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The Role of In-Vitro Fertilization for enhancing the Livestock Productivity

AUTHORS DETAIL

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Abstract

IVF playing an important role in livestock breeding and become a technological advancement by enhancing production through various means like improved reproductive efficiency and genetic selection. In this chapter we will discuss the basic techniques, methods and applications of IVF in livestock production. IVF is a simple procedure involves fertilization of oocyte outside the body and then embryos are transferred to recipient female thus playing crucial role in overcoming fertility problems, enabling genetic progress and reducing embryonic losses. Livestock traits are enhanced by genetic manipulation and selection resulting in creation of animals with superior genes and characters improving overall herd productivity. In this chapter various stages of IVF will be discussed including oocyte collection by different techniques like aspiration and slicing. It also includes oocyte maturation, fertilization and embryo transfer. IVF is optimized by different techniques like ovum pick-up, genomic analysis and use of sexed semen, allowing for the selection of superior traits and enhancing accuracy of breeding. IVF contributes advancements to number of technologies like embryo cryopreservation, embryo transfer and sexed semen that directly supports the sustainability of livestock production by conserving valuable genetics leading to reduction of risks of disease transmission. IVF enables manipulation of superior genetics and increases market values through better meat quality, fatty acid profiles and high-quality offspring thus having an economic impact. Generation interval is reduced and genetic gain is accelerated by combination of IVF and genomic selection ensuring efficient resource use and improved economic returns. However, despite of its applications IVF is facing challenges such as lower pregnancy rates as compared to conventional artificial insemination, suboptimal oocyte maturation and ethical concerns regarding animal welfare. IVF offers solution to different environmental challenges and enabling development of genetically enhanced breeds that are more productive, disease-resistant and are well suited to changing climatic conditions. IVF will remain a cornerstone of modern livestock breeding strategies as the technology advances, driving improvements in animal health, productivity and welfare.

Keywords: In-vitro Fertilization, Oocyte, Biotechnology, Reproduction, Genetics, Livestock

1. Introduction

Effective breeding is essential for the sustainable development of livestock, especially for the production of meat, milk, and draft but this productivity was affected by climate conditions and reproductive diseases (Mebratu et al., 2020). In-Vitro fertilization supports genetic selection and crossbreeding while enhancing lower pregnancy rates in low fertility herds (Hansen, 2006). In-Vitro fertilization began in late 1800s with the embryo transfer to rabbit, which leads to further success rates across various species. In-Vitro oocyte maturation was achieved by 1939 setting stage for modern IVF (Zhao et al., 2011). The first successful IVF procedure for cattle took place in 1977, and the first living calf from a four-cell embryo transfer was born in

1981. By 1987, all calves were created via in vitro culture, fertilization, and maturation (Elder, 2001). The milestone in Brazilian livestock IVF research was the production of first IVF calf using oocytes collected from slaughterhouse cows in 1993 (Rodrigues, 2018). IVF is a foundation in cloning and transgenesis through oocyte maturation and embryo culture techniques, however it is essential for generating embryos and stem cell production (Mapletoft, 2018).

Livestock production focus on refining efficient, cost-effective techniques like AI, sexed semen, and embryo transfer, while advancing research on cloning, transgenesis and stem cell production for applications in dairy farming (Binyameen et al., 2019). Estrous synchronization using hormones (PG, GNRH, CIDR, and Progesterone) play crucial role for the effectiveness of Artificial Insemination, IVF, cloning, embryo transfer, and the treatment of reproductive problems, which in turn increases livestock production (Arain et al., 2023). In Vitro embryo production (IVP) and genetic selection (GS) using sexed semen has advanced cattle breeding by enhancing embryo numbers, genetic gains & targeted sex selection despite of different challenges like, reduced fertility, oocyte quality etc (Ferré et al., 2020).

IVF enables faster genetic progress, addresses fertility issues & helps reduce embryonic losses. It offers significant potential for improving genetic selection and cross breeding in livestock (Hansen 2006). IVF enables the screening of embryos for desired genetic traits, contributing for genetic improvement. IVF improves reproductive efficiency in livestock by allowing in vitro fertilization (Wheeler et al., 2010). IVF enhances disease control by reduction of disease transmission risks; however, IVF supports planned mating, thus expending traits of interest, and enables genetic progress by shortening generation intervals (Mebratu et al., 2020).

By enabling genetic manipulation and embryo transfer, improving health and breeding potential of animals, IVF plays important role in boosting livestock productivity (Abraham & Pal et al., 2014). IVF enables rapid increase in offspring from selected females, thus conserving the indigenous breeds, and protection of vertical disease transmission by improving overall reproductive performance in livestock (Bharti et al., 2018).

2. Principles of In-Vitro Fertilization in Livestock

The process of creating embryos outside the body by fertilizing oocytes (eggs) in a laboratory and then moving them into an animal is known as in vitro fertilization, or IVF. This procedure involves like ovum pick-up (OPU), fertilization, genomic analysis to choose animals with desired qualities, and embryo transfer is becoming more common particularly in commercial dairy farms (Sanches et al., 2019).

2.1. Oocyte Collection for IVF:

Aspiration technique:

Bovine ovarian follicles of size 3-8 mm are selected for collection of oocytes. A syringe of size 18 gauge, containing aspiration medium in it is used to puncture follicle, drawing out cumulus-oocyte complexes with follicular fluid. This fluid is examined under microscope in a petri dish (Singh et al., 2018).

Slicing Technique:

The ovary collected is cleaned, washed and suspended in medium with antifungals and antibiotics. Ovary held in petri dish is sliced thinly to release oocyte into the medium, and then oocytes are examined (Saleh, 2017).

2.2. Evaluation of Oocyte:

There are some parameters to check the quality of oocyte,

Cumulus-Oocyte complex COC:

There should be no blood accumulation or clot formation that reduces the quality of oocyte that is directly related to fertilization rate (Lemseffer et al., 2022).

Polar Body:

We can check quality of oocyte by observing morphology of polar body after extrusion that marks the completion of first meiotic division indicates healthy oocyte (Younis et al., 2009).

Zona Pellucida:

It may influence embryo quality. Thinner zona pellucida may aid sperm penetration, but somehow it has mixed effect on fertilization (Lemseffer et al., 2022).

Cytoplasm:

Cytoplasmic markers, like glucose-6-phosphate dehydrogenase levels and mitochondria are linked to better fertilization and embryo outcomes, as they play role in energy production and metabolic health (Wang et al., 2006).

2.3. Oocyte Maturation:

It involves four stages, germinal vesicle, germinal vesicle breakdown, metaphase 1, and metaphase 2. In these stages sequence of events occurs like, chromatin configuration changes, hormonal regulation of cAMP, and cGMP and synchronized nuclear-maturation (Jiang et al., 2023). Cumulus-oocyte complexes (COCs) are cultured with media containing FSH and Granulocyte-Macrophage Colony-Stimulating Factor, and after 16 hours oocyte reached a MII stage (Saini et al., 2024).

2.4. Fertilization and implantation:

This process involves maturation of oocyte, fusion of egg and sperm, and then zygote develops, and all the process is carried outside the body, thus advancing in reproductive technology and genetic preservation (Sjunnesson, 2020). Zygote intra-Fallopian Transfer involves placing fertilized embryos into the functional fallopian tube, which allows verification of fertilization beforehand (Hafez, 2015). Summary of procedure of IVF is shown in Fig 1.

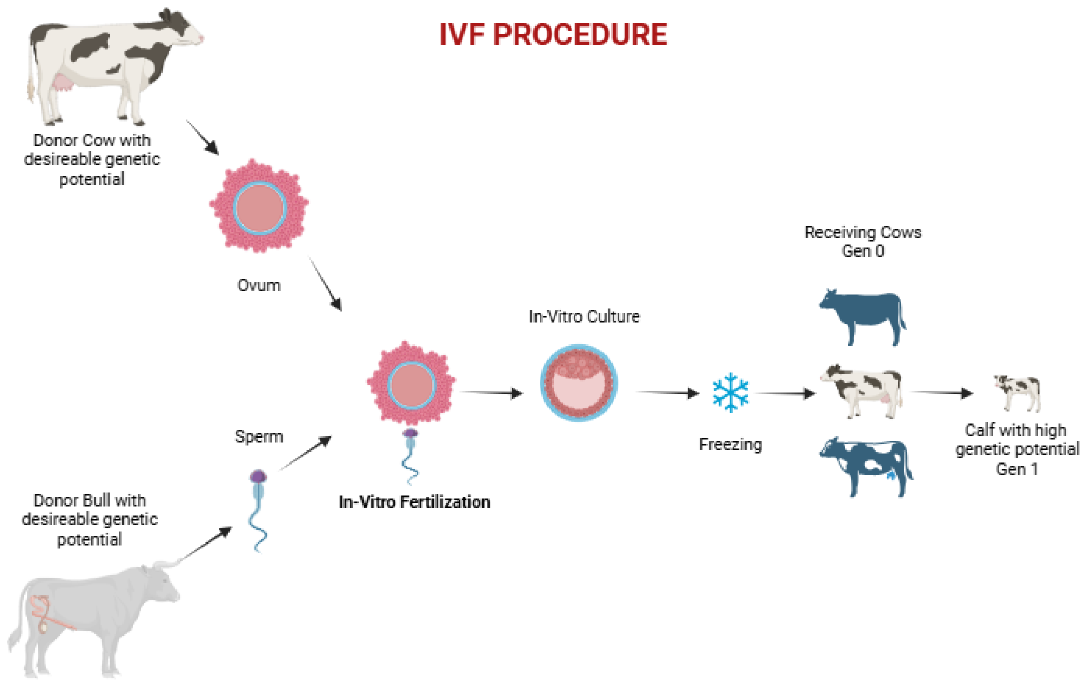

Fig. 1: IVF Procedure

2.5. Differences between IVF and traditional artificial insemination (AI):

IVF involves embryo culture producing multiple embryos and is associated with potential epigenetic changes and long-term health effects on offspring while AI introduces sperm to reproductive tract and has fewer epigenetic concerns (Lafontaine et al., 2023). IVF is costly and produces embryos from selected donors, which are then transferred to recipients, allowing for faster genetic improvement through intensified selection and greater accuracy but in AI produces per female and is less costly not improving herd genetics as much as in IVF (Kaniyamattam et al., 2017).

3. Biotechnological Techniques in Livestock Production:

These techniques are used for improving embryo production, ovum pick-up, genomic analysis, sexed semen, embryo cryopreservation (Sanches et al., 2019)’ estrus synchronization, artificial insemination and somatic cell transfer (Hufana & Duran, 2020).

3.1. Advances in oocyte retrieval and in-vitro maturation (IVM):

Transvaginal oocyte retrieval is preferred for simplicity and efficacy as compared to transcervical; animal is sedated by propofol with prophylactic antibiotics. Vagina is prepared then follicle flushing is done and embryo is aspirated (Healy et al., 2015). Needle is used by puncture method using 17–18-gauge needle. In transvaginal technique it is guided by ultrasound and double lumen needles used in flushing to maximize oocyte collection (Leung et al., 2016). Randomized clinical trials and pain management should be of keen importance, so conscious sedation and analgesia are used to reduce pain during retrieval (Buisman et al., 2022).

In mammals, only a small fraction of oocytes is naturally ovulated, IVM has become crucial, especially in cattle breeding where it is used for IVF to generate embryos that is directly dealing with infertility issues (Lonergan and Fair, 2016). By 1970s, oocyte retrieval evolved through laparoscopic techniques and ovarian stimulation become standard. IVM is gaining attention for its safety and low risk of ovarian hyperstimulation syndrome especially in patients with conditions like polycystic ovaries and poor ovarian reserve (Hatırnaz et al., 2018). IVM has contributed to field of embryo production, and benefits of its advancements includes higher embryo and pregnancy rates, broader donor range and reduction of sperm usage. It is facing some challenges like lower embryo cryotolerance and decreased pregnancy rates compared to in-vivo (Ferré et al., 2020).

3.2. Embryo culture and transfer techniques tailored to livestock:

Rising global demand for animal products has led to advancements in biotechnologies especially IVF and embryo transfer which boosts reproductive rates and genetic improvement, disease control and planned mating (Mebratu et al., 2020). In 2016, in-vitro produced embryos surpassed in vivo-produced embryos in transfers reflecting improved efficacy in assisted reproductive technologies, however embryo culture is a valuable tool for reproductive efficiency and genetic advancement in livestock (Ferré et al., 2020). Brazil has pioneered non-surgical embryo transfer techniques for sheep and goats enhancing efficiency in small ruminants. Advanced imaging methods like color doppler ultrasound support precise selection of donor and recipient animal (Fonseca et al., 2019).

4. Advantages of IVF in Livestock Productivity:

It has number of advantages as discussed earlier including genetic selection of superior trait animals, ability to use prepubertal females for breeding, integration of genomic testing to improve breeding accuracy and reduced costs (Sanches et al., 2019). Enhanced offspring quality allows for selection of embryos with superior genetics, and IVF enables reproductive flexibility that aid individual with fertility challenges (Lawson and Borgerhoff., 2016). IVF in livestock offers accelerated genetic gain, reduced generation intervals especially using the technologies like MOET and JIVET. When IVF is combined with genomic selection it increases selection accuracy, and their synergy optimizes breeding programs (Granleese et al., 2016). This approach ensures efficient resource use, enabling higher genetic merit, enhanced economic returns and sustainable livestock practices however it also manages inbreeding while optimizing the allocation of reproductive technologies based on cost and genetic impact (Granleese et al., 2019). IVF enables scalability in herd and flock sizes to meet demands, however by optimizing recipient selection and integrating advanced techniques will increase productivity of livestock. IVF has become a cornerstone of modern livestock breeding strategies (Daly et al., 2020). The use of prepubertal gametes to enhance genetic diversity, effective use of sexed semen, improvements in embryo culture media and cryopreservation further optimized reproductive outcomes, all these advancements make IVF a vital tool for accelerating genetic gains and meeting industry demands (Sanches et al., 2019).

5. Economic Impact of IVF in Livestock Management:

IVF enhances the market value of offspring due to Improved meet quality and fatty acid profiles, aligns with consumer demand and supports scalability for commercial operations, it also ensures consistent profitable production (Facioli et al., 2020). IVF allows for the rapid multiplication of the best genetics, as high merit female can produce multiple embryos, hence speeding up propagation of desirable traits. IVP-ET can help increasing the conception rates although IVF is a bit expensive but it has much

more advantages (Vries and Kaniyamattam., 2020). Global IVF market for livestock has expanded due to increase in production of sexed and frozen embryos, supporting long term genetic improvement goals such as producing high value breeding bulls and tailored replacement heifers (Ferré et al., 2023). IVF is the most effective application of sexed semen enabling production of offspring with predetermined sex, advancements like production of culture media incorporating cytokines growth factors and antioxidants that improve embryo quality enhanced success rates of IVF (Sanches et al., 2019). IVF has potential to incorporate precision breeding and gene editing aiding in production of disease resistant livestock, thus elite animals produced by IVF fetch higher market prices. IVF contributes to addressing global food security challenges (Mikkola et al., 2024).
IVF involves laboratory-based fertilization which incurs higher initial costs, and in addition use of cryopreserved embryos increases its cost but IVF has potential of genetic gain and combining superior traits from both parents. Whereas AI has significantly less expensive as it involves only semen processing (Crawford et al., 2016).

6. Challenges and Limitations of IVF in Livestock

As some challenges are discussed earlier, Suboptimal oocyte maturation is a major problem which hinders embryo development, difference between cattle breeds like Bos taurus often do not work effectively for Bos indicus as the latter is affected by differences in nutrition and management (Rodriguez., 2012). Embryo transfer procedures are restricted to veterinarians by law in many countries, and IVF is accompanied by lower pregnancy rates as compared to artificial insemination. Embryos produced in-vitro face developmental challenges, affecting their competence to reach blastocyst stage (Hansen, 2023). For IVF we need skilled personnel and more complex technical procedures which have great chances of mistake, however continuous refinement is required for commercial adoption and for improved success rates (Menchaca et al., 2018). Inadequate receptivity of endometrium may impede proper embryonic development leading to losses. The ovarian hormones play critical role in endometrial remodelling, the interaction between hormones and other factors make IVF challenging to assess receptivity consistently (Ulbrich et al., 2012). The ethical challenges of IVF lie in tension between the need for preclinical research which involves animal embryos and the growing ethical concerns about animal welfare (Jans et al., 2018).

7. Future Prospects of IVF in Livestock Productivity

The future of IVF is linked to growing demand for animal products, advancements in genetics and reproductive technologies and the need for sustainable ethical farming. IVF could improve productivity, genetic diversity and address environmental challenges in expanding livestock (Thornton, 2010). Combination of GS, IVF and sexed semen has been successful in improving reproductive importance, efficiency, and genetic gain in cattle production (Ferré et al., 2020). In context of breeding IVF could enable the creation of genetically enhanced breeds, improving productivity, disease resistance and other desirable traits (Harper et al., 2012). IVF technology enabled genetic improvement, efficient reproduction and meeting market demands for high quality embryos (Viana et al., 2018).

Conclusion

IVF offers plentiful benefits such as improved genetic selection, disease control, enhanced reproductive efficiency and has advanced livestock breeding. IVF supports the creation of genetically superior animals. IVF playing an important role in sustainability of livestock production. IVF continues to evolve with integration of advanced techniques like use of sexed semen, genomic selection and embryo cryopreservation and genomic selection despite of number of challenges like suboptimal oocyte maturation and different technical complexities. IVF has enormous potential to address environmental issues, the need for elite animal products, and global food security issues in the future. This is very costly technique and more researches should be carried out for finding cheapest ways of IVF.

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