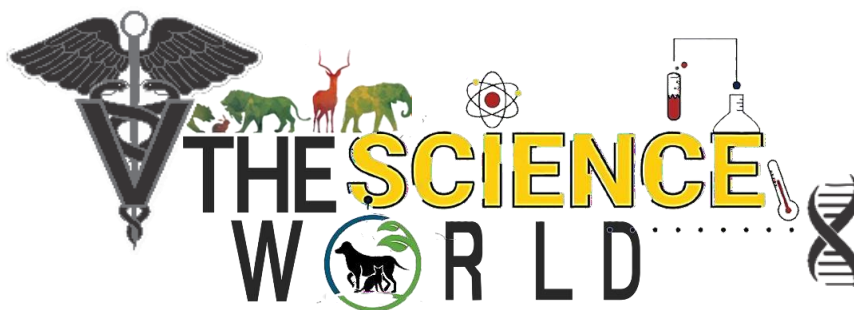




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Applications of Nutrigenomics in Modern Animal Science and Nutrition

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Abstract

Nutrigenomics is an emerging field that investigates how dietary nutrients and bioactive compounds influence gene expression, metabolic pathways, and physiological functions in animals. Advances in functional genomics and high-throughput technologies, including transcriptomics, proteomics, and metabolomics, have improved understanding of nutrition–gene interactions. These approaches help explain the effects of diet on growth, production efficiency, reproduction, immunity, disease resistance, and animal-product quality. Integrating molecular information can support precision feeding strategies tailored to genetic background and physiological requirements. Despite its potential, challenges related to data complexity, analytical methods, and multi-omics integration remain. Continued technological advances may facilitate the practical application of nutrigenomics in sustainable livestock production.

Keywords: Nutrigenomics; gene expression; animal nutrition; transcriptomics; proteomics; metabolomics; precision feeding

Introduction

Nutrigenomics examines how dietary components regulate gene expression and cellular functions, providing a molecular understanding of the relationship between nutrition and animal health [1,2]. Unlike conventional nutrition, which primarily focuses on nutrient requirements and physiological responses, nutrigenomics investigates the mechanisms through which nutrients influence metabolic pathways and phenotypic characteristics.

Nutrients and bioactive compounds can act as signaling molecules, modifying transcription factors, protein synthesis, enzyme activity, and metabolite production [7]. These responses are



influenced by genetic variation, which affects nutrient absorption, metabolism, utilization, and physiological adaptation. Therefore, understanding diet–gene interactions is essential for explaining differences in animal responses to similar feeding strategies.

The development of high-throughput technologies has expanded nutrigenomic research through transcriptomics, proteomics, and metabolomics. These approaches characterize changes in gene expression, protein abundance, and metabolic activity, respectively. Their integration provides a comprehensive understanding of nutritional responses and supports the development of targeted feeding strategies.

1. Interaction Between Diet and Genetic Background

Animals with different genetic backgrounds may respond differently to identical diets. Nutrigenomics helps identify these differences by examining how feed ingredients, supplements, and bioactive compounds influence gene expression and metabolic pathways. Such information may support genotype-responsive feeding programs that improve nutrient utilization, growth, health, and production efficiency.

2. Nutritional Regulation of Gene Expression

Dietary nutrients can regulate the activity of existing genes without altering the underlying DNA sequence. Carbohydrates, amino acids, vitamins, minerals, and phytochemicals influence signaling pathways associated with metabolism, growth, immunity, and stress adaptation. Consequently, nutrition functions not only as a source of essential nutrients but also as a regulator of cellular activity.

3. Growth, Productivity, and Nutritional Stress

Nutrigenomic studies help identify genes and pathways associated with feed efficiency, growth, production, and metabolic adaptation. Nutritional deficiencies and dietary restrictions can alter genes involved in protein turnover, oxidative stress, and cellular homeostasis [10,11]. These molecular changes may serve as indicators of nutritional stress and help guide appropriate dietary interventions.

4. Diet as a Regulator of Physiological Signaling

Dietary components participate in cellular signaling in addition to providing energy and essential nutrients. Antioxidants, plant secondary metabolites, and other bioactive compounds can influence inflammatory responses, transcriptional activity, and metabolic regulation [7]. Understanding these mechanisms helps explain how dietary composition affects animal physiology.

Table 1. Major dietary components, signaling pathways, and physiological responses



Dietary component	Major pathways or mechanisms	Physiological responses
Carbohydrates	Insulin–PI3K–AKT, mTOR, AMPK	Energy metabolism, growth, and fat deposition
Proteins and amino acids	mTORC1, GCN2	Protein synthesis, tissue repair, and growth
Vitamins	Nuclear receptors and antioxidant pathways	Immunity, reproduction, and antioxidant defense
Minerals	Calcium signaling and redox pathways	Skeletal development, enzyme activity, and immunity
Dietary fibre	Short-chain fatty acids and gut–immune signaling	Intestinal health, microbial balance, and energy metabolism
Phytochemicals	Nrf2, NF-κB, and AMPK	Oxidative-stress control and inflammatory regulation

5. Nutrigenomics and Immune Competence

Adequate nutrient supply is essential for maintaining immune function and resistance to disease. Nutritional deficiencies can disrupt cellular processes and compromise immune responses. Nutrigenomic approaches help identify molecular pathways through which dietary interventions influence immunity, disease susceptibility, and overall performance.

6. Nutritional Regulation of Disease Mechanisms

Nutrients and bioactive compounds can influence cellular growth, differentiation, metabolism, and tissue function. Gene-expression technologies, including DNA microarrays, enable researchers to identify molecular changes associated with nutritional disorders and disease. These findings may help identify biomarkers and improve understanding of interactions among diet, genetic variation, and environmental conditions [12,13].

7. Reproduction, Development, and Aging

Reproductive performance is influenced by nutrient availability, endocrine regulation, and genetic factors. Transcriptomic approaches, including microarray analysis, can identify gene-expression patterns associated with fertility and reproductive traits in cattle [14].

Nutrigenomics also provides opportunities to investigate age-related changes in metabolism and cellular function. Molecular profiling may help develop age-specific nutritional strategies that support physiological health and improve the management of older animals.

8. Omics Technologies in Nutritional Research

Omics technologies enable the investigation of nutritional responses at different biological levels. Genomics examines genetic variation, transcriptomics studies gene expression, proteomics characterizes proteins, and metabolomics investigates small-molecule metabolites. Bioinformatics and systems biology integrate these datasets to explain complex biological processes.



Nutrigenomics examines how nutrition influences gene-related processes, whereas nutrigenetics investigates how inherited genetic variation affects nutritional responses [15]. Both fields contribute to the development of individualized feeding strategies.

8.1. Transcriptomics

Transcriptomics examines changes in RNA expression following dietary interventions. Microarray studies have demonstrated that dietary protein sources and protein quantity can influence genes associated with lipid metabolism, energy regulation, and antioxidant activity [17–19]. In livestock, transcriptomic approaches have been applied to mammary-gland function, milk production, muscle development, and udder health [20–22].

8.2. Proteomics

Proteomics investigates the abundance, structure, and function of proteins in tissues and biological fluids. Techniques such as two-dimensional gel electrophoresis and mass spectrometry help identify proteins responsive to nutritional deficiency or supplementation. In broiler chickens, proteomic analysis has identified muscle proteins associated with dietary methionine status, demonstrating its potential for nutritional assessment [23,24].

8.3. Metabolomics

Metabolomics characterizes small molecules that reflect biochemical responses to dietary intake. Analytical techniques such as nuclear magnetic resonance spectroscopy and chromatography–mass spectrometry help identify changes in energy metabolism, amino acid turnover, and microbial fermentation. Studies in pigs have demonstrated that dietary fibre can alter plasma and urinary metabolite profiles [25,26].

9. Integrated Omics and Precision Feeding

Integrating genomic, transcriptomic, proteomic, metabolomic, and microbiome information provides a broader understanding of nutritional responses. These approaches connect dietary exposure with gene regulation, protein function, metabolic activity, and observable animal performance.

Table 2. Contributions of omics technologies to animal nutrition

Molecular approach	Main application
Genomics	Identifying genetic variation and nutrient-response potential
Epigenomics	Examining diet-associated changes in gene regulation
Transcriptomics	Detecting diet-responsive genes and pathways
Proteomics	Identifying changes in functional proteins
Metabolomics	Characterizing biochemical responses to feeding



Microbiome analysis	Investigating microbial contributions to digestion and metabolism
Multi-omics integration	Improving prediction of health, productivity, and feed efficiency

Integrated approaches may improve feed evaluation, nutrient requirement estimation, identification of nutritional biomarkers, and assessment of animal-product quality. However, their application requires reliable analytical methods, appropriate experimental designs, and effective computational tools to manage complex datasets.

Conclusion and Future Perspectives

Nutrigenomics provides a scientific framework for understanding how dietary components interact with the animal genome to influence health, growth, reproduction, immunity, and production efficiency. Transcriptomics, proteomics, and metabolomics offer complementary information about molecular and biochemical responses to nutrition. Integrating these technologies may support precision feeding strategies tailored to genetic background and physiological requirements.

Despite its potential, practical implementation remains limited by analytical complexity, data integration challenges, and the need for validated biomarkers. Continued advances in functional genomics, bioinformatics, and systems biology may improve the application of nutrigenomics in livestock production. Ultimately, nutrigenomics can contribute to more efficient feeding practices, improved animal health, and enhanced quality of animal-derived foods.

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