Chapter. 3. Applied biotechnologies in genetic improvement

1. Reproductive Biotechnologies

These technologies focus on multiplying the offspring of genetically superior animals.
- Artificial Insemination (AI) is the foundation of genetic programs. It allows for the widespread use of elite. High selection intensity (only the top 5-10% of males are used).

- Multiple Ovulation and Embryo Transfer (MOET): Superovulation of a donor cow (elite female) to produce 6-30 viable embryos, which are transferred to recipient (surrogate) cows. Shortens the generation interval. Allows for the selection of females (maternal lineage).
- In Vitro Fertilization (IVF):Oocytes (eggs) are collected from live donor cows (often prepubertal heifers or pregnant cows) via OPU (Ovum Pick-Up). They are fertilized in a lab and resulting embryos are transferred or frozen. Maximizes offspring from superior females. Allows for the use of sexed semen to produce offspring of a desired gender.

2. Genomic Tools

These technologies allow for the prediction of genetic merit without waiting for the animal to produce offspring.

Genomic Selection (GS): Instead of relying solely on pedigree or progeny testing (waiting for daughters to calve), DNA is extracted from a hair follicle or blood sample. A SNP chip (Single Nucleotide Polymorphism) analyses thousands of genetic markers to calculate a Genomic Estimated Breeding Value (GEBV).

Advantage:

- This reduces the generation interval dramatically. Calves can be screened for genetic potential (e.g., milk production, fertility, polled genetics) immediately after birth.
- Parentage Verification: Genomic tools are used to verify sire and dam lineages, ensuring the accuracy of herd books and preventing inbreeding.
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3. Semen Technologies

Sexed Semen: Sperm cells are sorted using flow cytometry (X-chromosome bearing for females, Y for males) before being frozen. This allows producers to deliberately produce heifers (for herd replacement) or steers (for beef).

Note: Sexed semen typically has a lower conception rate than conventional semen, so it is often used in heifers or with Fixed-Time AI (FTAI) protocols.

Semen Sexing + IVF: The most advanced programs combine sexed semen with IVF. This allows for the production of a guaranteed female embryo from a genetically elite donor, maximizing the rate of genetic progress.

4. Data Analytics and Phenomics

Modern genetic programs rely heavily on data integration.

- Phenotyping: Beyond just milk yield, modern programs collect high-density data such as:
- Feed Efficiency: Using systems like GreenFeed or GrowSafe to measure residual feed intake (RFI).
- Health Traits: Somatic Cell Count (SCC) for mastitis resistance, and data on hoof health, calving ease, and fertility.
- NIR (Near-Infrared Spectroscopy): Used to analyze milk samples for detailed components (fatty acids, protein fractions) which are used as indicators for metabolic efficiency in genetic indices.

5. Emerging Biotechnologies

Genome Editing (CRISPR-Cas9): While not yet mainstream in commercial production (mostly in research), this allows for the introduction of specific traits (e.g., the POLLED gene to eliminate dehorning, or resistance to diseases like Bovine Respiratory Disease) without crossing in external breeds.

Presynch Protocols: Advanced hormonal synchronization protocols (e.g., Double-Ovsynch, 5-day CIDR) are considered reproductive biotechnologies that allow for the widespread use of these genetic tools without the need for visual heat detection.

II. Artificial Insemination in Cattle

Introduction

Artificial insemination is the most widely used reproductive biotechnology in cattle production. It involves the deliberate introduction of semen into the female's reproductive tract using instruments rather than natural mating. When combined with estrus synchronization, genomics, and advanced semen technologies, AI forms the foundation of modern genetic improvement programs.

This has been found to result in a normal offspring. In this process, the semen is inseminated into the female by placing a portion of it either in a collected or diluted form into the cervix or uterus by mechanical methods at the proper time and under most hygienic conditions. The first scientific research in artificial insemination of domestic animals was performed on dogs in 1780 by the Italian scientist, Lazanno Spalbanzani. His experiments proved that the fertilizing power reside in the spermatozoa and not in the liquid portion of semen. Few further studies under research station conditions helped this technique to be used commercially all over the world including India.

Artificial insemination is not merely a novel method of bringing about impregnation in females. Instead, it is a powerful tool mostly employed for livestock improvement. In artificial insemination the germplasm of the bulls of superior quality can be effectively utilized with the least regard for their location in far away places. By adoption of artificial insemination, there would be considerable reduction in both genital and non-genital diseases in the farm stock.

1. Symptoms of heat

The various symptoms of heat are:

- The animal will be excited condition. The animal will be in restlessness and nervousness.
- The animal will be bellow frequency.
- The animal will reduce the intake of feed.
- Peculiar movement of limbo sacral region will be observed.
- The animals which are in heat will lick other animals and smelling other animals.
- The animals will try to mount other animals.
- The animals will standstill when other animal try to mount.. This period is known as standing heat. This extends 14-16 hours.
- Frequent maturation (urination) will be observed.
- Clear mucous discharge will be seen from the vulva, sometimes it will be string like the mucous will be seen stick to the near the pasts of valva.
- Swelling of the valva will be seen.
- Congestion and hyperemia of membrane.
- The tail will be in raised position.
- Milk production will be slightly decreased.
- On Palpation uterus will be turgid and the cervix will be opened.

2. Semen collection methods and evaluation

Various methods of collection of semen have been devised from time to time. The older unsatisfactory methods have gradually replaced by the new modern techniques.

There are three common methods.

- Use of artificial vagina
- By Electro-stimulation method.
- By massaging the ampulae of the duct us differences through rectal wall.
- The ideal method of semen collection is use of artificial vagina which is safe for sire. and the collector also.

2.1. Artificial vagina method

The artificial vagina has the following parts:

- A heavy hard rubber 2" lose, open at both ends with a nostle for air and water in and outlet.
- Inner sleeve of rubber or rubber liner.
- The semen receiving cone or rubber cone.
- Semen collection tube made of glass or plastic graduate in cc and its fraction correct to 0.1 CC
- Insulating bag Before using for semen collection all the parts are washed thoroughly and sterilized properly, and assembled as artificial vagina, the rubber liner is inserted into the hose; inverting both ends back by folding back from either side opening, and fastening with rubber bands. Now the space between the hard rubber hose and inner rubber liner forms a water tight compartment. The nostle at one end of the hose can be fixed.

2.1.1. Parts of artificial vagina

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Turning through the threaded nut up or down. The water jacket of the Artificial -vagina is- filled with hot water at a temperature of 45°C (113°F) by opening the nostle. The graduated semen collection tube is fixed to the narrow end of the artificial vagina hose, and fastened by a rubber band. The inner side of the rubber liner on the anterior side of the artificial vagina is lubricated with sterile jelly to a length of 3 to 4 inches. Air is blown through the nostle into the water jacket, to create pressure in if, and the same is exerted the rubber linear, to simulate natural vagina.

The temperature of the artificial vagina is to be checked, at each collection, and it should simulate natural vagina at mounting time. If the artificial vagina is to mount later. If it is too cold ejaculate may not be there after a thrust, or even if ejaculate is there; it may be contaminated with urine, and becomes unfit for use.

2.1.2. Semen collection method. (a.v.)

The cow or dummy is secured in service create. The artificial vagina assembled is held at 45° angle from the direction of penis, and the thrust is that angle. The artificial vagina is held with the left hand by a right handed person; and when the bull mounts the cow, the sheath of the bull will be graphed by the operator, directing the gland penis into the artificial vagina, and then the bull gives a thrust to ejaculate. The operator should evince care so as not to touch the exposed past of the penis. After the bull dismounts, the artificial vagina is taken off from penis and the air vent is opened to release the pressure from the jacket. The water from the jacket is also drained by opening the nostle. This allows the ejaculate to flow from the cone to the semen collection tube. The semen collection tube is detached from the cone, plugged with cotton wool, and taken to the laboratory for examination. The rubber cone and the semen collection tube can be protected from external contamination or heat or higher, by covering with an insulation bag with zip.

2.1.3. Semen storage

The discovery that bull semen could be successfully frozen and stored for indefinite periods has revolutionized AI in cattle. In 1949, British scientists discovered that addition of glycerol to the semen extender improved resistance of sperm to freezing. Glycerol acts to remove water from the sperm cell prior to freezing and prevents the formation of cellular ice crystals which would damage the sperm. There are two methods of freezing and storing semen: dry ice and alcohol (-100 degrees F) and liquid nitrogen (-320 degrees F). Liquid nitrogen is preferred because there is no evidence of fertility deterioration with age. Fertility gradually declines in semen stored in dry ice-alcohol.

Frozen semen can be stored indefinitely if proper temperature is maintained. A recent report told of a calf born from frozen semen stored for 16 years. Fresh, liquid semen can be successfully stored for 1 to 4 days at 40 degrees F. Semen is usually stored in glass ampoules. Other methods appear promising, particularly the French-straw. Several AI organizations have gone to this method exclusively. Artificial coloring is frequently added to semen extenders in order to distinguish one breed from another. Complete identification of the bull is required on each individual semen container.

2.2. Insemination methods

There-are different methods insemination in different species of animals i.e. speculum method, vaginal method and recto vaginal method.

2.2.1. Recto vaginal method

In cattle the safe and best method of insemination is “Recto vaginal method of insemination”. Cow which is in heat is well controlled placing it in a Travis. The inseminator will get ready by wearing a plastic apron, gumboots and gloves. The semen straw after thawing (keeping the semen straw in warm water for a minute to convert the freezed semen into liquid and the sperms become motile) is loaded in a sterilized A.I. gum and is covered with a plastic sheath. The inseminator will insert the gloved left hand into the rectum after applying the soft soap or other lubricant on the glove and back racked the animal, and the hand is further inserted

and will catch hold the cervix through rectal wall. The A.I gum loaded with semen straw is passed.

Through the vulva to ‘vagina and cervix and observed with the hand in rectum that the A. I gum reaches the cervix, then the semen is deposited by injecting the gun, and after depositing the semen the gun is removed, the empty straw and sheath are disordered.

2.2.2. Spectrum method

In this method spectrum is placed in the vagina of the cow, which provides passage outside to the site of insemination, then inseminating tube is passed through the speculum and semen is deposited at the cervix insemination method.

2.2.2.1.Vaginal method

Hand is passed through the vagina and the inseminating tube is guided by hand to the site of insemination and semen is deposited. Here there is a risk of contamination and injury of female genitalia.

2.3. Frozen semen and storage

Freezing of semen for successful preservation of spermatozoa, for long periods, is of great importance in livestock breeding and farm management. It has made it possible” to make available the use of outstanding proven sizes for larger number of cows, covering larger area, frozen semen shipment has become possible to different continents in the globe to any place connected with any service. Now a day if farmer wants to use of an outstanding size for inheritance of high milk yield, he can go in for frozen semen service provided his area is, covered by Artificial insemination, with supply of frozen semen.

At present frozen semen is used in most of the states in India. The technique of semen preservation in straws was developed in France. Freezing of semen is done with a special diluents, which has the following composition. Sodium citrate dihydrate (angular) 2.4 y. 2.0 gm 8.0 ml 25.0%byvolume 50,000 units per 100 ml of semen Fructose Glycerol Egg Yolk Penicillin dilulent. Dihydro-streptomycin 50.0 mg per .100m1 of semen dilulent. Distilled water double glass distilled 100.Om1. The addition of glycerol to the dilulent makes the cells more resistant to the rigours of freezing and icy crystals, which form are smaller and smoother thus creating less damage to the spermatozoa. The addition of fructose to the diluent luprores sperm resistance to glycerol; and also provides nutrition.

Frozen semen is packed in single dose glass vials or plastic straws at +5°C. The final level of glycerol should be 7.0 to 7.6% during the freezing process. The antibiotics are added to inhibit bacteria and to kill pathetic organisms. The semen to be diluted in such a way that one ml. of extended semen will contain 20 million motile spermatozoa. The semen must be cooled carefully for spermatozoa to remain with life. The final temperature is lowered to -79°C or still lower. Quick freezing is done for a period of 3 to 5 minutes to -75°C with the help of atmosphere created by liquid nitrogen. In the slow freezing technique cooling is done at the rate of 1 °C per minute from +5°C to -15°C. From -15°C to -31 °C at the rate of 2°C per minute. From -31°C to 75°C at the rate of 4 to 5°C per minute. Thus taking 40 minutes in total, further cooling to -96°C can be done quickly as it is not critical after freezing. Before freezing the diluted semen

in equilibrated for 3 to 5 hours or for the best 16 to 20, hours period in refrigerator at 5°C. Frozen semen facilitates the percent use of the semen diluted and frozen, and thus the delivery price is reduced, and it can be supplied with the gaps of months to the A.I technicians as against the supply of fluid semen every days or alternate days. Liquid nitrogen plays a vital role for storing the frozen semen straws, at a temperature of -196°C for longer periods.[1]

2.4. Benefits of artificial insemination

- Artificial insemination (AI) is the process of collecting sperm cells from a male animal and manually depositing them into the reproductive tract of a female. One can cite a number of potential benefits from the use of artificial insemination.
- Increased efficiency of bull usage: During natural breeding, a male will deposit much more semen than is theoretically needed to produce a pregnancy. In addition, natural breeding is physically stressful. Both of these factors limit the number of natural mating a male can make. However, collected semen can be diluted and extended to create hundreds of doses from a single ejaculate. Also, semen can be easily transported; allowing multiple females in different geographical locations to be inseminated simultaneously, and semen can be stored for long periods of time, meaning that males can produce offspring long after their natural reproductive lives end.
- Increased potential for genetic selection: Because artificial insemination allows males to produce more offspring, fewer males are needed. Therefore, one can choose only the few best males for use as parents, increasing the selection intensity. Furthermore, because males can have more offspring, their offspring can be used in a progeny test program to more accurately evaluate the genetic value of the male. Finally, individual farmers can use artificial insemination to increase the genetic pool with which his or her animals can be mated, potentially decreasing effects of inbreeding.
- Decreased costs: Male animals often grow to be larger than females and can consume relatively larger amounts of feed. Also, male animals are often more strong, powerful, and potentially ill-mannered and thus require special housing and handling equipment.
- Increased safety for animals and farmers: As mentioned, male animals can become large and aggressive. These factors mean that maintaining a bull on a farm may be dangerous. Also, because of the relatively larger size of adult males than females, natural mating is more likely to result accidents and injury to either the cow or the bull than is artificial insemination.
- Reduced disease transmission: Natural mating allows for the transfer of venereal diseases between males and females. Some pathogens can be transmitted in semen through artificial insemination, but the collection process allows for the screening of disease agents. Collected semen is also routinely checked for quality, which can help avoid problems associated with male infertility.

2.5. AI drawbacks

- Artificial insemination has some potential drawbacks, however, that must be considered. First, it can be more laborious. Male animals instinctively detect the females that are in the correct status for conception. With artificial insemination the detection work falls on the responsibility of the farmer. Poor detection results in decreased rates of fertility. Also, increasing the number of offspring per male has selective advantages only if the best males can be accurately determined. Otherwise this process only

[1] http://bieap.gov.in/DairyAnimalManagementTheory.pdf

decreases the genetic variability in a population. Increasing the number of offspring per male always reduces the gene pool. The benefits of more intense selection must be balanced against the negative effects of decreased variation.[2]

2.6. Artificial insemination techniques

The technique of inseminating a cow is a skill requiring adequate knowledge, experience and patience. Improper AI techniques can negate all other efforts to obtain conception. Semen must be deposited within the tract of the cow at the best location and at the best time to obtain acceptable conception rates. Early methods of AI involved deposition of the semen in the vagina, as would occur in natural mating. Those methods are not satisfactory. Fertility is low and greater numbers of sperm are required. Another method which gained popularity was the "speculum" method. This method is easily learned, but proper cleaning and sterilizing of the equipment is necessary, making it more impractical to inseminate than with the rectovaginal technique which is the most widely used AI method today.

In the recto-vaginal technique a sterile, disposable catheter containing the thawed semen is inserted into the vagina and then guided into the cervix by means of a gloved hand in the rectum. The inseminating catheter is passed through the spiral folds of the cow's cervix into the uterus. Part of the semen is deposited just inside the uterus and the remainder in the cervix as the catheter is withdrawn. Expulsion of the semen should be accomplished slowly and deliberately to avoid excessive sperm losses in the catheter. The body of the uterus is short; therefore, care should be taken not to penetrate too deeply which might cause physical injury. In animals previously inseminated, the catheter should not be forced through the cervix since pregnancy is a possibility. Since research data show little variation in conception rates when semen is placed in the cervix, uterine body or uterine horns, some people recommend incomplete penetration of the cervical canal and deposition of semen in the cervix.

The recto-vaginal technique is more difficult to learn and practice is essential for acceptable proficiency but the advantages make this method of insemination more desirable than other known methods. With practice, the skillful technician soon learns to thread the cervix over the catheter with ease. If disposable catheters are used and proper sanitation measures are followed, there is little chance of infection being carried from one cow to another.

2.7. Timing of Insemination for Maximum Conception

A frequent question concerning AI is: What time during estrus should cows be bred for greatest chance of conception? Since estrus may last from 10 to 25 hours there is considerable latitude in possible time of insemination. Much research work has been conducted on this subject.

Controlled investigations were conducted by Trim Berger and Davis at Nebraska in 1943. These and other studies show that conception rate is lower when cows are bred prior to mid estrus or later than 6 hours after cessation of estrus (standing heat in this case). Maximal conception is obtained when cows are inseminated between mid estrus and the end of standing estrus, with good results up to 6 hours after estrus.

[2] www.naweb.iaea.org

Success in insemination timing is dependent upon a good heat detection program. In large herds, this means assigning individual responsibility for heat detection and a continued education program for labor. A successful heat detection program and subsequent proper timing of insemination will pay dividends in increasing reproductive efficiency.

2.7.1. A practical recommendation for timing of insemination

Cows showing estrus should be inseminated	Too late for good results
In morning- the same day	Next day
In afternoon- morning of next day or early afternoon	After 3

2.7.2. Semen Handling and Storage

Proper semen handling is critical for maintaining fertility. Frozen semen is stored in liquid nitrogen at -196°C (-321°F).

Key Principles

- Storage: Semen straws must remain immersed in liquid nitrogen until use. Exposure to air (above the frost line) can cause temperature fluctuations that damage sperm.
- Thawing: Straws are thawed in a water bath at 95–98°F (35–37°C) for a minimum of 45 seconds (or according to the semen supplier's instructions).
- Drying: After thawing, the straw must be thoroughly dried with a paper towel. Water is toxic to sperm and can cause osmotic shock.
- Loading: The straw is loaded into a warmed AI gun (40–60 straws can be kept warm in a vest or gun warmer).

- Timing: Insemination should occur within 6–8 minutes of thawing to maximize sperm viability.

2.7.3. Detecting Estrus (Heat)

Accurate heat detection is the single most important factor determining AI success. The only reliable sign of estrus is standing to be mounted (standing heat).

- **Primary Signs of Estrus**

- Standing Heat: The cow stands immobile when mounted by another cow. This lasts an average of 6–12 hours.

- **Secondary Signs**

- Mounting other cows;
- Restlessness and increased walking;
- Mucus discharge (clear, stringy);
- Swollen, reddened vulva;
- Decreased feed intake

2.7.4. Timing of Insemination:

- Ovulation occurs 24–32 hours after the onset of standing heat.
- Sperm require 6–12 hours for transport and capacitation (to become fertilization-competent).

The "AM-PM" Rule:

- Cows seen in heat in the morning → inseminate that afternoon.
- Cows seen in heat in the afternoon → inseminate the following morning.

This rule ensures sperm are present in the oviduct at the time of ovulation.

2.8. The Insemination Procedure

Equipment Needed:

- AI gun (sterile, pre-warmed);
- Thawed semen straw;
- Scissors or straw cutter;
- Paper towels;
- Lubricant (non-spermicidal);
- Long-sleeved palpation glove;
- Restraint chute

Step-by-Step Technique:

Step	Description
1. Restrain the Cow	Secure the cow in a palpation chute. Proper restraint reduces stress and injury risk.
2. Rectal Palpation	Insert a gloved, lubricated arm into the rectum. Empty the rectum of feces. Locate the cervix.
3. Clean the Vulva	Wipe the vulva with a clean paper towel to prevent contaminants from being carried into the uterus.
4. Load the Gun	Cut the tip of the straw (1/8 inch), load it into the AI gun, and attach the protective sheath.
5. Insert the Gun	Hold the gun at a slight upward angle (to avoid the urethral opening) and advance it through the vagina until it contacts the external cervical os.
6. Guide Through Cervix	Using the hand in the rectum, grasp the cervix and manipulate it over the tip of the gun. Advance the gun through the annular rings of the cervix.

7. Deposit Semen Deposit the semen in the uterine body (just past the last cervical ring). Do not penetrate deep into the uterine horn, as this increases the risk of trauma and reduces fertility.

8. Withdraw Remove the gun slowly. Record the breeding details.

5. Estrus Synchronization Protocols

Estrus Synchronization allows a group of females to be inseminated at a predetermined time, eliminating the need for visual heat detection.

- **Common Protocols**

Protocol	Hormones	Timeline	Best For
Ovsynch	GnRH → PGF2α → GnRH	10 days	Fixed-time AI (FTAI) in lactating dairy cows
Double-Ovsynch	Presync + Ovsynch	23 days	Higher fertility in lactating dairy cows; controls follicular wave
5-day CIDR	CIDR + PGF2α + GnRH	8 days	Beef cows and heifers; good for fixed-time AI
7-day CIDR + FTAI	CIDR + PGF2α + GnRH	9 days	Heifers and suckled beef cows
PG 2-shot	PGF2α, repeat 11–14 days	14 days	Cycling cows with visual heat detection.

- **Key Hormonal Aids**
- GnRH (Gonadotropin-Releasing Hormone): Induces ovulation of a dominant follicle or initiates a new follicular wave.
- PGF2α (Prostaglandin F2α): Regresses the corpus luteum (CL), ending the luteal phase and initiating estrus.
- Progesterone (CIDR): Maintains the luteal phase; suppresses estrus until removal. Useful for anestrus cows.

2.9. Advanced Semen Technologies

- Sexed Semen

Sperm are sorted using flow cytometry to separate X-chromosome (female) from Y-chromosome (male) sperm.

Accuracy: 90–95% for the desired sex.

Considerations: Lower conception rates (70–85% of conventional semen) due to reduced sperm numbers per straw and sorting stress.

Best Use: Heifers (higher fertility), fixed-time AI protocols, and IVF.

Beef-on-Dairy

Using beef semen (Angus, Wagyu, etc.) on dairy females to produce high-value crossbred calves for beef production.

Increasingly common in dairy herds to add value to non-replacement heifers and dairy cows.

2.10. Factors Affecting AI Success

Factor Impact

Technician Skill Proper cervical manipulation and semen deposition are critical. Inexperienced technicians have significantly lower conception rates.

Heat Detection Accuracy Inseminating too early or too late relative to ovulation reduces fertility.

Nutrition Cows should be in good body condition (BCS 5–6 on 9-point scale) and on a rising plane of nutrition. Energy deficiency causes anestrus and reduces conception.

Stress Heat stress, handling stress, and transportation near breeding reduce pregnancy rates.

Uterine Health Uterine infections (endometritis) or retained placenta significantly impair conception.

Semen Quality Use only semen from reputable AI studs with documented fertility data.

2.11. Record Keeping and Pregnancy Diagnosis

Essential Records:

- Cow/heifer identification;
- Date and time of insemination;
- Bull identification (sire);
- Technician identification
- Type of semen (conventional, sexed, beef)
- Synchronization protocol used

2.12. Pregnancy Diagnosis

- Palpation per rectum: 35–45 days post-AI;
- Ultrasound: 28–35 days post-AI (allows earlier detection and determination of fetal sex if desired);
- Non-pregnant cows: Can be re-synchronized and re-inseminated or exposed to a clean-up bull.

2.13. Common Mistakes to Avoid

Mistake	Consequence
Improper semen thawing	Reduced sperm viability; lower conception
Depositing semen in the cervix or vagina results in failure	Sperm must reach the oviduct; cervical deposition
Rough manipulation of the cervix	Trauma, adhesions, and reduced fertility
Inseminating too deep into the uterine horn in conception	Increased risk of uterine damage; no improvement
Using dirty equipment	Introduction of bacteria into the uterus → endometritis
Inseminating cows not in heat	Wasted semen, time, and resources

2.14. Economic Considerations

AI is generally more economical than owning a bull, especially for herds under 50–100 cows, when considering:

- Bull purchase price;
- Feed and maintenance costs;
- Risk of injury or death;
- Genetic value of the bull

With AI, producers can access top-genetic bulls for $15–$50 per straw, with conception rates of 40–60% typical in well-managed programs.

Summary

Artificial insemination in cattle is a mature but continuously evolving technology. Success depends on:

- Proper semen handling from storage to deposition;
- Accurate heat detection or well-executed synchronization protocols;
- Skilled insemination technique;
- Sound herd management (nutrition, health, stress reduction);
- When integrated with genomics, IVF, and advanced reproductive technologies, AI enables rapid genetic progress and efficient herd reproduction.

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