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Review Article

Integrative Strategies for Optimising Livestock Performance: from Feed Efficiency to Genetic Potential and Physiological Resilience

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Abstract: Optimising livestock performance requires simultaneous consideration of nutrition, genetics, and physiology. This review synthesises current knowledge on feed efficiency in monogastric and ruminant systems, genetic selection for productivity and resilience, and physiological pathways regulating growth and metabolism. Integrating these domains offers a pathway to sustainable livestock production. Key strategies include enzyme supplementation in monogastric animals, rumen manipulation in ruminants, genomic selection for feed efficiency and disease resistance, and understanding stress-physiology interactions. Future research should focus on gut genome metabolism crosstalk.

Keywords: Feed efficiency, Monogastric nutrition, Ruminant nutrition, Animal breeding, Animal physiology, Livestock integration.

Introduction

The global demand for animal-derived protein continues to rise, driven by population growth, urbanisation, and increasing per capita consumption in developing economies [1]. Meeting this demand while maintaining environmental sustainability, animal welfare, and economic viability represents one of the most significant challenges facing contemporary animal agriculture. Livestock production systems must therefore achieve higher output per unit input, reduce greenhouse gas emissions, minimise land and water use, and preserve animal health all simultaneously.

Historically, livestock research has progressed within disciplinary silos: animal nutrition, breeding and genetics, and animal physiology have largely been studied independently [2]. Nutritionists focus on feed formulation and digestive efficiency; geneticists select for heritable production traits; physiologists examine hormonal regulation and metabolic pathways. However, the modern consensus is clear: animal performance emerges from the dynamic interaction of these three domains. A high-genetic-potential animal cannot perform optimally on poor nutrition; likewise, optimal nutrition cannot overcome physiological dysregulation caused by chronic stress or disease.

This review, therefore, adopts an integrative approach. It synthesises current evidence across monogastric (swine, poultry) and ruminant (cattle, sheep, goats) nutrition, animal breeding and genetics, and animal physiology. The primary objective is to identify synergistic strategies that enhance livestock productivity, health, and resilience.

A secondary objective is to highlight knowledge gaps where integrated research combining nutritional interventions, genomic selection, and physiological monitoring could yield the greatest returns. The review is structured thematically, beginning with nutrition, then genetics, then physiology, and finally their intersections as presented in Figure 1.

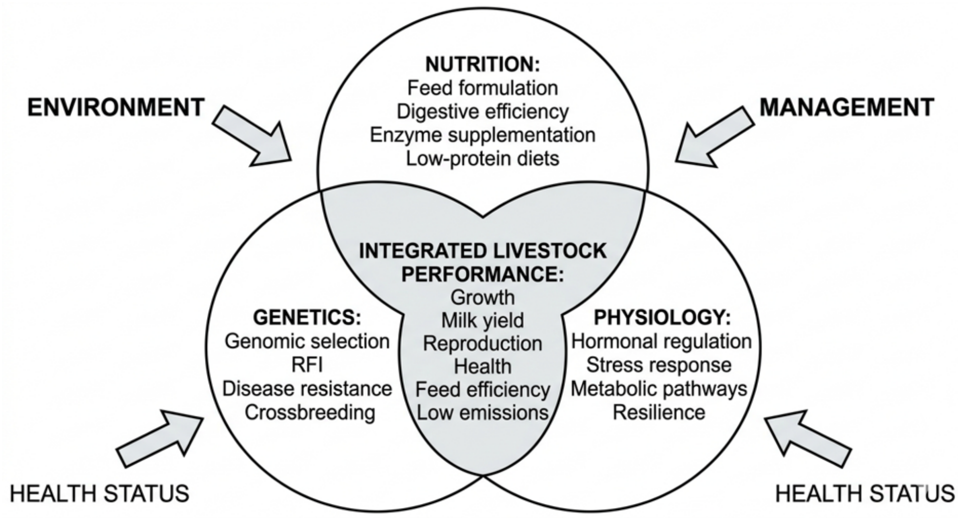

Figure 1: Conceptual framework of integrative livestock performance showing interactions among nutrition, genetics and physiology. Source: Researchers' design (2026).

The Role of Monogastric Nutrition in Feed Efficiency and Environmental Impact

Monogastric animals (pigs, chickens, and other non-ruminants) possess a simple stomach and rely on enzymatic digestion of dietary components. Feed costs account for approximately 60-70% of total production expenses in monogastric systems, making feed efficiency a primary economic driver [3]. Beyond economics, monogastric nutrition profoundly influences nitrogen and phosphorus excretion, which are major environmental pollutants. The effect of dietary manipulation on both productivity and waste output is therefore of critical importance.

One of the most effective nutritional strategies in monogastric animals is the supplementation of exogenous enzymes. Phytase, for example, breaks down phytic acid, an anti-nutritional factor present in plant-based feed ingredients thereby, releasing bound phosphorus and reducing phosphorus excretion by up to 50% [3]. Carbohydrase's such as xylanase and beta-glucanase degrade non-starch polysaccharides, improving energy availability and reducing digesta viscosity. The importance of these enzymes has increased as feed formulations incorporate more co-products (such as distillers' dried grains, canola meal) to reduce reliance on cereal grains.

Another major advance is the use of low-protein diets supplemented with crystalline amino acids (L-lysine, DL-methionine, L-threonine, L-tryptophan). Reducing crude protein by 2-4 percentage, while maintaining essential amino acid profiles, lowers nitrogen excretion by 20-30% without compromising growth performance [4]. This approach also reduces water consumption and ammonia emission from manure, improving barn air quality. However, careful formulation is required to avoid deficiencies of non-essential amino acids and to maintain gut barrier function.

Ruminant Nutrition: Rumen Manipulation, Methane Mitigation, and Fibre Utilisation

Ruminants (cattle, sheep, goats) possess a forestomach, the rumen which houses a complex microbial ecosystem of bacteria, protozoa, archaea, and fungi. This microbial fermentation enables ruminants to convert fibrous plant materials (forage, crop residues) into volatile fatty acids the animal's primary energy source. However, rumen fermentation also produces methane (CH_4) via methanogenic archaea, representing a 2-12% loss of gross energy intake and a significant greenhouse gas emission [5]. The effect of nutritional interventions on rumen function and methane output is therefore both economically and environmentally consequential. A comparison of mitigation options as shown in Table 1 shows that while ionophores are effective, plant secondary compounds offer more environmentally acceptable alternatives.

Manipulating the rumen microbiome has become a central strategy. Dietary inclusion of ionophores (such as monensin) shifts the rumen microbial population toward propionate-producing bacteria, which are energetically more efficient and produce less hydrogen thereby reducing methane synthesis. However, concerns about antimicrobial resistance have spurred interest in alternatives. Essential oils (thymol, eugenol), tannins, saponins, and probiotics (yeast, lactobacilli) have demonstrated methane-reducing effects, albeit with variable consistency across diets and animal species [5].

Table 1: Efficacy of various methane mitigation strategies in ruminants.

Strategy	Mechanism of Action	Average Methane Reduction (%)	Practical Limitations
Ionophores (monensin)	Shifts rumen toward propionate; reduces H_2 availability	10–25	Antimicrobial resistance concerns
Essential oils (thymol, eugenol)	Suppresses methanogen activity directly	8–20	Variable efficacy; high dose cost
Tannins (condensed)	Bind dietary protein; inhibits methanogen growth	10–30	Reduced palatability; anti-nutritional effects
Probiotics (yeast, Lactobacillus)	Alters rumen redox potential	5–15	Strain-specific; inconsistent results
Dietary lipids	Biohydrogenation intermediates inhibit methanogens	15–25	May reduce fibre digestion
High concentrate diet	Less fermentation; more propionate	15–35	Risk of SARA (subacute ruminal acidosis)

Source: Researchers' compilation (2026)

Forage-to-concentrate ratio remains a fundamental lever. High-concentrate (grain) diets increase propionate production and reduce methane per unit of meat or milk, but they increase the risk of subacute ruminal acidosis (SARA), which impairs fibre digestion, causes rumen epithelial damage, and leads to laminitis and liver abscesses [6]. The importance of balancing fermentable carbohydrate with effective fibre cannot be overstated a physiological constraint that distinguishes ruminant from monogastric feeding.

Genetic Selection for Productivity, Feed Efficiency, and Disease Resistance

Genetic improvement is cumulative, permanent, and cost-effective. Traditional selection for growth rate, milk yield, and litter size has achieved remarkable gains: dairy milk yields in developed countries have more than doubled since 1960 [7]. However, unintended consequences include reduced fertility, increased metabolic disorders, and lower heat tolerance. The importance of broadening selection goals to include functional traits is now widely recognised.

Genomic selection using genome-wide SNP markers to predict breeding values has accelerated genetic progress, especially for traits that are expensive to measure directly. Residual feed intake (RFI), a measure of feed efficiency independent of growth rate, is moderately heritable ($h^2 \approx 0.30$ 0.40) and has become a target in both monogastric and ruminant breeding programmes [8]. Selection for low RFI reduces feed intake by 10 - 15% without affecting body weight gain, with additive effects across generations. The heritability of various traits (Figure 2) indicates that feed efficiency and growth rate respond well to selection, whereas fertility and disease resistance are more influenced by environment.

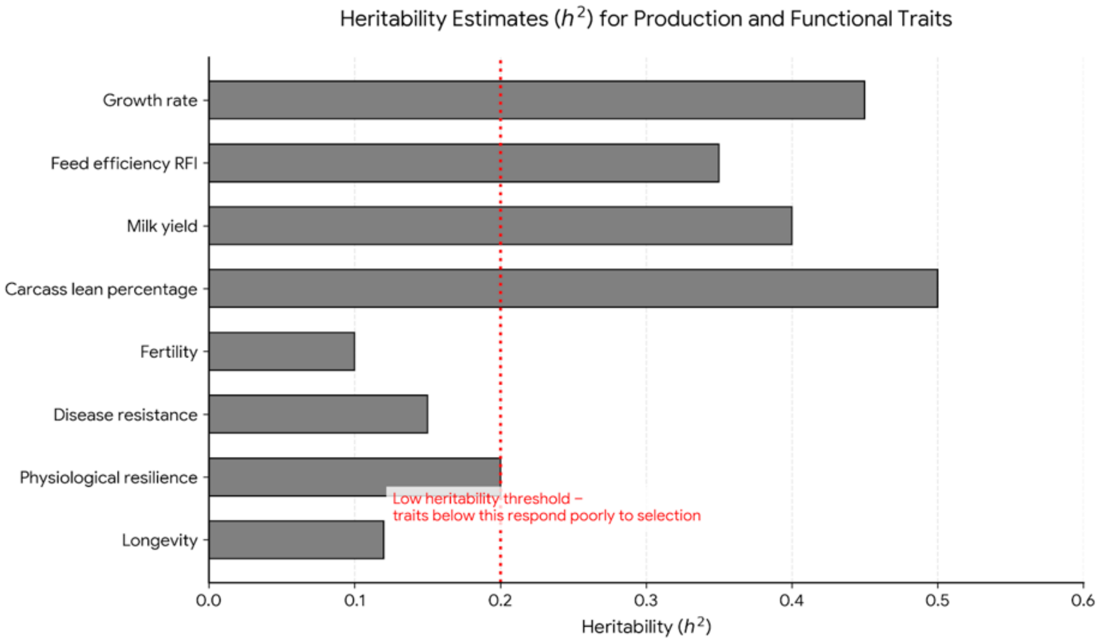

Figure 2: Heritability estimates (h2) for production and functional traits in livestock.
Source: Researchers' design (2026)

Disease resistance is another frontier. Genomic regions associated with mastitis resistance in dairy cattle, porcine reproductive and respiratory syndrome (PRRS) resilience in pigs, and necrotic enteritis tolerance in poultry have been identified [7]. The effect of selecting for such alleles is a reduction in antibiotic use, improved animal welfare, and lower mortality. However, unfavourable genetic correlations may exist for example, selection for high milk yield often reduces fertility and increases susceptibility to metabolic diseases. Physiological understanding of these trade-offs is essential.

Crossbreeding and heterosis (hybrid vigour) remain valuable, particularly for smallholder systems. The effect of crossbreeding on survival, disease resistance, and reproductive performance can be substantial, often exceeding the average of purebred parents. However, maintaining genetic diversity and avoiding inbreeding depression requires careful population management.

Physiological Regulation of Growth, Nutrient Partitioning, and Stress Responses

Physiology integrates genetic potential and nutritional input into observable performance. The growth hormone (GH), insulin-like growth factor (IGF)-I axis is the primary endocrine regulator of post-natal growth [9]. GH stimulates IGF-I production in the liver and other tissues; IGF-I then promotes protein synthesis, inhibits proteolysis, and stimulates muscle cell proliferation and differentiation. The effect of this axis on lean tissue accretion is profound: administering exogenous GH increases protein deposition by 15-30% in pigs and cattle, though regulatory and public acceptance barriers limit commercial use.

Insulin and glucagon partition nutrients between muscle, adipose tissue, and the liver. Insulin promotes glucose uptake, lipogenesis, and protein synthesis; glucagon stimulates gluconeogenesis and lipolysis. The balance between these hormones is influenced by diet composition (energy density, carbohydrate type), feeding frequency, and physiological state (lactation, growth, gestation). Understanding this hormonal interplay is crucial for designing feeding regimens that maximise lean gain while minimising fat deposition.

Stress physiology has gained prominence in the context of climate change and intensive production. Heat stress, transport stress, social stress (overcrowding), and handling stress activate the hypothalamic pituitary adrenal (HPA) axis, increasing cortisol secretion [10]. Chronic elevation of cortisol suppresses feed intake, reduces immune function, increases maintenance energy requirements, and impairs reproduction as summarized in Figure 3. The effect on productivity can be severe: heat stress alone costs the US livestock industry an estimated $12 billion annually. Nutritional countermeasures include antioxidants (vitamins C and E, selenium), electrolyte supplementation, and dietary fat to reduce metabolic heat production.

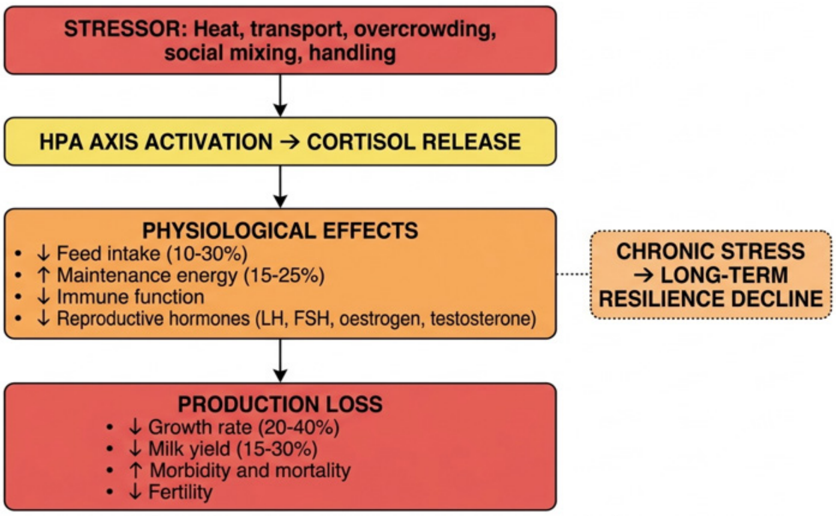

Figure 3: Physiological pathway of stress response and its impact on livestock production.
Source: Researchers' design (2026)

Physiological resilience defined as the capacity to maintain or rapidly recover normal function following a challenge is an emerging trait of interest. Resilient animals exhibit lower cortisol spikes, faster recovery of feed intake, and sustained growth under stress. This trait is heritable, offering opportunities for genetic selection, but also modifiable through early-life nutritional programming (maternal nutrition, neonatal colostrum management).

Intersections and Integrated Strategies: Nutrigenomics, Microbiome Interactions, and Precision Farming

The greatest advances lie at the intersections of the three disciplines. Nutrigenomics examines how dietary components influence gene expression. For example, maternal undernutrition during gestation alters the methylation of genes involved in metabolism, permanently programming the offspring toward insulin resistance and increased adiposity [11].

Conversely, supplementation with methyl donors (folate, choline, vitamin B12) can reverse some epigenetic marks. The effect of such programming on lifelong productivity is immense, with implications for replacement heifer and gilt management.

The gastrointestinal microbiome which includes the rumen in ruminants and the hindgut in monogastric animals, serves as a bridge between nutrition, genetics, and physiology. Rumen microbial composition is partially heritable ($h^2 \approx 0.20 - 0.30$) and correlates with feed efficiency [12]. This raises the possibility of selecting animals based on their microbiome profile, or of transplanting favourable microbiomes via rumen fluid transfer. Similarly, the chicken caecal microbiome affects energy harvest and immune development; genetic selection for beneficial microbial associations is an active research area. Table 2 presents examples of how two or more domains can be combined for synergistic effect.

Table 2: Examples of integrative interventions combining nutrition, genetics and physiology.

Intervention	Domains Integrated	Target Species	Reported Outcome	Key Citation
Early-life methyl donor supplementation (folate, B12, choline)	Nutrition + Physiology (epigenetics)	Swine, Cattle	Reduced adiposity; improved insulin sensitivity	Wu et al. (2016)
Genomic selection for low RFI + precision feeding	Genetics + Nutrition	Pigs, Broilers	12% reduction in feed costs; no growth loss	Gilbert et al. (2017)
Maternal nutrition + offspring genetic line selection	Nutrition + Genetics + Physiology	Dairy calves	Improved gut development; lower morbidity	Ingvartsen & Moyes (2015)
Rumen microbiome profiling + genetic selection	Genetics + Nutrition (ruminant)	Beef cattle	15% lower methane emissions; improved fibre digestion	Wallace et al. (2019)

Source: Researchers' compilation (2026)

Precision livestock farming (PLF) integrates real-time physiological sensors (rumen pH boluses, accelerometers, infrared thermography) with automated feeding systems and genomic data [13]. The effect of PLF is the Abi performance Andu clinical illness days before clinical signs appear, adjust diets individually based on performance, and reduce labour costs. For instance, a drop-in rumination time detected via collar-mounted accelerometers predicts ruminal acidosis or fever, prompting an automated dietary adjustment (such as increased forage). An integrated system that combines real-time physiological sensors, automated feeding and genomic data is illustrated in Plate 1.

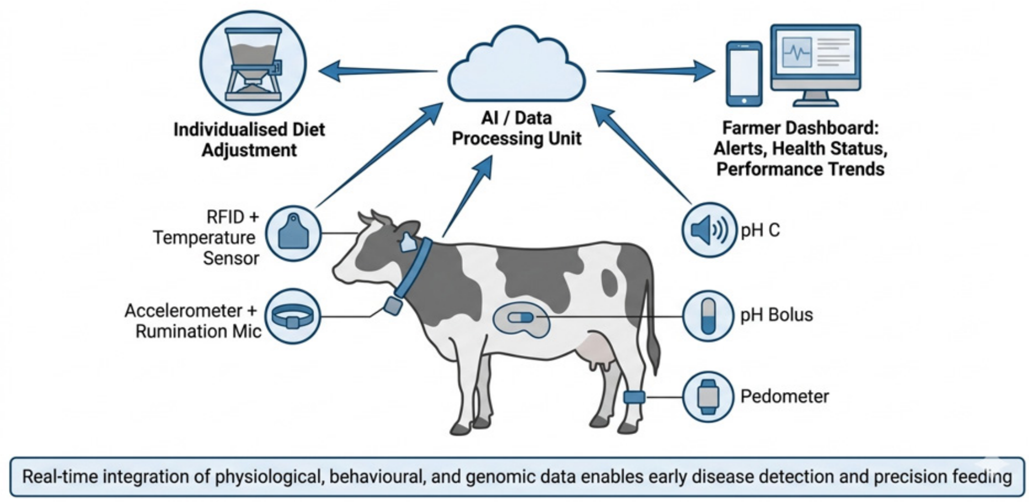

Plate 1: Schematic diagram of an integrated precision livestock farming (PLF) system combining sensors, data processing and automated feeding. Source: Researchers' design (2026)

Conclusion

Livestock production systems cannot afford to treat nutrition, genetics, and physiology as separate domains. Nutrition supplies the substrates for growth and milk synthesis; genetics sets the upper limits of performance potential; physiology translates nutritional and genetic inputs into actual outcomes, modulated by health and stress. Future research should prioritise longitudinal, cross-disciplinary studies that integrate nutritional history, genomic profiles, physiological responses, and microbiome dynamics from birth to slaughter, validate combined selection indices for feed efficiency, disease resistance, resilience, and methane reduction, and develop decision-support tools translating genomic and sensor data into real-time feeding recommendations, as only such integration can achieve both high productivity and environmental responsibility.

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Conflict of Interest

The authors declare no conflicts of interest.

Author Contributions

Olawale Mojeed, AKANBI: Conceptualisation, project administration, supervision, writing – original draft, writing – review & editing. Happiness, AJAYI: Literature search, data curation, writing – original draft, writing – review & editing. Olanrewaju Ahmed, BINUYO: Methodology, visualisation, writing – original draft, writing – review & editing. Hiqmat Busayo, LAWAL: Investigation, data analysis, writing – original draft, writing – review & editing. Oluwasegun Emmanuel, IBIDIRAN: Validation, formal analysis, writing – original draft, writing – review & editing. All authors read and approved the final manuscript.

Ethics Approval

Not applicable.

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