



DOI: <https://doi.org/10.71317/kjard.2.10.2026.925>

Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJARD>



Comparative Reproductive Performance of Dairy Cows and Buffaloes

Rao Najam Bilal Akhtar

Riphah College of Veterinary Science, Lahore

Email: najambilal7781@gmail.com

Sarmad Sher

Riphah College of Veterinary Science, Lahore

Email: raisarmadsher@gmail.com

Taimur Ali

Department of Theriogenology, University of Agriculture Faisalabad

Email: vet.taimur@gmail.com

Kamran Ahmed Soomro

Khairpur College of Agriculture and Management Science, S.A.U Tandojam

Email: kamranmub@gmail.com

Muhammad Waqas

Department of Theriogenology, University of Agriculture Faisalabad

Email: vet.waqaso306@gmail.com

Muhammad Zubair Ishfaq

Riphah College of Veterinary Science, Lahore

Email: zarry971@gmail.com

Roman

Department of Clinical Medicine and Surgery, University of Agriculture Faisalabad

Email: romanwaziri1234@gmail.com

Ahmad Ghazali

Faculty of Veterinary Sciences, University of Agriculture, Faisalabad

Email: ghazalikhan2024@gmail.com

Rana Abdul Rehman

Faculty of Veterinary Sciences, University of Agriculture, Faisalabad

Email: ranaabdulrehman1337@gmail.com

ARTICLE INFO

Received:

September 16, 2026

Revised:

October 15, 2026

Accepted:

October 20, 2026

Available Online:

October 27, 2026

Keywords:

Dairy cattle; water buffaloes; reproductive performance; estrous cycle; postpartum anestrus; heat stress; artificial insemination; conception rate; reproductive biotechnology.

Corresponding Author:

Rana Abdul Rehman

Email:

ranaabdulrehman1337@gmail.com

ABSTRACT

Dairy cattle (*Bos taurus* and *Bos indicus*) and water buffaloes (*Bubalus bubalis*) are important contributors to global milk production, food security, and rural livelihoods. However, differences in reproductive physiology, endocrine regulation, environmental adaptation, and management practices influence their reproductive efficiency and lifetime productivity. This review comparatively examines the reproductive performance of dairy cows and buffaloes, with particular emphasis on age at puberty, estrous cycle characteristics, follicular dynamics, postpartum reproductive recovery, and conception outcomes. Although both species share fundamental reproductive mechanisms, buffaloes commonly exhibit less conspicuous estrus, greater seasonal variation in reproductive activity, and delayed puberty under suboptimal nutritional and management conditions. Conversely, reproductive performance in dairy cattle is frequently compromised by metabolic stress associated with high milk production, postpartum negative energy balance, and heat stress. In both species, postpartum anestrus, uterine disorders, ineffective estrus detection, suboptimal insemination timing, and early embryonic mortality contribute to reduced fertility and prolonged calving intervals. Advances in reproductive ultrasonography, hormonal synchronization, timed artificial insemination, activity-monitoring systems, and emerging precision livestock technologies offer opportunities to improve reproductive management. Nevertheless, their effectiveness depends on species, breed, physiological status, season, nutrition, and farm management. Future research should prioritize comparative studies, validated fertility biomarkers, optimized synchronization protocols, climate-resilient reproductive strategies, and the application of genomic and epigenetic approaches to improve reproductive resilience. Overall, integrating reproductive biotechnology with appropriate nutrition, environmental management, and systematic fertility monitoring is essential for sustainable improvements in cattle and buffalo reproduction. Species-specific, evidence-based management strategies are therefore preferable to uniform reproductive interventions across different dairy production systems.

Introduction

Global Dairy Context

Importance of Cattle and Buffaloes in Meeting Worldwide Dairy Demand

Dairy production serves as a vital component of global agriculture, contributing significantly to human nutrition, food security, and rural economies worldwide (Adesogan & Dahl, 2020). Together, cattle (*Bos taurus* and *Bos indicus*) and water buffaloes (*Bubalus bubalis*) account for approximately 96% of the global milk supply, with dairy cows producing roughly 81% and water buffaloes supplying around 15% (Borghese & Mazzi, 2005). While cattle remain the primary drivers of volumetric fluid milk production globally due to advanced genetic selection, intensive management systems, and standardized breeding programs, water buffaloes play an indispensable role in fulfilling milk demand across key developing and tropical nations (de la Cruz-Cruz et al., 2026).

Beyond sheer volume, the two species differ markedly in milk composition, which directly influences their commercial utilization and industrial processing value. Buffalo milk contains a substantially higher concentration of total solids compared to cow milk, featuring a fat content ranging from 6.5% to 8.5% and elevated casein levels. This dense nutrient profile yields significantly higher efficiency during dairy processing, requiring fewer liters of raw milk to produce high-value dairy commodities such as cheese, butter, ghee, and milk powders. Consequently, buffalo milk commands a premium price in local and specialized global markets, serving as the essential raw material for products like authentic Italian Mozzarella di Bufala (Medhammar et al., 2012).

In addition to their nutritional contribution, dairy cattle and buffaloes are vital to the socioeconomic stability of rural communities, particularly within smallholder production systems. In many developing regions, dairy animals serve as liquid assets that offer daily household income through milk sales while providing financial security during emergency events. Buffaloes and indigenous cattle breeds are particularly valuable in these settings because of their superior capacity to digest low-quality forage and agricultural byproducts high in lignin and cellulose. Through efficient nitrogen recycling and specialized rumen microbial populations, buffaloes can convert low-cost crop residues into nutrient-rich milk, making them an economically resilient choice for resource-constrained farmers (Chiariotti et al., 2025).

Geographic Distribution: Bos Species vs. Water Buffaloes

The geographic distribution of dairy cattle and water buffaloes across the globe is dictated by evolutionary adaptations, environmental tolerances, feed resource availability, and regional economic structures. *Bos taurus* breeds, such as Holsteins and Jerseys, dominate temperate regions including North America, Europe, Oceania, and parts of South America. These animals are primarily managed under highly intensive, capital-intensive production systems characterized by total mixed ration (TMR) feeding, automated milking technologies, and controlled climate housing. While these breeds excel in volumetric milk yield under temperate conditions, their low heat tolerance makes them susceptible to thermal stress in tropical environments, leading to reduced voluntary feed intake and impaired reproductive efficiency (Zimin et al., 2009).

Conversely, *Bos indicus* (Zebu) cattle and water buffaloes (*Bubalus bubalis*) are predominantly concentrated in the tropical and subtropical regions of the world. Zebu cattle are geographically widespread across South America, South Asia, and sub-Saharan Africa, where their specialized physical adaptations such as elevated sweat gland density, loose skin, and heat-shock protein expression allow them to thrive in high-temperature and parasite-dense environments. Water buffaloes, specifically the dairy-type River buffalo (*Bubalus bubalis bubalis*), are heavily concentrated in South Asia (primarily India and Pakistan, which host over 80% of the world's buffalo population), the Middle East, Egypt, and parts of the Mediterranean (Beatty et al., 2006).

The farming systems housing water buffaloes are predominantly characterized by smallholder, crop-livestock integrated systems and peri-urban dairy setups rather than large-scale industrial operations. In these tropical smallholder environments, buffaloes are raised alongside crop production, relying on seasonal green fodders and cereal straws for nutrition. Although buffaloes display remarkable disease resistance and climatic hardiness in marshy and humid conditions, their dark skin and sparse sweat glands impair their ability to dissipate heat purely through sweating. As a result, buffalo housing and management in warm climates rely heavily on behavioural cooling strategies, such as wallowing in natural water bodies or utilizing artificial sprinklers and shade structures, to maintain physiological equilibrium and sustain production (Prasad et al., 2019).

The Economic Role of Reproductive Efficiency

Reproductive efficiency is the cornerstone of economic viability in both cattle and buffalo dairy operations, directly dictating lifetime milk yield, herd turnover, and overall profitability (Ingawale & Dhoble, 2004). Key reproductive performance metrics specifically calving interval (CI), days open (DO), and services per conception (SPC) serve as primary determinants of economic

return. The calving interval, defined as the time elapsed between two consecutive calvings, idealizes at 12–13 months for dairy cows and 13–14 months for water buffaloes. Prolonged calving intervals delay the onset of subsequent lactations, forcing animals to spend a higher proportion of their productive lives in late lactation or extended dry periods where daily milk revenues fail to offset maintenance feed costs (Nanda et al., 2003). The length of days opens the period between calving and successful conception is the main dynamic component influencing the calving interval. Every additional day an animal remains non-pregnant beyond the target voluntary waiting period (typically 60 days postpartum) incurs a direct economic loss (Shah & Chauhan, 2019). These financial losses stem from diminished cumulative milk production over time, increased veterinary intervention fees, elevated costs associated with hormonal estrus synchronization, and higher culling rates due to reproductive failure. In buffalo operations, where extended postpartum anestrus and unobserved "silent heats" frequently push days open past 150–200 days, the economic strain is intensified by the requirement to feed non-productive animals for prolonged intervals without a corresponding milk income. Insemination efficiency, measured by the number of services required per conception, directly reflects the technical precision of estrus detection and the biological fertility of the herd. Lower insemination efficiency increases overall farm expenditures through wasted semen doses (particularly costly when using high-value or sexed semen), repeated technician fees, and labor requirements. Furthermore, poor conception rates per service prolong the calving-to-conception window, accumulating compound financial losses. Optimizing these reproductive parameters minimizes involuntary culling, allows farmers to select superior replacement heifers strictly through voluntary culling, and maximizes the overall lifetime economic efficiency of both bovine and bubaline herds (Hassan et al., 2017).

Objectives and Scope of the Review

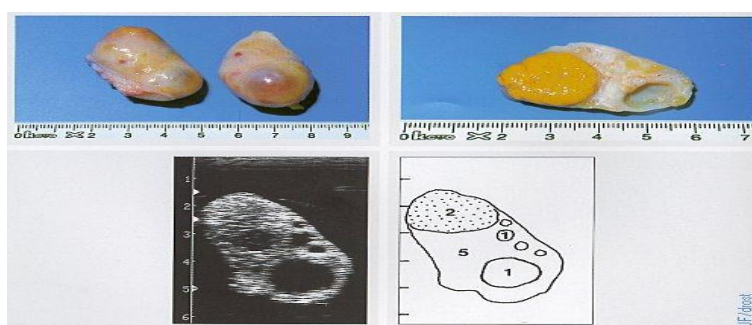
Historically, reproductive management frameworks developed for cattle have been indiscriminately applied to buffaloes, leading to sub-optimal fertility outcomes, mismanaged estrus detection, and poor synchronization response rates in bubaline herds. A rigorous comparative evaluation is therefore essential to delineate the unique biological characteristics of each species and to move away from a "one-size-fits-all" approach in large animal reproductive management. The scope of this review encompasses a comparative analysis of the anatomical, hormonal, and environmental constraints that govern fertility in cows and buffaloes. Anatomically, differences in ovarian follicle dynamics, corpus luteum morphology, and cervical structure require species-specific approaches to artificial insemination and assisted reproductive technologies. Hormonally, the subtle expression of estrus behaviour in buffaloes often termed "silent heat" combined with shorter LH surges and seasonal sensitivity to photoperiod, creates diagnostic challenges distinct from the clear standing estrus exhibited by cattle. Furthermore, environmental stressors like heat stress manifest differently in buffaloes due to their poor cutaneous thermoregulation, exacerbating postpartum anestrus and early embryonic mortality. By systematically synthesizing these comparative differences, this review aims to establish evidence-based guidelines tailored to the reproductive physiology of each species. The ultimate objective is to clarify the specific fertility bottlenecks inherent to both bovine and bubaline production systems and to evaluate modern management strategies including adapted hormonal synchronization protocols, precision estrus monitoring tools, microclimate control, and targeted nutritional interventions. This comprehensive synthesis serves as a benchmark for researchers, clinicians, and farm managers seeking to optimize reproductive performance and economic sustainability in diverse dairy environments globally.

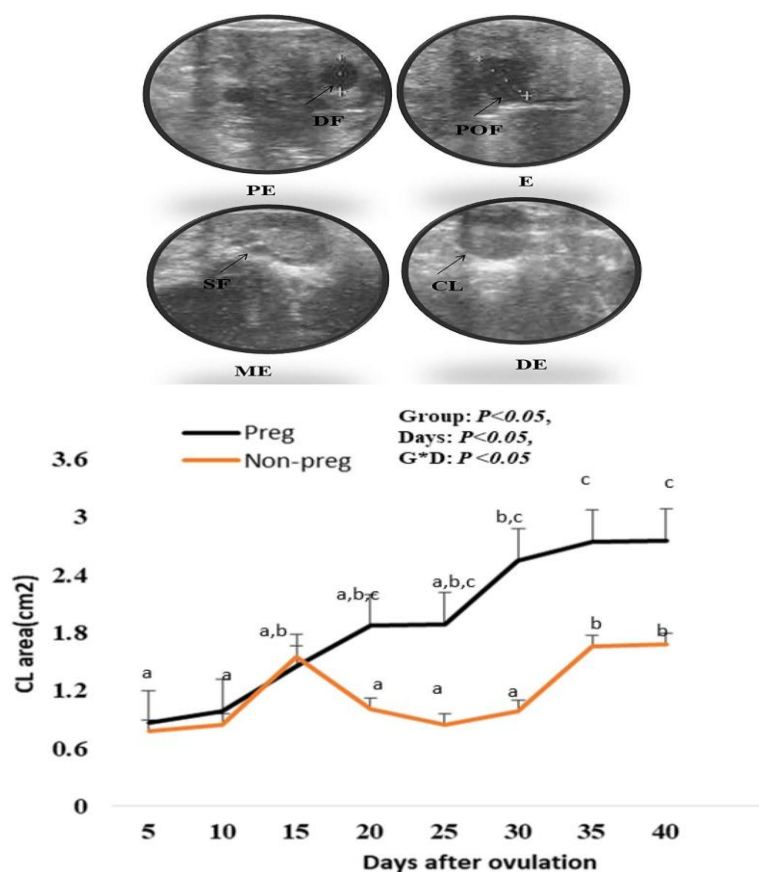
Comparative Anatomy and Endocrinology of Reproduction in Cows and Buffaloes

The key objective is to explain how anatomical, hormonal, and developmental differences between cows and buffaloes influence estrus expression, ovulation, artificial insemination (AI), conception, and overall reproductive efficiency (Mondal et al., 2006). Cattle and buffaloes share the same fundamental reproductive mechanisms, but differences in breed, nutrition, climate, season, and management can be as important as species differences.

Anatomical differences in the reproductive tract

Ovarian morphology, follicular reserve, and corpus luteum





The ovaries are the primary reproductive organs responsible for follicular development, ovulation, and secretion of steroid hormones (Horesh et al., 2017). In both cows (*Bos taurus* and *Bos indicus*) and water buffaloes (*Bubalus bubalis*), the ovaries contain follicles at different developmental stages, corpora lutea (CL), and stromal tissue (Rimon-Dahari et al., 2016). However, their apparent morphology and reproductive activity may differ with age, parity, breed, season, and physiological status.

A. Ovarian morphology

- **Cows:** Ovarian activity is generally readily detectable by rectal palpation and ultrasonography. Growing follicles, dominant follicles, and corpora lutea can be identified during reproductive examinations (Fricke & Lamb, 2002).
- **Buffaloes:** The ovaries are often described as relatively smaller or less prominent than those of cattle, although size varies considerably. Follicular structures may be less readily detected in some animals, especially when ovarian activity is low.
- **Clinical significance:** Smaller or less active ovaries, weak estrus expression, and difficulty detecting a developing dominant follicle can complicate reproductive examination and estrus management in buffaloes (El-Razek & Allam, 2019).

B. Follicle pool size and follicular development

The ovarian follicle pool consists of primordial follicles, which form the long-term reserve, and growing follicles, which progress through primary, secondary, antral, and potentially preovulatory stages (Shea et al., 2014). In both species, follicular development is regulated by follicle-stimulating hormone (FSH), luteinizing hormone (LH), estradiol, inhibin, and intraovarian growth factors.

- Cows typically show two or three follicular waves per estrus cycle, although one- and four-wave cycles also occur.
- Buffaloes also exhibit follicular waves, but reported wave patterns and follicular growth characteristics vary with breed, season, nutritional status, and study methodology.
- Buffaloes may exhibit lower estrus intensity and less conspicuous signs of impending ovulation, which can make the dominant follicle more difficult to identify using behavioural observations alone (Manasa et al., 2025).

C. Corpus luteum characteristics

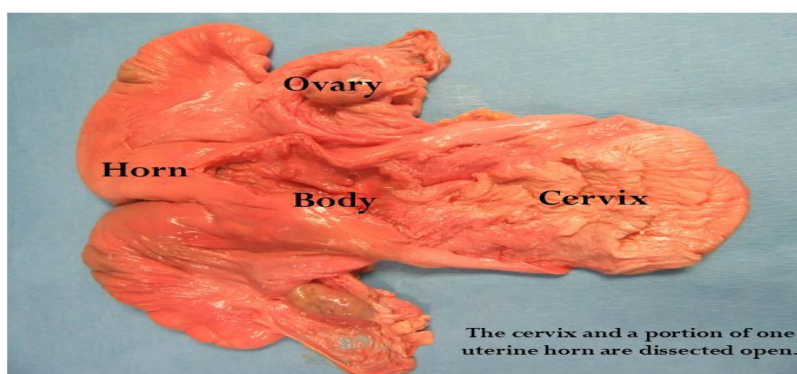
The corpus luteum develops from the ovulated follicle and secretes progesterone, which prepares and maintains the uterine environment for pregnancy (YENİ & AVDATEK, 2026).

In both species:

1. The preovulatory LH surge induces ovulation.
2. The ruptured follicle undergoes luteinization.
3. The developing CL secretes progesterone.
4. If pregnancy does not occur, uterine prostaglandin $F_2\alpha$ initiates luteolysis.
5. If pregnancy is established, maternal recognition mechanisms preserve luteal progesterone secretion.

In cows, the CL is commonly assessed using transrectal ultrasonography and ovarian palpation (Quintela et al., 2012). The same approaches are used in buffaloes, although the visibility of ovarian structures and the timing of examination can influence diagnostic accuracy.

Uterine and cervical structure and their implications for artificial insemination



The female reproductive tract of both species includes the vulva, vagina, cervix, uterine body, paired uterine horns, oviducts, and ovaries. Their basic organization is similar, but individual anatomical variation can influence the ease of reproductive examination and semen deposition.

A. Cervical anatomy

The cervix acts as a physical and immunological barrier between the vagina and uterus. It consists of fibrous tissue, smooth muscle, and mucosal folds (Simões & Stilwell, 2021).

- Cervical rings and the tortuous cervical canal can make passage of the AI catheter technically challenging in both species.
- Cervical dimensions, canal configuration, and tissue resistance vary between individuals and with age, parity, and reproductive status.
- In buffaloes, cervical passage may be challenging in some animals, particularly heifers or animals with a narrow or tightly folded cervix (Tandle & Purohit, 2013).

B. Uterine anatomy

Both cows and buffaloes have a bicornuate uterus with two uterine horns. The uterine horns are the primary sites of embryo development following fertilization in the oviduct (Kalita et al., 2026).

The uterine environment supports:

- Sperm transport and capacitation.
- Embryo movement into the uterus.

- Conceptus elongation and maternal recognition of pregnancy.
- Placental development and fetal growth.

Inflammation, abnormal uterine involution, endometritis, and disturbances in the uterine environment can impair fertility in either species.

C. Practical implications for AI

In routine bovine AI, semen is deposited in the uterine body after the catheter has passed through the cervix. The same general principle applies to buffaloes (Gietema, 2005).

Three factors are particularly important:

1. Correct catheter placement: Avoid accidental deposition in the cervix or excessive advancement into one uterine horn.
2. Appropriate timing: Insemination should be timed relative to estrus and expected ovulation, rather than relying on a fixed time that ignores variation in estrus onset.
3. Aseptic and atraumatic technique: Excessive manipulation can cause tissue irritation or contamination.

Endocrine dynamics of the estrous cycle

The estrous cycle is coordinated by the hypothalamic pituitary ovarian (HPO) axis. It regulates follicular growth, estrus, ovulation, CL formation, progesterone secretion, and the return to estrus when pregnancy does not occur (Dever, 2023).

The reproductive hormone pathway

- Hypothalamus
- Pulsatile secretion of GnRH
- Anterior pituitary
- FSH and LH secretion
- Ovarian follicles
- Follicular growth and estradiol production
- Estradiol rises
- Estrus and positive feedback triggering the LH surge
- Ovulation
- Follicle ruptures and the CL forms
- Corpus luteum
- Progesterone prepares and supports the uterus for pregnancy

Preovulatory LH surge and progesterone concentrations

Luteinizing hormone (LH) and progesterone (P_4) are central to understanding reproductive differences between cows and buffaloes.

A. LH surge and ovulation

During the follicular phase, the developing dominant follicle secretes increasing amounts of estradiol. When estradiol remains sufficiently elevated in the appropriate hormonal environment, it switches from negative to positive feedback on the hypothalamus and pituitary, triggering the preovulatory LH surge (Fortune et al., 2004).

The LH surge:

- Completes final maturation of the oocyte.

- Initiates change in the follicle wall required for rupture.
- Promotes ovulation and luteinization.
- Supports subsequent corpus luteum formation.

Cows and buffaloes share this basic mechanism. The important practical differences concern the timing and detection of estrus, the relationship between estrus onset and ovulation, and variability among animals. Buffaloes often exhibit less conspicuous behavioral estrus than dairy cattle. Consequently, a buffalo may be approaching ovulation even when behavioral signs are weak or easily missed. This is one reason why synchronization protocols and ultrasound-based monitoring can be useful in buffalo reproductive management.

B. Progesterone concentrations during the cycle

Progesterone is secreted mainly by the CL following ovulation. Its concentration is usually low during estrus and the early follicular phase, then increases as the CL develops and becomes functional.

Typical progesterone pattern across the estrous cycle

Relative progesterone concentration

Day 0 represents estrus. The declining phase represents luteolysis in a nonpregnant animal; timing is illustrative and is not identical in every cycle.

The main stages are:

1. Estrus and ovulation: Progesterone is low, allowing estradiol-driven estrus and the preovulatory endocrine events to occur.
2. Early diestrus: Progesterone begins increasing as luteal tissue develops.
3. Mid-diestrus: A functional CL produces relatively high progesterone.
4. Late diestrus: If pregnancy has not been established, uterine prostaglandin $F_{2\alpha}$ induces luteolysis, and progesterone falls.
5. Pregnancy: Maternal recognition of pregnancy prevents the normal luteolytic process, allowing the CL to continue supporting pregnancy.

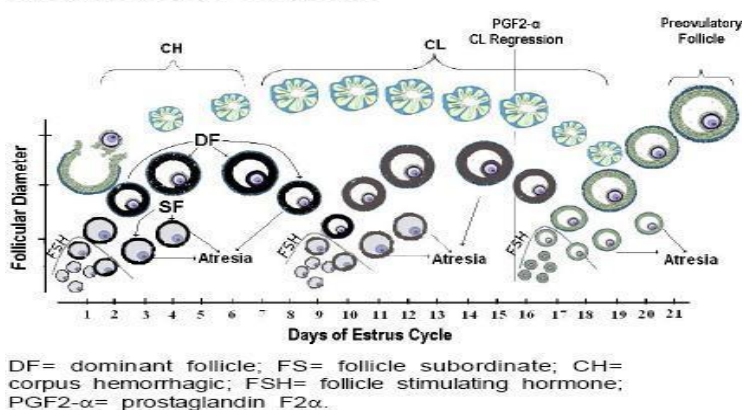
C. Are baseline progesterone concentrations different between cows and buffaloes?

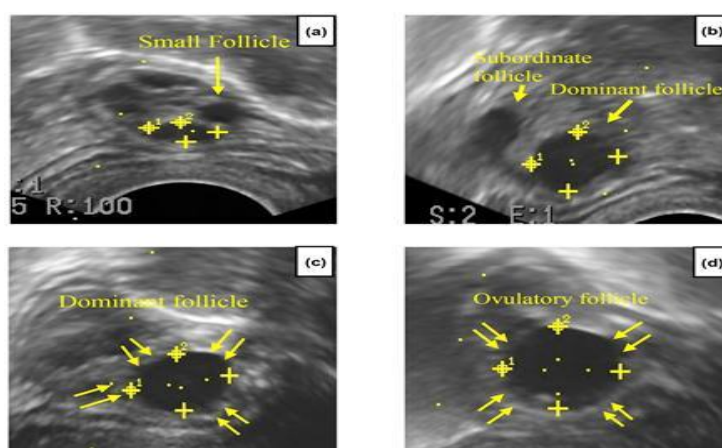
There is no single baseline progesterone value that reliably distinguishes a cow from a buffalo. Concentrations depend on whether the animal is cycling, the day of the cycle, CL size and function, pregnancy status, and the assay used.

Follicular wave dynamics and dominant follicle development

Figura 1. Modelo esquemático de las olas de crecimiento folicular y desarrollo del CL en bovinos

Figure 1. Schematic model of the follicular waves and development of the CL in cattle





Follicular waves are successive groups of growing antral follicles recruited under the influence of FSH. In each wave, a cohort of follicles grows, one generally becomes dominant, and the remaining follicles usually undergo atresia.

The process is broadly similar in cattle and buffaloes.

How a follicular wave develops

1. Wave emergence: FSH increases and stimulates a group of small antral follicles to grow.
2. Selection: One follicle acquires a developmental advantage and continues growing while the others become subordinate.
3. Dominance: The dominant follicle produces estradiol and inhibin, which help suppress FSH and limit further recruitment.
4. Outcome: If progesterone is low and the hormonal conditions permit, the dominant follicle may ovulate. If a functional CL maintains high progesterone, ovulation is generally suppressed and the follicle eventually regresses.

Cows versus buffaloes

Feature	Cows	Buffaloes
Number of waves	Commonly two or three per cycle	Two waves are frequently reported; three-wave cycles also occur
Dominant follicle	Grows under FSH and LH regulation	Same fundamental endocrine regulation
Follicular growth	Influenced by breed, nutrition, age, and ovarian status	Influenced by the same factors, with additional effects of season and environmental conditions
Estrus expression	Often more readily observed in well-managed dairy cows	Frequently weaker or less conspicuous
Application	Widely used for estrus synchronization and timed AI	Similar principles apply, but protocols may require species-specific adjustment

Buffalo research has established that follicular development follows a wave-like pattern like that of cattle. A review of ovarian physiology in buffaloes also discusses the implications of follicular dynamics for ovulation, CL development, and assisted reproduction.

Why does the number of follicular waves matter?

The number of waves influences when the dominant follicle develops and how long it remains present before ovulation or regression. This matters when designing hormonal protocols, because follicular age and developmental status at insemination can affect oocyte competence and reproductive outcomes. However, a two-wave cycle is not inherently inferior to a three-wave cycle. The reproductive significance depends on the quality and timing of follicular development, not wave number alone.

Melatonin, photoperiod, and seasonal reproduction

Melatonin is secreted by the pineal gland, primarily during darkness. It communicates information about day length to the brain and contributes to the seasonal regulation of reproductive activity (Arendt & Aulinas, 2019). The distinction between cows and buffaloes is often described as nonseasonal versus short-day breeding, but this requires qualification.

Cattle: Many dairy cattle, particularly intensively managed commercial breeds, can cycle throughout the year. Nevertheless, high temperatures, humidity, reduced feed intake, and heat stress can impair follicular development, estrus expression, conception, and embryo survival. Some cattle populations also show seasonal reproductive patterns.

Buffaloes: Buffaloes are commonly classified as short-day breeders because reproductive activity and fertility often improve as day length decreases. This pattern is particularly evident in many populations at temperate latitudes. However, buffaloes can reproduce throughout the year, and seasonality varies with latitude, breed, feeding, management, and local climate.

The proposed pathway is:

1. Shorter days extend the duration of nocturnal melatonin secretion.
2. Photoperiodic information is processed through neural and neuroendocrine pathways.
3. Seasonal changes influence reproductive hormone signaling and ovarian function.
4. In susceptible buffalo populations, this can increase reproductive activity during the favorable breeding season.

Melatonin may also have direct antioxidant effects in reproductive tissues, although the magnitude of these effects and the practical benefit of supplementation depend on the treatment and circumstances.

Onset of puberty and sexual maturity

Puberty is the developmental stage at which a heifer first becomes capable of ovulation and reproduction. It reflects maturation of the hypothalamic–pituitary–ovarian axis, growth of reproductive organs, and acquisition of sufficient body reserves to support reproductive function.

Age and body weight at puberty

The age at puberty varies substantially between cattle and buffaloes, and even among breeds within each species.

Characteristic	Dairy cattle	River buffaloes	Swamp buffaloes
Puberty under favourable management	Often around 9–15 months in well-grown dairy heifers	Commonly around 15–18 months under favourable conditions	Commonly around 21–24 months under favourable conditions
Major determinants	Breed, growth rate, nutrition, body condition, and health	Genotype, nutrition, growth, climate, and management	Genotype, nutrition, growth, climate, and management
General principle	Puberty is strongly related to body weight and growth	Puberty is strongly related to body weight and growth	Puberty is strongly related to body weight and growth

In buffaloes, puberty is often reported when heifers reach approximately 55–60% of mature body weight, although the appropriate threshold varies by breed and production system. This illustrates why body weight and growth trajectory are often more informative than chronological age alone.

Factors influencing puberty

Genetics and breed

Genetic differences affect mature body size, growth rate, age at puberty, and endocrine regulation. Early maturing dairy cattle may attain puberty sooner than later maturing or poorly adapted animals. River and swamp buffaloes also differ in typical age at puberty, although considerable variation occurs within each group.

Nutrition and growth rate

Adequate energy, protein, minerals, and vitamins support growth and reproductive development (Waqas, Hasan, et al., 2025). Undernutrition can reduce insulin and IGF-1 signalling, delay GnRH and LH activity, and postpone the first ovulation. Excessive feeding can also be undesirable if it promotes inappropriate fat deposition or compromises future productivity.

Body condition and metabolic status

Body condition reflects energy reserves, while body weight and growth rate help indicate whether the heifer is approaching the size associated with puberty. Neither should be interpreted in isolation: a heavy animal with excessive fat deposition may not be equivalent to a well-grown, appropriately conditioned heifer.

Climate and season

Heat stress may reduce feed intake and alter endocrine function. In buffaloes, seasonal reproductive patterns can further influence ovarian activity. Climate effects interact with nutrition, housing, cooling, and breed adaptation.

Endocrine mechanisms underlying puberty

Before puberty, the hypothalamus and pituitary do not yet produce the pattern of GnRH and LH secretion required for sustained ovarian maturation and ovulation (Waqas, Afzal, et al., 2025).

As the heifer grows:

- Metabolic signals, including insulin and IGF-1, communicate nutritional and growth status.
- Hypothalamic pathways become more permissive to pulsatile GnRH secretion.
- LH pulse frequency and ovarian steroidogenesis increase.
- Follicles become capable of producing sufficient estradiol to support the preovulatory endocrine cascade.
- The first ovulation occurs, sometimes followed by a short or behaviourally inconspicuous first cycle.

This general mechanism applies to both cows and buffaloes. Delayed puberty in buffaloes should not be attributed solely to species-specific endocrine differences; poor nutrition, inadequate growth, disease, and management can contribute substantially.

Why puberty matters for reproductive performance

Delayed puberty postpones first insemination and conception, extending the nonproductive rearing period and increasing the cost of raising replacement heifers. Conversely, breeding too early, before adequate growth and body development, may compromise health and future performance.

Key Performance Indicators (KPIs): Cows vs Buffaloes

Parameter	Dairy Cows (<i>Bos taurus</i>)	Water Buffaloes (<i>Bubalus bubalis</i>)
Age at Puberty (months)	12 – 15	18 – 24
Estrous Cycle Length (days)	21 (18–24)	21 (18–24)
Duration of Estrus (hours)	12 – 18	4 – 12 (often nocturnal/subtle)
Gestation Length (days)	~280 – 285	~305 – 320
Calving Interval (days)	365 – 400	420 – 500+
Services per Conception	1.5 – 2.2	1 – 3.0

Future Directions and Conclusion

Gaps in Current Knowledge

Despite substantial progress in reproductive physiology, hormonal synchronization, artificial insemination (AI), and reproductive biotechnology, important gaps remain in our understanding of the differences between dairy cattle and water buffaloes (*Bubalus bubalis*). These gaps are particularly relevant to buffalo production systems in South Asia, where reproductive performance is influenced by seasonal variation, heat stress, nutritional limitations, and differences in farm management.

Development of species-specific hormonal formulations and reproductive protocols

A major research priority is to determine whether hormonal formulations, doses, and treatment schedules optimized for cattle are equally effective in buffaloes. Although both species respond to gonadotropin-releasing hormone (GnRH) (Waqas et al., 2026), prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$), progesterone, and equine chorionic gonadotropin (eCG), their reproductive responses can differ according to ovarian status, follicular development, season, body condition, and management. In buffaloes, inconsistent estrus expression, variation in follicular activity, and seasonal changes in reproductive efficiency can influence the outcomes of synchronization and timed AI programs. Consequently, protocols developed primarily in cattle may require adjustments to

treatment timing or selection of animals according to ovarian status. However, such modifications should be supported by comparative trials rather than assumptions that buffaloes always require higher or lower hormone doses.

Concluding Remarks

Dairy cattle and water buffaloes share the fundamental reproductive mechanisms that govern follicular development, ovulation, fertilization, and pregnancy maintenance. Nevertheless, differences in ovarian activity, estrus expression, seasonal reproductive patterns, age at puberty, and responses to reproductive interventions can influence fertility outcomes under practical farming conditions. A central conclusion of this review is that reproductive efficiency cannot be improved through a single intervention applied uniformly across species, breeds, and production environments. Successful reproductive management requires an integrated understanding of reproductive physiology, endocrine regulation, nutritional status, climate, and herd-level management.

In cattle, established synchronization programs, timed artificial insemination, reproductive ultrasonography, and systematic fertility monitoring provide useful tools for improving reproductive efficiency. In buffaloes, these approaches also offer substantial potential, but their outcomes may be more dependent on seasonal reproductive activity, ovarian status, estrus detection limitations, and the suitability of the selected protocol. Consequently, reproductive interventions should be selected according to the physiological and management characteristics of the target population rather than transferred directly from cattle without evaluation. Nutrition, body condition, heat abatement, and uterine health remain fundamental components of fertility management in both species. Reproductive biotechnology is most effective when these underlying determinants are addressed alongside hormonal treatment and AI. Similarly, improvements in conception should be evaluated together with pregnancy maintenance, calving interval, calf survival, and economic returns to provide a more complete assessment of reproductive performance. Research should also prioritize practical solutions that can be implemented under both commercial and smallholder farming conditions.

References

- Adesogan, A. T., & Dahl, G. E. (2020). MILK Symposium Introduction: Dairy production in developing countries. *Journal of Dairy Science*, 103(11), 9677-9680.
- Arendt, J., & Aulinas, A. (2019). Physiology of the pineal gland and melatonin.
- Beatty, D., Barnes, A., Taylor, E., Pethick, D., McCarthy, M., & Maloney, S. (2006). Physiological responses of *Bos taurus* and *Bos indicus* cattle to prolonged, continuous heat and humidity. *Journal of animal science*, 84(4), 972-985.
- Borghese, A., & Mazzi, M. (2005). Buffalo population and strategies in the world. *Buffalo production and research*, 67, 1-39.
- Chiariotti, A., Borghese, A., Boselli, C., & Barile, V. L. (2025). Water buffalo's adaptability to different environments and farming systems: A review. *Animals*, 15(11), 1538.
- de la Cruz-Cruz, L. A., Roldán-Santiago, P., Larrondo, C., Orozco-Gregorio, H., Bonilla-Jaime, H., González-Hernández, M., Rodríguez-Florentino, R., & Yáñez-Pizaña, A. (2026). Economic, Social, and Environmental Contributions of Water Buffalo (*Bubalus bubalis*) Production to the Sustainable Development Goals: A Review. *Sustainability*, 18(11), 5216.
- Dever, J. (2023). The female reproductive cycle: ovarian cycle, menstruation cycle, and estrus. *Female Biology*, 184.
- El-Razek, E., & Allam, T. S. (2019). Some biochemical parameters and hematological picture in cases of smooth inactive ovaries in buffalo-cows.
- Fortune, J., Rivera, G., & Yang, M. (2004). Follicular development: the role of the follicular microenvironment in selection of the dominant follicle. *Animal Reproduction Science*, 82, 109-126.
- Fricke, P. M., & Lamb, G. C. (2002). Practical applications of ultrasound for reproductive management of beef and dairy cattle. *Proceeding: Applied reproductive strategies in beef cattle, manhattan. pp*, 228-245.
- Gietema, B. (2005). Reproduction in dairy cattle II. *Agromisa Foundation. Wageningen*, 65.
- Hassan, F. A., Ali, M. A., & El-Tarabany, M. S. (2017). Economic impacts of calving season and parity on reproduction and production traits of buffaloes in the sub-tropics. *Environmental Science and Pollution Research*, 24(11), 10258-10266.
- Holesh, J. E., Bass, A. N., & Lord, M. (2017). Physiology, ovulation.

- Ingawale, M., & Dhoble, R. (2004). Buffalo reproduction in India: An overview. *Buffalo Bull*, 23(1), 4-9.
- Kalita, M. K., Patowary, P., & Khargharia, S. (2026). General reproduction and reproductive management in cattle. In *Clinical Diseases, Production, and Management of Cattle* (pp. 141-157). Elsevier.
- Manasa, V., Sejian, V., Venkataswamy, G. K., Bogapathi, S. K., & Nagalingam, R. S. (2025). DYNAMICS OF ESTRUS BEHAVIOUR IN BUFFALOES: LOOKING AT VARIOUS REPRODUCTIVE ASPECTS RELATED TO ESTRUS AND METHODS FOR DETECTION. *Buffalo Bulletin*, 44(3), 231-250.
- Medhammar, E., Wijesinha-Bettoni, R., Stadlmayr, B., Nilsson, E., Charrondiere, U. R., & Burlingame, B. (2012). Composition of milk from minor dairy animals and buffalo breeds: a biodiversity perspective. *Journal of the Science of Food and Agriculture*, 92(3), 445-474.
- Mondal, S., Prakash, B., & Palta, P. (2006). Endocrine aspects of oestrous cycle in buffaloes (*Bubalus bubalis*): an overview. *Asian-Australasian journal of animal sciences*, 20(1), 124-131.
- Nanda, A., Brar, P., & Prabhakar, S. (2003). Enhancing reproductive performance in dairy buffalo: major constraints and achievements. *REPRODUCTION-CAMBRIDGE-SUPPLEMENT*, 27-36.
- Prasad, C. S., Anandan, S., Gowda, N. K., Schlecht, E., & Buerkert, A. (2019). Managing nutrient flows in Indian urban and peri-urban livestock systems. *Nutrient Cycling in Agroecosystems*, 115(2), 159-172.
- Quintela, L., Barrio, M., Peña, A., Becerra, J., Cainzos, J., Herradón, P., & Díaz, C. (2012). Use of ultrasound in the reproductive management of dairy cattle. *Reproduction in Domestic Animals*, 47, 34-44.
- Rimon-Dahari, N., Yerushalmi-Heinemann, L., Alyagor, L., & Dekel, N. (2016). Ovarian folliculogenesis. *Molecular mechanisms of cell differentiation in gonad development*, 167-190.
- Shah, S. M., & Chauhan, M. S. (2019). Modern biotechnological tools for enhancing reproductive efficiency in livestock. *Indian J. Genet*, 79(1 Suppl 241), 249.
- Shea, L. D., Woodruff, T. K., & Shikanov, A. (2014). Bioengineering the ovarian follicle microenvironment. *Annual review of biomedical engineering*, 16(1), 29-52.
- Simões, J., & Stilwell, G. (2021). Reproductive anatomy and physiology of the nonpregnant and pregnant cow. In *Calving management and newborn calf care: an interactive textbook for cattle medicine and obstetrics* (pp. 1-23). Springer.
- Tandle, M., & Purohit, G. (2013). Genital tract affections in the female buffalo. *Bubaline Theriogenology. IVIS, Ithaca NY A*, 5724, 0713.
- Waqas, M., Afzal, M. A., Yousaf, Z., Sultan, M. A., Ahmad, A., Khan, H. H., & Masood, A. (2025). Prevalence and Risk Factors of Repeat Breeding in Smallholder Dairy Cows in Kot Addu, Pakistan. *Planta Animalia*, 4(6), 203-208.
- Waqas, M., Hasan, W., Asghar, Y., Tariq, M. S., Munawar, A., Hassan, M. M., & Jamil, H. (2025). Effect of Methionine supplementation on reproductive performance of Nili-Ravi buffaloes (*Bubalus bubalis*) treated with double Ovsynch protocol of synchronization. *Pure and Applied Biology (PAB)*, 14(1), 1-7.
- Waqas, M., Mudassar, H., Qaiser, H., Haroon, R. M., Saad, H. U., Shah, B. H., & Salam, A. (2026). Effect of GnRh Administration at Artificial Insemination and on Day 6 Post Insemination on Pregnancy Outcomes in Holstein Friesian Cows. *Kashmir Journal of Academic Research and Development*, 2(10), 219-224.
- YENİ, D., & AVDATEK, F. (2026). BUFFALO REPRODUCTION AND REPRODUCTIVE HORMONE CLINICAL APPLICATION. *Animal Reproduction and Reproductive Hormone Clinical Application*, 139.
- Zimin, A. V., Delcher, A. L., Florea, L., Kelley, D. R., Schatz, M. C., Puiu, D., Hanrahan, F., Pertea, G., Van Tassell, C. P., & Sonstegard, T. S. (2009). A whole-genome assembly of the domestic cow, *Bos taurus*. *Genome biology*, 10(4), R42.

