GLOBAL JOURNAL OF ANIMAL SCIENTIFIC RESEARCH

G.J.A.S.R

Journal homepage: www.gjasr.com

Print ISSN:2345-4377 Online ISSN:2345-4385

Review Article

Review on Current Animal Breeding and Genetic Technologies to Increase Production and Productivity of Cattle

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ABSTRACT

This comprehensive review delves into the intricate landscape of contemporary animal breeding and genetic technologies, with a specific focus on enhancing cattle production and productivity. The analysis encompasses critical issues such as management challenges, animal welfare considerations, environmental impacts, and socio-cultural nuances associated with genetic engineering in agriculture. The document offers insights into the economic hurdles faced by developing nations in adopting biotechnology and explores the ethical and cultural dimensions surrounding these advancements. Emphasizing the delicate balance required for leveraging the potential of genetic technologies, this review provides valuable perspectives on navigating challenges while harnessing the benefits of cutting-edge biotechnological approaches in the realm of animal agriculture.

Keywords: Breeding, Genetics, Technologies, Cattle, Production, Ethiopia

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Cite this Article: Yousuf, M., Yusuf, A., and Mohammed, I. (2024). Review on Current Animal Breeding and Genetic Technologies to Increase Production and Productivity of Cattle. *Global Journal of Animal Scientific Research,* 12(1), 19-36.

Retrieved from http://www.gjasr.com/index.php/GJASR/article/view/191

Article History: Received: 2023.12.04 Accepted: 2024.03.06

INTRODUCTION

Livestock farming plays a crucial role in mitigating risks for vulnerable communities, providing essential nutrients, and supporting crop cultivation through traction (Madan, 2005). While developed countries attribute over half of agricultural production to livestock, the share in developing countries is approximately one-third (Madan, 2005). Livestock products contribute significantly to global kilocalorie (17%) and protein (33%) consumption, with variations between developed and developing nations (Rosegrant *et al.,* 2019). As public consumption of animal products rises, a 'livestock revolution' is evident, with projections indicating growth in meat (2.9%) and milk (2.7%) consumption from 1990 to 2020. Developing countries are expected to drive two-thirds of global meat consumption and over half of global milk consumption, influenced by population growth, income increases, urbanization, and evolving consumption patterns (Gale *et al.,* 2005). Reproduction stands as the cornerstone of animal production, with reproductive inefficiency causing significant economic losses globally. Despite advancements in reproductive physiology, issues such as low conception rates and high embryonic mortality persist (Verma *et al.,* 2012). To meet future agricultural needs, researchers must leverage emerging technologies, including modern reproductive biotechnologies (Holtz, 2005). Assisted reproductive techniques, such as artificial insemination (AI), embryo transfer (ET), in vitro fertilization (IVF), cloning, and transgenesis, have been developed to enhance breeding efficiency, overcome infertility, and control diseases (Widayati, 2012; Mapletoft, 2018). These technologies aim to reduce generational intervals and propagate genetic material among breeding populations. The commercialization of reproductive technologies, including sperm separation techniques such as sex-sorting, is on the rise (Garner and Seidel, 2008). Genetic engineering, involving direct modification of DNA, has emerged as a powerful tool for manipulating organisms or populations (Izquierdo, 2001; Karp, 2002). Techniques range from modifying DNA to express specific genes to incorporating DNA markers for selection (marker-assisted selection, MAS). Genetic engineering's primary focus is the direct manipulation of DNA sequences, which involves isolating, cutting, and transferring specific DNA pieces corresponding to particular genes (Lewin, 2000; Klug and Cummings, 2006).

Given the larger size and more complex organization of the mammalian genome, genetic modification of animals is challenging and costly compared to simpler organisms. However, the potential benefits, such as gene therapy to cure genetic diseases like cystic fibrosis, drive interest in genetic engineering of mammalian cells (Izquierdo, 2001; Coutelle, 2002). The general objectives of this review are to explore and evaluate modern animal breeding and genetic technologies aimed at enhancing cattle production and productivity. This involves a comprehensive examination of various reproductive biotechnologies and genetic engineering methods, considering their applications, implications, and potential contributions to advancing livestock farming practices. The review aims to provide valuable insights into the evolving landscape of animal breeding and genetics, fostering sustainable and efficient agricultural production.

Roles of Modern Animal Breeding and Genetic Technology in Animal Production and Productivity

Biotechnology, defined as the use of living organisms to modify and enhance products, has driven the development of reproductive technologies. These technologies aim to increase the number of offspring from genetically superior animals and safeguard the genetic pool of infertile or sub-fertile animals, offering opportunities for broader use of superior germplasm (Moore and Thatcher, 2006). In the face of challenges such as climate change, modern reproductive technologies play a vital role in studying, treating, and manipulating reproductive phenomena to enhance performance in various livestock species (Choudhary *et al.,* 2016). In cattle, techniques like estrus synchronization and artificial insemination (AI) maximize reproductive potential by incorporating superior genetics. Timed AI protocols reduce labour, minimize animal handling, and enhance efficiency for farmers (Cameron *et al*., 1994). Additional techniques, such as assessing sperm fertilization capacity, sexing sperm, superovulation, embryo transfer, and in vitro embryo production, contribute to improved reproductive efficiency and pregnancy rates. The use of reproductive biotechnologies aligns with objectives to increase production, reproductive efficiency, and genetic improvement (Getachew, 2016).

Modern Animal Breeding and Genetic Technologies

Modern reproductive biotechnologies aim to increase production, productivity, reproductive efficiency, and genetic improvement. Artificial insemination (AI) and semen preservation are widely used, with AI being a simple, economical, and successful tool for enhancing production efficiency in cattle (Lamb, 2019). AI's success relies on sperm survival outside the body, effective reintroduction into the female genital tract, and identification of the fertile period in females (Holm *et al.,* 2008). AI contributes significantly to genetic improvement, with about 90% of commercial herd genetic progress attributed to AI utilization.

Artificial Insemination

Artificial insemination (AI) has been defined as a process by which sperm is collected from the male, processed, stored, and artificially introduced into the female reproductive tract for the purpose of conception by using means other than sexual intercourse or natural insemination (Long, 2008).

Artificial insemination (AI) is used as a tool to enhance production efficiency in cattle and the successful use of AI as a means of animal breeding relies upon three major premises: firstly, that spermatozoa can survive outside the body; secondly, that they can be reintroduced into the female genital tract in a way that results in an acceptable conception rate; and thirdly, that the fertile period of the female can be identified (Holm *et al.,* 2008; Manafi, 2011). Artificial insemination involves collecting, processing, storing, and introducing sperm into the female reproductive tract without natural insemination. Successful AI relies on timing insemination with estrus, ovulation, and fertilization rates. AI's efficiency lies in passing high genetic merits from selected males to numerous females, making it more efficient than female-based technologies like embryo transfer for producing large numbers (Johnson *et al.,* 2005).

Multiple Ovulation and Embryo Transfer

Embryo transfer, a commonly used biotechnology after AI, allows for the collection of embryos from donor females and transfer into recipients, increasing the number of offspring from selected females. This technique involves superovulation, embryo collection, and transfer to recipients (Tappa *et al.,* 1994). Embryo transfer preserves breeds, creates disease-free herds, facilitates economical livestock transport, multiplies elite female breeding stock rapidly, and serves research applications (Betteridge, 2003). Successful embryo transfer programs involve procedures such as donor and recipient selection, embryo handling, evaluation, storage, and practical embryo transfer (Larson *et al.,* 2010). Donor and recipient cow selection are critical for success, focusing on genetic superiority for donors and reproductive soundness for recipients. Proper recipient herd management is essential for success, requiring expertise in recipient selection, nutrition, estrus synchronization, disease management, and marketing (Widayati, 2012; Warriach *et al*., 2015).

Figure 1: The first embryo transfer calf (RAS) in Ethiopia (Tegegne, 1994).

Estrus Synchronization

Estrus synchronization, an alternative to estrus detection, brings female animals to the heat state using hormonal interventions, increasing the probability of estrus detection and facilitating timely insemination for improved conception rates (Paul *et al.,* 2015). Synchronization can be achieved by manipulating the length of the estrus cycle, either by inducing luteolysis using prostaglandin or extending the di-estrus phase through progesterone administration (Worku, 2015). Efficient synchronization strategies contribute to enhanced reproductive outcomes in cows. Synchronization of estrus in cows is feasible by either curtailing or extending the length of estrus cycle, which can be maintained based on two principles; first one is using in-situ luteolytic agent (prostaglandin) that induces luteolysis of corpus luteum (CL) and exogenous administration of such agents mimics premature luteolysis and hence results in shortening of diestrus phase of estrus cycle; whereas, the second principles is lengthening of diestrus phase through maintenance of CL in terms of progesterone production which determines the length of diestrus phase (Figure 2). Hence, with the administration of progesterone hormone, the diestrus phase can be extended (Worku, 2015).

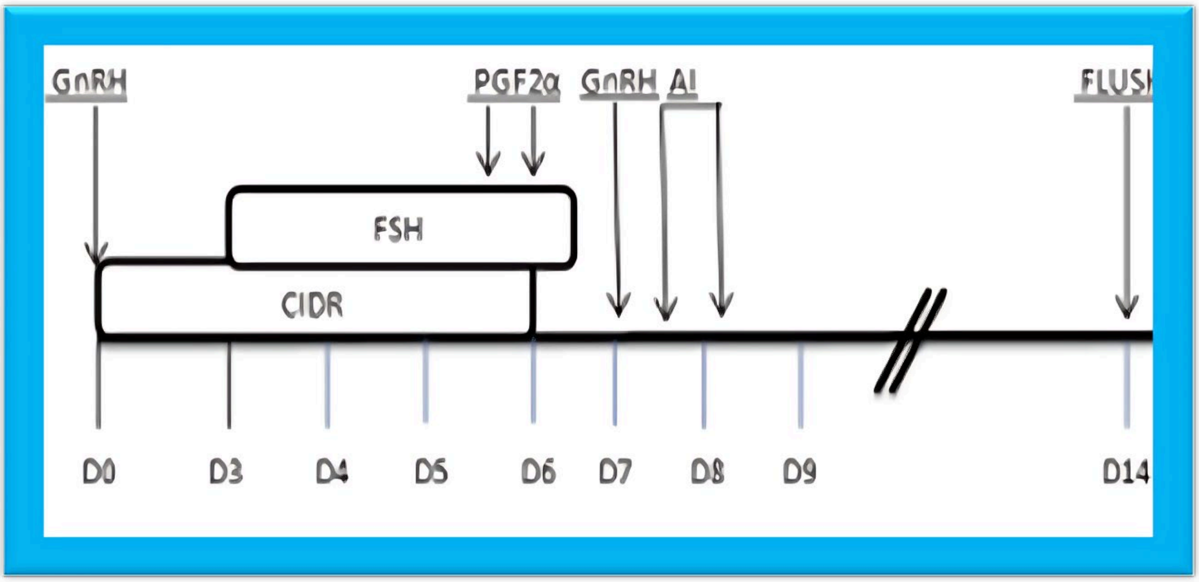

Figure 2: Synchronization of estrus in cows is feasible by either curtailing or extending the length of estrus cycle

Cloning

Cloning, a scientific marvel synonymous with asexual reproduction, unlocks the potential to forge genetic replicas, ensuring the continuity of a single genetic lineage. Employing methods like embryo splitting and nuclear transfer, cloning operates at the microscopic intersection of cellular maturation and gene duplication. The strategic division of embryos during the 6-to 8-cell stage, an art mastered in the realm of in vitro fertilization (IVF), allows for a controlled expansion of genetic diversity, enhancing the arsenal of available embryos (Reik, 2007). Beyond the laboratory, cloning emerges as a sentinel for preserving indigenous livestock breeds. The fusion of cloning with assisted reproduction becomes a guardian of genetic trials and environmental adaptability. It acts as a conduit, swiftly channelling superior genetic blueprints from nucleus breeding flocks to commercial farmers.

In Vitro Fertilization (IVF)

In vitro fertilization (IVF), a testament to human ingenuity, orchestrates the symphony of life outside the confines of the natural womb. With precision akin to a maestro, technicians delicately retrieve unfertilized eggs, incubating them in a controlled environment conducive to life's genesis. The dance of fertilization with sperm, nurtured in vitro, unfolds a narrative of zygotes maturing in laboratory chambers before finding their sanctuary in a recipient cow's womb (Cowan and Becker, 2019). The rhythmic choreography of IVF extends beyond conception, venturing into the realm of sex determination. Techniques such as chromosomal analysis, immunological detection, and ultrasonic examinations dance on the fine line between science and art, shaping the genetic destiny of offspring. A symphony of DNA content disparities orchestrates the separation of X and Y-chromosome-bearing spermatozoa, unveiling possibilities for the deliberate predetermination of offspring sex (Zoheir and Allam, 2010).

Sex Determination

Sex determination, an intricate symphony of molecular precision, unfolds at the embryonic and spermatozoa levels, reshaping the genetic landscape with scientific finesse.

Embryo Sex Determination

In the delicate ballet of embryo sex determination, the orchestra plays to the genetic cues embedded in the Y chromosome. Commercially, a repertoire of techniques graces this stage - from chromosomal analysis of demi-embryos to the eloquent immunological detection of embryonic H-Y antigen. Y-specific probes and Fluorescence in situ hybridization choreograph the genetic narrative, while a rapid sexing method utilizing loop-mediated isothermal amplification (LAMP) conducts a symphony in the pre-implantation embryos of bovine. Ultrasonic examination of fetal structures adds a sonorous note to this genetic composition (Zoheir and Allam, 2010). The predetermination of offspring sex emerges as a beacon, illuminating pathways for tailored genetic improvement. With known sexes of embryos, resource management in ET programs becomes a strategic dance, yielding more heifer calves per ET and paving the way for selecting individuals with superior genetic makeup for the next generation (Plummer and Beckett, 2006). Semen sexing adds another layer to this genetic ballet, intertwining seamlessly with in vitro fertilization (IVF) and artificial insemination (AI) programs, ensuring a harmonious blend of science and reproductive artistry (Zoheir and Allam, 2010).

Semen Sexing

The genetic tapestry extends to semen, where the art of sex determination reaches a crescendo. Semen sexing becomes a process of meticulous separation, dividing spermatozoa into two subpopulations bearing the X and Y chromosomes. This dance of precision employs modified flow cytometric cell sorting of fluorescent dye-loaded living spermatozoa, guided by the nuanced differences in deoxyribonucleic acid (DNA) content—about 3.8% between X and Y-chromosome bearing spermatozoa in cattle.

Enter the stage, Sperm Sexing Technology (SST), revolutionary force empowering livestock producers to predetermine the sex of offspring prior to conception. This technology, a virtuoso performance in genetic potential maximization, profitability, and productivity, aligns with the nuanced preferences in commercial animal breeding. The sexed sperm, a versatile ensemble, takes center stage in artificial insemination or in vivo and in vitro embryo production, shaping the future of livestock genetics (Seidel, 2007; Garner and Seidel, 2008). In this precision-engineered symphony, sex determination emerges not just as a scientific marvel but as a key orchestrator in the grand composition of genetic destiny. It is a saga where genetics meets art, and where the predetermination of sex becomes a powerful brushstroke in the canvas of livestock breeding.

Trans-genesis

Trans-genesis, an alchemical fusion of foreign genes and indigenous genomes, bequeaths us with living canvases altered at the molecular level. These transgenic animals, the result of meticulous DNA micro-injections and electroporation, stride into the realms of both breeding and biomedicine. The genetic tapestry, woven with disease resistance and enhanced traits, elevates livestock to guardians of sustainability and reservoirs of improved genetics (Niemann *et al.,* 2005). In this symphony of genes, transgenic cows emerge as champions, producing milk enriched with specific proteins, contributing to antibacterial resistance. As the orchestra of genetic engineering plays on, the harmonious notes of resistance to mastitis resound, echoing the potential for a new era in livestock production and biomedicine (Van Berkel *et al,* 2002).

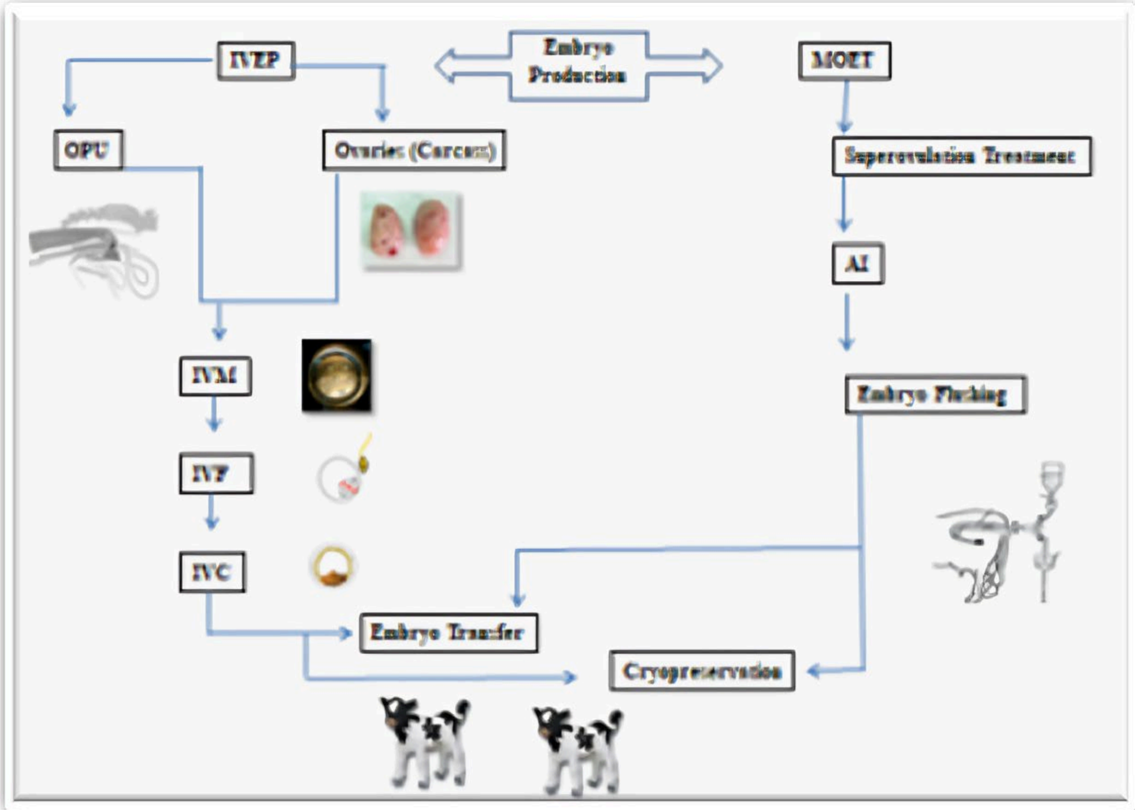

Figure 3: Schematic representation of embryo transfer technology. Note: AI- Artificial Insemination; IVC- In-vitro Culture; IVF- In-Vitro Fertilization; IVEP- In-Vitro Embryo Production; IVM- In-Vitro Maturation of oocytes; MOET- Multiple Ovulation and Embryo Transfer; OPU- Transvaginal Ultrasound-guided Ovum Pick-Up.

Application of Genetic Engineering in Animal Breeding and Genetics

Gene Therapy

A brush dipped in the palette of molecular manipulation, paints a canvas of hope. Whether altering germ-line cells or somatic cells, gene therapy emerges as a beacon in the eradication of hereditary diseases. The genetic ripples created in marmoset monkeys beckon towards a future where diseases are not just treated but expunged from the very fabric of a species (Sasaki *et al,* 2009). As the genetic symphony continues, milk composition becomes a canvas for modification. Unique genes coding for milk proteins are altered, introducing human lactoferrin into bovine milk. The biological alchemy extends to sheep, where the quest for improved wool production becomes a genetic odyssey. Through transgenic manipulation, the very essence of wool is sculpted, from its quality and color to its yield and ease of harvest (Powell *et al,* 1994). In this genetic ballet, where art meets science, the future of animal breeding and genetics unfolds—a tapestry woven with the threads of cloning, in vitro fertilization, sex determination, and trans-genesis. It is a narrative where science and nature dance hand in hand, scripting the genetic destiny of tomorrow's livestock.

Increases Milk Composition

Genetic modification has been employed to alter milk composition in transgenic cows. For instance, introducing human lactoferrin into bovine milk enhances iron transport and inhibits bacterial growth (Van Berkel *et al.,* 2002). Additionally, expressing antibacterial substances like proteases aims to increase mastitis resistance, altering concentrations of proteins such as lysozyme and transferrin in the milk (Felmer, 2004).

Improving Wool Production

Efforts to enhance sheep wool production involve modifying fiber properties. Initially focusing on increasing cysteine production for wool synthesis, later approaches explored manipulating fiber quality, length, and fineness using transgenic methods (Murray *et al.,* 199). Future endeavors aim to focus on the surface of fibers to decrease garment shrinkage (Powell *et al.,* 1994; Bawden *et al.,* 1999).

Enhancing Growth Rates and Carcass Composition

Transgenic technology enables the manipulation of growth factors, receptors, and modulators to influence postnatal growth in mammals. Incorporating genes related to growth hormone (GH) and IGF in transgenic sheep and pigs has been explored. However, challenges with promoter control and varied results indicate the need for more precise transgene expression control (Murray *et al*., 1999; Adams *et al.,* 2005).

Vaccine Production

Recombinant vaccines fall into three categories: live genetically modified organisms, recombinant inactivated vaccines, and genetic vaccines (Ellis, 1999). Live genetically modified vaccines involve viruses or bacteria with genes deleted or carrying foreign genes. Recombinant inactivated vaccines are subunit vaccines containing part of the organism, while genetic vaccines consist of DNA injected into the target animal (Asaye *et al*., 2014; Rodriguez and Whitton, 2000; Streatfield, 2005; Uzzau *et al*., 2005).

Improving Reproductive Performance

Identification of genes like estrogen receptor (ESR) and Boroola fecundity (FECB) genes provides opportunities to enhance reproductive performance. Introducing mutated ESR genes can increase litter size in pigs, while the FECB gene in Merino sheep increases ovulation rate (Rothschild *et al*., 1994; Piper *et al.,* 1985; Gottlieb and Wheeler, 2007).

Increasing Resistance to Disease

Genetic selection and engineering contribute to disease resistance in animals. Genetic engineering allows the integration of disease resistance genes, enhancing overall animal health and reducing the incidence of transmissible diseases. Approaches include introducing resistance-conferring gene constructs and depleting susceptibility genes or loci (Pohlmeier and Van Eenennaam, 2009; Müller and Brem, 1998).

Agricultural Applications

Genetic engineering in agriculture has found practical applications, such as the use of recombinant bovine somatotropin (BST) derived from genetically engineered bacteria. This protein, which increases milk production in lactating cows, is widely used in the U.S. dairy industry. Notably, administering r-BST does not modify the DNA of cows, and they do not become genetically engineered. The FDA approved BST in 1993, following extensive testing with no identified health or safety concerns for consumers (Bauman, 1999).

Modern animal Breeding and Genetic Technology in Ethiopia

In Ethiopia, genetic improvement through crossbreeding has been introduced in the past four decades, involving distribution of crossbred heifers, artificial insemination services, and bull service stations. Despite these efforts, uncontrolled cattle breeding in Ethiopia hampers the establishment and application of appropriate bull selection criteria, impeding genetic improvement (Ahmed, 2003; Gebremedhin, 2008). The National Artificial Insemination Center (NAIC) in Kaliti has played a crucial role in producing and distributing cattle semen, primarily from selected exotic sires (NAIC, 1995). Artificial insemination (AI) has been operational in Ethiopia for over 30 years, contributing to genetic improvement. Efforts to refine super ovulatory regimes for Boron cattle and the production of identical twins using embryo-splitting techniques have been undertaken. However, the efficiency and impact of AI operations have not been well-documented (Engidawork, 2012; Tegegne *et al.,* 1994).

Sexed semen is increasingly used for specific breeding purposes, primarily in virgin heifers, aiming to optimize calf sex and overall productivity (Anonymous, 2008). Despite the potential benefits of reproductive biotechnologies, constraints such as lack of financial, human, and technical resources hinder their systematic transfer to the national agricultural research and extension system in Ethiopia. However, on-going efforts aim to apply multiple ovulation and embryo transfer technology using indigenous breeds (Abraham, 2009).

Modern Application of Animal Breeding and Genetic Technology in Dairy Cattle

The main objectives of using animal breeding and genetic technologies in livestock, particularly dairy cattle, include increasing production, productivity, reproductive efficiency, and rates of genetic improvement. Artificial insemination (AI) and semen preservation are extensively used technologies, reducing disease transmission, improving pedigree recording, and minimizing the cost of introducing improved genetics (Wilmu *et al.,* 1997; ISAAA, 2012).

Additional reproductive technologies such as assessing sperm fertilization capacity, sexing sperm, synchronization, fixed-time insemination, superovulation, embryo transfer (ET), and in vitro embryo production (IVEP) can further enhance reproductive efficiency and pregnancy rates (Madan, 2002). AI and MOET (multiple ovulation and embryo transfer) accelerate genetic progress, reduce disease transmission risk, and allow for the breeding of more animals from superior parents (FAO, 2004). In urban and peri-urban farming environments, AI services have proven advantageous for dairy farmers who may face challenges in keeping a bull for breeding. The use of exotic milking cattle breeds and AI services started in the 1960s in Uganda (Nakimbugwe, 2004). Animal cloning serves to preserve the desirable phenotype of genetically elite animals, particularly males, ensuring the sustainability of high-quality and safe food production. Cloning allows farmers to replicate the best animals in their herds, upgrading overall herd quality (FDA, 2014). Embryo transfer procedures have been instrumental in diagnosing, treating, and salvaging reproductive function in so-called infertile cows. Committees like the Health and Safety Advisory Committee contribute to the scientific understanding and dissemination of information on disease control through bovine embryo transfer (Gordon & Lu, 1990; Gray *et al.,* 1991).

Drawbacks And Challenges in Animal Breeding and Genetic Technology

Issues Related to Management

In the realm of reproductive technologies, the effective management of procedures is crucial (Gordon, 2004). However, challenges arise, notably in terms of cost implications for farmers. The success of adopting new procedures, such as artificial insemination, is closely linked to the management expertise within a cattle enterprise. Mismanagement of artificial insemination can lead to the spread of diseases and genetic defects, emphasizing the need for meticulous procedures during semen collection to avoid contamination. Detection of heat remains a significant challenge in AI programs, affecting reproductive performance, especially in periods of stress caused by inadequate nutrition or high milk yield (Nebel and Jobst, 1998; Rodriguez *et al.,* 2008).

The Issue of Animal Welfare in Animal Breeding and Genetic Technology

The implementation of reproductive technologies raises ethical concerns regarding animal welfare (Kruip *et al.,* 1994). Multiple ovulation induction in cattle and sperm collection in artificial insemination subject’s animals to potential pain and frustration.

Additionally, non-surgical embryo transfers, while common, pose risks of uterine horn piercing and require epidural anaesthesia, which, if administered poorly, can result in paralysis. The process of super ovulating donor animals through hormone injections and reproductive tract insertions adds physical and physiological burdens to the animals (Joyce and Peter, 1995).

Issues Related to Environment

Genetic technology in agriculture poses potential risks to the environment, including unintended effects on non-target organisms, ecosystems, and biodiversity (Sears, 2003). Insect-resistant genetically modified crops, for instance, may have detrimental effects on beneficial insects and induce resistance in harmful ones, impacting the delicate balance of ecosystems.

Religious, Cultural, and Ethical Issues

The rapid advancements in biotechnology and genetic engineering raise concerns about their impact on religious, cultural, and ethical values (Curran and Koszarycz, 2004). Questions arise about the constructive use of these technologies without compromising fundamental ethical principles, such as respect for human life. Genetic engineering that breaches species barriers or interferes with the inherent nature of animals is particularly contentious. Public opinion reflects discomfort with the idea of genetically engineering animals, and ethical concerns revolve around the potential commodification of life for economic gain (Brunk and Coward, 2009; Van Eenennaam, 2008).

Issues Related to Economy

The establishment of biotechnology companies is contingent on adequate infrastructure, posing a challenge, especially in developing countries (Tonukari, 2004). While research and development budgets for biotechnology are increasing, start-up funding remains scarce. Overcoming these economic challenges necessitates avenues such as seed funding, improved access to loans, and venture funds to facilitate the early stages of business development in the biotechnology sector.

CONCLUSION

In conclusion, the integration of modern animal breeding and genetic technologies into livestock farming represents a dynamic and transformative shift in agricultural practices. This comprehensive exploration has delved into the crucial role of livestock farming in global agriculture, emphasizing its impact on vulnerable communities, nutrient provision, and support for crop cultivation. The 'livestock revolution' has been evident, with rising consumption of animal products and projections indicating significant growth in meat and milk consumption, particularly in developing countries.

Reproduction, as the cornerstone of animal production, remains a critical focus, with persistent challenges like low conception rates and high embryonic mortality. To meet the evolving needs of agriculture, researchers are increasingly turning to emerging technologies, particularly modern reproductive biotechnologies and genetic engineering methods. Artificial insemination, embryo transfer, in vitro fertilization, cloning, and transgenesis are among the techniques developed to enhance breeding efficiency, overcome infertility, and control diseases. These technologies aim to reduce generational intervals and propagate genetic material among breeding populations. The commercialization of reproductive technologies, including sperm separation techniques like sex-sorting, and the rise of genetic engineering, present new avenues for manipulating organisms and populations. Despite the challenges posed by the complexity of mammalian genomes, genetic modification of animals holds potential benefits, from gene therapy to addressing genetic diseases. The primary objectives of this review have been to explore and evaluate modern animal breeding and genetic technologies, considering their applications, implications, and potential contributions to advancing livestock farming practices. The literature review has provided insights into the roles of modern animal breeding and genetic technology in animal production and productivity. Biotechnology, defined as the use of living organisms to modify and enhance products, has driven the development of reproductive technologies. These technologies aim to increase the number of offspring from genetically superior animals, safeguard the genetic pool of infertile or sub-fertile animals, and contribute to broader genetic improvement. Techniques such as artificial insemination, multiple ovulation and embryo transfer, estrus synchronization, cloning, and in vitro fertilization play vital roles in achieving these objectives. The document has further explored the specific methods and technologies, such as artificial insemination, multiple ovulation and embryo transfer, estrus synchronization, cloning, in vitro fertilization, sex determination, semen sexing, and trans-genesis. Each of these technologies has been discussed in detail, shedding light on their applications and implications in animal breeding. From enhancing reproductive efficiency to predetermining the sex of offspring, these technologies form a symphony that orchestrates the genetic destiny of livestock. Challenges and opportunities in the application of these technologies have been thoroughly examined. Ethical concerns, social and cultural barriers, regulatory hurdles, environmental impacts, and economic constraints are among the challenges that need careful consideration. On the other hand, opportunities lie in increased productivity and efficiency, genetic diversity preservation, disease resistance and control, improved livelihoods, and scientific advancements. The document has also highlighted the specific challenges related to management, animal welfare, environment, religious and cultural issues, and economic factors. Issues such as cost implications, disease spread, and heat detection challenges in artificial insemination, as well as ethical concerns regarding animal welfare in reproductive technologies, require attention. Environmental impacts, cultural sensitivities, and economic challenges, especially in developing countries, add layers of complexity to the adoption of these technologies. Looking ahead, future directions and mitigation strategies have been proposed to address these challenges and capitalize on the opportunities. Improving management practices through education and training, enhancing animal welfare standards, prioritizing sustainable environmental practices, respecting cultural and ethical values, and promoting inclusive economic models are key aspects of these strategies. In summary, the landscape of animal breeding and genetic technology is evolving rapidly, offering immense potential for advancing agriculture. However, a balanced and holistic approach, considering ethical, social, environmental, and economic dimensions, is essential to ensure the responsible and sustainable application of these technologies. The harmonious integration of scientific innovation with ethical considerations will shape the genetic destiny of tomorrow's livestock, contributing to a resilient, efficient, and humane agricultural future.

ACKNOWLEDGEMENT

We extend our heartfelt gratitude to Dembi Dollo University for their generous sponsorship, enabling the first author to pursue his PhD study at Haramaya University. This support has been instrumental in facilitating valuable academic and research endeavours, for which we are truly thankful.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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