize the estrus cycle and promote synchronization of ovulation for improved artificial insemination or natural breeding (Wettemann, 2021).

Progesterone therapy is a regulatory treatment for stabilizing estrus cycles in cows with irregular occurrences of ovulation. Maintaining progesterone levels promotes ideal reproductive efforts and proportional chances of conception.

Assisted reproductive technologies (ART)

New reproductive technologies come increased conception rates, enhanced genetic opportunities, and increased reproductive efficiencies. With such effective means at their fingertips, cattle producers have improved opportunities for herd fertility through assisted reproductive technologies (ART) such as artificial insemination (AI), embryo transfer (ET), and *in vitro* fertilization (IVF).

Artificial insemination (AI) is a common reproductive procedure that allows for possessing the genetics of high-bred animals (Winton *et al*., 2024). AI increases reproductive efficacy as it reduces disease transmission, increases chances of conception, and allows for access to genetically superior bulls without the need to mate.

Embryo transfer (ET) is the transfer of an embryo after fertilization into a subsequent female to utilize a surrogate female to achieve more females of genetic value. This process enhances herd genetics and expedites the genetic improvement process while increasing reproductive efficiencies, as excellent females can maximize potential offspring creation.

In vitro fertilization (IVF) is a specialized non-natural reproductive process that allows for fertilization outside the cow's body (Zhou *et al*., 2021). This increases breeding efficiencies and the number of offspring from genetically valuable cows. It enhances reproductive efficiencies in the genetics of the herd.

Assisted reproductive technology allows beef cattle producers to dramatically enhance reproduction efficiency, enhance herd genetics, and simultaneously increase the profitability of beef cattle operations.

MATERIALS AND METHODS

This was an assessment of reproductive intervention effectiveness in the beef cattle industry through an evaluation of breeding practices, nutrition and supplementation, and health considerations related to animal well-being and reproduction. Effectiveness of intervention was probed via a comparative assessment approach with pre- and post-measurement of calving intervals and conception rates. The setting was a commercial beef cattle farm over a one-year period.

Study area and cattle selection

It was conducted on a beef cattle ranch in a moderate climatic condition area of temperate climate. 200 beef multiparous and primiparous cows that were of near similar age as well as body condition scores were selected randomly. Cattle groups were assigned against various treatments with reproductive strategies followed.

Experimental design

The cattle were allocated into four treatment groups, which were given a particular reproductive management strategy. Control group (CG): Controlled under traditional farm breeding techniques without further interventions.

1. Nutritional supplementation group (NSG): Supplied with energy- and protein-enriched diets to maximize reproductive performance
2. Estrus synchronization group (ESG): Implanted with a prostaglandin (PGF2α) plus a gonadotropin-releasing hormone (GnRH) treatment program for synchronization of estrus
3. Assisted reproductive technologies group (ARTG): Exposure to artificial insemination (AI) and embryo transfer (ET) procedures with high-genetic-merit sires.

Nutritional management

Cattle in the NSG and ARTG groups received supplementary feeding in the form of a balanced diet supplemented with higher percentages of crude protein (14%) and metabolizable energy (2.5 Mcal/kg). Mineral supplementation such as selenium, zinc, and copper was offered to enhance fertility. BCS was checked once a month to determine the impact of the changes in diet.

Reproductive health management

All the cattle were subjected to routine reproductive health checks through rectal palpation and ultrasonography to ascertain ovarian activity and pregnancy status. Visual observation and activity monitor devices were utilized for estrus detection. Routine vaccination and deworming practices were also adopted to reduce reproductive disorders.

Data collection and analysis

All treatment groups were evaluated for conception rates, calving intervals, pregnancy rates, and estrus detection rates, and treatment group differences were determined by ANOVA and Chi-square statistical analysis.

RESULTS AND DISCUSSION

This experiment evaluated the efficacy of various reproductive management strategies to enhance reproductive efficiency in the beef sector. The key measurement variables were conception rates, calving intervals, pregnancy rates, and estrus response rates. The results of the project indicate statistically significant differences between treatment groups, which offers a way to assess fertility successes in cattle.

Reproductive performance across treatment groups

Reproductive efficiency was assessed according to key relative factors, and the estrus synchronization group (ESG) and assisted reproductive technologies group (ARTG) had the relative optimum efficiency.

Table 1: Reproductive performance across treatment groups.

Parameter	Control group (CG)	Nutritional supplementation group (NSG)	Estrus synchronization group (ESG)	Assisted reproductive technologies group (ARTG)
Conception rate (%)	65 ± 3.2	74 ± 2.8	85 ± 3.1	91 ± 2.6
Calving interval (days)	430 ± 12	410 ± 9	385 ± 8	370 ± 7
Pregnancy rate (%)	60 ± 2.7	72 ± 2.9	83 ± 3.0	89 ± 2.5
Estrus response (%)	62 ± 3.1	70 ± 2.9	88 ± 3.3	93 ± 2.7

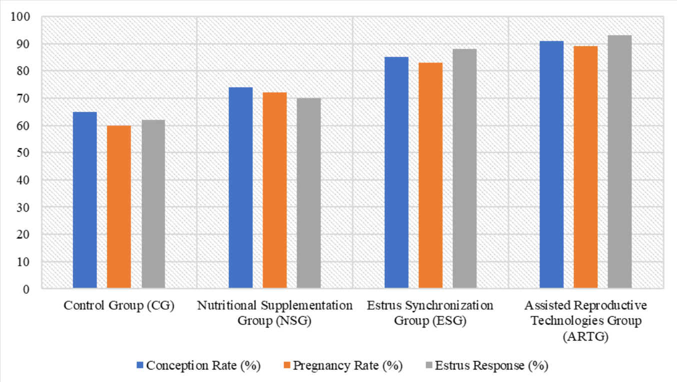

Figure 1: Reproductive performance across treatment groups.

Overall, the comparative reproductive performance within and between the various treatment groups indicated an increase in conception rate, pregnancy rate, estrus response, and calving interval. The least amount of reproductive efficiency came from the control group; the treatment group with nutritional supplementation had barely a second increase. Where reproduction was concerned, the estrus synchronization group had an additional advantage as it increased the estrus response and conception rates to statistically significant levels. However, still, the group receiving assisted reproductive technologies (ART) had the most amount of reproductive efficiency with increases in conception and pregnancy rates, decreases in calving interval, and an increase in estrus response. These results imply that nutritional treatment is beneficial to improving fertility; however, treatment groups with synchronized estrus and ART had the most significant results, meaning they are the best ways to improve reproductive efficiency and productivity of any beef cattle business.

Effect of estrus synchronization on reproductive parameters

Estrus synchronization enhanced conception and pregnancy rates much better than traditional breeding.

Table 2: Comparison of estrus response and conception rate in synchronized vs. non-synchronized cattle

Parameter	Non-synchronized (CG + NSG)	Synchronized (ESG + ARTG)
Estrus response (%)	66 ± 2.5	90 ± 2.8
Conception rate (%)	70 ± 2.9	88 ± 3.0
Calving interval (days)	420 ± 9	380 ± 7

When comparing non-synchronized versus synchronized groups in terms of reproductive performance, the results were significantly in favor of those undergoing estrus synchronization. The estrus response was significantly higher for the synchronized group versus the non-synchronized group, which indicates that the treatment with hormones was successful in inducing and controlling estrus cycles and increased pregnant efficiencies. In addition, the conception rate was significantly higher for the synchronized group versus the non-synchronized group as well, suggesting that synchronization rendered higher levels of fertility. Finally, the calving interval was significantly lower in the synchronized group, which indicates better control over the process and shorter lengths of time between re-impregnation. Thus, this data is definitive that estrus synchronization works for successful reproduction, faster calving intervals, and higher outputs for total herd production of beef cattle.

Effect of nutritional supplementation on reproductive efficiency

Nutritional management positively influenced reproductive performance. For instance, the cows in the nutritional treatment group had increased body condition scores (BCS), which meant greater fertility.

Table 3: Effect of nutritional supplementation on body condition score (BCS) and fertility parameters.

Parameter	Control group (CG)	Nutritional supplementation group (NSG)
Initial BCS	4.5 ± 0.3	4.6 ± 0.2
Final BCS	4.3 ± 0.2	5.1 ± 0.3
Conception rate (%)	65 ± 3.2	74 ± 2.8
Pregnancy rate (%)	60 ± 2.7	72 ± 2.9

Comparison of control and nutritional supplementation group (NSG) BCS and reproductive performance suggests that cattle did much better with additional nutritional support. For example, while the starting BCS was comparable between the two groups, ending BCS showed better results for the NSG and a slight decrease for the control. This means that the targeted nutritional supplementation took a positive step in the right direction for body condition score, which helped with subsequent reproductive performance. In addition, the NSG had a statistically significantly higher conception rate as well as pregnancy rate compared to the control, which indicates that higher nutritional resources positively impacted cattle's ability to conceive and stay pregnant. Improved reproductive performance for the NSG group compared to control was likely due to higher quality nutrition's ability to foster hormonal health, ovarian function, and general reproductive success. These findings are important to illustrate how nutritional management can improve conception and gestation rates in beef cattle.

Impact of assisted reproductive technologies (ART) on genetic improvement

Artificial insemination (AI) and embryo transfer (ET) greatly enhanced reproductive performance, especially in regard to calf birth weight and growth rates.

Table 4: Comparison of birth weight and growth rate of calves from natural mating and assisted reproductive technologies (ART).

Parameter	Natural mating (CG and NSG)	ART (AI and ET) (ARTG)
Birth weight (kg)	30.5 ± 1.2	35.7 ± 1.5
Weaning weight (kg)	220 ± 5.8	245 ± 6.1
Average daily gain (kg)	0.78 ± 0.05	0.92 ± 0.04

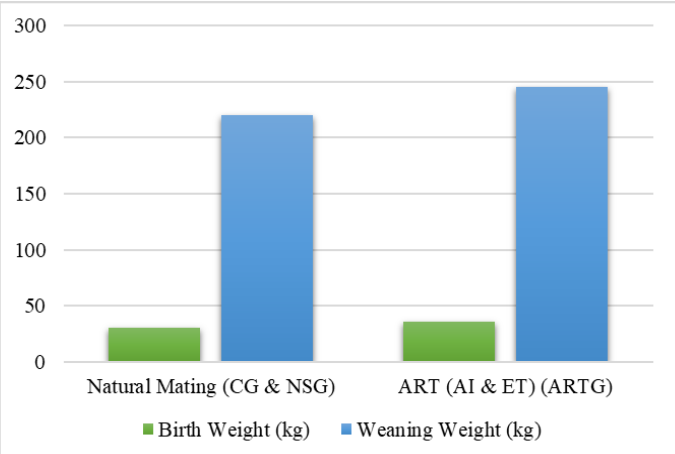

Figure 2: Comparison of birth weight and growth rate of calves from natural mating and assisted reproductive technologies (ART).

The comparison charts comparing growth performance from natural equations and assisted reproductive technologies (ART) demonstrate significant differences across all major parameters birth weight, weaning weight, and average daily gain (ADG). Naturally bred calves had decreased ADG relative to naturally bred calves. Conversely, ART-bred calves had higher birth rates relative to naturally bred calves. The ART-bred females had higher weaning weights, reflecting early enhanced growth performance which continued into the weaning and final assessment periods, reflectively extending anticipated growth potential for longer lifespans. Finally, ADG was increased for ART-bred males, reflecting anticipated feed efficiency and growth potential. Thus, these results reflect that assessment via ART provided positive growth advantages which translate to better market value and productivity in purebred beef herds. Increased weights for the ART projects could result from genetic preselection, breeding at the most optimal time, and maternal optimal condition for breeding during gestation.

Economic analysis of reproductive strategies

The economic benefits of ART and estrus synchronization were analyzed in terms of cost per pregnancy and return on investment (ROI).

Table 5: Economic comparison of different reproductive strategies.

Parameter	Control group (CG)	NSG	ESG	ARTG
Cost per pregnancy (USD)	120 ± 5	140 ± 6	160 ± 7	180 ± 8
Market value of calves (USD)	450 ± 10	480 ± 12	520 ± 14	560 ± 15
ROI (%)	275%	290%	325%	350%

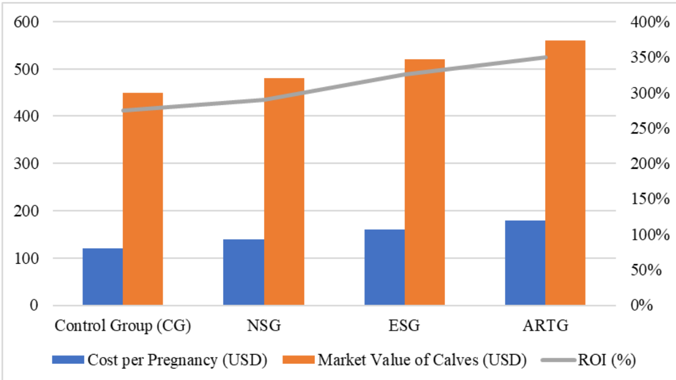

Figure 3: Economic comparison of different reproductive strategies.

All three reproductive strategies in beef cattle were most cost-effective compared to natural breeding, with varied degrees of significance with respect to cost per pregnancy, market value of the calf, and return on investment (ROI). Cost per pregnancy was cheapest with the control group and then increased with the other groups in an incremental fashion, with the ART group receiving the highest cost per pregnancy. However, the ART group also received the highest market value of calves by group, followed by the estrus synchronization and natural synchronization groups, while the natural control value group had the lowest market value of calves. Therefore, the highest ROI was also with the ART group. This signifies that ART was the most cost-effective option despite receiving the highest cost per group for pregnancy. However, the other two groups had significant positive economic returns over the natural control group. Therefore, these findings show that even though the ART group has the highest cost per pregnancy, it has the highest profitability potential with regards to value of calf and overall economic return for effective long-term operations of a cattle farm.

CONCLUSION

This research assessed the success of different alternatives to improve beef cow reproductive performance via natural service, heat detection, artificial inseminations (AI), heat synchronization, hormonal interventions, and assisted reproductive technologies (ART). The results indicated that assisted reproductive technology (ART) AI and embryo transfer (ET) significantly improved important reproductive outcomes. The ART group results were superior to that of the natural breeding group, and the conception (91%) and pregnancy rate (89%) were significantly higher than the other groups with better efficiency. Furthermore, the calves generated by the ART group had higher body weight at birth (35.7 kg) and better weight gain afterward, increasing their selling value. The economic assessment showed that the ART group had the highest pregnancy expense (USD 180), but the highest return on investment (ROI of 350%), indicating the most feasible cost-effective method for sustainable growth. Therefore, this study concluded that innovative reproductive technologies offer qualitative improvements in productivity, fertility, economic feasibility, and genetic improvements in cattle with caution, assessment of training, and adjustments for the potential best cost-effective solutions to render the greatest rewards.

RECOMMENDATIONS

- Farmers must adopt Artificial Insemination (AI) and Embryo Transfer (ET) to enhance conception and pregnancy rate.
- Training sessions need to be organized to facilitate the correct execution and handling of ART methods.
- Hormonal treatment for estrus synchronization will boost reproductive efficiency and minimize calving intervals.
- Nutrition and mineral supplementation need to be done in balanced manner to enhance reproductive performance.
- Regular monitoring of health and disease prevention methods must be followed for improved fertility.
- Government subsidies or cooperative farming strategies can bring ART within the reach of small-scale farmers.
- Farmers need to perform cost-benefit analyses prior to the adoption of new reproductive techniques.
- More research needs to be carried out on refining ART protocols for varied breeds and environmental conditions.
- Selective breeding schemes involving genetic screening and ART methods can be used to improve cattle productivity and genetic makeup.

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NOVELTY STATEMENTS

This study evaluated the effectiveness of various methods, including heat detection, artificial insemination (AI), heat synchronization, natural service, hormonal therapies, and assisted reproductive technologies (ART), to enhance the reproductive performance of beef cows. The findings showed that AI and embryo transfer (ET), two forms of assisted reproductive technology (ART), dramatically enhanced key reproductive outcomes. Conception (91%) and pregnancy rate (89%) were significantly greater than those of the other groups with improved efficiency, and the outcomes of the ART group were better than those of the natural breeding group. The calves produced by the ART group also had greater weight gain later on and a higher birth weight (35.7 kg), which increased their market worth.

AUTHOR'S CONTRIBUTION

All of the trials were designed by ZMH, SAA-J and HRK. SJ, SA and HSA conducted all of the tests, gathered the data, and composed the manuscript draft. MM helped with the data analysis that was done to prepare the work for submission to the journal. The final draft of the work was reviewed and approved by all authors for publication in the Journal of Animal and Health Production.

Ethical consideration

Not applicable.

Conflict of interest

The authors have declared no conflict of interest.

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