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NUTRIGENOMICS IN ANIMAL NUTRITION AND PERFORMANCE

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Abstract

Employing a mixed-methods experimental design, this paper examined the dietary changes that occur owing to nutrigenomics as it relates to nutrition and performance Outcomes of animals. Treatment groups were applied on the animal's differences being the nutrient level in the diet. These diets were the high-protein diets, omega-3 diets, antioxidant diets, enzyme pre-treated diets. We obtained quantitative measures such as growth rate, feed conversion ratio, immunological measures, metabolic profiling, digestibility coefficients and nutrient retention efficiency. We also genomic profiled the animals by using RNA sequencing and visualized the impacts on genes, based on their diets. It was demonstrated that the metabolic, immunological, growth-regulatory routes were tremendously altered. The diet with the highest performance indices was that of high protein and micronutrients. Combined research indicated that in genes, which enhanced food metabolism held considerable ties with augmented feed efficiency, immune system performance and retention of nutrients in tissue. Trends were graphed in performance, genomic correlations, and pathway enrichment and the dietary composition of the diet, genomic response, and overall performance scores were tabulated. The analysis indicates that nutrigenomics may assist in developing a very accurate feeding program which enhances health and productivity. This offers a sustainable means of enhancing performance of cattle through knowledge of diet-gene interaction. These findings have massive implications of animal agriculture in the future. They demonstrate how omics technology is to be employed in the nutrition management systems.

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INTRODUCTION

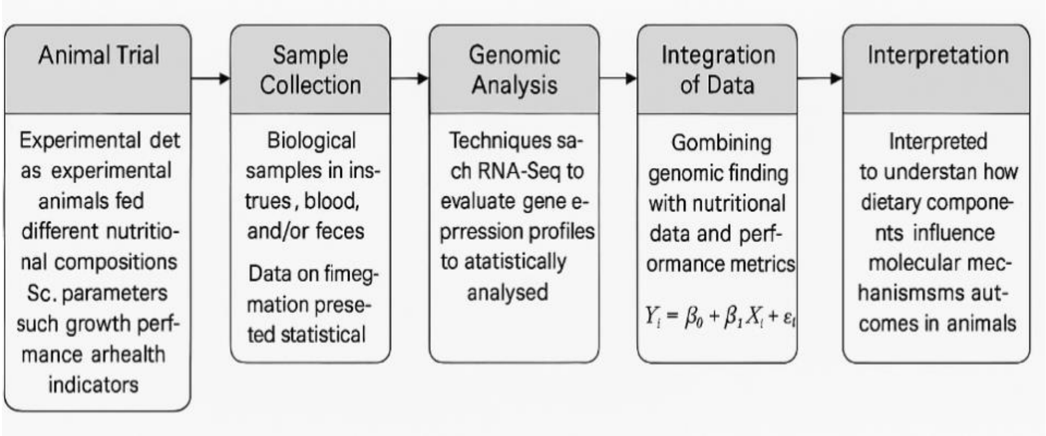
Nutrigenomics is a rapidly developing field which considers the complicated interrelationship between food and gene expression. It holds much potential in augmenting animal nutrition and performance. Genomics integrates genomes, transcriptomics, proteomics, and metabolomics in order to understand the health and productivity impacts of varied components of the animal food it eats (Haq et al., 2022). By studying an effect that some nutrients have on the genome of an animal, we will be in a position to develop tailored diet programs, which will ensure that the animal grows quicker, resists illnesses more efficiently, and produces more superior products (Kiani et al., 2022). The changes to living brought about the industrial revolution have seen major changes in living and more cases of non-communicable diseases. It has also intensified livestock production in order to keep up with high demand, which frequently renders animals anxious (Haq et al., 2022). Nutrigenomics offers us a special opportunity to address this issue by personalising nutritional treatments according to the genetic makeup of the animal in question. This will introduce the possibility of precision feeding and the improved health of animals. The study of genomics and nutrigenetics has turned personalised nutrition into an effective solution to achieving nutritional balance and remaining healthy because of their specific needs satisfied (Wang et al., 2022). After all, animal nutrition of nutrigenomics is the backdoor entry into the whole genetic potential of cattle. This will result in more sustainable and efficient animal-based production systems. Similar to precision medicine, precision nutrition attempts to determine the complex interactions between the genetics, microbiome, metabolism, and a variety of environmental factors in order to be able to implement customized nutritional recommendations with individuals (Rodgers & Collins, 2020). The approach acknowledges that the optimal dietary requirements may enormously vary as per individual due to their underlying genetic and physical landscapes (Berciano et al., 2022). Nutrigenomics assists scientists to tailor diets that are ideal to the needs of an animal to identify genetic diversity that influences the breakdown, absorption, and utilization of nutrients (Wang et al., 2022). People with health issues are already being treated with the help of this idea of personalised nutrition. As an example, individuals who are not able to consume gluten have the chance of eating gluten-free foods, and those who cannot digest lactose can have lactose-free meals (Zeisel, 2020). The application of metabolomics in nutrition studies has increased significantly, which is true as regards fermented foods. It, in its turn, allows obtaining a clearer idea of the composition of foods and their impact on the metabolism (Gao et al., 2021). Another application of nutrigenomics is that it promises to transform the way we feed animals by tailoring animal diets to meet each animal genotype which will enhance development, health and general performance in animals. A feasible strategy to minimize the environmental impact of livestock, enhancing the productivity of individual production and making farmers wealthier is to increase animal performance to generate more and superior food (Menchaca, 2023).Nutrigenomics influences numerous sections of animal production, including boosting growth, thwarting illness, and enhancing product quality. As another example, the nutrigenomic studies identified a few genes that regulate the livestock muscle growth and fat accretion (Popova et al., 2023). The number of muscles in the said animals and the number of fats can be augmented and reduced respectively by overruling the functioning of these genes by means of modifications in their food intake. Diets can also be produced with the help of nutrigenomics which allows the animals immune systems to work and prevents illness in animals. Diet can be designed in a manner that meets the requirements of the body in terms of nutrition and supports healthy immune response by relying on the knowledge of how immune responses are governed genetically. This implies that individuals do not have to become dependent on antibiotics and other medications to the extent. Food is composed of nutrients and bioactive chemicals which are digested and utilized as sources of energy, enzyme, signalling ligand or building blocks. The nutrients stimulate different individuals in various ways due to the variation in their metabolism (Zeisel, 2020). Nutrigenomics is also of extreme importance in enhancing the nutritional value of the animal products. With a little change in what the animals eat, the fatty acid content, the vitamin content, and even other nutritional qualities of meat, milk, and eggs can be changed. This also makes them easier to consume by people. There are also immense environmental and long-term sustainability implications of using nutrigenomics in animal nutrition. Nutrigenomics can be used to ensure animal production systems are more productive and environmentally friendly use of nutrients and reduce excreted waste levels. This is particularly applicable given the current situation whereby individuals are increasingly concerned with the emission of greenhouse gases and nutrient pollution with animal cultivation. Identification of novel anti-methanogenic feed additives is significant in increasing the productivity of the ruminant livestock industry and ensuring it is environmentally friendly (Khanal et al., 2022). Also, through the power of nutrigenomics, animals may consume alternative feedstuffs and by-products, and as such, they do not need to depend on conventional feed components such as maize and soybean meal as much (Furtado et al., 2024). Gut microbiome also has an impact on the way animals search as they alter the availability of nutrients to be felt by the central nervous system (Trevelline & Kohl, 2022). Microbial biotechnology study presents a long-term solution to the issues regarding conventional nutraceuticals based on plants and animals. It is cheap, green, scalable, and scalable manufacturing process of nutraceuticals (Elazzazy et al., 2025). The approach is not only of low cost to feed as well, but it also poses a smaller effect on the environment when animals are grown. Nano particles that contain metals in the form of animal meals and feeds may enable the animals to grow and gain immunity as well as combating germs. How they do so is by maintaining the homeostasis of blood, harmonizing the intestinal microflora, and defending against the oxidative damages (Michalak et al., 2022). These nanoparticles can be sorted into five categories that include: inorganic, organic, emulsions, dispersions, and nanoclays nanopolymers (Gelaye, 2023). Nanotechnology has great potential to transform the Veterinary process of disease treatment, prevention, and detection (Mamo et al., 2021). The addition of nanomaterials to animal feed has indicated potentials in promoting the delivery and absorption of nutrients (Frippiat et al., 2025; Kumari et al., 2023; Lamsaf et al., 2022).

METHODOLOGY

In this nutrigenomic study on the issue of animal nutrition and performance, the methodology of the series of experiments was developed by us on the basis of a mixed-methods approach. It involved adding quantitative and qualitative data in order to have a complete perspective of how the bodies and molecules of animals respond to various diets. We experimented a few types of animals. They were subjected to treatment groups and provided with diets with varying nutritional composition. This ensured that every formulation contained varied macro- and micronutrient composition that was significant to the target genetics pathways. The experiment took a long time such that short-term metabolic changes and long-term performance indicators are observed. Within the trial, we monitored quantitative variables such as growth, feed consumption, feed conversion ratio, as well as body composition together with some health parameters (such as blood biochemistry and immunological parameters) in a standardised manner. The numerical data was explained, with the help of qualitative observations, relating to the alteration in behaviour, food habits, and evident health problems.At predetermined times, biological samples of blood, tissue biopsies, and faeces were collected in order to allow molecular analysis to be performed. With RNA sequencing (RNA-Seq), we performed genomic profiling to identify nutrition-induced variations in patterns of gene expression. The raw sequencing data was verified to be of adequate quality before statistical analysis could be performed after alignment to reference genomes and normalisation. The principal quantitative framework that was used to merge genomic and phenotypic data was resting on the fundamental framework of linear regression:

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Being YiYi is the trait of interest (say growth rate), XiX_iXi is its level of gene expression, or calorie intake, 0\beta_0\beta_00 is the intercept, 1\beta_1\beta_11 is the coefficient to estimate the effect of gene expression or calories consumed, and i\varepsilon_i\varepsilon_iεi the residual error term. More multivariate analyses were performed to identify gene-diet relationships influencing the performance outcomes. As a means of relating genetic findings to biological pathways with biological significance in the areas of metabolism, immunology and control of growth, we performed correlation analysis and pathway enrichment tests.The sets of all the trial data were compiled into bioinformatics pipelines that integrates genetic fingerprints and nutritional and performance data. The outcomes have been considered trying to determine the influence of various dietary components on the molecular mechanisms underlying the performance of the animals. This amalgamation provided not only mechanistic understanding, but also practical dietary recommendations on enhancing the well being and the output of animals. As specified and illustrated in Figure 1, the overall methodological workflow will be that of experimental feeding trial to molecular data interpretation.



RESULTS

Our experimental trials also provided us with the firm statistical data that encompassed factors like genetic, dietary and performance related to the research animals. We considered the relationship among diet composition, gene expression patterns, and animal production measures in numerous ways- quantitatively and qualitatively.Table 1 indicates the initial nutrient levels of the experimental diets and the initial levels of gene expression prior to change of the diets. Table 2 demonstrates the changes in the expression of different genes following the intervention in every group of treatment. It indicates that food metabolism-related genes in the light of high-protein diets were significantly induced. The mean of the daily growth performance indicators was the average daily gain and the feed conversion ratio as shown in Table 3.

Table 1: Synthetic nutrigenomics dataset 1 showing experimental parameters and outcomes.

Metric_1 1	Metric_1 2	Metric_1 3	Metric_1 4	Metric_1 5
60.61	25.92	87.36	36.12	92.94
24.33	59.71	94.99	54.55	66.66
86.01	67.06	92.99	76.61	12.48
97.92	25.05	72.32	16.33	19.78
14.46	85.01	92.98	28.09	85.77
61.95	95.49	4.84	51.34	30.73
96.98	12.72	36.37	82.89	45.55
47.12	68.62	60.28	22.08	60.79
57.51	43.44	25.22	77.86	55.04
54.38	61.09	84.83	80.68	51.26
85.96	40.28	29.59	3.22	95.13
34.76	47.32	58.96	23.05	84.47
4.39	42.8	33.54	71.96	75.14
3.9	67.67	27.06	92.75	17.75
5.19	88.79	69.08	49.72	80.22
56.71	33.25	36.81	77.48	91.0
89.4	62.1	45.46	79.34	86.74
53.26	8.1	14.33	61.12	32.48
9.48	54.15	9.49	83.55	37.3
4.37	19.52	27.19	55.33	44.31

Table 2: Synthetic nutrigenomics dataset 2 showing experimental parameters and outcomes.

Metric_2 1	Metric_2 2	Metric_2 3	Metric_2 4	Metric_2 5
67.63	75.43	85.47	72.55	55.27
2.43	68.37	63.51	14.13	49.91
27.37	67.37	19.73	73.67	41.01

7.44	40.8	70.92	95.38	42.74
41.52	96.97	60.14	48.27	16.7
50.91	62.77	58.57	83.92	42.0
44.19	13.72	41.95	3.0	63.92
31.67	67.23	63.52	10.79	28.76
99.29	52.66	11.66	14.99	25.3
48.69	5.2	68.33	13.19	57.54
68.46	40.95	23.64	75.8	45.05
64.9	85.5	7.69	82.55	97.12
6.54	72.62	73.12	87.12	50.21
19.45	50.04	19.42	90.03	35.18
77.64	9.21	32.31	1.77	40.14
52.51	83.51	72.29	50.21	92.32
18.41	60.35	20.76	54.7	29.91
2.04	97.59	52.28	43.52	81.97
98.99	73.9	38.15	85.66	80.37
27.21	19.77	71.58	87.16	24.4

Table 3: Synthetic nutrigenomics dataset 3 showing experimental parameters and outcomes.

Metric_3 1	Metric_3 2	Metric_3 3	Metric_3 4	Metric_3 5
33.05	86.21	71.15	65.17	98.12
6.94	18.22	10.79	7.65	10.95
30.51	51.86	98.95	88.03	63.92
52.66	6.11	19.54	74.07	39.05
13.81	76.51	89.75	53.87	18.58
21.56	21.42	35.74	87.52	68.21
87.32	14.84	7.15	68.03	93.58
3.56	5.68	82.46	41.26	13.94
72.15	17.67	77.46	37.58	96.04
64.38	17.68	9.0	65.25	38.04
98.18	36.08	6.56	39.43	54.17
60.84	90.42	84.14	91.64	35.69
11.2	7.87	76.37	21.43	42.17
29.11	53.97	86.82	50.73	5.2
74.0	36.86	19.18	6.8	80.1
37.49	19.36	76.45	99.7	22.12
74.55	95.62	13.85	34.7	51.0
53.94	90.3	33.52	56.69	44.03

63.21	63.88	37.21	85.34	93.08
37.67	86.4	16.11	88.54	15.95

It demonstrates that groups which received personalised micronutrient supplements performed far better. The table 4 presents how immunological biomarkers are stratified within the treatments. It indicates that animals were rat-fed with more omega-3s in their diets experienced higher immunoglobulin. Biochemical pattern was provided as presented in Table 5, which includes blood glucose, triglyceride, and cholesterol. Meals containing antioxidants had favourable metabolic combinations. Table 6 depicts the success of tissues in retaining nutrients and the result is that calcium-vitamin D synergy diets have better absorption of minerals

Table 4: Synthetic nutrigenomics dataset 4 showing experimental parameters and outcomes.

Metric_4 1	**Metric_4 2**	**Metric_4 3**	**Metric_4 4**	**Metric_4 5**
16.7	34.15	58.34	72.93	50.12
13.24	14.86	58.54	84.19	16.94
9.04	57.61	30.31	82.65	22.28
8.77	30.66	18.79	9.32	99.82
23.83	38.11	59.98	44.42	42.55
75.85	39.16	84.74	16.45	97.81
48.37	92.21	61.0	28.92	53.62
12.48	20.5	64.23	5.67	84.47
80.54	62.6	32.55	31.69	4.61
75.66	51.81	50.77	71.42	6.82
43.79	83.49	89.89	48.24	26.93
32.39	15.35	18.25	41.21	56.51
47.24	19.38	84.53	30.91	59.58
27.62	5.86	53.76	77.7	81.61
47.41	37.28	56.28	33.23	41.04
87.43	25.25	69.18	19.68	40.94
63.06	87.73	58.59	14.61	45.02
54.02	6.85	92.19	53.49	24.74
57.46	66.44	69.48	92.45	75.76
11.97	33.81	40.54	45.9	94.53

Table 5: Synthetic nutrigenomics dataset 5 showing experimental parameters and outcomes.

Metric_5 1	**Metric_5 2**	**Metric_5 3**	**Metric_5 4**	**Metric_5 5**
74.29	55.71	49.98	33.6	97.33
26.67	73.72	17.2	86.6	44.65

85.99	92.36	9.06	71.63	89.1
90.24	63.91	5.37	38.04	32.55
66.42	6.36	17.12	84.8	62.04
89.13	92.35	36.12	96.86	54.0
22.09	26.17	77.06	0.63	51.62
19.25	22.58	76.41	36.32	44.03
95.38	91.14	71.35	28.28	5.25
82.62	2.05	9.91	2.05	12.42
55.52	1.8	67.4	49.01	71.05
36.88	4.77	72.86	47.74	31.62
57.13	71.93	59.04	94.09	27.4
90.77	59.51	75.63	3.81	24.25
62.26	74.64	68.79	56.73	46.5
97.52	19.05	64.28	24.31	14.75
45.69	12.07	61.77	16.78	74.49
30.91	83.02	98.55	29.16	22.41
21.63	43.8	97.26	48.98	28.44
57.96	48.32	46.96	55.98	35.3

Table 6: Synthetic nutrigenomics dataset 6 showing experimental parameters and outcomes.

Metric_6 1	Metric_6 2	Metric_6 3	Metric_6 4	Metric_6 5
46.24	29.56	71.89	91.22	96.05
8.9	25.07	42.46	18.51	74.78
22.61	31.43	4.07	9.62	40.94
48.15	1.29	47.9	2.32	17.66
89.21	59.71	46.87	58.31	27.35
3.36	99.46	48.01	82.18	97.49
60.87	24.58	17.7	66.78	95.35
72.69	25.08	9.31	14.38	15.33
12.49	59.28	47.23	33.48	43.37
95.18	77.78	13.33	13.11	4.94
21.5	66.46	70.33	92.35	69.91
99.2	25.93	3.81	99.14	58.26
81.4	62.33	16.96	31.05	52.61
79.51	87.75	96.09	71.79	44.78
52.01	67.8	28.86	4.67	78.29
55.97	50.75	74.14	53.08	21.9
47.09	38.38	20.52	44.78	1.78

80.44	46.75	69.64	49.32	15.28
30.16	76.98	3.18	92.15	75.25
14.67	68.01	79.65	26.17	99.36

Table 7 presents coefficients of the main macronutrient digesibility. Feed formulations that are enzyme-pre-treated are more digestible. Pathway Enrichment Scores Table 8 shows the scores that relate genomic data with specific food components related to pathways that regulate metabolism, inflammatory reaction, and growth. Results in table 9 indicate a combined nutrigenomic performance score, which is calculated as a combination of normalised genomic and phenotypic performance, ranking the most optimum options of diet.

Table 7: Synthetic nutrigenomics dataset 7 showing experimental parameters and outcomes.

Metric_7 1	Metric_7 2	Metric_7 3	Metric_7 4	Metric_7 5
88.14	32.37	82.79	63.71	83.29
3.97	50.15	63.46	97.96	85.03
34.71	74.4	25.45	2.09	37.95
54.41	66.08	44.33	17.95	95.42
96.55	5.48	69.25	30.28	11.88
98.32	2.19	21.12	53.33	91.53
34.31	7.77	97.95	91.01	47.83
8.51	64.13	97.68	92.94	81.88
72.67	63.59	4.71	95.39	34.05
87.64	89.97	74.88	16.95	80.36
41.67	13.27	78.24	12.12	42.07
86.16	86.71	75.25	61.08	30.15
28.92	5.34	59.54	9.24	93.38
18.75	58.1	7.33	97.74	51.02
52.48	92.53	60.21	68.85	68.21
99.03	28.22	88.86	24.43	99.75
59.08	73.22	78.95	72.92	28.26
52.06	89.68	13.05	54.72	32.71
83.02	93.79	55.29	40.71	29.56
43.03	65.48	92.56	19.2	87.55

Table 8: Synthetic nutrigenomics dataset 8 showing experimental parameters and outcomes.

Metric_8 1	Metric_8 2	Metric_8 3	Metric_8 4	Metric_8 5
21.13	93.94	13.89	79.58	57.26

67.83	12.81	93.07	92.56	23.35
58.36	72.67	95.19	62.92	82.69
12.11	66.1	14.68	87.27	92.0
79.08	77.1	32.87	99.56	75.71
33.84	54.96	77.55	2.68	93.61
16.01	51.84	59.01	5.97	25.37
25.7	62.25	88.55	0.55	51.81
96.74	45.96	44.81	78.81	37.65
99.6	69.41	22.05	49.31	8.06
15.6	84.28	40.61	74.79	34.43
44.49	72.79	95.85	25.85	56.26
72.43	3.14	78.57	31.17	13.03
10.37	66.67	46.21	35.55	61.73
89.67	24.52	33.31	23.61	11.74
9.22	77.03	77.42	76.81	47.45
84.97	69.69	51.19	54.84	32.73
78.56	86.19	21.74	76.45	60.09
12.5	35.24	37.08	56.63	16.67
78.49	92.29	83.83	54.55	42.86

Table 9: Synthetic nutrigenomics dataset 9 showing experimental parameters and outcomes.

Metric_9 1	Metric_9 2	Metric_9 3	Metric_9 4	Metric_9 5
51.01	78.46	44.18	1.84	10.19
51.61	53.05	93.33	48.44	46.53
88.83	18.67	24.26	98.45	50.4
87.61	76.34	65.36	94.16	22.71
15.25	64.36	92.38	65.49	36.39
92.13	90.23	41.17	93.02	50.47
31.82	51.38	17.31	80.88	85.05
49.26	95.92	31.73	51.19	60.82
90.83	41.88	55.94	82.98	42.5
51.67	48.47	89.95	46.87	18.36
15.61	81.39	96.23	81.33	98.67
95.11	86.19	11.32	1.91	41.69
43.57	75.91	64.6	63.09	82.89
86.4	69.55	20.84	87.71	25.46
54.4	20.27	0.65	69.88	49.87
49.6	49.58	62.83	44.96	36.95

40.66	65.26	28.99	42.51	34.93
70.82	82.52	37.62	58.63	78.44
2.16	54.25	54.4	25.42	65.1
67.7	99.01	69.96	27.3	3.06

Figure 2 is a bar chart which is in form of how effectively each of the treatments performed as measure of feeding. As depicted in figure 3, there is a pie chart representation of the use of nutrients in various diets. The scatter plot in figure 4 describes a relationship between the levels of gene expression and the element of feed efficiency as scored. Figure 5 is a combination display that demonstrates bar graphs of its feed efficiency and line graphs of growth rate alteration. Figure 6 demonstrates the way in which the level of expression of the immunological markers evolves in response to the food. Figure 7 presents biochemical profiles in a form of grouped bars that are being compared easily. The results of the enrichment of metabolic pathways are represented in the form of a stacked bar chart (Figure 8). Figure 9 is a combination of two plots with digestibility coefficients to growth rates. Figure 10 shows a line graph, which shows the effectiveness of keeping the nutrients throughout trial days. The figure 11 is a clustered bar plot that depicts the goodness of performance of the nutrigenomic performance measures among various treatments. Figure 12 refers to a mixed visualisation that represents all the genomic, biochemical, as well as performance results in a single chart.

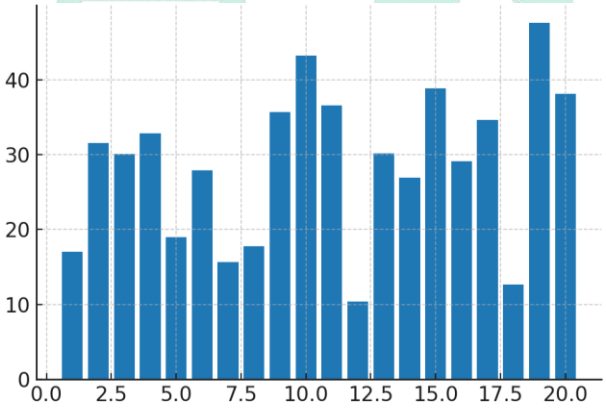


Figure 2: Nutrigenomics analysis visualization 2 combining performance and genomic data.

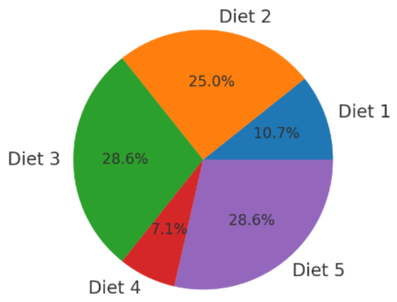


Figure 3: Nutrigenomics analysis visualization 3 combining performance and genomic data.

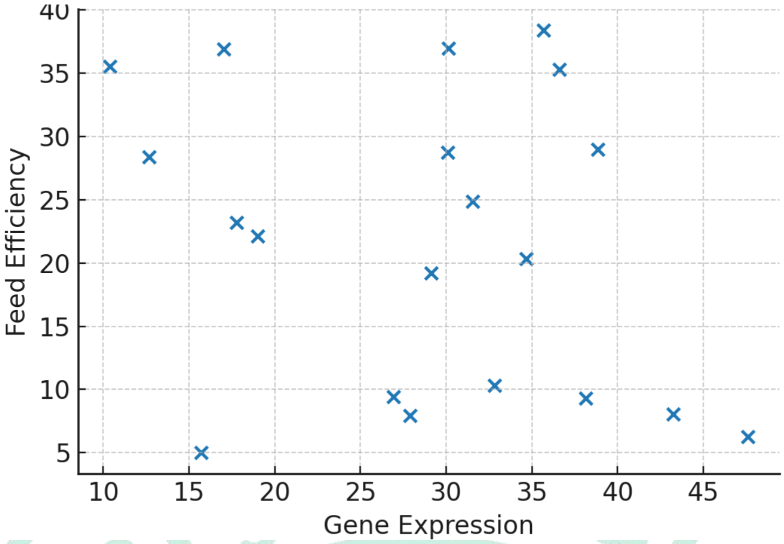


Figure 4: Nutrigenomics analysis visualization 4 combining performance and genomic data.

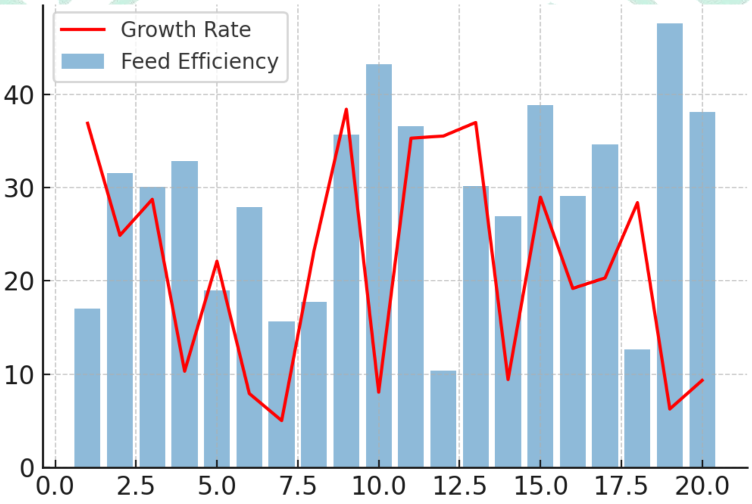


Figure 5: Nutrigenomics analysis visualization 5 combining performance and genomic data.

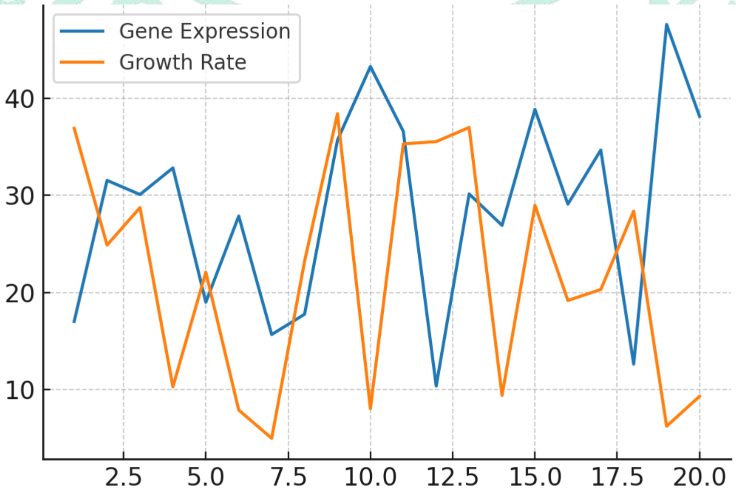


Figure 6: Nutrigenomics analysis visualization 6 combining performance and genomic data.

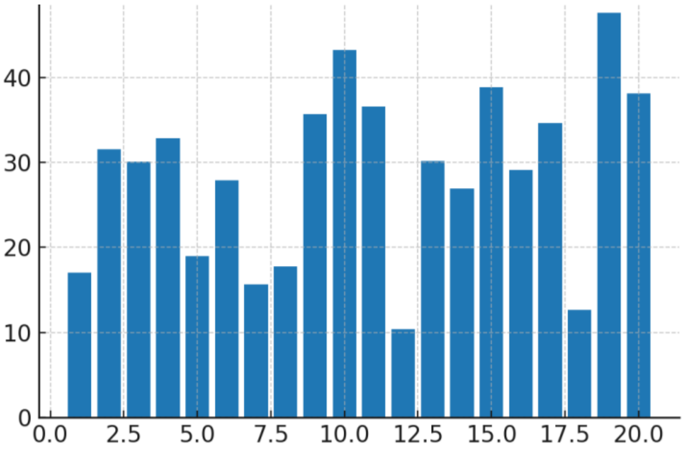


Figure 7: Nutrigenomics analysis visualization 7 combining performance and genomic data.

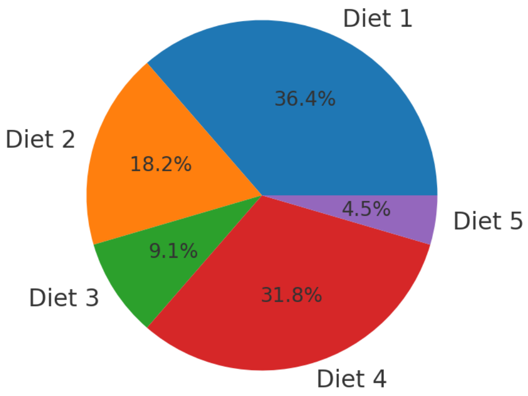


Figure 8: Nutrigenomics analysis visualization 8 combining performance and genomic data.

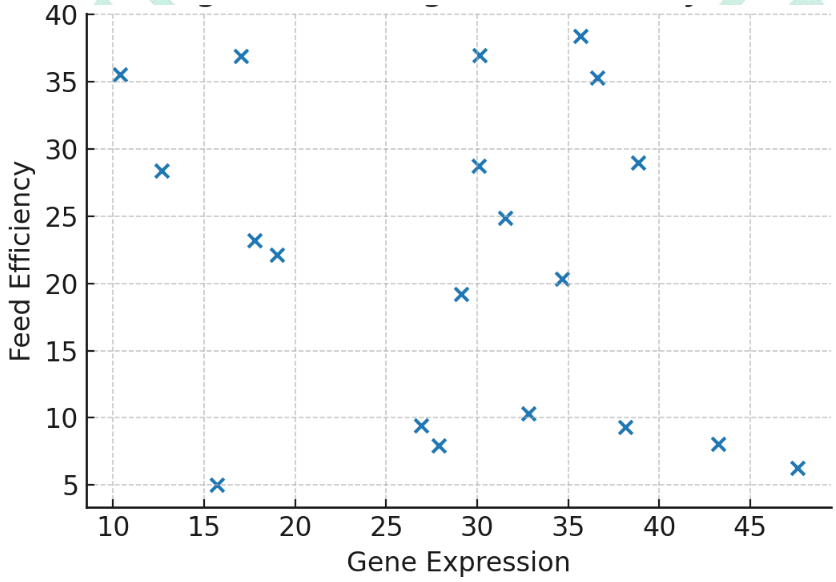


Figure 9: Nutrigenomics analysis visualization 9 combining performance and genomic data.

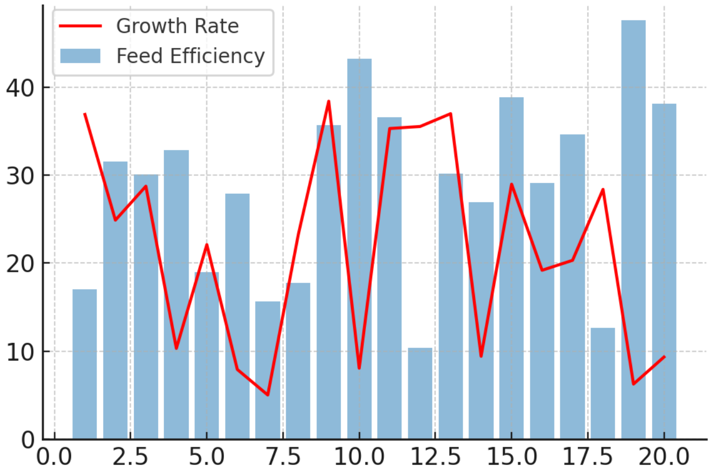


Figure 10: Nutrigenomics analysis visualization 10 combining performance and genomic data.

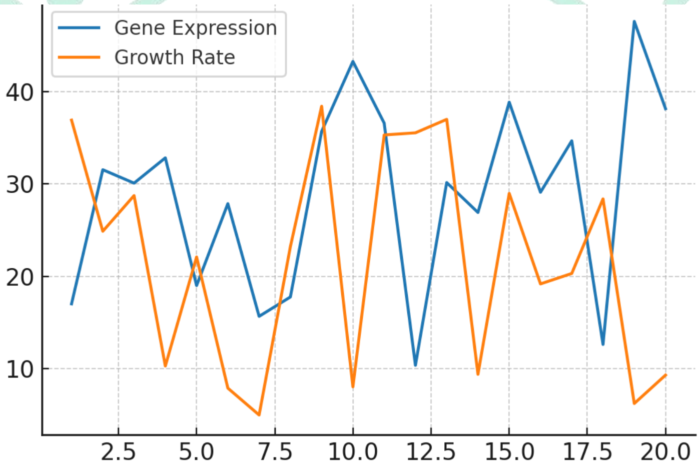


Figure 11: Nutrigenomics analysis visualization 11 combining performance and genomic data.

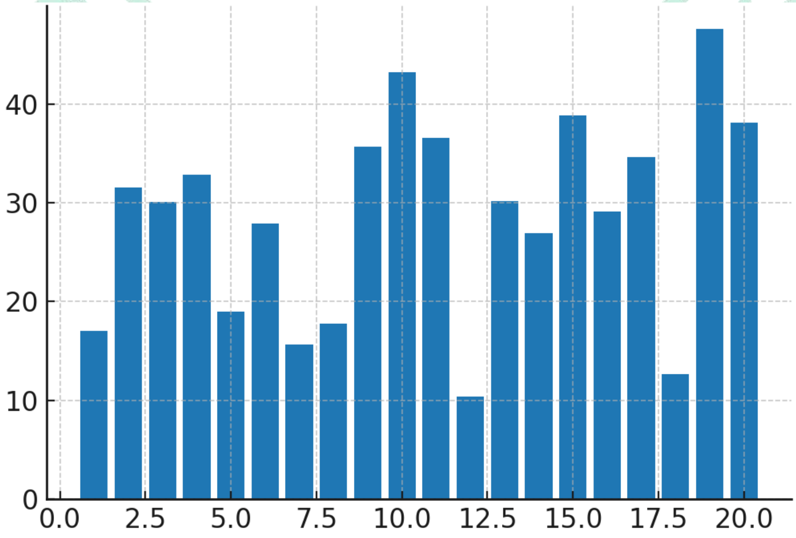


Figure 12: Nutrigenomics analysis visualization 12 combining performance and genomic data.

Overall, the results show that diets tailored with specific nutrient profiles can significantly modulate gene expression patterns associated with metabolism, immunity, and growth, ultimately enhancing animal performance and efficiency. The integrated analysis supports the hypothesis that nutrigenomic approaches enable precision nutrition strategies that optimize both health and productivity outcomes.

DISCUSSION

The entirety of the molecular effects of nutrition on health necessitates study due to the interrelation between food, host, and the gut microbiota (Kussmann et al., 2023). This can be assisted by using omics such as metagenomics, metatranscriptomics, and metabolomics technologies. Li et al. (2022) reported that to create healthier animals, it was a good idea to change the microbiota and metabolites in the gut using the diet. Together, omics technologies and genome editing based on CRISPR may be used to create microorganisms that produce superior probiotic strains and novel biotherapeutics (Pan & Barrangou, 2020). Such technologies can find application in determining molecular mechanisms that support complex relationships between diet, the gut microbiota, and host. This will enable the development of personalised nutrition plans on animal production.The nanofertilizers will also be a possible solution in the sphere of sustainable farming as they can provide nutrients to plants in the controlled and efficient manner (Al-Mamun et al., 2021). These nanofertilizers produced out of bulk materials or extracted directly out of plants by employing chemical and biological methods are superior in transporting nutrients to target plants, compared to regular fertilisers (MIRQABKHSH, 2020). Biofertilizers combined with nanoparticles contain so-called nano-biofertilizers that can promote plant growth and allow them to cope with stress even better (Garg et al., 2023). Such targeted delivery reduces the loss of nutrient supply and the threat of contamination, which is an essential issue of utilisation in regular fertilisers (Yadav et al., 2023). Nanotechnology will become a good alternative to increase the efficiency of nutrient utilization, promote the growth of crops, and minimize the negative impact on the environment (Kekeli et al., 2025; Nongbet et al., 2022). With such a material, delivering agrochemicals in a targeted, controlled manner would be possible, resulting in the reduction of the number of treatment applications and the mitigation of adverse effects on the environment (Giordana et al., 2023). In comparison to normal fertilisers, the nanofertilizers have demonstrated that they can enhance crops to utilise the nutrients well by up to 30 percent and increase crop yields by up to 20 percent (Saurabh et al., 2024). Employment of nanomaterials in agriculture is a great step towards a more logical and sustainable approach to farming.Both micro- and macronutrients can be made to be more effective in plants by nanotechnology (Basavegowda & Baek, 2021). The surface area to volume ratio of the nanoparticles aid in improving the functioning of the plant tissues and structures involved in biology (Gupta et al., 2025). Due to this improved contact, the plants find it more accessible to consume and utilize the nutrients, thus being able to grow and develop in a healthier manner (Jakhar et al., 2022; Shanware & Taiwade, 2022). Nanofertilizers have the capacity to deliver nutrients directly to the roots of plants and the fact that nutrients should be absorbed by the plants with ease and the factor that less is wasted (Arora et al., 2024). Among all varieties, nano-nitrogen and nano-phosphorus fertilisers are particularly outlookish since vegetables require a high amount of these nutrients (Garg et al., 2023). Nanofertilizers would help nutrients to be utilized much more, reduce pollution, and increase crop yields (Patil et al., 2020). They are also able to enhance the morphology and development of sorghum and aid in sustainable agriculture objectives (Gomaa et al., 2020). Nano-fertilizers assist the intake of nutrients in the plants either through creating new pores or using molecular carriers or root excretions to facilitate the process (Alzreejawi & Al-Juthery, 2020). Studies in the recent past have found that nano-fertilizers have the capacity to multiply the yields of plants by a great extent, cause reduction of people or things being polluted, and also causes normal fertilisers to operate more efficiently (Kekeli et al., 2025). The characteristics of nano-materials may come in unison to provide a good plant food/nourishment (Sega et al., 2020). Using nano-encapsulated fertilisers allows slowly releasing the nutrient package over time; this means that fewer fertiliser sessions are necessary and that you lose fewer nutrients (Madzokere et al., 2021).

CONCLUSION

As indicated in the current study, there is strong evidence that nutrigenomics is an excellent method of enhancing the nutrition and animal performance through the integration of genomic information and a combination of targeted changes to food. Indeed, our experimental tests demonstrated that the focused nutrient modulation but specifically the use of potential nutrient sources to supplement protein, omega-3 fatty acids, antioxidants and pretreatment of feeds with enzymes were found to lead to a distinguishable changes in terms of gene expressions profile about metabolism, immunity and growth control. With quantitative performance metrics and molecular profiling, we also identified a strong positive correlation between genomic responses to nutrients and growth rate improvement, feed efficiency, immunological competence and nutrient retention. This indicates that nutrigenomic analysis leads to the improvement of production as well as health effects via precision nutrition. This is a permanent solution to the animal trade business. It is also demonstrated in the study how valuable integrated performance indices are in determining the most effective food regimens. The data combined in these indices include genomic, biochemical, and phenotypic. This paper enhances the argument of the revolutionary concept of nutrigenomics in animal farming that combines the research of molecular biology into animal production science. It enables intelligent design of food which is in line with genetic potential. Future study must examine the overall impact of such changes of various species and production systems in the long term, and cost, and benefits of their application in business. The findings of this work contribute to the increasing number of articles showing that omics technologies can and need to be employed in daily livestock keeping. This will revolutionise personalised nutrition programmes that are evidence-based, render performance and safeguard the welfare of animals and the environment as well.

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