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Review Article

A Review of Pregnancy Rates in Beef Cattle via Timed Artificial Insemination Utilizing CIDR-based 5 and 7-Day CO-synch Protocols

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ABSTRACT

Although timed artificial insemination programs (TAI) are widely implemented, the effectiveness of field CO-Synch programs is less known. A clear understanding of overall pregnancy rates (PRs) from controlled internal drug release (CIDR)-based TAI programs like 7-day CO-Synch (7DCOS) or effectiveness of various prostaglandin delivery in 5-day CO-Synch (5DCOS) is not available. This paper aimed to review pregnancy rates in 7DCOS and 5DCOS (with different methods of prostaglandin delivery). An analysis of 74 studies retrieved from Google Scholar, PubMed, and ScienceDirect was done. The TAI-PRs were expressed as Weighted TAI-PR (WTAI-PR) to account for different trial sizes across various studies. The WTAI-PR was 54.91% in cows and 53.50% in heifers under 7DCOS, and 51.75%, 50.38%, and 57.98% for cows and 52.84%, 51.90%, and 58.42% for heifers treated with 5DCOS+CIDR® with a single (25 mg), double (50 mg)/two simultaneous doses (25 mg each) or two separate doses (25 mg, 2-24 hours apart) of prostaglandin (PGF). Other factors like cyclicity at treatment initiation, breeding season, estrus expression before AI, and body condition score affected the TAI-PRs. Although two doses

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of PGF were effective, the cost was higher due to the extra labor for handling and purchase of hormones. Both 5DCOS and 7DCOS showed satisfactory pregnancy rates, but progesterone device discomfort due to two additional days (7DCOS) are a welfare concern. There is a lack of studies evaluating these programs in tropical climates. Future research should focus on the effect of unique environmental conditions in the tropics on the success of these protocols.

Keywords: Beef cattle, CIDR, CO-synch, pregnancy rates, timed artificial insemination

INTRODUCTION

The beef production industry plays a crucial role in alleviating poverty and contributes to achieving food security by providing essential nutrients and high-quality proteins, particularly in regions where protein from other sources is limited (McAllister et al., 2020). While one of the fundamental strategies for meeting this increasing demand is via the increase in the number of calves per breeding season, breeders need to optimize their production by reducing the cost of production (Dahlen et al., 2014).

Timed Artificial Insemination (TAI) programs were developed to bypass the need for estrus detection, thereby reducing labor expenses and improving breeding efficiency to overcome these challenges (Colazo & Mapletoft, 2014; Sá Filho et al., 2013). The pioneering TAI protocol, Ovsynch, was first developed in the early 19th century and facilitated the use of embryo transfer and Artificial Insemination at predetermined times by controlling follicular dynamics, the luteal phase, and triggering synchronized ovulation of the dominant follicle (Bó & Baruselli, 2014; Pursley et al., 1995). This protocol is mostly used in intensive systems for dairy cattle, where multiple handling can be realized. However, it is less feasible for beef cattle to be raised in extensive systems with less controlled environments. Frequent handling is costly to breeders and more stressful for cattle. Thus, protocols involving fewer animal handlings are more practical for beef cattle (Colazo & Mapletoft, 2014; Geary et al., 2001).

Timed Artificial Insemination (TAI) protocols relevant to beef cattle, such as 7-day CO-Synch (7DCOS) and 5-day CO-Synch (5DCOS) plus Controlled Internal Drug Release (CIDR), have been developed to reduce animal handling and improve practicality for breeders (Colazo & Mapletoft, 2014). CO-Synch protocols reduce the number of animal handling by injecting a second GnRH Gonadotropin Releasing Hormone (GnRH) concurrently at TAI (Geary et al., 2001). Although CO-Synch programs are commonly utilized, the variability of PRs remains a challenge. For example, TAI-PRs from 7DCOS ranged from 38.2 to 61.1% across studies, indicating that factors such as management practices, environmental conditions, and physiology of cattle significantly affect pregnancy outcomes (Dobbins et al., 2009). Whereas in 5DCOS, Prostaglandin F2α (PGF) is delivered using three methods: single dose, two separate doses, and double dose, but it is difficult to determine which method is the most effective. Stevenson et al. (2011) reported pregnancy rates of 44.2% (for a single dose), 57.4% (for two separate doses) and 51.8% (for a double dose), again demonstrating the variability of pregnancy outcomes and how different factors affect it. This evidence shows that although various TAI programs are widely studied and implemented, the effectiveness of CO-Synch programs at the field level is less known. Moreover, a clear understanding of pregnancy rates resulting from CIDR-based TAI programs such as 7DCOS or the effectiveness of various PGF delivery in 5DCOS is not available. By clearly understanding CO-Synch protocols, breeders can identify and choose the most effective protocol that benefits them economically.

However, there are practical implications that cattle breeders may face. For instance, one of the major practical challenges faced by breeders is enhancing reproductive efficiency in extensive production systems where the cost of labor for estrus detection is expensive and difficult to manage. Though effective, traditional breeding protocols that require heat detection demand a huge amount of time and labor, which can be impractical for breeders in extensively managed farms (Santos et al., 2022). It is particularly important in regions with scarce labor resources and large cattle heads. Although CO-Synch protocols may offer a potential solution to enhance reproductive efficiency in beef cattle, the cost of drugs, labor and animal handling stress remains a key concern. In addition, different AI protocols will have different cost implications arising from the duration of synchronization, number of animal handlings, and quantity of hormone used. With an increase in global meat demand, the beef cattle industry will have a significant role in future meat supply. Improvement in AI technology will be necessary for enhancing reproduction and increasing the beef cattle population. While such measures might have bigger implications for breeders in top beef exporting countries such as the United States, European Union and Brazil, technological transfer and use of AI by breeders in low-income countries will also become relevant because of increasing meat consumption in these countries.

Therefore, this paper aims to review pregnancy rates in 7DCOS, pregnancy rates obtained from different methods of prostaglandin delivery in 5DCOS and other factors affecting TAI-PRs outside of treatments in TAI programs.

METHODOLOGY

Literature Search Strategy

Literature was retrieved using the keywords: "Estrus Synchronization," "Timed Artificial Insemination," "Pregnancy Rates," 'Beef Cattle," "CO-Synch," "CO-Synch," "CIDR," and "Controlled Internal Drug Release." Data extraction and calculation of Weighted Timed Artificial Insemination Pregnancy Rates (WTAI-PRs) were carried out manually in Microsoft Excel. The details of the literature selection process are presented in Figure 1.

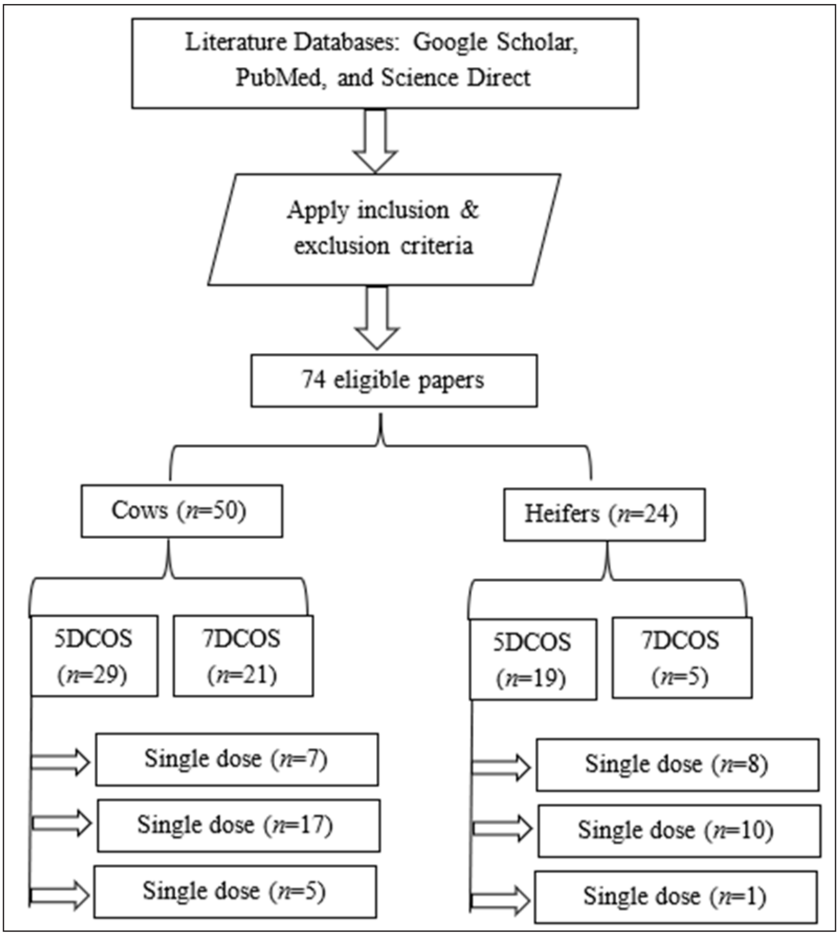

Figure 1. Flowchart for the process of literature selection

Selection of Literature for Review

Inclusion Criteria

This review included CO-Synch programs that relied solely on GnRH and PGF, with an interval of five to seven days between initial GnRH and PGF. The interval duration between CIDR® removal and TAI must be 48 to 72 hours and 56 to 72 hours for 7DCOS and 5DCOS, respectively. Furthermore, CO-Synch programs must exclusively utilize CIDR® as a P4 source. Modified 5DCOS programs (without initial GnRH with a single PGF) were included. Likewise, 5DCOS programs that administered two PGF2α doses (25 mg each) concurrently, a single dose (25 mg), a double dose (50 mg) at CIDR® removal, and two separate doses (25 mg each) at certain time intervals (initial dose at CIDR® removal) were included. And lastly, the studies must be strict on beef cattle.

Exclusion Criteria

The review excluded studies that utilized hormones other than GnRH and PGF, such as eCG (equine chorionic gonadotropin), estradiol benzoate (EB), and hCG (human chorionic gonadotropin). Similarly, studies that utilized intravaginal P4 devices other than CIDR® or that did not utilize any P4 device between initial GnRH and PGF were excluded.

CO-SYNCH PROGRAMS AND VARIATIONS

Beef cattle subjected to 7DCOS received an intravaginal insert (CIDR®) and GnRH at the initiation of synchronization. Seven days later, CIDR® was removed concurrently with an injection of PGF. Fixed-time AI was performed 54 to 60 hours and 48 to 72 hours after the CIDR® removal for heifers and cows, respectively. Cows and heifers subjected to 5DCOS protocol either received an initial GnRH or no GnRH concurrent with CIDR® insertion. At the time of CIDR® removal, cattle received either a single standard dose (25 mg), a single large dose (50 mg)/double dose (2 × 25 mg concurrently), or two separate (2 to 24 hours apart) doses of PGF on D5 (initial dose at CIDR® removal). Fixed time AI occurred 56 to 72 hours and 60 to 72 hours, respectively, for heifers and cows following CIDR® removal. In both protocols, cattle received a second GnRH dose at the time of FTAI

The proestrus period, the time duration between luteolysis and Luteinizing Hormone (LH) surge, was found to be associated with increased TAI-PRs. Bridges et al. (2008) conducted a series of experiments to modify the traditional 7-day Cosynch program by reducing the duration of P4 device exposure from 7 to 5 days to allow an extended proestrus period, resulting in a 5-day Cosynch program. The authors compared TAI-PRs between 7DCOS (proestrus = 60 hours) and 5DCOS (proestrus = 60 hours) programs in these experiments. Their result showed similar TAI-PRs. However, in the two other experiments, when proestrus duration in 5DCOS was increased to 72 hours (60 hours in 7DCOS), TAI-PRs were 13.3% (n=223) and 9.1% (n = 400) higher than 7DCOS program ($p < 0.05$). An increased pregnancy rate in a lengthened proestrus duration in 5DCOS was a result of a lower incidence of ovulating immature follicles and increased gonadotropin exposure to the preovulatory follicle. It leads to increased estradiol concentration before ovulation, a key fertility determinant (Day, 2018). Estradiol is indispensable as it contributes to the expression of uterine genes and proteins, which are responsible for the establishment of pregnancy (Perry, Cushman et al., 2020).

Variations of 7DCOS plus CIDR® Protocol

The initial goal of the 7DCOS program was to breed 48 hours after PGF injection. However, later studies have shown increased conception rates when artificial insemination was performed 54-56 hours after PGF (Bridges et al., 2012). There are several variations in the interval between PGF and TAI. The 7DCOS program begins with an initial GnRH on D0, PGF on D7, and a second GnRH injection concomitantly on the day of TAI: 60–66 hours (Lansford, 2018), 54–66 hours (Bridges et al., 2012) 60 hours (Bridges et al., 2008), 72 hours (Mellieon et al., 2012; Randi et al., 2021), and 66 hours (Andersen et al., 2021) after the P4 device removal.

Variations of 5DCOS plus CIDR® Protocol

The increased length of proestrus (the duration between PGF and GnRH-induced LH surge or interval from the removal of the P4 device to GnRH/TAI) demonstrated an increased pregnancy rate (Bó et al., 2016; Day, 2018; de la Mata et al., 2018). To allow a longer proestrus, Bridges et al. (2008) modified the traditional 7DCOS by shortening the duration of intravaginal device exposure from 7 to 5 days, resulting in the 5DCOS protocol. However, this modification led to the formation of immature Corpus Luteum (5 days old) on the day of PGF that resists complete luteolysis. Thus, researchers proposed delivering two doses of PGF to completely lyse the young 5-day-old CL. As a result, there have been concerns among researchers that the extra handling of animals and the cost associated with additional PGF may discourage the implementation of the 5DCOS program. Greater pregnancy rates were reported for 5DCOS compared to 7DCOS. However, increased TAI pregnancy rates in the former failed to offset the extra cost associated with additional PGF dose and animal handling (Peel et al., 2010). To reduce the cost of implementing the 5DCOS program, Gunn et al. (2015) conducted a trial with and without a P4 device. Significantly lower pregnancy rates in cows without the P4 device were observed.

Generally, 5DCOS yielded greater TAI-PRs than the 7DCOS program. Several biological mechanisms have been proposed for increased PRs observed in the former program. The reduced P4 exposure in the 5DCOS program improves the development of follicles. It restricts the emergence of older, less viable follicles, which results in the ovulation of younger, healthier follicles with good oocyte quality (Day, 2015). This results in more precise control of ovulation and LH surge because of tighter ovulation synchronization with TAI (Bridges et al., 2018). Additionally, 5DCOS supports the healthy development of CL, which produces a higher concentration of progesterone and is essential for early embryonic development and maintaining pregnancy (Lamb et al., 2006). In contrast, 7DCOS due to extended P4 exposure, risk of ovulating persistent follicles with low-quality oocytes, and weaker CL with low P4 level may lead to early embryonic loss and reduce PRs (Bridges et at., 2010). Although 5DCOS showed greater TAI-PRs compared to 7DCOS, it is suggested that the choice of protocol must be based on the local condition and management practices (Whittier et al., 2013).

One or Two Doses of PGF in the 5DCOS Protocol

Several studies have investigated the need for one or two doses of PGF in a 5DCOS program. Studies have shown improved pregnancy rates when two doses were given six to eight hours apart, with an initial dose administered concomitantly at P4 device removal. For instance, Stevenson et al. (2011) conducted a multi-location study, which included 2420 postpartum beef cows, to compare the effectiveness of single, double and two separate doses of PGF at 8-hour intervals. The highest TAI-PR was observed in cows receiving two PGF doses 8 hours apart, followed by doubled and single doses. A similar study by Kasimanickam et al. (2009) found significantly greater TAI-PRs in cows that received two separate doses of PGF (Dinoprost: 7 hours apart, 69.0%) compared to a single PGF dose (Diniprost: 52.0%) and a single dose of Cloprostenol (54.3%).

Timing of TAI in 7DCOS Protocol

The timing for TAI in the 7DCOS plus CIDR® protocol ranged from 48 to 72 hours after P4 device removal, with varying pregnancy rates. A comparison of FTAI-PR in postpartum beef cows resulting from inseminations performed 54 and 66 hours after CIDR® removal resulted in significantly greater PRs when inseminated at 66 hours (61 vs. 67%, $p = 0.05$) (Busch et al., 2008). Similarly, the pregnancy rate in beef cows after inseminating at 56 and 64 hours after PGF administration was greater compared to 48 hours ($p < 0.01$), but it was not different from 72 hours (Dobbins et al., 2009). The breeding time for beef cows and heifers has been recommended at 60 to 66 hours and 52 to 56 hours after P4 device withdrawal (Johnson et al., 2010). An expert review article published by Bridges et al. (2012) reported an average TAI-PR of 55%, 54%, and 51% when TAI was performed at 48, 54-66, and 72 hours, respectively, after CIDR® removal, with a range of 45 to 66%.

Timing of TAI in 5DCOS Protocol

When 5DCOS was first developed, PR from TAI at 60 and 72 hours after CIDR® removal in postpartum beef cows was 56.8% and 65.3%, respectively (Bridges et al., 2008). Likewise, an acceptable pregnancy rate of (52% to 57%) was achieved using 5DCOS + CIDR® by inseminating at 72 hours after CIDR® withdrawal (Whittier et al., 2010). Whereas most beef heifers were observed to express estrus behaviors 24 hours before TAI occurred. Based on this observation, Kasimanickam et al. (2012) hypothesized that the TAI-PRs in beef heifers would improve if breeding were performed 56 hours after CIDR® removal instead of 72 hours, and this was shown when the TAI-PR was 10.3% higher in heifers inseminated at 56 compared to 72 hours after CIDR® removal.

Comparison of Efficiency and Cost Effectiveness Between 5DCOS and 7DCOS

In general, there are some differences between 5DCOS and 7DCOS in terms of efficiency and cost-effectiveness (Table 1). For instance, higher pregnancy rates were observed in 5DCOS when two PGF were given compared to 7DCOS. However, an extra PGF dose in 5DCOS will increase the overall cost of implementation, and there is a need to assess whether the extra cost offers the advantage of having higher pregnancy rates in 5DCOS compared to the 7DCOS program.

Table 1
Summary comparison of 5DCOS and 7DCOS

Parameter	5DCOS	7DCOS
Pregnancy rates	Slightly higher in some studies (5-10%)	Moderate to high but variable
Hormonal treatments	Require 2PGF	Single PGF
Labor and cost	Higher due to additional treatment	Lower, fewer animal handling
Follicular dynamics	Younger dominant follicle (High Estradiol production)	Older dominant follicle (Low estradiol production)
Corpus luteum (CL) regression	Complete with 2 Prostaglandin F2α (PGF) doses	Single PGF dose
Duration of P4 device exposure	5 Days	7 Days
Cost-effectiveness	Higher cost but effective with two doses of PGF	Lower cost and effective with a single PGF dose

PREGNANCY RATES IN CO-SYNCH PROGRAMS

Based on the inclusion and exclusion criteria, a total of 74 trials were thoroughly reviewed (50 on cows and 24 on heifers). Of these, 48 trials implemented the 5DCOS +CIDR® protocol, while the remaining 26 implemented the 7DCOS+CIDR® protocol (Figure 1). The TAI-PRs were expressed as weighted timed-AI pregnancy rates (WTAI-PR) to account for different trial sizes across various studies. It was calculated as:

$$\text{WTAI-PR (\%)} = (\text{Sum of weighted values/Total number of animals}) \qquad [1]$$

where, weighted values = Number of Animals × TAI-PR%

The consolidated WTAI-PR for different methods of PGF delivery in 5DCOS + CIDR® is presented in (Figure 2, Tables 2, 3, 4, and 5). The highest WTAI-PRs were observed with two separate doses of PGF. Meanwhile, in the 7DCOS program, TAI-PRs between cows and heifers were similar (Figure 3, Table 5). Irrespective of the animal category, the WTAI-PRs among experimental regions varied from 53% to 58.7% for 5DCOS and

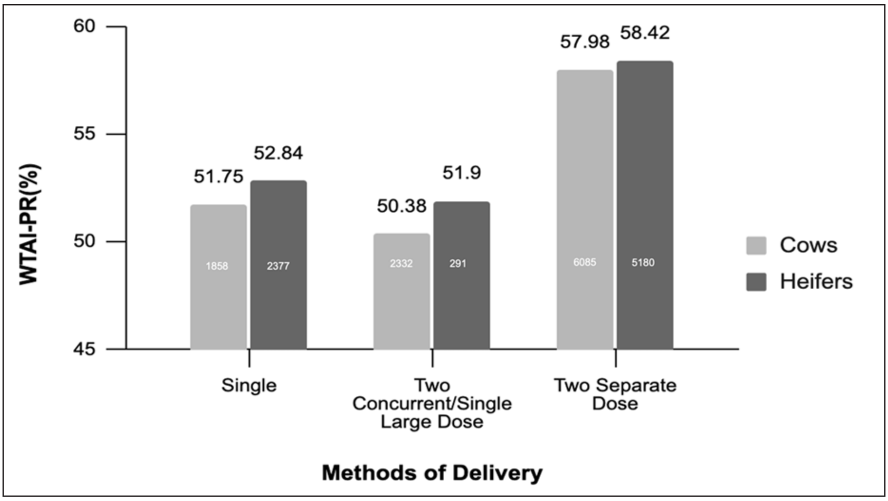

Figure 2. Weighted Timed Artificial Insemination Pregnancy Rates (WTAI-PR) in cows and heifers with 5DCOS +CIDR® program based on different methods of Prostaglandin delivery. The numbers in the center of the bar indicate the total number of animals

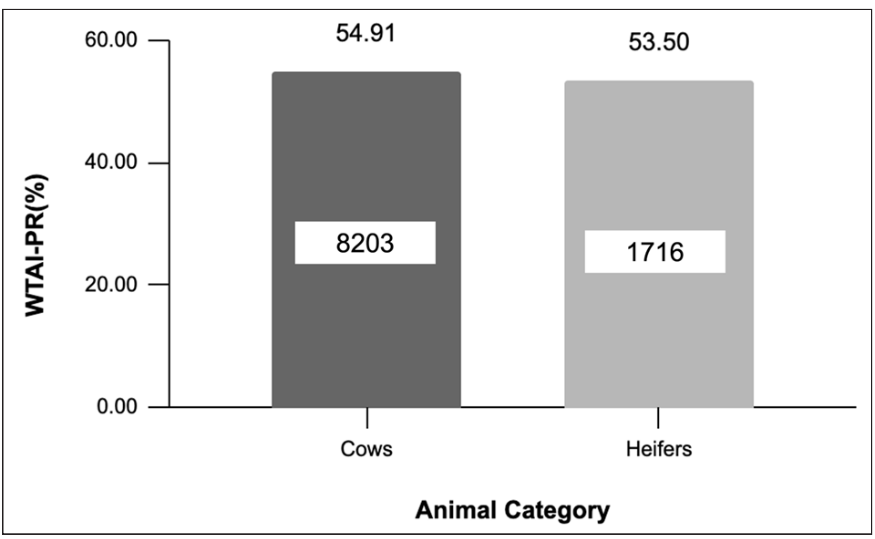

Figure 3. Weighted Timed Artificial Insemination Pregnancy Rates (WTAI-PR) in cows and heifers with the 7DCOS +CIDR® program. The numbers in the center of the bar indicate the total number of animals

7DCOS programs and were similar (Figure 4). Five studies, Russia (n=2) and Canada (n=2), have been excluded because of regional differences (outside USA). However, their data was included for breed-based TAI-PRs analysis. Among the cattle breeds employed, WTAI-PRs varied from 53.48% to 58.11% and were similar. Table 6 and Table 7 show WTAI-PRs resulting from sex-sorted semen using the 7DCOS program in cows and heifers. The WTAI-PRs varied from 40.67% to 44.14%. However, there were no studies that employed 5DCOS for sex-sorted semen. Overall, WTAI-PR was 54.91% in cows and 53.50% in heifers under 7DCOS, and 51.75%, 50.38%, and 57.98% for cows and 52.84%, 51.90%, and 58.42% for heifers treated with 5DCOS plus CIDR® with a single (25 mg), double (50 mg)/two simultaneous doses (25 mg each) or two separate doses (25 mg, 2 to 24 hours apart) of prostaglandin (PGF).

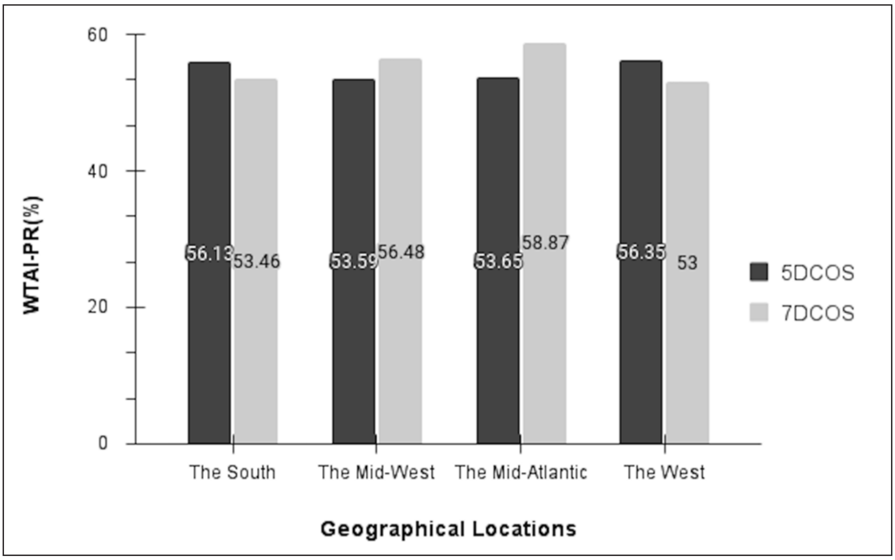

Figure 4. Comparison of Weighted Timed Artificial Insemination Pregnancy Rates (WTAI-PR) between 5DCOS and 7DCOS programs across geographical locations

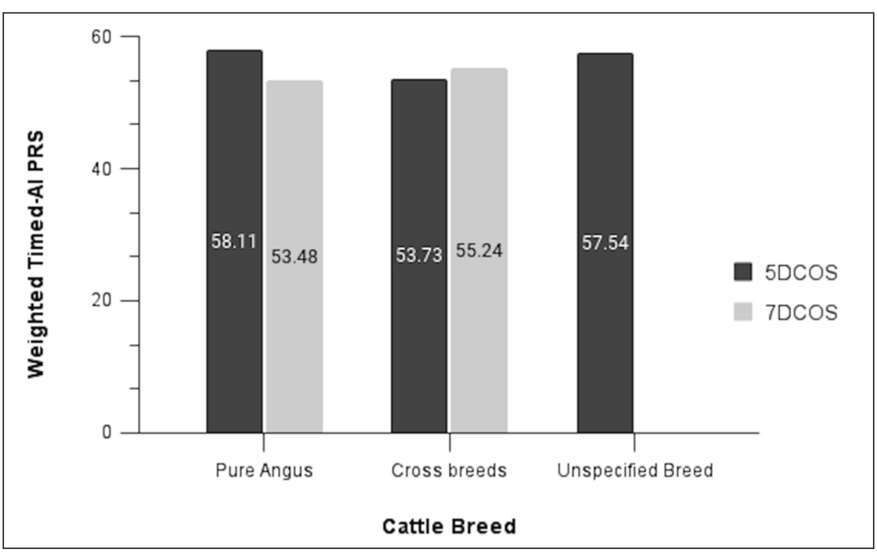

Figure 5. Comparison of weighted timed-AI pregnancy rates between 5DCOS and 7DCOS programs across cattle breeds

Timed AI Pregnancy Rates from Various Published Reports

The Weighted Timed Artificial Insemination Pregnancy Rates (WTAI-PRs) resulting from single (standard), single large dose (double dose), two separate doses (2-24 hours part) of PGF are provided below (Table 2-4). While Table 5 shows WTAI-PRs resulting from 7DCOS + CIDR protocol in beef cattle.

Table 2
WTAI-PR for 5DCOS +CIDR® protocol in beef cattle using a single standard dose of PGF at CIDR® withdrawal

Cows				
n	**PGF to AI (h)**	**TAI-PR (%)**	**Notes**	**Reference(s)**
277	72	52.0	25 mg Dinoprost	Kasimanickam et al. (2009)
271	72	54.3	500 µg Cloprostenol	
197	72	44.2	25 mg Dinoprost	Stevenson et al. (2011)
815	72	48.0	25 mg Dinoprost	Bridges et al. (2012)
100	72	62.0	25 mg (Lutalyse® HighCon, Zoetis)	Corpron et al. (2019)
90	66	63.0	500 µg Cloprostenol (modified 5DCOS)	Macmillan et al. (2020)
108	72	68.0		
WTAI-PRs		51.75	293	
Heifers				
264	72	54.2	25 mg Dinoprost	Peterson et al. (2011)
290	56	50.3	Modified 5DCOS (25 mg Dinoprost)	Kasimanickam et al. (2014)
263	56	59.7	25 mg Dinoprost	
408	72	50.5	Modified 5DCOS (25 mg Dinoprost)	Cruppe et al. (2014)
415	72	54.9	25mg Dinoprost	
144	56-59	63.9	Modified 5DCOS (25 mg Dinoprost)	Ahmadzadeh et al. (2015)
293	56	54.9	25 mg Dinoprost	White et al. (2016)
300	72	41.1	500 µg Cloprostenol	Macmillan et al. (2020)
WTAI-PRs		52.84		

Note. PGF-AI (h) = Time interval between CIDR® removal to TAI, TAI-PR (%) = Pregnancy rates to timed artificial insemination, 5DCOS + CIDR® = Initial GnRH + CIDR® insertion (D0), single PGF (25 mg standard dose on D5) at CIDR® removal, TAI of 72 and 56-72 hours (beef cows and heifers respectively) after CIDR® removal, Modified 5DCOS: Same as standard 5DCOS protocol except without initial GnRH and second PGF

Table 3
WTAI-PR for 5DCOS +CIDR® protocol in beef cattle using a single large dose or two standard doses (i.e., doubled dose) concurrently

Cows				
n	**PGF to AI (h)**	**TAI-PR (%)**	**Notes**	**Reference(s)**
199	72	51.8	50 mg Dinoprost as single dose	Stevenson et al. (2011)
829	72	51.0	Concurrently (2 × 25 mg each)	Bridges et al. (2012)
203	72	51.0	Concurrently (2 × 25 mg each)	Ahmadzadeh et al. (2021)
551	72	49.5	Concurrently (2 × 500 µg Cloprostenol) with 100 µg initial GnRH	Rojas Canadas et al. (2023)
550	72	49.6	Concurrently (2 × 500 µg Cloprostenol) with 200 µg initial GnRH	
WTAI-PRs		50.38		
Heifers				
291	56	51.9	50mg Dinoprost as single dose	White et al. (2016)
WTAI-PRs		51.9		

Note. PGF-AI (H) = Interval from CIDR® removal to TAI (Timed-AI), TAI-PR (%) = Timed AI pregnancy rate, 5DCOS +CIDR® = Initial GnRH + CIDR® insertion (D0), double PGF (Either two doses of 25 mg concurrently or single large dose of 50mg) at CIDR® removal, TAI at 72 and 56-72 hours (for beef cows and heifers respectively) after CIDR® removal

Table 4
WTAI-PRs for 5DCOS +CIDR® protocol in beef cattle using two separate doses of PGF (2 – 24 hours interval; initial PGF at CIDR® removal)

Cows					
n	**PGF-AI (h)**	**TAI-PR (%)**	**PGF Delivery**	**Notes**	**Reference(s)**
111	60	56.8	12 hours later	25 mg each Dinoprost	Bridges et al. (2008)
105	72	80.0	12 hours later	25 mg each Dinoprost	
199	72	65.3	12 hours later	25 mg each Dinoprost	
282	72	69.0	7 hours later	25 mg each Dinoprost	Kasimanickam et al. (2009)
89	72	54.5	3 hours later	500µg Cloprostenol	Johnson et al. (2009)
210	72	67.0	12 hours later	25 mg each Dinoprost	Wilson et al. (2010)
881	72	52.7	2.25±0.05 hours later	25 mg each Dinoprost	Whittier et al. (2010)
901	72	57.2	6.45±0.03 hours later	25 mg each Dinoprost	
217	72	50.3	6 hours later	25 mg each Dinoprost	Peel et al. (2010)
216	72	51.1	12 hours later	25 mg each Dinoprost	
195	72	57.4	8 hours later	25 mg each Dinoprost	Stevenson et al. (2011)
821	72	55	8 hours later	25 mg each Dinoprost	Bridges et al. (2012)
911	72	58.1	6 hours later	25 mg each Dinoprost	Whittier et al. (2013)
438	72	62.3	2 to 10 hours later	N/A	Gunn et al. (2015)

Table 4 *(continue)*

n	PGF-AI (h)	TAI-PR (%)	PGF Delivery	Notes	Reference(s)
Cows					
100	72	71.0	7-11 hours later	25 mg each Dinoprost	Corpron et al. (2019)
201	72	52.0	8 hours later	25 mg each Dinoprost	Ahmadzadeh et al. (2021)
208	72	61.0	24 hours later	500µg Cloprostenol	Zwiefelhofer et al. (2021)
WTAI-PRs		57.98			
Heifers					
298	72	62.1	6 hours later	25 mg each Dinoprost	Peterson et al. (2011)
554	56	66.2	6 hours later	25 mg each Dinoprost	Kasimanickam et al. (2012)
544	72	55.9	6 hours later	25 mg each Dinoprost	
237	56	50.2	6 hours later	25 mg each Dinoprost (without initial GnRH)	Kasimanickam et al. (2014)
228	56	58.3	6 hours later	25 mg each Dinoprost (with initial GnRH)	
270	72	62.6	> 4 hours later	25 mg each Dinoprost	Bridges et al. (2014)
1887	56	55.5	6 hours later	25 mg each Dinoprost	Kasimanickam et al. (2015)
718	72	57.8	6 hours later	25 mg each Dinoprost	
291	56	63.6	6 hours later	25 mg each Dinoprost	White et al. (2016)
153	72	66.7	24 hours later	500µg Cloprostenol	Zwiefelhofer et al. (2021)
WTAI-PRs		58.42			

Table 5
WTAI-PR to 7DCOS + CIDR® protocol in beef cattle

n	PGF-AI (h)	TAI-PR (%)	Notes	Reference(s)
Cows				
539	60	54.0	25 mg Dinoprost	Larson et al. (2006)
365	64	44.7	25 mg Dinoprost	Kasimanickam et al. (2006)
599	60	52.0	25 mg Dinoprost	Kasimanickam et al. (2008)
112	60	52.7	25 mg Dinoprost	Bridges et al. (2008)
111	60	66.7	25 mg Dinoprost	
201	60	56.2	25 mg Dinoprost	
424	54	61.0	25 mg Dinoprost	Busch et al. (2008)
427	66	67.0	25 mg Dinoprost	
89	56	53.4	500 µg, Cloprostenol	Johnson et al. (2009)
736	66	51.5	Fresh semen (25 mg Dinoprost)	Bucher et al. (2009)
719	66	59.0	Frozen semen (25 mg Dinoprost)	

Table 5 *(continue)*

n	PGF-AI (h)	TAI-PR (%)	Notes	Reference(s)
Cows				
136	48	38.2	25 mg Dinoprost	Dobbins et al. (2009)
157	56	61.1	25 mg Dinoprost	
170	64	51.8	25 mg Dinoprost	
142	72	47.2	25 mg Dinoprost	
209	66	67.0	25 mg Dinoprost	Wilson et al. (2010)
619	60	54.6	25 mg Dinoprost	Echternkamp & Thallman (2011)
906	66-72	55.1	25 mg Dinoprost	Whittier et al. (2013)
773	66	54.0	25 mg Dinoprost	Mercadante et al. (2015)
383	66	60.0	Conventional semen (500 µg Cloprostenol)	
386	66	44.0	Sexed semen (500 µg Cloprostenol)	
WTAI-PRs		54.91		
Heifers				
531	60	53.0	25 mg Dinoprost	Lamb et al. (2006)
109	54	47.0	25 mg Dinoprost	Busch et al. (2007)
145	57.5	53.0	Without initial GnRH (25 mg Dinoprost)	Ahmadzadeh et al. (2015)
498	54	55.0	25 mg Dinoprost	Mercadante et al. (2015)
433	60	54.2	Lutalyse® HighCon (25 mg Dinoprost)	Kasimanickam et al. (2021)
WTAI-PRs		53.50		

Note. 7DCOS + CIDR® = Initial GnRH + CIDR® insert (D0), PG (single PG, 25mg) on D7, TAI/GnRH: 48–72 and 54–60 hours in cows and heifers respectively after CIDR® removal

Table 6
Cows under 7DCOS (Sex-sorted)

n	TAI-PR (%)	Reference(s)
187	22.32	MacMurracy et al. (2020)
405	48.00	Thomas et al. (2019)
338	44.00	Andersen et al. (2021)
88	40.20	Aubuchon et al. (2022)
386	44.00	Mercadante et al. (2015)
276	53.30	Crite et al. (2018)
40	55.00	Crite et al. (2018)
n= 1720	WTAI-PRs (44.14)	

Table 7
Heifers under 7DCOS (Sex-sorted)

n	TAI-PR (%)	Reference(s)
356	36.90	Oosthuizen et al. (2021)
360	42.10	Oosthuizen et al. (2021)
78	51.30	Crite et al. (2018)
n= 794	WTAI-PRs (40.67)	

Table 8
Country and experimental area climatic zones

Country	Authors	Climate
Virginia, USA	Kasimanickam et al. (2009)	Humid, Subtropical
Manhattan, USA	Stevenson et al. (2011)	Humid subtropical
Florida, USA	Mercadante et al. (2015)	Humid subtropical
Colorado, USA	Bridges et al. (2012)	Semi-arid
Moscow, Russia	Corppron et al. (2019)	Humid continental
Alberta, Canada	Macmillan et al. (2020)	Continental
Washington, USA	Peterson et al. (2011)	Temperate
Washington, USA	Kasimanickam et al. (2014)	Temperate
Ohio, USA	Cruppe et al. (2014)	Humid- continental
Idaho, USA	Ahmadzadeh et al. (2015)	Temperate
Washington, USA	White et al. (2016)	Temperate
Manhattan, USA	Stevenson et al (2011)	Humid subtropical
Colorado, USA	Bridges et al. (2012)	Semi-arid
Idaho, USA	Ahmadzadeh et al. (2021)	Temperate
Ohio, USA	Rojas Canadas et al. (2023)	Humid continental
Washington, USA	White et al. (2016)	Temperate
Colorado, USA	Bridges et al. (2008)	Semi-arid
Virginia, USA	Kasimanickam et al. (2009)	Humid subtropical
Manhattan, USA	Johnson et al. (2009)	Humid subtropical
Missouri, USA	Wilson et al. (2010)	Continental
Virginia, USA	Whittier et al. (2010)	Humid subtropical
Colorado, USA	Peel et al. (2010)	Semi-arid
Manhattan, USA	Stevenson et al. (2011)	Humid subtropical
Colorado USA	Bridges et al. (2012)	Semi-arid
Virginia, USA	Whittier et al. (2013)	Humid subtropical
Pardue, USA	Gunn et al. (2015)	Continental
Moscow, Russia	Corpron et al. (2019)	Humid continental
Moscow, Russia	Ahmadzadeh et al. (2021)	Humid continental
Alberta, Canada	Zwiefelhofer et al. (2021)	Continental
Washington, USA	Peterson et al. (2011)	Temperate
Virginia, USA	Kasimanickam et al. (2012)	Humid subtropical
Washington, USA	Kasimanickam et al. (2014)	Temperate
Colorado USA	Bridges et al. (2014)	Semi-arid
Virginia, USA	Kasimanickam et al. (2015)	Temperate
Washington, USA	White et al. (2016)	Temperate
Alberta, Canada	Zwiefelhofer et al. (2021)	Continental
Minnesota, USA	Larson et al. (2006)	Humid continental
Virginia, USA	Kasimanickam et al. (2006)	Humid subtropical
Virginia, USA	Kasimanickam et al. (2009)	Humid subtropical

Table 8 *(continue)*

Country	Authors	Climate
Colorado, USA	Bridges et al. (2008)	Semi-arid
Missouri, USA	Busch et al. (2008)	Continental
Manhattan, USA	Johnson et al. (2009)	Humid subtropical
Virginia, USA	Bucher et al. (2009)	Humid, Subtropical
Manhattan, USA	Dobbins et al. (2009)	Humid subtropical
Missouri, USA	Wilson et al. (2010)	Continental
Nebraska, USA	Echternkamp and Thallman (2011)	Humid continental/semi-arid
Virginia, USA	Whittier et al. (2013)	Humid, Subtropical
Virginia, USA	Whittier et al. (2013)	Humid, Subtropical
Florida, USA	Mercadante et al. (2015)	Humid subtropical
Minnesota, USA	Lamb et al. (2006)	Humid continental
Missouri, USA	Busch et al. (2007)	Continental
Idaho, USA	Ahmadzadeh et al. (2015)	Temperate
Florida, USA	Mercadante et al. (2015)	Humid subtropical
Virginia, USA	Kasimanickam et al. (2021)	Humid subtropical

FACTORS AFFECTING TAI-PREGNANCY RATES

A variety of factors influence the TAI-PRs in cattle, and these can differ based on specific synchronization methods used, management practices, and characteristics of the cattle population. The meta-analysis report by Richardson et al. (2016) revealed that the body condition score, expression of estrus before AI, and cyclicity had the greatest influence on conception rates in beef cows exposed to TAI programs. Some of the key factors impacting TAI-PRs are discussed below.

Body Condition Score (BCS)

The impact of BCS on reproductive performance in cattle has been extensively studied (D'Occhio et al., 2019; Nazhat et al., 2021; Wang et al., 2019). Body condition scores serve as a crucial indicator of the adipose tissue content in cattle, and it is widely acknowledged by both animal scientists and livestock producers as a fundamental element of dairy cow management and is considered a valuable tool for subjectively assessing the levels of body energy reserves (Pfeifer et al., 2021; Roche et al., 2009). Negative energy balance (NEB) affects the resumption of the postpartum ovarian cycle by impeding LH pulse frequency as well as decreasing blood glucose and insulin growth factor-1 (IGF-1), which altogether prevents E2 production by preovulatory follicles (Butler, 2001). In cows with high milk yield, persistent NEB increases the incidence of anestrus due to smaller dominant follicles, leading to insufficient E2 production to cause ovulation (Roche & Diskin, 2001). Inadequate body condition causes failure to resume cyclicity and prolongs the calving interval, a good indicator of herd productivity (Eversole et al., 2005).

Furthermore, cattle with low energy levels fail to express estrus, which is an important indicator of pregnancy success (Wiltbank et al., 1962). For instance, cattle with poor BCS at calving take longer to resume cyclicity (D'Occhio et al., 2019). The overall reproductive parameters such as calving rate, weaning weight, and number of calves weaned are greater in beef cows with BCS > 5 compared to cows with BCS < 5 (1-9 scale) (Cooke et al., 2021). Similarly, Vedovatto et al. (2022) demonstrated greater pregnancy rates and estrus expression in cows with BCS < 5 than BCS < 5 in beef cattle. Furthermore, in suckling beef cows that were exposed to TAI, PRs were greater in high (≥ 3.5) and moderate (2.75–3.25) BCS compared to low (2–2.5) in 1–5 scale BCS) (Nishimura et al., 2018). It was reported that one of the major reasons for suckling beef cows failing to resume cyclicity after calving is due to inadequate BCS at calving time (Crowe et al., 2014). Whittier et al. (2013) also observed lower TAI-PRs for cows with BCS ≤ 4 (49.3%) compared to those > 6 (55.8%).

Apart from BCS alone, understanding other factors that interact together to impact TAI outcomes is crucial in improving herd productivity. For instance, older cows with good BCS may fail to give satisfactory pregnancy rates due to reduced ovulation rates, inadequate GnRH release, and poor egg quality. Similarly, heifers with ideal BCS may not perform well in the tropics due to heat stress. On the other hand, an effective synchronization protocol coupled with good BCS may contribute positively to pregnancy outcomes. For optimizing breeding programs, breeders must be aware of such interactions while implementing TAI programs. Setiaji et al. (2023) reported that BCS and breeding season affected conception rates whereby, cows with BCS 3 and 4 (1 to 5 scale) had better conception rates during autumn, while cows with BCS of 5 showed the highest conception rates during autumn and winter. However, lower rates during spring and summer indicating some seasons have more favorable conception rates than others. Furthermore, the success of postpartum rebreeding is attributed to the combined effect of BCS and nutrient availability in the feed, as higher BCS causes increased plasma P4, which is crucial for maintaining pregnancy (Randel., 1990; Vedovatto et al., 2022).

Expression of Estrus Before TAI

The impact of estrus expression in cattle subjected to TAI programs has been substantially documented. The occurrence of estrus before TAI has a beneficial effect on pregnancy rates. It is attributed to its ability to modify the uterine environment, enhance the number of accessory sperm, improve fertilization rates, and promote embryo survival (Richardson et al., 2016). Additionally, sex steroids alter the composition of cervical mucus during estrus, facilitating the movement of spermatozoa through the cervix to achieve successful fertilization (Tsiligianni et al., 2011). The effect of estrus expression before TAI was revealed in the meta-analysis by Richardson et al. (2016), where beef cows that had exhibited estrus before TAI had 27% greater PRs compared to those not expressing estrus. Similarly, Cedeño et al. (2020) examined the influence of estrous expression on pregnancy rates in an embryo transfer (ET) program and found that recipient cows that exhibited estrus had a significantly higher PR/ET compared to cows that did not exhibit estrus (39.0% vs. 25.0%) regardless of the type of treatments. They also observed higher calving rates and lower pregnancy losses in recipient cows that exhibited estrus. Furthermore, Sá Filho et al. (2011) demonstrated larger follicle size, greater ovulation rate, larger CL, and a higher P4 concentration in cows that expressed estrus prior to AI. This knowledge is of particular importance in programs that utilize expensive sex-sorted semen. By selectively distributing sex-sorted semen to females that exhibit estrus, the cost per pregnancy may be lowered, and pregnancy rates may be enhanced. In the study by Perry, Walker et al. (2020), higher conception rates for both conventional and sexed-sorted semen were observed in females who exhibited estrus in a TAI program—additionally, Bó and Cedeño. (2018) also observed greater PRs and lower pregnancy losses in cows displaying estrus that utilized embryos generated from *in-vitro* and *in-vivo* methods. Furthermore, the overall TAI-PRs in postpartum cows were significantly higher ($p = 0.01$) in cows that showed estrus behaviors before TAI compared to those that did not (73.0 Vs. 45.0%) (Nash et al., 2012). The results from these studies indicate a positive impact of estrus expression on pregnancy outcomes in a TAI Program.

The expression of estrus is dependent on several factors, irrespective of its detection efficiency. Estradiol from the dominant follicle plays a vital role in inducing sexual behavior in cattle, and it triggers luteinizing hormone surge to cause ovulation. Thus, a hormonal environment that supports intense estrus behaviors is closely associated with timely ovulation and fertilization. The interaction between BCS and estrus expression is well-documented. Cows with higher BCS are more likely to show estrus behaviors than those with low BCS, which, in turn, improves their likelihood of successful breeding (Nazhat et al., 2021). Conversely, cows with low BCS may either fail to express estrus behaviors or lack intensity, resulting in reduced TAI-PRs following synchronization because of low energy reserve, which impacts the production of reproductive hormones. In contrast, over-conditioned cows may suffer from metabolic disorders (Bisinotto et al., 2010).

Stage of Estrous Cycle at the Initiation of the TAI Program

The estrous cycle stage at the initiation of the TAI program can be determined by ultrasound examination to identify the presence or absence of CL. Additionally, transrectal palpation and quantification of milk or blood P4 can be used to determine the presence of CL. Significantly higher PRs were observed in beef heifers that possessed CL at the initiation of the TAI program compared to those that did not (71.3 vs. 59.0%) (Núñez–Olivera et al., 2022). This finding also aligns with the report of Stevenson et al. (2011), where cyclic lactating postpartum beef cows subjected to 5DCOS plus CIDR® protocol had greater TAI-PRs than those not-cycling (53.4 vs. 45.6%). They also observed that those cows possessing CL at the initiation of the program were 1.5 times more likely to get pregnant. Similarly, the conception rate of cyclic beef cows (66.0%) was significantly higher than that of anestrus cows (53.0%), irrespective of the TAI protocols used (Geary et al., 2001). In the meta-analysis by Borchardt et al. (2020), lactating cows that had functional CL at the initiation of the TAI program had a 10.0% improved PR/AI. A greater TAI-PR was also reported by Mercadante et al. (2015) in suckling beef cows, where cows with CL at the initiation of the TAI program had significantly higher pregnancy rates compared to those that did not (66.3% vs. 39.4%, $p = 0.012$). The increased pregnancy rates in cows with CL may be due to increased endogenous P4 concentration, which improved ovulation synchronization and oocyte/follicle maturation, and due to a positive effect on the endometrium (Bisinotto et al., 2015).

Cyclicity during protocol initiation has been closely linked to animal's BCS. Cattle with BCS of 3-4 (5-scale point) are more likely to be cyclic and better respond to TAI programs. Furthermore, cyclicity is not only affected by BCS but also impacts how cows respond to hormonal treatments in TAI programs (Lucy, 2007). The likelihood of estrus rates in heifers synchronized using a modified 5DCOS program revealed a significant interaction between the presence of corpus luteum, the treatment protocol, and eCG treatment (Macmillan et al., 2020). CL on the ovary indicates a normal estrous cycle in cattle. It serves as an important source of P4, which in turn improves estrus synchronization, which is one of the possible reasons for stimulating puberty in heifers and helps resume postpartum estrus in cows supplemented with P4 at the initiation of synchronization (Kasimanickam et al., 2020).

Breeding Season

The impact of TAI programs on pregnancy rates was variable across several breeding seasons. It suggests that the efficacy of treatment protocols depends on the breeding season under consideration. For instance, a significant effect of the breeding season on pregnancy rates was observed in suckled beef cows (Bilbao et al., 2019; Randi et al., 2021). The conception rate for dairy cattle after the first post-calving insemination was lowest during the summer (Souames & Berrama, 2020) and this may be attributed to the increased ambient temperature leading to heat stress as it negatively impacts fertilization and embryo survival. Spring is commonly targeted for cattle breeding as it allows calves to be born in more favorable weather conditions that minimize the risks of cold stress to newborns and increase calf survivability (Keskin et al., 2016).

However, in tropical regions of the world, cattle breeding requires careful consideration of environmental, nutritional, and reproductive factors, as extreme heat and rainfall may negatively affect fertility. Targeting cooler and drier months of the year can help reduce heat stress and improve pregnancy rates. Additionally, scheduling breeding after the rainy season will ensure sufficient fodder availability to maintain a healthy body condition score.

Anestrus is a common condition among cattle in tropical regions characterized by shorter estrus periods, mostly occurring at night, affecting AI programs. The use of hormonal treatments consisting of progesterone device, GnRH, PGF, eCG, and Estradiol benzoate results in consistent pregnancy rates in *Bos indicus* cows adapted in this region and could be an alternative to improve breeding efficiency (Baruselli et al., 2004).

Environmental and Management Factors

Environmental and managemental factors play a vital role in TAI-PRs in beef cows by influencing cows' physiology, reproductive efficiency, and overall herd fertility. Extreme temperature, particularly heat stress, impairs ovarian functions, reduces oocyte quality, affects embryo development, and lowers PRs (De Rensis & Scaramuzzi, 2003). Deficiency of nutrients and inadequate BCS cause a delay in estrus expression with poor response to synchronization, leading to reduced conception rates (Bó et al., 2002). Furthermore, management practices such as poor estrus detection, improper animal handling during synchronization and AI, and faults in semen storage or handling can lower AI success (Diskin & Morris, 2008). Proper herd management, optimizing nutritional requirements, and reducing stress are essential to enhancing TAI-PRs in beef cows.

LIMITATIONS

Exclusive Focus on Beef Cattle

The techniques examined in this review solely relied on data obtained from beef cattle studies, which may restrict the results' applicability to other cow populations and breeds. Further studies should strive to include a broader spectrum of cattle demographics in conducting a more thorough and complete assessment.

Restriction to CIDR® as a Progesterone Source

The review selectively considered manuscripts that employed CIDR® as the source of progesterone, which may have restricted the findings' applicability to other progesterone devices. Future reviews could incorporate a more diverse range of progesterone devices to provide a more holistic understanding of the efficacy of different protocols.

Inclusion of Data from Sex-sorted Semen

Pregnancy rates resulting from sexed semen are usually lower than conventional semen. Thus, the inclusion of data from sexed sorted semen may have contributed nuance to the overall findings. Future reviews should consider adding information for non-conventional semen.

Potential Biases in Reviewed Studies

The overall WTAI-PRs reported in our review may also be limited because of potential biases. Firstly, the trial size of the reviewed papers ranged from a minimum of 40 to a maximum of 1887 across studies. The applicability of results from a small trial size may affect the reliability of the findings and complicate application in a larger population in the practical setting. Secondly, most studies reviewed were from the states of the United States of America, where heat stress is seasonal, unlike in the tropics, where heat stress is year-round, which may negatively affect breeding outcomes. Thirdly, the type of cattle breeds used for experiments are mostly exotic or their crosses. Such results cannot be generalized to *Bos indicus* and other local breeds in tropical regions. Lastly, most reviewed studies do not specify the management practices of experimental animals. Therefore, our WTAI-PRs were unable to account for the effect of different management practices, including diet, humidity, and type of husbandry practices.

DISCUSSION

This paper reviewed pregnancy rates in 7DCOS and pregnancy rates obtained from different methods of prostaglandin delivery in 5DCOS. Other factors besides the treatments used in TAI programs were also observed. A WTAI-PR of 54.91% and 53.5% in 7DCOS for cows and heifers were observed (Figure 3). The WTAI-PR for 5DCOS were reviewed separately for single, double, and two separate doses, with the results showing 51.75% and 52.84% (single dose), 50.38% and 51.90% (double), and 57.98% and 58.42% (two separate doses) for cows and heifers respectively (Figure 2). Outside of these treatment protocols, factors such as body condition score, breeding season, estrus expression prior to TAI, and cyclicity prior to treatment initiation also influenced TAI-PRs. The WTAI-PRs based on geographical locations of the experiment and cattle breed is shown in Figure 4 and 5 respectively.

Although the increased length of proestrus indicated by the duration between PGF and GnRH-induced LH surge or the interval from the ejection of P4 device to GnRH/TAI should show increased pregnancy rates (Bó et al., 2016; Day, 2018; de la Mata et al., 2018), WTAI-PRs in both 7DCOS and 5DCOS when PGF is delivered in a single and double dose were comparable. It shows that reducing the number of synchronization durations (from a minimum of nine days in 7DCOS to eight days in 5DCOS) and CIDR® exposure duration (from seven days in 7DCOS to five days in 5DCOS) has no impact on TAI-PRs. However, two separate PGF doses had a higher WTAI-PR in 5DCOS compared to 7DCOS, in which PGF is always delivered as a one-time dose (single and double). Reducing the P4 device exposure from seven days to five resulted in a young immature corpus luteum that resisted complete luteolysis, and two PGF doses in 5DCOS are required (Bridges et al., 2012). However, WTAI-PR for both 7DCOS and 5DCOS were within the range reported for TAI-PRs (Bó et al., 2018).

While most evidence of PRs through CO-Synch programs is based on experimental research with different trial sizes, they do not truly understand the program's overall effect on PRs. This review employed a weighted average approach to provide a more reliable estimate of pregnancy rates under CO-Synch programs. This method of weighted timed artificial insemination accounts for the disparity in animal numbers across studies by dividing trial sizes in each study in the review by the sum of all the trial sizes, thereby enabling all the studies reviewed to have the same animal numbers.

Beef farmers were seen to be slow in adopting AI technology primarily because of the labor-intensive nature of the tasks involved and the considerable time needed for detecting heat (Colazo & Mapletoft. 2014). Although labor can be saved with TAI programs, multiple doses (especially two separate) are needed to increase PRs under 5DCOS, which involves extra labor for animal handling and added hormonal costs. The advent of TAI programs has enhanced pregnancy rates because cattle are inseminated irrespective of estrus expression prior to AI (Colazo & Mapletoft, 2014). With two separate PGF doses in 5DCOS, TAI is more effective in achieving high pregnancy rates. Since beef cattle are typically raised in extensive systems where less time is spent monitoring them compared to dairy cattle, synchronization programs that depend on heat detection are not feasible (Taponen, 2009). Beef farmers would have to incur added costs just to improve PRs. It could lead to a further decrease in adoption rates of AI technology among beef producers.

As this review focused on beef cattle, the applicability of results to other cattle breeds not bred for beef is limited. Focus was made on CO-Synch programs mainly because there is a lack of understanding of the average effect of CO-Synch programs on pregnancy rates in beef cattle. Additionally, CO-Synch programs are mostly implemented in beef cattle compared to dairy cattle (Colazo & Mapletoft, 2014). This review's applicability is also limited to CIDR® and no other progesterone devices such as PRID, PRID-Delta, and TRIU-B. CIDR® mainly due to its widespread adoption and effectiveness in releasing progesterone. Furthermore, CIDR® has regulatory approval and standardization, providing consistent synchronization outcomes in breeding programs (Klabnik & Horn, 2023).

Results obtained from our review are not applicable outside the use of conventional semen. Sex-sorted semen is prevalent in 7DCOS, and PRs are relatively lower than conventional semen in both cows and heifers. Sex-sorted semen via 7DCOS showed WTAI-PR of 44.14% and 40.67% in cows and heifers, respectively (Tables 6 -7).

Despite discussing different hormonal inductions and ART such as Ovsynch, 7DCOS and 5DCOS, these methods basically fall under ART in cattle and remain a hot subject, particularly in farms managed in precision and tuned to profit from high-quality animals. Because this is actively being pursued in two types of cattle industries (dairy and specialized beef cattle breeding farms), rates of use of CO-Synch protocols in beef cattle are understandably lower for sex-sorted semen. Our review used fewer publications since publications are also far apart in dates. Although AI technology is not new, and in the 90 years of its use, the achievement of more than 50% PR from hormonally induced ovulation + AI can teach us important lessons. In this review, results of the percentage of PRs have been sought from data involving thousands of animals, and the highest rate for this protocol is settled at this point. Even in beef cattle, the focus of using ART should never be for common farms and/or common breeds. However, ART might be an important tool to quickly propagate high-quality beef cattle to impact population size and contribute to the industry. This review provides a guide as to when the CO-Synch protocols would be an important tool for the beef cattle industry and which protocols would be a choice in achieving higher PRs.

Most papers that were reviewed took place in temperate and sub-tropical climates, and therefore, the results cannot be generalized to countries with tropical conditions (Table 8). This review attempted to look at the application of CO-Synch protocols in the tropics, but this proved difficult given the lack of publications in tropical climates. Nevertheless, a good number of studies have been carried out in some of the states in the United States of America that have humid subtropical climate zones. It indicates an opportunity for breeders to explore the potential of CO-Synch programs in the tropics due to the closely related climatic zone.

CO-Synch protocols are unsuitable for extensive beef cattle farming, whereby the animals' body condition is determined largely by environmental factors. Careful management of environmental conditions such as heat stress and adequate nutrition are still required for intensive beef cattle farms in the tropics. In general, 7DCOS would be appropriate for both intensive and extensive beef farms, provided beef farmers are willing to invest labor and time. The employment of 5DCOS with two doses of PGF may increase the number of animal handlings, which may negatively impact the farm's profitability. Therefore, a modified version with a single-double-dosed PGF would be an alternative to reduce the number of animal handlings.

While the reviewed studies show various P4-based TAI programs, it is important to note that these studies were conducted mostly under controlled experimental conditions that may not fully reflect real-world breeding environments. For instance, common tropical climate features such as excessive heat and humidity are not accounted which may potentially limit the generalizability of findings to regions where such conditions exist (De Rensis & Scaramuzzi, 2003). Furthermore, some studies used optimally managed herds with good nutrition, estrus detection, and AI techniques, which may not reflect more variable management practices encountered by cattle breeders. Although various P4 devices are available for use, this review specifically focused on CIDR (Reason cited elsewhere in this review) with exposure duration of either 5 (5DCOS) or 7 (7DCOS) days. However, the articles reviewed herein did not assess the long-term impact of CIDR devices, especially for management systems that are under-resourced. Likewise, the efficacy of CIDR-based programs in minimizing early embryonic loss and improving PRs in tropical regions remains underexplored. Since the absorption rates of P4 and response to hormonal induction may vary under extreme heat stress, future research should aim to assess the reproductive performance of different P4 devices in tropical regions (Bó et al., 2002). Additionally, most studies focused on immediate TAI success rates without long-term follow-up on reproductive efficiency and health. It may result in an insufficient understanding of the implications of treatment protocols in real-world settings. Most studies in TAI protocols are focused on the effectiveness of TAI programs on PRs without studying the economic implications of these protocols. So, future studies should study CO-Synch protocols' cost-effectiveness and economic efficiency.

CO-Synch protocols are not commonly employed in Malaysia, with reported lower pregnancy rates of 18-23.3% using the CIDR-based TAI program (Azizah et al., 2014; Malik et al., 2012). With the growing enthusiasm for genetic improvement in Malaysian cattle through AI, future studies could look at the use of CO-Synch protocols in Malaysia as the demand for better genetics increases. Although CO-Synch programs are predominant in the Western world in temperate climates, it would be a good opportunity for beef producers to use native beef cattle well adapted to the warm tropics like the Kedah-Kelantan and their crossbreeds.

CONCLUSION

This review examined the reproductive outcomes associated with 5DCOS and 7DCOS plus CIDR® protocols in beef cattle. The importance of selecting the most appropriate PGF administration method in the 5DCOS protocol to optimize reproductive success in cattle production and factors other than the protocols themselves when implementing TAI protocols, such as body condition, breeding season, nutritional management, and estrus expression before AI, were highlighted. The CO-Synch programs looked at had different trial sizes, and this variability did not provide a true understanding of the program's overall effect on PRs. Therefore, this review employed a weighted average approach. As beef cattle are typically raised in extensive systems where less time is spent monitoring, synchronization programs that depend on heat detection are not feasible for beef cattle. Additional costs would be incurred to employ programs like the 5DCOS with two separate PGF injections. The increase in economic cost for extra animal handling and hormone purchase might discourage adoption rates of AI technology among beef producers. Among the protocols presented, 7DCOS would be appropriate for both intensive and extensive beef farms, provided farmers are willing to invest time and labor.

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REFERENCES

Ahmadzadeh, A., Corpron, M., Hall, J. B., Ahmadzadeh, A., & Dalton, J. (2021). 234 pregnancy and hormonal response in suckled beef cows administered high-concentration prostaglandin F2α in a 5-day CO-Synch + CIDR synchronization program. *Journal of Animal Science, 99*(Supplement 3), 122–123. https://doi.org/10.1093/jas/skab235.224

Ahmadzadeh, A., Gunn, D., Hall, J. B., & Glaze, J. B. (2015). Evaluation of treatment with a 5-day versus 7-day controlled internal drug-release insert on reproductive outcomes of beef heifers using a modified timed–artificial insemination protocol. *The Professional Animal Scientist*, *31*(3), 270–277. https://doi.org/10.15232/pas.2014-01378

Andersen, C. M., Bonacker, R. C., Smith, E. G., Spinka, C. M., Poock, S. E., & Thomas, J. M. (2021). Evaluation of the 7 & 7 Synch and 7-day CO-Synch + CIDR treatment regimens for control of the estrous cycle among beef cows prior to fixed-time artificial insemination with conventional or sex-sorted semen. *Animal Reproduction Science*, *235*, 106892. https://doi.org/10.1016/j.anireprosci.2021.106892

Aubuchon, K. W., Odde, J. A., Bronkhorst, C., Bortoluzzi, E. M., Goering, M. J., Fike, K. E., & Odde, K. G. (2022). Field trial assessing the use of sex-sorted semen in beef cattle. *Kansas Agricultural Experiment Station Research Reports*, *8*(1), 14. https://doi.org/10.4148/2378-5977.8233

Azizah, A., Ariff, O. M., Ahmad Nazri, A. R., Wahid, H., Ahmad, J., & Saadiah, J. (2014). Pregnancy rate from timed-artificial insemination and natural service of oestrus synchronized Kedah-Kelantan and crossbred cows in two management systems. *Malaysian Journal of Animal Science*, *17*(2), 11-21.

Baruselli, P. S., Reis, E. L., Marques, M. O., Nasser, L. F., & Bó, G. A. (2004). The use of hormonal treatments to improve reproductive performance of anestrous beef cattle in tropical climates. *Animal reproduction science*, *82*, 479-486. https://doi.org/10.1016/j.anireprosci.2004.04.025

Bilbao, M. G., Zapata, L. O., Harry, H. R., Wallace, S. P., Farcey, M., Gelid, L., Palomares, R. A., Ferrer, M. S., & Bartolome, J. (2019). Comparison between the 5-day CO-Synch and 7-day estradiol-based protocols for synchronization of ovulation and timed artificial insemination in suckled Bos taurus beef cows. *Theriogenology*, *131*, 72–78. https://doi.org/10.1016/j.theriogenology.2019.01.027

Bisinotto, R. S., Greco, L. F., Ribeiro, E. S., Martinez, N., Lima, F. S., Staples, C. R., & Santos, J. E. P. (2018). Influences of nutrition and metabolism on fertility of dairy cows. *Animal Reproduction (AR)*, *9*(3), 260-272.

Bisinotto, R., Lean, I., Thatcher, W., & Santos, J. (2015). Meta-analysis of progesterone supplementation during timed artificial insemination programs in dairy cows. *Journal of Dairy Science*, *98*(4), 2472–2487. https://doi.org/10.3168/jds.2014-8954

Bó, G. A., & Baruselli, P. S. (2014). Synchronization of ovulation and fixed-time artificial insemination in beef cattle. *Animal*, *8*(s1), 144–150. https://doi.org/10.1017/s1751731114000822

Bó, G. A., & Cedeño, A. (2018). Expression of estrus as a relevant factor in fixed-time embryo transfer programs using estradiol/progesterone-based protocols in cattle. *Animal Reproduction*, *15*(3), 224–230. https://doi.org/10.21451/1984-3143-AR2018-0060

Bó, G. A., Baruselli, P. S., Moreno, D., Cutaia, L., Caccia, M., Tríbulo, R., & Mapletoft, R. J. (2002). The control of follicular wave development for self-appointed embryo transfer programs in cattle. *Theriogenology*, *57*(1), 53-72. https://doi.org/10.1016/S0093-691X(01)00657-4

Bó, G. A., de la Mata, J. J., Baruselli, P. S., & Menchaca, A. (2016). Alternative programs for synchronizing and resynchronizing ovulation in beef cattle. *Theriogenology*, *86*(1), 388–396. https://doi.org/10.1016/j.theriogenology.2016.04.053

Borchardt, S., Pohl, A., & Heuwieser, W. (2020). Luteal presence and ovarian response at the beginning of a timed artificial insemination protocol for lactating dairy cows affect fertility: A meta-analysis. *Animals*, *10*(9), 1551. https://doi.org/10.3390/ani10091551

Bridges, A., Lake, S., Lemenager, R., & Claeys, M. (2008). *Timed artificial insemination in beef cows: What are the options?* Purdue University. https://www.extension.purdue.edu/extmedia/as/as_575_w.pdf

Bridges, G. A., Ahola, J. K., Brauner, C., Cruppe, L. H., Currin, J. C., Day, M. L., Gunn, P. J., Jaeger, J. R., Lake, S. L., & Lamb, G. C. (2012). Determination of the appropriate delivery of prostaglandin F2α in the five-day CO-Synch + controlled intravaginal drug release protocol in suckled beef cows. *Journal of Animal Science*, *90*(13), 4814–4822. https://doi.org/10.2527/jas.2011-4880

Bridges, G. A., Helser, L. A., Grum, D. E., Mussard, M. L., Gasser, C. L., & Day, M. L. (2008). Decreasing the interval between GnRH and PGF2α from 7 to 5 days and lengthening proestrus increases timed-AI pregnancy rates in beef cows. *Theriogenology*, *69*(7), 843-851. https://doi.org/10.1016/j.theriogenology.2007.12.011

Bridges, G. A., Lake, S. L., Kruse, S. G., Bird, S. L., Funnell, B. J., Arias, R., Walker, J. A., Grant, J. K., & Perry, G. A. (2014). Comparison of three CIDR-based fixed-time AI protocols in beef heifers. *Journal of Animal Science*, *92*(7), 3127–3133. https://doi.org/10.2527/jas.2013-7404

Bridges, G. A., Mussard, M. L., Burke, C. R., & Day, M. L. (2010). Influence of the length of proestrus on fertility and endocrine function in female cattle. *Animal reproduction science, 117*(3-4), 208-215. https://doi.org/10.1016/j.anireprosci.2009.05.002

Bucher, A., Kasimanickam, R., Hall, J. B., DeJarnette, J. M., Whittier, W. D., Kähn, W., & Xu, Z. (2009). Fixed-time AI pregnancy rate following insemination with frozen-thawed or fresh-extended semen in progesterone supplemented CO-Synch protocol in beef cows. *Theriogenology*, *71*(7), 1180–1185. https://doi.org/10.1016/j.theriogenology.2008.12.009

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 CO-Synch + controlled internal drug-release protocol. *Journal of Animal Science*, *86*(7), 1519–1525. https://doi.org/10.2527/jas.2008-0925

Busch, D. C., Wilson, D. J., Schafer, D. J., Leitman, N. R., Haden, J. K., Ellersieck, M. R., Smith, M. F., & Patterson, D. J. (2007). Comparison of progestin-based estrus synchronization protocols before fixed-time artificial insemination on pregnancy rate in beef heifers. *Journal of Animal Science*, *85*(8), 8. https://doi.org/10.2527/jas.2006-845

Butler, W. R. (2001). Nutritional effects on resumption of ovarian cyclicity and conception rate in postpartum dairy cows. *BSAP Occasional Publication*, *26*(1), 133–145. https://doi.org/10.1017/S0263967X00033644

Rojas Canadas, E., Battista, S. E., Kieffer, J. D., Wellert, S. R., Mussard, M. L., & Garcia-Guerra, A. (2023). GnRH dose at initiation of a 5-day CO-Synch + P4 for fixed time artificial insemination in suckled beef cows. *Animal Reproduction Science*, *250*, 107210. https://doi.org/10.1016/j.anireprosci.2023.107210

Cedeño, A., Tríbulo, A., Tríbulo, R. J., Andrada, S., Mapletoft, R. J., & Bó, G. A. (2020). Effect of estrus expression or treatment with GnRH on pregnancies per embryo transfer and pregnancy losses in beef recipients synchronized with estradiol/progesterone-based protocols. *Theriogenology*, *157*, 378–387. https://doi.org/10.1016/j.theriogenology.2020.08.023

Colazo, M. G., & Mapletoft, R. J. (2014). A review of current timed-AI (TAI) programs for beef and dairy cattle. *The Canadian Veterinary Journal = La Revue Veterinaire Canadienne*, *55*(8), 772–780.

Cooke, R. F., Lamb, G. C., Vasconcelos, J. L. M., & Pohler, K. G. (2021). Effects of body condition score at initiation of the breeding season on reproductive performance and overall productivity of Bos taurus and Bos indicus beef cows. *Animal Reproduction Science*, *232*, 106820. https://doi.org/10.1016/j.anireprosci.2021.106820

Corpron, M. R., Menegatti Zoca, S., Reynolds, M., Carnahan, K., Hall, J. B., & Ahmadzadeh, A. (2019). Evaluating the effects of a high-concentration dose of prostaglandin F2α in a 5-d CO-Synch + controlled internal drug release protocol on fertility in beef cows. *Translational animal science*, *3*(Suppl 1), 1754–1757. https://doi.org/10.1093/tas/txz081

Crites, B. R., Vishwanath, R., Arnett, A. M., Bridges, P. J., Burris, W. R., McLeod, K. R., & Anderson, L. H. (2018). Conception risk of beef cattle after fixed-time artificial insemination using either SexedUltra™ 4M sex-sorted semen or conventional semen. *Theriogenology*, *118*, 126-129. https://doi.org/ 10.1016/j.theriogenology.2018.05.003

Crowe, M. A., Diskin, M. G., & Williams, E. J. (2014). Parturition to resumption of ovarian cyclicity: Comparative aspects of beef and dairy cows. *Animal*, *8*, 40–53. https://doi.org/10.1017/s1751731114000251

Cruppe, L. H., Day, M. L., Abreu, F. M., Kruse, S. G., Lake, S., Biehl, M.V., Cipriano, R.S., Mussard, M.L. & Bridges, G. A. (2014). The requirement of GnRH at the beginning of the five-day CO-Synch + controlled internal drug release protocol in beef heifers. *Journal of Animal Science*, *92*(9), 4198–4203. https://doi.org/10.2527/jas.2014-7772

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. https://doi.org/10.1016/j.theriogenology.2018.11.010

Dahlen, C., Larson, J., & Lamb, G. C. (2014). Impacts of reproductive technologies on beef production in the United States. In *Current and future reproductive technologies and world food production* (pp. 97–114). Springer. https://doi.org/10.1007/978-1-4614-8887-3_5

Day, M. L. (2015). State of the art of GnRH-based timed AI in beef cattle. *Animal Reproduction*, *12*(3), 473-478.

De La Mata, J. J., Núñez-Olivera, R., Cuadro, F., Bosolasco, D., De Brun, V., Meikle, A., Bó, G. A., & Menchaca, A. (2018). Effects of extending the length of pro-oestrus in an oestradiol- and progesterone-based oestrus synchronisation program on ovarian function, uterine environment and pregnancy establishment in beef heifers. *Fertility and Development, 30*(11), 1541-1552. https://doi.org/10.1071/rd17473

De Rensis, F., & Scaramuzzi, R. J. (2003). Heat stress and seasonal effects on reproduction in the dairy cow—A review. *Theriogenology*, *60*(6), 1139-1151. https://doi.org/10.1016/S0093-691X(03)00126-2

Diskin, M. G., & Morris, D. G. (2008). Embryonic and early foetal losses in cattle and other ruminants. *Reproduction in Domestic Animals*, *43*, 260-267. https://doi.org/10.1111/j.1439-0531.2008.01171.x

Dobbins, C. A., Eborn, D. R., Tenhouse, D. E., Breiner, R. M., Johnson, S. K., Marston, T. T., & Stevenson, J. S. (2009). Insemination timing affects pregnancy rates in beef cows treated with CO-Synch protocol including an intravaginal progesterone insert. *Theriogenology, 72*(7), 1009-1016. https://doi.org/10.1016/j.theriogenology.2009.06.025

Echternkamp, S. E., & Thallman, R. M. (2011). Factors affecting pregnancy rate to estrous synchronization and fixed-time artificial insemination in beef cattle. *Journal of animal science*, *89*(10), 3060–3068. https://doi.org/10.2527/jas.2010-3549

Eversole, D. E., Browne, M. F., Hall, J. B., & Dietz, R. E. (2009). *Body condition scoring beef cows.* https://vtechworks.lib.vt.edu/server/api/core/bitstreams/dacc5413-82f2-4c0e-b5b6-d89b9e5837da/content

Geary, T. W., Whittier, J. C., Hallford, D. M., & MacNeil, M. D. (2001). Calf removal improves conception rates to the Ovsynch and CO-Synch protocols. *Journal of Animal Science*, *79*(1), 1-4. https://doi.org/10.2527/2001.7911

Gunn, P. J., Lemenager, R., & Bridges, A. (2015). Efficacy of the 5-day CO-Synch estrous synchronization protocol with or without the inclusion of a controlled internal drug release device in beef cows. *Iowa State University Animal Industry Report*, *12*(1), 1-3. https://doi.org/10.31274/ans_air-180814-1270

Johnson, S. K., Funston, R. N., Hall, J. B., Lamb, G. C., Lauderdale, J. W., Patterson, D., & Perry, G. (2010). Protocols for synchronization of estrus and ovulation. In *Proceedings Applied Reproductive Strategies in Beef Cattle San Antonio, TX* (pp. 262-270). Beed Reproduction Task Force. https://beefrepro.org/wp-content/uploads/2020/09/22-protocols.pdf

Johnson, S. K., Jaeger, J. R., Harmoney, K. R., & Bolte, J. W. (2009). Comparison of a modified 5-day CO-Synch plus CIDR protocol with CO-Synch plus CIDR in mature beef cows. In *Proceedings, Western Section* (p. 248). American Society of Animal Sciences. https://www.asas.org/docs/western-section/2009-western-section-proceedings.pdf?sfvrsn=0#page=243

Kasimanickam, R. K., Firth, P., Schuenemann, G. M., Whitlock, B. K., Gay, J. M., Moore, D. A., Hall, J. B., & Whittier, W. D. (2014). Effect of the first GnRH and two doses of PGF2α in a 5-day progesterone-based CO-Synch protocol on heifer pregnancy. *Theriogenology*, *81*(6), 797-804. https://doi.org/10.1016/j.theriogenology.2013.12.023

Kasimanickam, R. K., Kasimanickam, V. R., Oldham, J., & Whitmore, M. (2020). Cyclicity, estrus expression and pregnancy rates in beef heifers with different reproductive tract scores following progesterone supplementation. *Theriogenology*, *145*, 39-47. https://doi.org/10.1016/j.theriogenology.2020.01.028

Kasimanickam, R., Asay, M., Firth, P., Whittier, W. D., & Hall, J. B. (2012). Artificial insemination at 56 h after intravaginal progesterone device removal improved AI pregnancy rate in beef heifers synchronized with five-day CO-Synch + controlled internal drug release (CIDR) protocol. *Theriogenology*, *77*(8), 1624-1631. https://doi.org/10.1016/j.theriogenology.2011.12.007

Kasimanickam, R., Collins, J. C., Wuenschell, J., Currin, J. C., Hall, J. B., & Whittier, D. W. (2006). Effect of timing of prostaglandin administration, controlled internal drug release removal and gonadotropin releasing hormone administration on pregnancy rate in fixed-time AI protocols in crossbred Angus cows. *Theriogenology*, *66*(2), 166–172. https://doi.org/10.1016/j.theriogenology.2005.10.019

Kasimanickam, R., Day, M. L., Rudolph, J. S., Hall, J. B., & Whittier, W. D. (2009). Two doses of prostaglandin improve pregnancy rates to timed-AI in a 5-day progesterone-based synchronization protocol in beef cows. *Theriogenology*, *71*(5), 762-767. https://doi.org/10.1016/j.theriogenology.2008.09.049

Kasimanickam, R., Hall, J. B., Currin, J. F., & Whittier, W. D. (2008). Sire effect on the pregnancy outcome in beef cows synchronized with progesterone based Ovsynch and CO-Synch protocols. *Animal Reproduction Science*, *104*(1), 1–8. https://doi.org/10.1016/j.anireprosci.2007.01.003

Kasimanickam, R., Kasimanickam, V., & Kappes, A. (2021). Timed artificial insemination strategies with or without short-term natural service and pregnancy success in beef heifers. *Theriogenology*, *166*, 97–103. https://doi.org/10.1016/j.theriogenology.2021.02.023

Kasimanickam, R., Schroeder, S., Hall, J. B., & Whittier, W. D. (2015). Fertility after implementation of long- and short-term progesterone-based ovulation synchronization protocols for fixed-time artificial insemination in beef heifers. *Theriogenology*, *83*(7), 1226–1232. https://doi.org/10.1016/j.theriogenology.2015.01.004

Keskin, A., Mecitoğlu, G., Bilen, E., Guner, B., Orman, A., Okut, H., & Gumen, A. (2016). The effect of ovulatory follicle size at the time of insemination on pregnancy rate in lactating dairy cows. *Turkish Journal of Veterinary & Animal Sciences*, *40*(1), 68–74. https://doi.org/10.3906/vet-1506-59

Klabnik, J., & Horn, E. (2023). When the plan goes awry: How to negotiate estrus synchronization errors in beef cattle. *Clinical Theriogenology*, *15*, 1-9. http://doi.org/10.58292/CT.v15.9265

Lamb, G. C., Larson, J. E., Geary, T. W., Stevenson, J. S., Johnson, S. K., Day, M. L., Ansotegui, R. P., Kesler, D. J., DeJarnette, J. M., & Landblom, D. G. (2006). Synchronization of estrus and artificial insemination in replacement beef heifers using gonadotropin-releasing hormone, prostaglandin F2α, and progesterone. *Journal of Animal Science*, *84*(11), 3000–3009. https://doi.org/10.2527/jas.2006-220

Lansford, A. (2018). *Supplementation and reproductive strategies for beef females as part of a may-calving herd in the Nebraska Sandhills.* [Master's thesis, University of Nebraska-Lincoln, USA]. Theses and Dissertations in Animal Science. https://digitalcommons.unl.edu/animalscidiss/159/

Larson, J. E., Lamb, G. C., Stevenson, J. S., Johnson, S. K., Day, M. L., Geary, T. W., Kesler, D. J., DeJarnette, J. M., Schrick, F. N., DiCostanzo, A., & Arseneau, J. D. (2006). Synchronization of estrus in suckled beef cows for detected estrus and artificial insemination and timed artificial insemination using gonadotropin-releasing hormone, prostaglandin F2α, and progesterone. *Journal of Animal Science*, *84*(2), 332-342. https://doi.org/10.2527/2006.842332x

Lucy, M. C. (2007). Fertility in high-producing dairy cows: Reasons for decline and corrective strategies for sustainable improvement. *Society of Reproduction and Fertility supplement*, *64*, 237-254. https://doi.org/10.5661/rdr-vi-237

Macmillan, K., Gobikrushanth, M., Sanz, A., Bignell, D., Boender, G., Macrae, L., Mapletoft, R. J., & Colazo, M. G. (2020). Comparison of the effects of two shortened timed-AI protocols on pregnancy per AI in beef cattle. *Theriogenology*, *142*, 85–91. https://doi.org/10.1016/j.theriogenology.2019.09.038

Malik, A., Wahid, H., Rosnina, Y., Kasim, A., & Sabri, M. (2012). Effects of timed artificial insemination following estrus synchronization in postpartum beef cattle. *Open Veterinary Journal*, *2*(1), 1-5.

McAllister, T. A., Stanford, K., Chaves, A. V., Evans, P. R., Eustaquio de Souza Figueiredo, E., & Ribeiro, G. (2020). Nutrition, feeding and management of beef cattle in intensive and extensive production systems. In F. W. Bazer, G. C. Lamb & G. Wu (Eds.), *Animal agriculture* (pp. 75–98). Academic Press. https://doi.org/10.1016/B978-0-12-817052-6.00005-7

Mellieon, H. I., Pulley, S. L., Lamb, G. C., Larson, J. E., & Stevenson, J. S. (2012). Evaluation of the 5-day versus a modified 7-day CIDR breeding program in dairy heifers. *Theriogenology*, *78*(9), 1997-2006. https://doi.org/10.1016/j.theriogenology.2012.07.014

Mercadante, V. R. G., Kozicki, L. E., Ciriaco, F. M., Henry, D. D., Dahlen, C. R., Crosswhite, M. R., Larson, J. E., Voelz, B. E., Patterson, D. J., Perry, G. A., Funston, R. N., Steckler, T. L., Hill, S. L., Stevenson, J. S., & Lamb, G. C. (2015). Effects of administration of prostaglandin F2α at initiation of the seven-day CO-Synch + controlled internal drug release ovulation synchronization protocol for suckled beef cows and replacement beef heifers. *Journal of Animal Science*, *93*(11), 5204–5213. https://doi.org/10.2527/jas.2015-8967

Nash, J. M., Mallory, D. A., Ellersieck, M. R., Poock, S. E., Smith, M. F., & Patterson, D. J. (2012). Comparison of long- versus short-term CIDR-based protocols to synchronize estrus prior to fixed-time AI in postpartum beef cows. *Animal Reproduction Science*, *132*(1–2), 11–16. https://doi.org/10.1016/j.anireprosci.2012.03.013

Nazhat, S. A., Aziz, A., Zabuli, J., & Rahmati, S. (2021). Importance of body condition scoring in reproductive performance of dairy cows: A review. *Open Journal of Veterinary Medicine, 11*(07), 272-288. https://doi.org/10.4236/ojvm.2021.117018

Nishimura, T. K., Martins, T., da Silva, M. I., Lafuente, B. S., de Garla Maio, J. R., Binelli, M., Pugliesi, G., & Saran Netto, A. (2018). Importance of body condition score and ovarian activity on determining the fertility in beef cows supplemented with long-acting progesterone after timed-AI. *Animal Reproduction Science*, *198*, 27–36. https://doi.org/10.1016/j.anireprosci.2018.08.042

Núñez–Olivera, R., Bó, G. A., & Menchaca, A. (2022). Association between length of proestrus, follicular size, estrus behavior, and pregnancy rate in beef heifers subjected to fixed–time artificial insemination. *Theriogenology*, *181*, 1–7. https://doi.org/10.1016/j.theriogenology.2021.12.028

Oosthuizen, N., Fontes, P. L. P., Oliveira Filho, R. V., Dahlen, C. R., Grieger, D. M., Hall, J. B., ... & Lamb, G. C. (2021). Pre-synchronization of ovulation timing and delayed fixed-time artificial insemination increases pregnancy rates when sex-sorted semen is used for insemination of heifers. *Animal Reproduction Science*, *226*, 106699. https://doi.org/10.1016/j.anireprosci.2021.106699

Peel, R. K., Whittier, J. C., Enns, R. M., Grove, A. V., & Seidel, G. E. (2010). Effect of 6- versus 12-hour interval between 2 prostaglandin F2α injections administered with 5-day CO-Synch + controlled internal drug-release protocol on pregnancy rate in beef cows. *The Professional Animal Scientist*, *26*(3), 307-312. https://doi.org/10.15232/S1080-7446(15)30598-2

Perry, G. A., Cushman, R. A., Perry, B. L., Schiefelbein, A. K., Northrop, E. J., Rich, J. J., & Perkins, S. D. (2020). Role of preovulatory concentrations of estradiol on timing of conception and regulation of the uterine environment in beef cattle. *Systems Biology in Reproductive Medicine*, *66*(1), 12-25. https://doi.org/10.1080/19396368.2019.1695979

Perry, G. A., Walker, J. A., Rich, J. J. J., Northrop, E. J., Perkins, S. D., Beck, E. E., Sandbulte, M. D., & Mokry, F. B. (2020). Influence of SexcelTM (gender ablation technology) gender-ablated semen in fixed-time artificial insemination of beef cows and heifers. *Theriogenology*, *146*, 140–144. https://doi.org/10.1016/j.theriogenology.2019.11.030

Peterson, C., Alkar, A., Smith, S., Kerr, S., Hall, J. B., Moore, D., & Kasimanickam, R. (2011). Effects of one versus two doses of prostaglandin F2alpha on AI pregnancy rates in a 5-day, progesterone-based, CO-Synch protocol in crossbred beef heifers. *Theriogenology*, *75*(8), 1536-1542. https://doi.org/10.1016/j.theriogenology.2010.12.017

Pfeifer, L. F. M., Rodrigues, W. B., & Nogueira, E. (2021). Relationship between body condition score index and fertility in beef cows subjected to timed artificial insemination. *Livestock Science*, *248*, 104482. https://doi.org/10.1016/j.livsci.2021.104482

Pursley, J. R., Mee, M. O., & Wiltbank, M. C. (1995). Synchronization of ovulation in dairy cows using PGF2α and GnRH. *Theriogenology*, *44*(7), 915-923. https://doi.org/10.1016/0093-691X(95)00279-H

Randel, R. D. (1990). Nutrition and postpartum rebreeding in cattle. *Journal Of Animal Science*, *68*(3), 853-862. https://doi.org/10.2527/1990.683853x

Randi, F., Kelly, A. K., Parr, M. H., Diskin, M. G., Lively, F., Lonergan, P., & Kenny, D. A. (2021). Effect of ovulation synchronization program and season on pregnancy to timed artificial insemination in suckled beef cows. *Theriogenology*, *172*, 223–229. https://doi.org/10.1016/j.theriogenology.2021.06.021

Richardson, B. N., Hill, S. L., Stevenson, J. S., Djira, G. D., & Perry, G. A. (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. *Animal Reproduction Science*, *166*, 133–140. https://doi.org/10.1016/j.anireprosci.2016.01.013

Roche, J. F., & Diskin, M. G. (2001). Resumption of reproductive activity in the early postpartum period of cows. *BSAP Occasional Publication*, *26*(1), 31–42. https://doi.org/10.1017/S0263967X00033577

Roche, J. R., Friggens, N. C., Kay, J. K., Fisher, M. W., Stafford, K. J., & Berry, D. P. (2009). Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. *Journal of Dairy Science*, *92*(12), 5769-5801. https://doi.org/10.3168/jds.2009-2431

Sá Filho, M. F., Santos, J. E. P., Ferreira, R. M., Sales, J. N. S., & Baruselli, P. S. (2011). Importance of estrus on pregnancy per insemination in suckled Bos indicus cows submitted to estradiol/progesterone-based timed insemination protocols. *Theriogenology*, *76*(3), 455–463. https://doi.org/10.1016/j.theriogenology.2011.02.022

Santos, C. A. D., Landim, N. M. D., Araújo, H. X. D., & Paim, T. D. P. (2022). Automated systems for estrous and calving detection in dairy cattle. *AgriEngineering, 4*(2), 475-482. https://doi.org/10.3390/agriengineering4020031

Setiaji, A., Oikawa, T., & Arakaki, D. (2023). Relation between body condition score and conception rate of Japanese Black cows. *Animal bioscience*, *36*(8), 1151. https//doi.org/10.5713/ab.22.0329

Souames, S., & Berrama, Z. (2020). Factors affecting conception rate after the first artificial insemination in a private dairy cattle farm in North Algeria. *Veterinary World, 13*(12), 2608–2611. https://doi.org/10.14202/vetworld.2020.2608-2611

Stevenson, J. S., Pulley, S. L., Mellieon, H. I., Olson, K. C., Johnson, S. K., Grieger, D. M., Jaeger, J. R., & Breiner, R. M. (2011). Optimizing a new 5-day CIDR-CO-Synch timed artificial insemination program. *Kansas Agricultural Experiment Station Research Reports*, (1), 14–17. https://doi.org/10.4148/2378-5977.2880

Taponen, J. (2009). Fixed-time artificial insemination in beef cattle. *Acta Veterinaria Scandinavica*, *51*, 1-6. https://doi.org/10.1186/1751-0147-51-48

Thomas, J. M., Locke, J. W. C., Bonacker, R. C., Knickmeyer, E. R., Wilson, D. J., Vishwanath, R., ... & Patterson, D. J. (2019). Evaluation of SexedULTRA 4M™ sex-sorted semen in timed artificial insemination programs for mature beef cows. *Theriogenology*, *123*, 100-107. https://doi.org/10.1016/j.theriogenology.2018.09.039

Tsiligianni, T., Amiridis, G. S., Dovolou, E., Menegatos, I., Chadio, S., Rizos, D., & Gutierrez–Adan, A. (2011). Association between physical properties of cervical mucus and ovulation rate in superovulated cows. *Canadian Journal of Veterinary Research = Revue Canadienne de Recherche Veterinaire*, *75*(4), 248–253.

Vedovatto, M., Lecciolli, R. B., Lima, E. D. A., Rocha, R. F. A. T., Coelho, R. N., Moriel, P., da Silva, L. G., Ferreira, L. C. L., da Silva, A. F., Alves dos Reis, W. V., de Oliveira, D. M., & Franco, G. L. (2022). Impacts of body condition score at beginning of fixed-timed AI protocol and subsequent energy balance on ovarian structures, estrus expression, pregnancy rate and embryo size of Bos indicus beef cows. *Livestock Science*, *256*, 104823. https://doi.org/10.1016/j.livsci.2022.104823

Wang, Y., Huo, P., Sun, Y., & Zhang, Y. (2019). Effects of body condition score changes during peripartum on the postpartum health and production performance of primiparous dairy cows. *Animals*, *9*(12), 1159. https://doi.org/10.3390/ani9121159

White, S. S., Kasimanickam, R. K., & Kasimanickam, V. R. (2016). Fertility after two doses of PGF2α concurrently or at 6-hour interval on the day of CIDR removal in 5-day CO-Synch progesterone-based synchronization protocols in beef heifers. *Theriogenology*, *86*(3), 785-790. https://doi.org/10.1016/j.theriogenology.2016.02.032

Whittier, W. D., Currin, J. F., Schramm, H., Holland, S., & Kasimanickam, R. K. (2013). Fertility in Angus cross beef cows following 5-day CO-Synch + CIDR or 7-day CO-Synch + CIDR estrus synchronization and timed artificial insemination. *Theriogenology*, *80*(9), 963-969. https://doi.org/10.1016/j.theriogenology.2013.07.019

Whittier, W. D., Kasimanickam, R. K., Currin, J. F., Schramm, H. H., & Vlcek, M. (2010). Effect of timing of second prostaglandin F2α administration in a 5-day, progesterone-based CO-Synch protocol on AI pregnancy rates in beef cows. *Theriogenology*, *74*(6), 1002-1009. https://doi.org/10.1016/j.theriogenology.2010.04.029

Wilson, D. J., Mallory, D. A., Busch, D. C., Leitman, N. R., Haden, J. K., Schafer, D. J., Ellersieck, M. R., Smith, M. F., & Patterson, D. J. (2010). Comparison of short-term progestin-based protocols to synchronize estrus and ovulation in postpartum beef cows. *Journal of Animal Science*, *88*(6), 2045–2054. https://doi.org/10.2527/jas.2009-2627

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*(2), 219–225. https://doi.org/10.2527/jas1962.212219x

Zwiefelhofer, E. M., Macmillan, K., Gobikrushanth, M., Adams, G. P., Yang, S. X., Anzar, M., Asai-Coakwell, M., & Colazo, M. G. (2021). Comparison of two intravaginal progesterone-releasing devices in shortened-timed artificial insemination protocols in beef cattle. *Theriogenology*, *168*, 75–82. https://doi.org/10.1016/j.theriogenology.2021.03.023