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Integration Stability and Phenotypic Regulation in Genetically Engineered Livestock from a Molecular Ecology Perspective

Qibin Xu
Animal Science Research Center, Cuixi Academy of Biotechnology, Zhuji, 311800, Zhejiang, China
Corresponding author: Qibin.xu@cuixi.org
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Abstract This study systematically analyzes the genetic stability and phenotypic evaluation framework of transgenic livestock, providing a comprehensive overview of key technologies for phenotypic data collection and analysis. It focuses on the integration patterns of exogenous genes within host genomes, the effects of copy number variation, and the stability of gene expression across generations. Through case studies on transgenic cattle and pigs, the research reveals a strong correlation between genetic stability and phenotypic consistency. The results indicate that combining non-viral vectors with gene-editing technologies not only facilitates long-term stable gene expression but also effectively ensures physiological health and production reliability in livestock. This study offers a solid theoretical foundation and methodological support for the safety assessment and industrial application of transgenic livestock.
Keywords Transgenic livestock; Genetic stability; Phenotypic evaluation; Gene editing; Multi-omics integration

1 Introduction

With the rapid advancement of molecular biology and genetic engineering technologies, transgenic technology has become an essential tool in modern livestock breeding. It offers unprecedented opportunities to improve production performance, disease resistance, and the quality of animal products (Wheeler and Walters, 2001; Laible et al., 2015; Hryhorowicz et al., 2020). By introducing exogenous genes into animal genomes, scientists can endow livestock with new economic traits, such as accelerated growth rate, improved feed conversion efficiency, enhanced disease resistance, or superior product quality (Laible et al., 2015; Shaukat, 2021). For instance, transgenic cows can produce milk enriched with specific nutrients, while transgenic pigs are widely used in human disease modeling and xenotransplantation studies (Hryhorowicz et al., 2020; Park, 2023). These groundbreaking achievements have not only transformed livestock production systems but also provided new insights into biomedicine, food safety, and ecological sustainability. However, the research and application of transgenic livestock face critical scientific challenges related to genetic stability and phenotypic consistency, which pose obstacles at the technical, ethical, and regulatory levels (Laible et al., 2015; Eriksson et al., 2018).

Genetic stability serves as the foundation of transgenic livestock research, determining the accuracy and long-term controllability of exogenous gene transmission across individuals and generations (Van Cott et al., 1997; Yum et al., 2018). If the insertion site of an exogenous gene in the chromosome is unstable or if copy number variations and epigenetic modifications occur, this may lead to gene silencing, expression deviation, or undesirable phenotypes, thereby compromising the reliability of research results and the predictability of animal performance (Pursel et al., 1989; Evangelou et al., 2018). For example, studies have shown that certain transgenic pigs initially exhibit the desired disease resistance, but this trait diminishes in subsequent generations, suggesting that the exogenous gene may be influenced by epigenetic regulation or genomic rearrangement (Yum et al., 2018). Similar phenomena have been observed in transgenic sheep and goats, where expression levels of milk protein genes vary among individuals (Van Cott et al., 1997; Evangelou et al., 2018). Therefore, systematic evaluation of genetic stability in transgenic livestock not only helps elucidate the integration behavior of exogenous genes within host genomes but also provides theoretical guidance for improving gene-editing strategies and transformation efficiency (Laible et al., 2015; Wang et al., 2022).