

Table 1 Comparison of different transgenic vector methods

Method	Efficiency	Control of Integration Site	Safety Risk	Typical Applications
Microinjection	Low	Random	Risk of uncontrolled insertion sites	Early models of mice, pigs, and cattle
Viral Vector	Medium	Random but stable integration	Risk of insertional mutagenesis	Transgenic large animals
Gene Editing (CRISPR)	High	Site-specific	Controllable off-target risk	Disease-resistant pigs, transgenic cattle, chickens

## 2.2 Major application areas

Transgenic livestock technology demonstrates broad and profound application potential in both agriculture and biomedicine. In growth performance improvement, the introduction of genes regulating growth hormone (GH) or insulin-like growth factor (IGF) can significantly enhance animal growth rate and feed conversion efficiency (Niemann and Kues, 2003). In disease resistance enhancement, researchers have successfully developed livestock resistant to specific pathogens by introducing antiviral or immune-related genes. For instance, transgenic cattle carrying the NRAMP1 gene exhibit remarkable resistance to tuberculosis, while pigs expressing interferon show improved defense against viral infections compared with conventional breeds.

In terms of product quality optimization, transgenic techniques can regulate metabolic pathways involving milk proteins, fatty acids, and amino acids, enabling the production of dairy and meat products with higher nutritional value and enhanced functionality (Wheeler and Walters, 2001).

Moreover, transgenic livestock are widely used as animal bioreactors for the efficient production of pharmaceutical proteins. Cows and goats capable of expressing recombinant human antithrombin III, insulin, or human serum albumin in their milk have become essential platforms for the continuous production of high-value biopharmaceuticals (Bertolini et al., 2016).

## 2.3 Ethical and regulatory challenges arising from technological development

Despite the significant scientific and economic value brought by transgenic livestock technology, its development continues to raise complex ethical debates and regulatory challenges.

On the ethical level, public concerns focus on issues such as animal welfare, the naturalness of life, and potential health risks (Eriksson et al., 2018). Early studies revealed that some transgenic animals exhibited reduced fertility and immune system disorders during experiments, sparking ethical reflections on the boundaries of biotechnological intervention in living organisms.

On the regulatory level, policy orientations differ significantly across countries. The United States and Europe typically adopt risk-based regulatory frameworks, emphasizing the properties and safety of the final product; whereas Asian regions tend to prioritize process-based supervision and ethical review (Bertolini et al., 2016). In China, research and commercialization of transgenic livestock are approached with prudence, following the guiding principle of “scientific research first, regulation in parallel”, which emphasizes both technological innovation and strict oversight.

## 3 Theoretical Basis of Genetic Stability

### 3.1 Definition and importance of genetic stability

Genetic stability refers to the ability of an exogenous gene to maintain structural integrity, a relatively constant level of expression, and stable transmission to offspring according to genetic laws across generations within the host genome. Its connotation encompasses three aspects: structural stability (absence of unintended mutations, rearrangements, or deletions), expression stability (absence of sustained silencing or abnormal fluctuations), and transmission stability (following Mendelian segregation and predictable inheritance in populations) (Yum et al., 2018; Yum et al., 2024).