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Evaluation of Synchronization Protocols and Semen Quality Characteristics on Reproductive Efficiency and Fertility Outcomes in Zimbabwean Dairy Cattle Production.

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Abstract

This review addresses the technical challenges affecting the success rate of artificial insemination (AI) in dairy cattle, with a specific focus on heat synchronization protocols and semen quality for artificial insemination. Both heat synchronization and semen quality play significant roles in determining artificial insemination success rates. Furthermore, the influence of body condition score on reproductive performance and AI outcomes has been reviewed, particularly in dairy cattle in Zimbabwe. In Zimbabwe, artificial insemination success rates are notably low, particularly on communal farms, despite over 80% of the country's cattle population being located in the smallholder sector. A systematic literature review was conducted from January 2022 to January 2024 utilizing Google Scholar and PubMed to assess how heat synchronization protocols, semen quality, and body condition scores affect artificial insemination success, mainly in dairy cattle in Zimbabwe. The review also considered the impact of body condition scores on offspring sex determination. A total of 62 full articles were included, consisting of 45 research papers and 17 narrative reviews. In Zimbabwe, the demand for artificial insemination services has significantly risen over the past four years across both communal and commercial farms. However, many farmers are unaware of the factors influencing artificial insemination success. Various elements contribute to the low artificial insemination success rates in the country which are poor heat detection and timing, inseminator skill,animal healh and nutrition and semen handling technics. In conclusion, systematically identifying the factors that affect AI success in cattle can aid AI technicians and farmers in better understanding the animal requirements and technical procedures involved, fostering cooperation to enhance AI outcomes.

Keywords: Artificial Insemination, Heat synchronization, semen quality, Reproductive performance, Zimbabwean dairy cattle industry.

Introduction

Reproductive inefficiencies remain a major barrier to Zimbabwe's dairy industry, which is essential to the country's livestock business. AI has a key role in increasing fertility rates when combined with carefully considered heat synchronization and semen selection(Zuidema et al., 2021). With an emphasis on Zimbabwe dairy industry, this review critically investigates these elements. Dairy farming's sustainability and profitability depend heavily on reproductive efficiency, especially in Zimbabwe, where milk production is essential to both economic growth and food security.Cow's body condition score (BCS),along with heat synchronisation and semen quality , are some of the important factors affecting the success of reproduction(Roche *et al.,* 2007). Dairy farmers in Zimbabwe continue to struggle with low conception rates, inadequate estrus detection, and less than ideal fertility results despite the growing use of AI in the country (Rashidi et al. 2023).

The quality of the semen used is one of the most important factors that determines AI success.Sexed semen used in Zimbabwe is imported from semen producers around the world since the semen centres in Zimbabwe have no equipment for semen sexing although they are a number of players currently producing conventional dairy semen the likes of Chinhoyi University of Technology, Matopos Research Institute and Mazowe bull centre.There is no article which has evaluated the quality of semen from these suppliers to see which producer in Zimbabwe is supplying the best semen.Sperm motility, viability, morphology, and concentration are among the characteristics commonly used to evaluate semen quality, and they have a direct impact on the success of fertilization (Hallap et al., 2006). Dairy producers may now predict the sex of their progeny through the development of sexed semen technology, mainly to boost the proportion of female calves available for milk production (Seidel et al, 2014).

Semen Quality and its influence on reproductive success

However, due to the sorting procedure, which may affect sperm concentration and longevity, studies indicate that sexed semen typically has poor motility and post-thaw viability compared to conventional semen (Bisinotto et al., 2014). Advanced methods like Computer-Assisted Semen Analysis (CASA) can be used for objective evaluation because there is little research in Zimbabwe comparing the quality of conventional and sexed semen from various dairy breeds. Cattle semen production benefits greatly from computer-aided semen analysis (CASA), especially in artificial insemination (AI) programs where high reliability and accuracy are crucial. One of the primary advantages of CASA is its capacity to produce consistent and objective results by reducing human error and variability, which are common in manual semen examination.

In large-scale cow breeding operations, where consistency and standardization are essential to maintaining quality control, this objectivity is especially crucial (Amann and Waberski, 2014). In AI centers that handle semen from numerous bulls, CASA systems are essential for efficiency as they enable quick evaluation of thousands of sperm cells in a matter of seconds (Zuidema, Kerns, and Sutovsky, 2021). Furthermore, CASA offers a thorough evaluation of sperm motility and kinetics, providing a full profile that aids in more accurate fertility prediction than conventional techniques. This includes metrics that are essential markers of sperm function and fertilizing capacity, such as amplitude of lateral head displacement (ALH), curvilinear velocity (VCL), straight-line velocity (VSL), and total and progressive motility (Tesfay et al., 2020).

Sperm morphology can be assessed using CASA systems, which can detect defects in the head, midpiece, or tail that could reduce fertility. Before semen doses are sent out for insemination, this automated method guarantees that they fulfill international criteria while also increasing diagnostic accuracy. CASA is a crucial tool for routine semen quality monitoring as well as research since it offers digital records, high-throughput analysis, data archiving, and longitudinal tracking of bull fertility. Overall, by improving the precision, speed, and repeatability of semen analysis, CASA technology helps create more effective and successful cow reproductive programs (Ayad, 2018).

Estrus Synchronisation and its Influence on Fertility

The synchronization of dairy cows' estrus is another element that influences reproductive efficiency(Bisinotto et al., 2014). Better estrus detection and fixed-time AI are made possible by heat synchronization techniques (Pursley et al., 1995). Ovsynch, which uses prostaglandin (PGF2α) and gonadotropin-releasing hormone (GnRH), and CIDR-based protocols, which comprise controlled internal drug-releasing devices containing progesterone, are the two most widely utilized synchronization procedures in cows(Dahiri *et al.,* 2022). The efficiency of synchronization protocols varies by breed, environmental conditions, and management techniques, even though they have enhanced reproductive performance in numerous dairy sectors globally (Bisinotto et al., 2014). To determine the best approach for raising conception rates in dairy breeds in Zimbabwe, it is necessary to evaluate the efficacy of various synchronization techniques in the local environment.

Body Condition Score and its influence on reproductive performance

A visible indicator of body fat stores, BCS has a big impact on reproductive outcomes like conception rates and pregnancy maintenance (Berry et al., 2007). While cows with an abnormally high BCS (3–5) are more likely to suffer from metabolic diseases that impair fertility, cows with a low BCS (1–2.5) frequently have delayed estrus, inconsistent ovulation, and increased embryo loss(Hendrikse et al., 2020). A possible correlation between BCS and offspring sex ratio has been proposed by several researchers, who postulate that hormonal factors during conception increase the likelihood that cows in superior physical condition will give birth to female calves (Cameron et al., 2017).

However, further research is needed to ascertain how dietary management might be adjusted to affect offspring sex ratio and reproductive performance, as this relationship has not been well researched in Zimbabwean dairy herds. Given the importance of these factors, the purpose of this review is to compare the conception rates of AI between two heat synchronization protocols in dairy breeds, evaluate the impact of cow BCS on the sex of offspring after AI, and use of CASA to analyze the quality of sexed and conventional dairy bull semen from a commercial semen supplier in Zimbabwe. This study offers a thorough grasp of how these reproductive management techniques might be modified to enhance fertility results in Zimbabwean dairy cattle by combining the available research and identifying knowledge gaps.

Dairy Production in Zimbabwe

Cattle farming is a vital part of the agricultural economy and rural livelihoods in developing nations like Zimbabwe, where the effectiveness of artificial insemination (AI) is crucial to raising the genetic quality and production of livestock (Kumar Patel *et al.,* 2017). Zimbabwe's dairy industry has experienced significant growth in recent years, driven by strategic investments, improved farming practices, and collaborative efforts between the government and the private sector. In 2023, the country achieved a notable 9% increase in milk production, reaching 90.31 million litres, up from 83.06 million litres in 2022 . This upward trajectory continued into 2024, with raw milk production soaring 14.9% to a record 114.7 million litres, surpassing the previous peak of 100 million litres achieved in 2005. The national dairy herd expanded by 13.4% from 53,250 in 2022 to 60,398 in 2023, and the number of milking cows increased by 122% from 17,968 to 39,811 over the same period(Dairy Industry Targets Fourfold Milk Production...,)

Despite these advancements, Zimbabwe's per capita milk consumption remains below the World Health Organization's recommended 45 litres for low- to middle-income countries. In response, the dairy industry has set an ambitious target to quadruple milk production to 480 million litres annually by 2030, aiming to meet rising domestic demand and reduce reliance on imports. Key strategies to achieve this goal include expanding the population of lactating cows to 100,000 by 2030, enhancing milk yields per cow from 3,000 to 5,000 litres annually, and increasing per capita milk consumption to 30 litres(Zimbabwe's Raw Milk Production Soars 14.9%, Reaches Record 114.7 Million Litres in 2024 - ZiMetro News).

The dairy sector's growth has been supported by various government initiatives, such as the Presidential Silage Inputs Scheme and the Livestock Recovery and Growth Plan, which aim to reduce feed costs and improve overall productivity. Additionally, public-private partnerships have played a crucial role in revitalizing the industry, with investments in processing plants, cold storage, and distribution systems enhancing milk handling and reducing post-harvest losses . However, challenges such as power and water shortages, high feed costs, limited access to financing, and competition from smuggled dairy products continue to pose obstacles to the sector's growth(Zimbabwe's Raw Milk Production Soars 14.9%, Reaches Record 114.7 Million Litres in 2024 - ZiMetro News).

The bulk of Zimbabwe's cattle herd found in communal agricultural systems, which is where AI success rates are low despite the potential advantages (Rashidi et al., 2023). Reproductive failure has a direct impact on production and financial results, making it a major concern for the livestock industry (Inchaisri *et al.,* 2010). Enhancing reproductive efficiency is critical to increasing yields in dairy and beef cattle, and this requires a deeper comprehension of the variables affecting AI effectiveness.

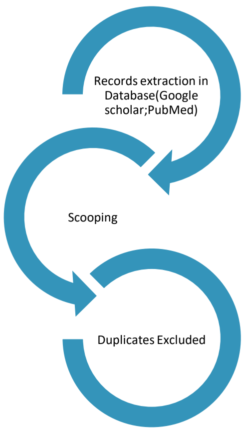
Therefore, this systematic review aims to compile the body of research on these crucial elements and offer a thorough examination of how they affect AI success in Zimbabwe. By doing this, the project will provide farmers, policymakers, and AI Technicians with insightful information that will help them decide on reproductive control strategies. In the end, raising AI success rates will help boost rural livelihoods, improve food security, and increase cattle productivity, all of which are in line with Zimbabwe's larger objectives for sustainable agricultural development.

Materials and Methods

Procedure

A systematic review of the literature was carried out by Kitchenham & Charters' (2007) recommendations. The years 2000–2023 were included in the search. Google Scholar and PubMed were used to retrieve articles that were selected for their thorough coverage of peer-reviewed literature and ease of use. Grey literature, including newspaper stories, conference proceedings, and unpublished reports about heat synchronization procedures and semen quality in dairy cattle, was not included in the search; it was limited to published journal papers that were accessible online. The trustworthiness and usefulness of grey literature are questioned because it is frequently not subjected to thorough peer review (Paez, 2017).

Figure 1 below provides a comprehensive search strategy, including the identification and selection procedure for the publications considered in this study.



Results and Discussion

Identification and selection of articles for inclusion

As shown in Figure 2, a total of 943 full-text articles were assessed for research relevance. Figure 2 also shows the breakdown of the articles that were found using particular search phrases. The search terms Heat Synchronization Protocols, Semen Quality," "Reproductive Efficiency, Body condition score" and "Fertility Outcomes in Zimbabwean Dairy Cattle" were used to extract articles.

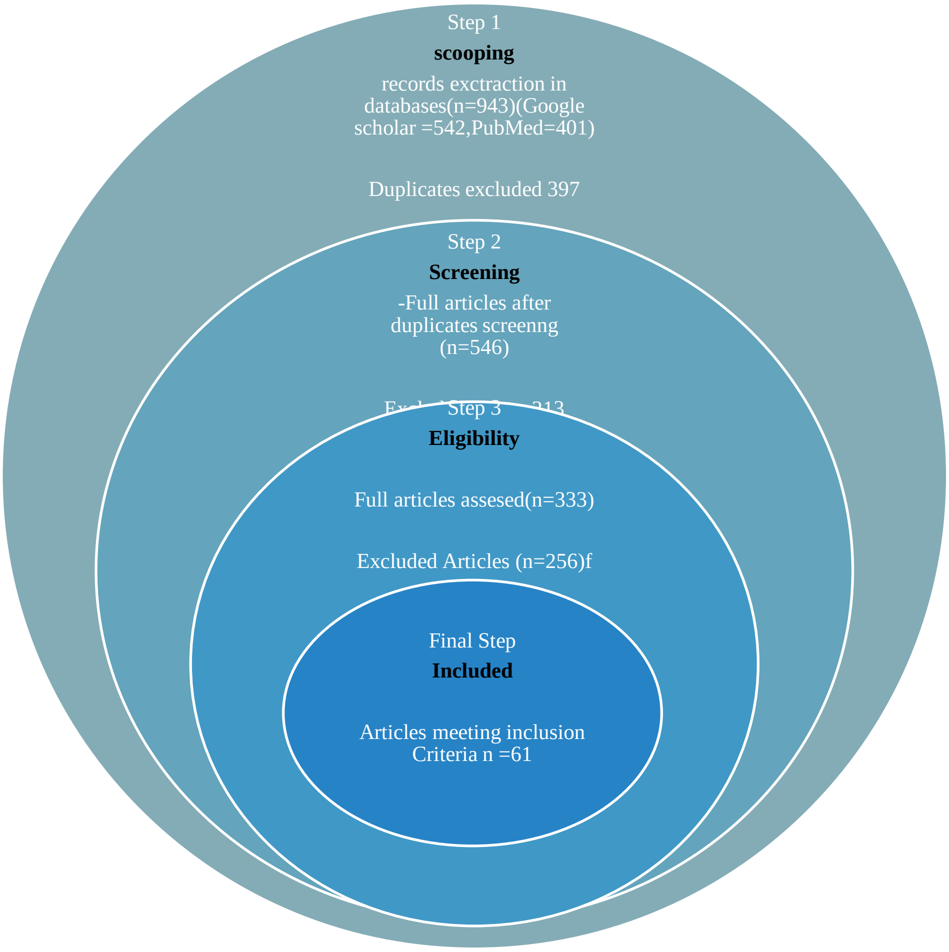


Figure 2: Summary of identification and selection of articles for the study

Sixty-two (62) full-text journal articles satisfied the requirements for inclusion. Of them, seventeen were narrative reviews, and forty-five were research studies. Artificial Insemination (AI) is one reproductive technology that can improve fertility and reproductive efficiency in Zimbabwean dairy cattle, especially when combined with heat synchronization protocols to increase semen usage and conception rates.

1 Semen Quality in Artificial Insemination Success

Since semen quality has a direct impact on fertilization rates, embryo development, and overall reproductive efficiency, it is a crucial factor in determining the success of artificial insemination (AI) programs in cattle (Baruselli *et al.*, 2017). The fertilizing potential of semen doses utilized in AI is determined by important semen quality indicators, such as sperm motility, viability, morphology, and concentration (Aman et al., 2014). Improved conception rates are linked to high sperm motility because these sperm have a higher chance of effectively fertilizing the oocyte and navigating the female reproductive system(Demetrio *et al.*, 2007). The percentage of living sperm in a sample, or sperm viability, is equally important because damaged or dead sperm cannot successfully initiate fertilization. For frozen-thawed semen used in artificial insemination (AI), studies have indicated that post-thaw sperm viability above 40% is required for optimal conception rates (DeJarnette *et al.,* 1992). Significant improvements in semen quality have been made in Zimbabwe's cattle breeding business in recent years due to increased investments in artificial insemination (AI), better management practices, and enhanced quality control measures. Standardizing the production and distribution of semen has been made possible by the development of the Zimbabwe National Cattle breeding centres, which are now equipped with advanced semen analysis equipment including Computer-Aided Semen Analysis (CASA). This guarantees that farmers can only access high-quality semen. The adoption of modern reproduction technologies and the thorough training of AI staff have significantly aided these efforts.

Additionally, structural abnormalities in the sperm head, midpiece, or tail might hinder motility and the capacity to penetrate the oocyte's zona pellucida, making sperm morphology a crucial factor in fertility outcomes (Barth and Oko, 1991; Brito *et al.*, 2003). Research has shown that AI success rates are considerably reduced for semen samples containing above 20% defective spermatozoa (Gillan et al., 2005; Walsh et al., 2011).Additionally ,due to sperm competition or impaired capacitation, over dilution or high sperm concentration might result in decreased fertility (DeJarnette *et al.,* 2011). By increasing post-thaw sperm viability and longevity, improvements in semen processing and storage methods have greatly increased AI success rates (Bailey et al., 2000). Long-term sperm preservation is possible with cryopreservation, a popular method for storing semen, but it also causes oxidative stress and osmotic damage, which lowers sperm motility and viability (Anger et al., 2003). It has been demonstrated that adding cryoprotectants such as glycerol and antioxidants to semen extenders reduces cryo-damage and enhances the quality of post-thaw sperm. Furthermore, sperm survivability during storage and transit has been further improved by the invention of better semen extenders, such as formulations based on egg yolk and milk (Holt , 2000).

2 Recent Developments in Sperm Quality Assesments

Technological advancement in cattle breeding programmes worldwide have significantly enhanced reproductive efficiency(Vishwanath, 2003)**.**By offering accurate and objective measurements of sperm motility, viability, and morphology, contemporary semen evaluation methods like flow cytometry and Computer-Assisted Sperm Analysis (CASA) have completely changed the evaluation of semen quality(Amann and Waberski, 2014). Researchers and AI Technicians have improved semen selection for AI by using CASA technology to identify minute variations in sperm dynamics that could affect reproductive outcomes (Kastelic, 2014). Furthermore, the selection of bulls with superior reproductive performance is now possible because of proteomic and genomic studies that have revealed important biomarkers linked to high-fertility semen (Gillan et al., 2005).

However, there are still difficulties in guaranteeing consistent semen quality for AI, especially in commercial semen production and distribution, even with improvements in semen processing and evaluation (Baruselli et al., 2017).

3 Environmental factors affecting semen quality

Strict quality control procedures are required to maximize fertility results due to the variation in semen quality among bulls, even within the same breed (Pérez-Cerezales *et al.,* 2018). Furthermore, environmental factors like heat stress and malnutrition can have a detrimental effect on the quality of semen, underscoring the necessity of managing breeding bulls properly to preserve peak reproductive performance. Lower AI success rates in warmer climates can result from heat stress, which has been shown to decrease sperm motility and increase sperm abnormalities dramatically (Hansen, 2009). Therefore, negative consequences can be minimized and AI success can be improved by putting measures like controlled housing, nutritional supplementation, and optimal semen storage protocols into practice (Brito *et al.,* 2003; Kastelic, 2014).

In summary, sperm motility, viability, morphology, and concentration are important factors that determine reproductive outcomes, and semen quality is a vital component impacting the success of AI in cattle. A more accurate selection of superior semen for breeding operations is now possible due to large improvements in AI success rates brought about by advancements in semen processing, cryopreservation, and evaluation technology. To optimize reproductive efficiency, however, issues such as environmental factors and bull variability call for more research and improvement of semen management techniques. AI systems can increase conception rates and promote genetic development and productivity worldwide in the beef and dairy cattle sector by ensuring the use of high-quality semen through rigorous evaluation and ideal storage conditions (Baruselli *et al.,* 2017).

4 Comparative Quality of Sexed and Conventional Semen

In cattle reproductive management, the relative quality of sexed and conventional semen has been the focus of much research, especially in artificial insemination (AI) programs that seek to improve genetic selection and reproductive efficiency and more importantly in the dairy industry. Because of its greater post-thaw survivability and higher conception rates, conventional semen—which contains roughly equal amounts of X- and Y-bearing sperm—has been employed extensively in artificial insemination for decades (Garner and Seidel, 2008; Seidel, 2014). By allowing producers to predict the sex of their offspring, sexed semen technology—which separates sperm bearing X and Y chromosomes—has transformed the dairy and beef industries and improved herd replacement strategies and financial returns. Notwithstanding its benefits, sexed semen has drawbacks, including lower sperm quality, lower conception rates, and higher processing expenses, which calls for more research to determine how effective it is in comparison to traditional semen. The reduced sperm quality of sexed semen is one of the main stressors, mostly because of the flow cytometric sorting method that separates sperm according to DNA content (Seidel, 2014). The sorting process exposes spermatozoa to high-pressure flow, laser stimulation, and electrical charging, all of which can cause physical and biochemical stress and lower sperm motility, membrane integrity, DNA damage and overall survival.Reduced embryo development rates and early pregnancy losses may result from sperm sorting's association with higher DNA fragmentation (Pérez-Cerezales *et al.,* 2018). Nevertheless, recent advancements in sorting methods , like cutting down on pressing time and maximizing laser intensity , have reduced DNA damage and may enhance the fertility results of AI algorithms that use sexed semen(Gillan, Evans and Maxwell, 2005). Additionally, depending on the breed and processing circumstances, sexed semen can have post-thaw motility decreases of up to 20–30% when compared to conventional semen (Hallap et al., 2006). Further contributing to lower fertility outcomes is the fact that the sorting process requires dilution of semen, which results in fewer sperm per AI dose (usually 2 to 4 million sperm per straw in sexed semen compared to 10 to 20 million in conventional semen(Seidel, 2014). To illustrate the reproductive disadvantage of sperm sorting, Seidel and Schenk (2008) reported that conception rates in Holstein cows utilizing sexed semen varied from 60 to 70 percent of those attained with conventional semen. Sperm damage during sorting, decreased sperm counts per

AI dose, and changes in capacitation and acrosomal integrity—all of which hinder sperm's capacity to properly access the oocyte are the reasons for the decreased fertility of sexed semen (Seidel, 2014).

In the dairy business, where female progeny are preferred for milk production, sexed semen is nevertheless a useful tool for genetic improvement despite the semen quality challenges. Dairy farmers can maximize herd replacement rates, reduce the need for culling, and increase genetic gain by producing heifer calves with an accuracy of over 90% (Garner and Seidel, 2008). Furthermore, sexed semen's fertility performance has increased over time due to advancements in sperm sorting technology, cryopreservation methods, and artificial intelligence strategies, making it more competitive with conventional semen for instance, the creation of "SexedULTRA" semen processing that has resulted in higher post-thaw motility and conception rates that are on par with conventional semen (Vishwanath and Shannon, 2000).

To maximize the success of sexed semen, aspects such as cow fertility status, estrus synchronization methods, and AI timing should be optimized in addition to technological advancements (Bisinotto et al 2014). Despite that poor reproductive health might further lower conception rates, research indicates that sexed semen works best in heifers and cows with excellent body condition scores(Pryce et al., 2001). Additionally, deep uterine insemination techniques and fixed-time AI (FTAI) procedures have been suggested as ways to increase the fertility of sexed semen, guaranteeing that fewer sperm per dosage nevertheless achieve sufficient fertilization success (DeJarnette *et al.,* 2011). When used strategically, sexed semen can improve genetic progress and reproductive efficiency in cow breeding, even though it poses problems on sperm quality, fertility, and cost (Amann and Waberski, 2014). Because of its greater conception rates and better post-thaw survivability, conventional semen is still the gold standard for AI and is the recommended option for commercial breeding operations aiming to maximize reproductive results (Larson *et al.,* 2006). The performance difference between sexed and conventional semen is, however, closing as sorting technology advances and AI management techniques are improved, making sexed semen a more viable reproductive tool in contemporary cattle breeding (Garner and Seidel, 2008). To further increase the effectiveness and success rates of sexed semen, future studies should concentrate on improving cryopreservation techniques, discovering biomarkers of high-fertility sperm, and improving sperm sorting protocols (Pérez-Cerezales *et al.,* 2018). Although sexed semen allows for sex selection, which is advantageous for herd expansion, its viability may be weakened in comparison to conventional semen.

5 Heat Synchronization Protocols and Conception Rates

In dairy and beef production systems, cattle heat synchronization techniques are essential for increasing reproductive efficiency, raising artificial insemination (AI) success rates, and maximizing calving intervals. Controlling and regulating the estrous cycle in a herd of cows or heifers to accomplish timed artificial insemination (TAI) without the use of heat detection is the main objective of estrus synchronization (Gebremichael, 2015) The use of exogenous hormones, including prostaglandins, gonadotropin-releasing hormone (GnRH), progesterone, and estrogen, to control follicular growth and ovulation timing has led to the creation of several synchronization procedures (Lucy, 2001) Breed, physiological state, and environmental factors all affect how effective these protocols are, therefore selecting the right synchronization plan is crucial to maximizing fertility results (Perry et al., 2007). The prostaglandin-based procedure, which uses prostaglandin F2-alpha (PGF2α) to produce luteolysis and synchronize estrus in cyclic cows, is one of the oldest and most popular synchronization techniques (Ayantoye *et al.*, 2025)The conventional method is giving one or two doses of PGF2α at intervals of 11–14 days, with AI carried out either at a predetermined time after treatment or based on observed estrus (Bisinotto et al., 2014; Tadesse et al., 2015). Cows that do not cycle or are in the early stages of diestrus do not respond well to PGF2α because it is only effective in animals with a functional corpus luteum (CL) (Santos *et al.*, 2004).

GnRH-based synchronization methods, like Ovsynch, have been developed to address the shortcomings of estrus detection and offer a more regulated method of ovulation timing(Dahiri *et al.*, 2022). Ovsynch protocol entails sequentially administering GnRH to promote ovulation and start a fresh follicular wave, then PGF2α to induce luteolysis, and a second GnRH injection to trigger final follicular maturation and ovulation. This method increases the reproductive efficiency of both dairy and beef cattle by doing away with the requirement for estrus identification and permitting TAI at a specified time(Pursley et al., 1995). By guaranteeing adequate follicular condition before synchronization, modified variants of the Ovsynch protocol, such as Pre-Synch Ovsynch and Double Ovsynch, have been developed to increase conception rates. Presynchronization increases the chance of ovulation in response to the initial GnRH injection, which raises the probability of conception in dairy cows (Wiltbank et al., 2014).The progesterone-based protocol is another popular synchronization technique that uses progesterone-releasing intravaginal devices (PRID) or controlled internal drug release (CIDR) devices to maintain high progesterone levels and synchronize estrous in both cyclic and anestrous cows.The standard procedure is to place a CIDR for 7–10 days, administer PGF2α to cause luteolysis, remove the device, and then utilize either fixed-time AI or estrus detection (Bó and Baruselli, 2014). Research has demonstrated that CIDR-based procedures increase conception rates more than PGF2α alone, particularly in heifers and postpartum anestrous cows with body condition ratings below optimum(Bisinotto et al., 2014).

Protocols like the Co-Synch + CIDR and the G6G protocol, which further optimize estrus synchronization to increase fertility, were developed as a result of the interaction of progesterone, GnRH, and PGF2α (Wiltbank et al., 2014). To ensure accurate ovulation control, the Co-Synch + CIDR procedure includes giving GnRH at CIDR insertion, PGF2α at CIDR removal, and a second GnRH injection at TAI(Larson *et al.*, 2006). Because it can increase pregnancy rates while requiring less work, this approach has been widely used in beef cattle AI programs (Bó *et al.*, 2019).In high-producing dairy cows, where metabolic issues frequently threaten fertility, emerging synchronization tactics concentrate on optimizing hormone combinations and enhancing reproductive efficiency (Wiltbank et al., 2014). To increase conception rates in repeat breeders, new protocols like Double Ovsynch and Resynch seek to optimize pre-synchronization and resynchronization techniques. Furthermore, studies on estradiol-based synchronization protocols and long-acting GnRH analogs are still being conducted. According to some research, synchronization success in Bos indicus breeds—which differ from Bos taurus cattle in terms of ovarian dynamics may be enhanced by the addition of estradiol cypionate (Colazo et al., 2003)

In conclusion, over the past several decades, heat synchronization techniques for cattle have changed dramatically, giving farmers a variety of choices to maximize AI success rates and reproductive efficiency. While GnRH-based protocols, such as Ovsynch, provide precise ovulation control and ease timed artificial insemination, PGF2α-based procedures are still extensively utilized but need rigorous estrus diagnosis. Anestrous cows respond especially well to progesterone-based treatments that use CIDR devices, increasing fertility in animals with low ovarian activity. Conception rates and synchronization success are further increased by combining several hormonal strategies, as demonstrated by Co-Synch + CIDR and Double Ovsynch. To optimize fertility results and financial efficiency in the cattle sector, more research are required to improve synchronization methods for various breeds, could be optimized for various breeds, production systems, and environmental variables as reproductive technologies develop.

6 Environmental and Management Factors Affecting Synchronization Success

One commonly used reproductive management strategy for dairy cattle is synchronization of estrus, which aims to increase fertility and reproductive efficiency. In dairy farming operations, where improving output and profitability requires optimizing reproduction rates, this technique is very important. However, several environmental and managerial factors, which might differ depending on the region and farming system, affect the efficacy of estrus synchronization works. Around the world, a complicated interplay between genetics, nutrition, environmental factors, and farm management techniques affects how effective synchronization measures are. It has been demonstrated that environmental factors including temperature, humidity, and photoperiod have an impact on how well synchronization procedures work. By increasing heat stress, which affects ovarian function and estrus expression, high ambient temperatures, particularly during the summer, might have a detrimental effect on reproductive performance (El-Tarabany and El-Tarabany, 2015). Heat stress has been shown to decrease the release of reproductive hormones, which can lead to a decreased rate of pregnancy after synchronization therapies (De Rensis et al., 2015). It has been suggested that cooling devices be included to lessen the impacts of heat stress and that synchronization time be changed to avoid periods of high temperatures in tropical regions where heat stress is common (Hansen and Aréchiga, 1999).For synchronization measures to be successful, dietary control is just as important as environmental factors. Hormonal regulation required for proper estrus synchronization might be disrupted by nutritional deficits, especially in energy and protein. Pre-synchronization feeding techniques can increase estrus expression and pregnancy rates, while cows with low body condition scores (BCS) are less likely to react favorably to synchronization treatments (Kasimanickam *et al.*, 2011; Segura *et al.*, 2013). Effective heat detection, herd health management, and the choice of suitable synchronization methods are all examples of management techniques that have a significant impact on synchronization success. Nutritional and environmental factors, including body condition score (BCS), heat stress, and postpartum interval, also affect how effective heat synchronization techniques are (Berry et al., 2007). Negative energy balance, which affects ovarian function and synchronization response, frequently results in decreased fertility in high-producing dairy cows. According to studies, cows with a BCS of less than 2.5 on a 5-point scale are less likely to conceive after synchronization than cows with a BCS of 3.0 to 4.0(Wiltbank et al., 2014). The effectiveness of synchronization is also adversely affected by heat stress; studies have shown that conception rates are reduced by 20–30% during hot seasons (El-Tarabany and El-Tarabany, 2015).

According to studies, results can be enhanced by employing techniques that are customized for particular herd conditions, such as the use of scheduled artificial insemination (AI) as opposed to natural heat detection. The herd's overall health affects synchronization success because conditions like mastitis and infections of the reproductive tract can impair fertility and estrus expression (Klopfenstein, 2021).Furthermore, it has been determined that combining synchronization techniques with genetic selection for better reproductive qualities is a viable way to improve fertility results globally (Brito *et al.,* 2021).

In conclusion, a variety of environmental and managerial factors, such as climate, nutritional status, herd health, and the particular protocols used, affect the successful synchronization of estrus in dairy cows. To increase the efficacy of estrus synchronization programs and boost reproductive efficiency in dairy farming globally, these aspects must be addressed with the right solutions. Farmers must take managerial and environmental factors into account and modify their methods appropriately, utilizing scientific research and technological advancements, to attain the best results.

7 Body Condition Score as an Indicator of Reproductive Performance

It is commonly acknowledged that the body condition score (BCS) is a trustworthy predictor of dairy cattle's ability to reproduce. Since BCS is a reflection of dairy cows' energy stores and general health, which have a direct impact on their capacity to conceive, the relationship between BCS and reproductive results has been well investigated. Higher conception rates, normal reproductive cycles, and favorable responses to estrus synchronization treatments are all more likely to occur in cows with an ideal BCS. On the other hand, cows with poor BCS whether too high or too low frequently face reproductive challenges, such as poor embryo quality, delayed estrus, and decreased pregnancy rates (Lucy, 2001). The significance of preserving an optimal BCS range for maximizing reproductive success has been emphasized by numerous studies.According to studies, cows with a BCS of less than 2.5on a 5-point scale are less likelyto conceive after synchronisation than cowswith a BCS of 3.0 to 4.0(Wiltbank et al., 2014). According to several studies (Makki et al., 2022), cows with a BCS of 3.0 to 3.5 (on a scale of 1 to 5) typically had better reproductive outcomes than those with either excessive or inadequate body condition. Low BCS can cause hormonal imbalances that interfere with estrus cycles and lower the chance of conception, it is frequently observed in underfed cows or those that are experiencing negative energy balance (NEB) after giving birth, cows with overfeeding or sedentary management practices tend to have abnormally high BCS, which is associated with a higher risk of metabolic diseases that impair reproduction .BCS can affect long-term fertility in addition to the immediate postpartum period when it comes to reproductive performance(Morley and Murray, 2014). According to (Makki et al., 2022) cows with low BCS at calving had decreased first-service conception rates and delayed uterine involution when compared to cows with appropriate body condition. Moreover, extended anestrus and poor reproductive results are more likely to occur in cows which undergo major variations in BCS during the lactation cycle, especially those that lose a significant amount of body condition after giving birth (Morley and Murray, 2014).Early identification of cows at risk for reproductive issues through BCS monitoring during the lactation cycle allows for prompt interventions, such as nutrition modifications or alterations to management techniques (Roche *et al.*, 2007).

Beyond just measuring body fat, BCS is used as a tool for controlling reproductive health. It is an essential part of a larger reproductive health plan that also involves efficient synchronization procedures, appropriate heat detection, and routine veterinary monitoring. Farmers and veterinarians can improve herd fertility and overall production by using BCS, an inexpensive and commonly available indication of the nutritional and metabolic health of dairy cows (Vanholder *et al.*, 2005).

8 The Influence of body condition score on Offspring Sex Ratio

Despite that the body condition score (BCS) of cows has long been known to have a significant impact on overall fertility and reproductive performance in dairy cattle, animal scientists are becoming increasingly interested in how it affects the offspring sex ratio. It has been suggested that BCS, which gauges an animal's body fat and general health, affects a number of reproductive outcomes, including calving ease, gestation length, and conception rates(Roche *et al.*, 2007, 2009) . Recent research, however, indicates that a cow's body condition score may also influence the sex of its progeny; however, this relationship is not fully understood and varies between studies and species. Given the potential financial implications of skewing the sex ratio in favor of one sex, typically females, which are more valued for milk production, research has centered on the effect of maternal BCS on the offspring sex ratio in dairy cows. According to some research, cows with higher body condition score at conception or calving might give birth to more male calves, while cows with lower BCS might give birth to more females (Arango et al., 2002). According to the Trivers-Willard hypothesis, a mother's ability to produce one sex over the other may be influenced by her health and the resources she has available. Male children are more likely to be produced by a mother in good health, whereas female offspring are more likely to be produced by a mother in poor health. This theory was confirmed by a study by (Pike & Petrie (2005), which discovered that peafowl with a greater BCS at conception had a higher chance of reproducing more male offsprings although this have not been confirmed in cattle yet.

Other studies, however, have produced contradictory findings; according to certain studies, there is no meaningful correlation between body condition score and sex ratio(Pryce et al., 2001). Apart from BCS, the offspring sex ratio has also been discovered to be influenced by maternal age, diet, and hormonal conditions. Cows are not the only animals whose progeny sex ratio is impacted by BCS and maternal health. Similar patterns, although with differing degrees of effectiveness in reproducing the Trivers-Willard hypothesis, have been noted in other animals, including horses and monkeys. According to certain studies, mares with better body condition scores are more likely to give birth to male foals in horses, whereas mares with lower body condition scores are more likely to give birth to females (Cameron *et al.,* 1999). Similar to this, research on a variety of wild mammal species has revealed that the mother health affects the sex ratio of offspring, especially in species that exhibit sexually dimorphic features, where it is more expensive to produce a male child (Pike and Petrie, 2005).

However, it is crucial to remember that there is ongoing debate on the relationship between BCS and offspring sex ratio. The results that maternal condition affects offspring sex have not been confirmed by several research, indicating that the factors influencing sex determination may be more complicated than only BCS. In certain instances, it is believed that genetic variables and environmental factors, including stress, temperature, and seasonality, significantly influence the sex of calves(Rezende *et al.,* 2020) and affect the sex ratio of offspring in cows and other animals. Sex ratio results are further influenced by factors that interact with BCS, including maternal age, energy balance, and nutritional condition. In livestock management and breeding operations, more research is required to better understand the underlying mechanisms and ascertain whether maternal body condition may be employed as a valid predictor of offspring sex.

Conclusions and Recommendations

To enhance the success of artificial insemination (AI) in Zimbabwe's dairy industry, it is crucial to address several key factors that influence fertility rates. Semen quality, synchronization procedures, and body condition score (BCS) management play significant roles in AI outcomes. Semen quality, which can vary due to factors such as management practices, environmental stress, and the genetic quality of the bulls, is critical for improving fertilization rates. Enhancing semen quality through better management of bull diets, semen collection, and cryopreservation methods can help reduce discrepancies and boost AI success.

Synchronization protocols are vital to ensure that cows are inseminated at the optimal time for conception. While traditional methods like prostaglandin-based systems are common, newer approaches using GnRH and progesterone-based protocols show promise in improving synchronization and conception rates. In Zimbabwe, where climatic factors and resource limitations may affect synchronization, adapting these protocols to local conditions is necessary. Additionally, utilizing heat detection technology can improve estrus detection, ensuring that insemination occurs at the right moment.

BCS management is an essential aspect of reproductive success. Cows with an ideal BCS are more likely to have regular estrous cycles and respond well to synchronization procedures. Poor BCS, often due to malnutrition or energy deficiencies, can result in lower conception rates and poor reproductive performance. Conversely, an excessively high BCS can also impair fertility. Proper feeding programs and regular BCS monitoring can significantly improve reproductive outcomes in Zimbabwe, where nutritional challenges are common, especially in smallholder systems.

Future research should focus on evaluating the cost- effectiveness of AI compared to natural breeding, particularly in resource- limited settings, and assess its impact on herd genetics, milk production, and overall farm profitability. Such studies will help develop affordable, multi faceted solutions tailored to a sustainable reproductive technologies driven Zimbabwe' s dairy sector.

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