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NARRATIVE REVIEW: DEVELOPMENTS IN ANIMAL GENETIC ENGINEERING AND ANIMAL DNA REPLICATION

Dirga Anugrah Mokoginta*[1], Sekar Ayu Kedaton[2], Aulia Nisfatuzzahra[3], Beatrix Magdalena Ottay[4], Deya Arisca Tuina[5], Beby Triana Arafah Z. Muis[6]
[1,2,3,4,5,6] Gorontalo State of University, Gorontalo, Indonesia
*Corresponding Author: wiwit@ung.ac.id

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Abstract: *DNA (Deoxyribonucleic Acid) is the primary genetic material responsible for heredity, regulation of cellular activities, and protein synthesis through DNA replication and gene expression. This study aims to review the roles of DNA, DNA replication, and gene expression in supporting the success of animal genetic engineering. The method employed was a literature review of national and international scientific publications from 2016 to 2023 obtained through Google Scholar using keywords related to genetic engineering, animal biotechnology, and DNA replication. The results indicate that recombinant DNA technology and transgenesis have successfully improved productivity, product quality, and disease resistance in animals, such as transgenic fish expressing growth hormone genes and transgenic goats overexpressing antithrombin III (ATIII). DNA replication ensures the stability of modified genetic traits, while gene expression determines the successful production of functional proteins. However, the application of animal genetic engineering requires careful consideration of biosafety, ethics, animal welfare, and environmental impacts. Overall, a comprehensive understanding of DNA molecular mechanisms supports the sustainable development of animal biotechnology.*

Abstrak: DNA (Deoxyribonucleic Acid) merupakan materi genetik utama yang berperan dalam pewarisan sifat, pengaturan aktivitas sel, serta sintesis protein melalui proses replikasi dan ekspresi gen. Penelitian ini bertujuan untuk mengkaji peran DNA, replikasi DNA, dan ekspresi gen dalam mendukung keberhasilan rekayasa genetika pada hewan. Metode yang digunakan adalah studi literatur dengan menelaah publikasi ilmiah nasional dan internasional periode 2016–2023 yang diperoleh melalui Google Scholar. Hasil kajian menunjukkan bahwa teknologi DNA rekombinan dan transgenesis mampu meningkatkan produktivitas, kualitas produk, serta ketahanan penyakit pada hewan, seperti ikan dan kambing transgenik. Replikasi DNA berperan dalam menjaga stabilitas genetik hasil modifikasi, sedangkan ekspresi gen menentukan keberhasilan produksi protein fungsional. Meskipun demikian, penerapannya memerlukan perhatian terhadap aspek etika, keamanan, kesejahteraan hewan, dan dampak lingkungan. Secara keseluruhan, pemahaman mekanisme molekuler DNA mendukung pengembangan bioteknologi hewan yang berkelanjutan.

INTRODUCTION

DNA (Deoxyribonucleic Acid) is a molecule that stores genetic information that regulates the growth, development, and biological functions of organisms. This genetic information is stored in a sequence of nucleotides that determines the shape and function of proteins. Az Zahra et al. (2025) explain that DNA acts as the center of protein synthesis regulation through the stages of transcription and translation, so that changes in DNA can affect cellular activity and the phenotype of organisms. The understanding of DNA as hereditary material is also reinforced in human genetics studies, which show that the structure of DNA nucleotides forms the basis for biological traits (Rohman & Ulfah, 2017).

DNA replication is a semi-conservative process of duplicating DNA molecules, in which one old strand serves as a template for the formation of a new strand. This process ensures the continuity of genetic information from parent cells to daughter cells. According to Aisyah (2023), DNA replication involves various enzymes such as helicase, primase, and DNA polymerase, which ensure accurate duplication. An academic module on DNA replication (Fauziah, 2017) also emphasizes that replication is a fundamental function of DNA as hereditary material that enables the stable inheritance of traits in eukaryotic and prokaryotic organisms.

The relationship between DNA and DNA replication is fundamental, because replication is the main way of maintaining genetic information continuity. This process begins with the opening of the DNA double helix by the helicase enzyme, so that the two DNA strands separate and each functions as a template for the formation of new strands. The DNA polymerase enzyme then assembles new nucleotides based on the rules of complementary base pairing, namely adenine pairs with thymine and guanine with cytosine, resulting in the formation of two new DNA molecules, each consisting of one old strand and one newly synthesized strand. This mechanism is known as semi-conservative replication, which ensures the accuracy of genetic information copying. Without proper and controlled replication, DNA cannot be inherited stably, so tissue growth, cell repair, and trait inheritance in organisms cannot proceed normally. Thus, DNA and DNA replication have an inseparable relationship (Aisyah, 2023).

Gene expression is the process by which information in DNA is translated into RNA and functional proteins. Gene expression regulation determines when a gene is active and how much product is produced. Maritska et al. (2021) state that the regulation of transcription, translation, and post-translational modification stages greatly determines cell differentiation, phenotype, and adaptive responses of organisms. Tahmasebi et al. (2019) also emphasize that protein synthesis is a tangible form of gene expression, which converts DNA instructions into molecular structures that perform biological functions.

Genetic engineering is essentially a genetic manipulation technique that allows DNA modification, both within a single organism and between different organisms. Mahrus (2014) defines genetically modified organisms as transgenic organisms or genetically modified organisms (GMOs), which often have superior traits compared to their original organisms. This definition is in line with the description by Sutrisno and Wardani (2023), who explain that genetic engineering uses recombinant DNA technology to insert, alter, or combine new genes to produce organisms with specific characteristics.

In modern biotechnology practices, recombinant DNA technology is used to insert new genetic material into host cells so that genes can be multiplied and expressed. Harahap et al. (2024) show that the use of microbial fermentation and medium optimization can increase protein production in certain expression systems. This technology is the foundation for more complex genetic engineering, including the development of transgenic organisms. In the livestock sector, genetic engineering is used to improve the genetic quality of livestock through gene marker analysis and gene expression manipulation (Bilyaro et al., 2023). In the aquaculture sector, Sari (2021) reports that the integration of growth genes in farmed fish increases growth rates and production efficiency through stable recombinant gene expression.

Thus, DNA replication and expression are not only basic concepts in molecular biology, but also the main foundation for the success of genetic engineering. Replication ensures the stability of modified gene inheritance, while gene expression determines whether the gene is capable of producing the desired functional protein. A deep understanding of these two mechanisms enables the more effective and targeted use of genetic engineering in aquaculture, animal husbandry, health, and the modern biotechnology industry.

METHOD

This study uses a literature review method by examining various relevant scientific publications related to the development of genetic engineering in animals. Literature sources were obtained from national scientific databases, including Google

Scholar, with a publication range of 2016-2023 to ensure the relevance and currency of the information. The search process was conducted using a combination of keywords such as Genetic Engineering, Animal Biotechnology, and Animal DNA Replication. Literature selection was based on relevance to the topic, data completeness, and research methodology quality. All selected sources were then analyzed descriptively and comparatively to identify developments in genetic engineering in animals.

RESULTS AND DISCUSSION

Results

Table 1. Developments In Animal Genetic Engineering And Animal DNA Replication

No	References	Research Focus	Key Findings	Synthesis	Development
1.	Sari, D. U. (2021)	Genetic engineering in farmed fish.	The use of growth hormone (GH) where GH transgenic fish show higher growth.	Recombinant DNA techniques and microinjection and electroporation methods are effective for accelerating the formation of superior strains compared to conventional selective breeding methods.	Further research developments are aimed at improving the efficiency of transgenesis, gene expression stability, and assessing safety, ethical, and environmental impact aspects to ensure the sustainable application of this technology in the aquaculture sector.
2.	Sutarno, (2016)	Genetic engineering in the livestock sector	The application of genetic engineering, recombinant DNA technology, marker-assisted selection (MAS), cloning, artificial inseminat ion, embryo trans fer, and livestock production	Genetic manipulation techniques enable the targeted insertion of superior traits across species, while also improving the efficiency of genetic selection in livestock breeding programs.	optimization of transge nesis and cloning techn iques, livestock genome mapping, expansion of MAS use, and utilizat ion of recombinant DNA to produce livest ock with high producti on performance and disease resistance.
3.	Yan, *et al* (2023)	Genetic Engineerin g In Goats	ATIII transgenic goats showed normal physiologi cal and biochemical conditions, improv ed milk quality, and lower inflammatory responses (IL-6, TNF-α, IFN-β ↓) after LPS compared to controls (WT).	Overexpression of ATIII has been proven to be physiologically safe and effective in enhancing immune resistance and livestock product quality.	Further research will focus on elucidating the molecular mechanism of ATIII, long-term safety testing, and ethics.

In the first journal Genetic modification, commonly referred to as Genetically Modified Organism (GMO), is the manipulation of an organism's genes using biotechnology. In the context of aquaculture, the result of genetic engineering in the form of fish whose genetic material has been altered is called transgenic fish, which allows for the combination or recombination of genes from different sources in vitro. The production of transgenic organisms in aquatic species began in 1984 with rainbow trout and in 1985 with carp. Since then, many other species have been made into GMOs, including Atlantic salmon and coho salmon, tilapia, catfish, medaka, and zebrafish.

One of the tangible and significant results of genetic engineering is in research focusing on growth hormone (GH). Studies conclude that GH transgenic fish show much higher growth rates than non-transgenic fish, which clearly offers economic benefits for aquaculture. Growth hormone has even become the most frequently used gene as a target gene in the transgenesis process. In addition to increased growth, genetic manipulation has also been used to improve fish resistance to pathogens, as well as to modify behavior and control the fertility of aquaculture organisms.

The main technique used to produce transgenic fish is microinjection into fertilized eggs or early embryos. However, the process of transgenesis is known to be relatively inefficient. It is said that out of a hundred microinjected eggs, only one is successful, in which the inserted recombinant DNA sequence cooperates stably. Other alternatives to gene transfer methods that have also proven successful include sperm electroporation, which has been applied to zebrafish and Chinook salmon, as well as the use of vectors such as liposomes and pantropic retroviral vectors.

In aquaculture development, the production of transgenic organisms offers great opportunities for more efficient and effective cultivation. However, the application of GMOs also requires serious attention to four main issues: human health (risk of allergies or pathogens), biodiversity (risk of damaging ecosystems and eliminating native species), animal welfare (risk of reduced quality of life and anatomical damage), and the impact on poor communities (issues of economic value, patent rights, and strain competition). This second journal discusses developments in biotechnology, particularly genetic engineering, and its application in animal husbandry to improve livestock productivity and quality. Biotechnology is described as the use of biological systems, both whole organisms and their cellular components, to produce products that are beneficial to humans. In the context of animal husbandry, the development of modern biotechnology is inseparable from advances in molecular genetics, which enable the targeted manipulation of DNA to obtain superior traits in livestock.

One specific animal discussed in detail in this journal is sheep, particularly through the example of Dolly the sheep, which was produced using cloning techniques involving nuclear transplantation. The success of cloning this sheep demonstrates that somatic cell nuclei can be used to produce new individuals that are genetically identical to their parents. In addition, the journal also describes the development of transgenic sheep that have been inserted with human genes, such as factor VIII genes, so that the sheep's milk contains blood-clotting proteins that are useful for treating hemophilia patients. This shows that sheep not only play a role as food producers, but also as bioreactors that produce therapeutic proteins.

Besides sheep, cattle are also widely discussed in this journal, especially in the context of transgenic cattle and increased milk production. Genetic engineering in cattle is carried out through the technique of microinjecting DNA into a single-cell embryo, which is then implanted into the recipient mother's uterus. Through this approach, cattle with faster growth rates, better meat quality, and the ability to produce high quantities of milk are produced. The journal also explains the use of bovine somatotropin hormone produced through genetically engineered Escherichia coli bacteria to increase cow milk production by about twenty percent, although its use still raises debates regarding livestock health. Other animals mentioned in the journal are mice, which are used as model animals in genetic and veterinary research. Transgenic mice are used to study gene function, disease mechanisms, and test new therapies before they are applied to large livestock or humans. In addition, the journal also mentions the use of animals such as rabbits, pigs, and zebras in the context of developing transgenic technology and preserving rare species, for example through cross-species surrogate mother techniques.

Overall, this journal confirms that the application of genetic engineering in livestock such as sheep, cattle, and mice has great potential in increasing livestock production efficiency, providing important medical materials, and supporting species conservation. However, the journal also suggests the need for ethical considerations, animal health, and long-term impacts before this technology is widely applied in modern livestock systems. In this third journal, research was conducted using Laoshan dairy goats as test animals, a type of dairy goat commonly used in research and milk production. The goats used were approximately three years old and were divided into two groups, namely transgenic goats that overexpressed antithrombin III or ATIII in the mammary glands and normal goats as controls. The main objective of this study was to assess whether ATIII overexpression affected the general health of the animals, milk quality, and inflammatory response when the goats were stimulated with lipopolysaccharide or LPS, which simulates bacterial infection.

The results of the study indicate that ATIII overexpression in the mammary gland does not cause disturbances in the physiological condition of dairy goats. Blood parameters such as white blood cell count, red blood cell count, hemoglobin levels, and biochemical indicators such as total protein, cholesterol, urea nitrogen, uric acid, and total bilirubin were within normal ranges and did not differ significantly from those of control goats. This indicates that genetic modification in Laoshan dairy goats is safe and does not have a negative impact on the systemic health of the animals. In addition to being safe, ATIII overexpression also has a positive impact on the quality of milk produced. Milk from transgenic goats has higher fat and dry matter content compared to normal goats. In addition, the number of somatic cells in transgenic goat milk is lower, indicating healthier mammary glands and a lower risk of mastitis. Thus, ATIII expression in the mammary glands not only functions biologically, but also contributes to improving the quality of goat milk.

When goats were given LPS injections to trigger an inflammatory response, transgenic goats showed a better and more controlled immune response. Immunoglobulin levels such as IgA and IgM were higher in goats expressing ATIII than in control goats, indicating an increase in the body's defense against pathogens. At the same time, levels of proinflammatory cytokines such as IL-6, TNF alpha, and IFN beta were lower in transgenic goats. This indicates that ATIII plays a role in suppressing excessive inflammatory reactions that can damage tissue. Examination of ear tissue at the LPS injection site showed no severe local inflammation in either group of goats. In addition, analysis of the gut microbiota using 16S rDNA sequencing showed that the composition of the gut microflora of transgenic goats was relatively similar to that of normal goats. These findings indicate that ATIII overexpression does not disrupt the balance of the gut microbiota, which plays an important role in maintaining animal health and the immune system.

Overall, this study shows that Laoshan dairy goats with overexpression of ATIII in the mammary gland remain in good health, produce higher quality milk, and have a more effective anti-inflammatory response to LPS stimulation. These results support the potential use of transgenic goats as a large animal model for inflammation research and as a biotechnology platform for the development of therapeutic proteins and the improvement of dairy cattle quality and health.

CONCLUSION

Developments in animal genetic engineering and the understanding of animal DNA replication have shown remarkable progress over recent decades. Genetic engineering enables precise manipulation of genetic material through recombinant DNA technology, gene expression control, and other genetic modification techniques, contributing significantly to improved livestock productivity, enhanced product quality, increased disease resistance, and the development of animal models for biomedical research. At the same time, a comprehensive understanding of DNA replication mechanisms in animals serves as a fundamental basis for the successful application of genetic engineering. Accurate and well-regulated DNA replication ensures genetic stability, supports normal cell division, and minimizes harmful mutations. The integration of DNA replication knowledge with genetic engineering techniques allows for more precise and sustainable control of gene expression. Despite these advancements, the application of genetic engineering in animals continues to face challenges, including ethical concerns, biosafety issues, animal welfare considerations, and potential long-term impacts on the environment and human health. Therefore, the development of this technology must be accompanied by strict regulatory frameworks, ethical considerations, and continuous scientific evaluation. Overall, advances in animal genetic engineering supported by a deeper understanding of DNA replication hold great potential for enhancing food security, advancing scientific research, and driving innovation in health-related fields, provided that these technologies are applied responsibly and sustainably.

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