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PRECISION METABOLOMICS AND BIOMARKER-DRIVEN NUTRITION IN COMPANION ANIMALS: A COMPREHENSIVE REVIEW OF EMERGING RESEARCH

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Precision nutrition, a discipline once limited to human personalized health, has rapidly emerged as a transformative paradigm in companion animal science. Recent advances in metabolomics, microbiome analysis, multi-omics integration, and artificial intelligence (AI) have created unprecedented opportunities to formulate diets tailored to an individual animal's metabolic profile rather than relying solely on population-level nutrient requirements. This review summarizes the most recent (2020–2025) developments in pet metabolomics, including blood, urine, fecal, salivary, hair, and skin metabolic biomarker discovery; their association with health outcomes; and their relevance in designing biomarker-driven diets for dogs and cats. The integration of metabolomics with microbiome sequencing, wearable biosensors, dietary response prediction algorithms, machine learning-based disease risk scoring, and emerging commercial tools in personalized pet nutrition is also examined. The review concludes with research gaps, regulatory implications, and future directions, including metabolomic passports, dynamic diet optimization, precision amino-acid balancing, microbiome-modulatory formulations, and AI-driven individualized feeding systems. Precision metabolomics is poised to redefine the scientific and commercial landscape of pet nutrition over the next decade.

Keywords: pet food, nutrition, multi-omics, biomarker, metabolomics.

ЖЕКЕЛЕНДІРІЛГЕН МЕТАБОЛОМИКА ЖӘНЕ БИОМАРКЕРЛЕРГЕ НЕГІЗДЕЛГЕН ҮЙ ЖАНУАРЛАРЫНЫҢ ТАМАҚТАНУЫ: ЖАҢА ЗЕРТТЕУЛЕРГЕ КЕШЕНДІ ШОЛУ

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Жекелендірілген тамақтану, бұрын тек адамның дербестендірілген денсаулығымен шектеліп келген бағыт, үй жануарлары ғылымында жылдам дамып келе жатқан трансформациялық парадигмаға айналды. Метаболомика, микробиомды талдау, мультиомикалық деректерді біріктіру және жасанды интеллект (ЖИ) салаларындағы қазіргі жетістіктер жануардың метаболикалық бейініне бейімделген рациондарды жасауға бұрын-соңды болмаған мүмкіндіктер ашты. Бұл тәсіл дәстүрлі популяциялық нормаларға ғана сүйенбей, әр жануардың жеке қажеттіліктерін ескеруге мүмкіндік береді. Бұл шолуда 2020–2025 жылдар аралығындағы үй жануарлары метаболомикасының ең жаңа жетістіктері қарастырылады. Атап айтқанда, қан, несеп, нәжіс, сілекей, жүн және теріден алынатын метаболиттік биомаркерлерді анықтау, олардың жануар денсаулығы көрсеткіштерімен байланысы және иттер мен мысықтарға арналған биомаркер-негізді рациондарды әзірлеудегі маңызы талданады. Сонымен қатар метаболомиканың микробиом секвенирлеумен, тағатын биосенсорлармен, диеталық жауапты болжау алгоритмдерімен, ауру қаупін машиналық оқыту арқылы бағалау жүйелерімен және үй жануарларына арналған жекелендірілген тамақтанудың жаңа коммерциялық құралдарымен интеграциясы қарастырылды. Шолу зерттеу олқылықтары, реттеушілік талаптар және болашақ бағыттармен аяқталады. Олардың қатарында метаболомикалық паспорттар, рациондардың динамикалық оңтайландырылуы, аминқышқылдарының дәл теңгерімі, микробиомды модуляциялайтын формулалар және ЖИ арқылы басқарылатын дербестендірілген азықтандыру жүйелері бар. Жекелендірілген метаболомика алдағы онжылдықта үй жануарларының тамақтануына қатысты ғылыми және коммерциялық ландшафтты түбегейлі өзгертуге дайын.

Негізгі сөздер: үй жануарларына арналған азық, тамақтану, мультиомика, биомаркер, метаболомика.

ПЕРСОНАЛИЗИРОВАННАЯ МЕТАБОЛОМИКА И ПИТАНИЕ, ОСНОВАННОЕ НА БИОМАРКЕРАХ, У ДОМАШНИХ ЖИВОТНЫХ: КОМПЛЕКСНЫЙ ОБЗОР НОВЕЙШИХ ИССЛЕДОВАНИЙ

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Персонализированное питание, ранее ограниченное сферой персонализированного здоровья человека, стремительно развивается как трансформирующая парадигма в науке о домашних животных. Современные достижения в метаболомике, анализе микробиома, интеграции мультиомикс-данных и искусственном интеллекте (ИИ) создали беспрецедентные возможности для разработки рационов, адаптированных к индивидуальному метаболическому профилю животного, а не основанных исключительно на популяционных нормах потребности в питательных веществах. В данном обзоре представлены новейшие (2020–2025 гг.) достижения в области метаболомики домашних животных, включая выявление метаболических биомаркеров крови, мочи, фекалий, слюны, шерсти и кожи; их связь с показателями здоровья; а также их значение для разработки рационов, основанных на биомаркерах, для собак и кошек. Также была рассмотрена интеграция метаболомики с секвенированием микробиома, носимыми биосенсорами, алгоритмами прогнозирования пищевых реакций, машинным обучением для оценки риска заболеваний и новыми коммерческими инструментами персонализированного питания домашних животных. Обзор завершается анализом исследовательских пробелов, нормативных аспектов и будущих направлений, включая метаболомические паспорта, динамическую оптимизацию рационов, прецизионный баланс аминокислот, формулы, модулирующие микробиом, и ИИ-управляемые индивидуализированные системы кормления. Персонализированная метаболомика готова переопределить научный и коммерческий ландшафт питания домашних животных в течение следующего десятилетия.

Ключевые слова: корма для домашних животных, питание, мультиомика, биомаркер, метаболомика.

Introduction

Precision nutrition has emerged as one of the most rapidly expanding frontiers in companion animal science, fueled by transformative advances in metabolomics, multi-omics technologies, and artificial intelligence (AI)-driven data analysis [1,2] . Historically, canine and feline diets have been developed using population-based nutrient guidelines provided by organizations such as the Association of American Feed Control Officials (AAFCO), the European Pet Food Industry Federation (FEDIAF), and the National Research Council (NRC). These guidelines assume that animals of similar species, age, and physiological stage require broadly similar nutrient intakes to maintain health, growth, and reproductive capacity [3,4]. While these frameworks have successfully ensured baseline nutrient adequacy, they fail to account for the substantial metabolic, genetic, and physiological heterogeneity that exists among individual pets. Emerging evidence indicates that factors such as breed-specific metabolic traits, genetic polymorphisms, variations in gut microbiome composition, age, hormonal status, immune function, chronic or subclinical disease states, and lifestyle parameters, including activity level and environmental stressors, profoundly influence nutrient digestion, absorption, metabolism, and systemic utilization. Consequently, two animals consuming identical diets may exhibit dramatically different metabolic responses, growth trajectories, and long-term health outcomes, highlighting the limitations of “one-size-fits-all” feeding strategies [5,6,7].

The recognition of this individual variation has catalyzed a paradigm shift in pet nutrition toward personalized or precision feeding, an approach in which dietary composition is tailored to the unique biological and metabolic characteristics of each animal. Precision nutrition seeks to move beyond generalized nutrient requirements by integrating measurable biomarkers of metabolism, organ function, gut health, and immune status to optimize health outcomes, improve longevity, and prevent diet-related diseases [10]. At the heart of this transformation is metabolomics, the comprehensive analysis of small-molecule metabolites produced during cellular metabolism. Unlike genomics, which provides a static blueprint of genetic potential, or proteomics, which measures relatively slower changes in protein expression, metabolomics offers a dynamic snapshot of an organism’s current physiological and nutritional state. It allows researchers and clinicians to monitor real-time biochemical responses to diet, detect subtle

metabolic imbalances, identify early markers of disease, and evaluate interactions between diet, gut microbiota, and systemic metabolism [11,12].

Recent studies have demonstrated that metabolomic profiling in dogs and cats can reveal individual differences in amino acid utilization, lipid metabolism, carbohydrate processing, micronutrient status, and oxidative stress, all of which may influence disease risk and overall health. For instance, breed-specific susceptibilities to taurine deficiency, obesity, diabetes, and chronic inflammation are increasingly linked to identifiable metabolomic signatures that can be used to guide tailored dietary interventions. Furthermore, the integration of metabolomics with other omics approaches, such as metagenomics of the gut microbiome, transcriptomics, and epigenomics, provides a multidimensional view of an animal's metabolic network, highlighting the complex interplay between diet, host metabolism, microbial metabolism, and environmental influences. Advanced computational modeling and AI algorithms now enable the analysis of these vast datasets, allowing researchers to generate predictive models of dietary response and to design individualized feeding strategies that optimize health outcomes for each pet [13,14].

The implications of this paradigm shift are profound. Precision nutrition has the potential to improve the management of chronic diseases such as obesity, diabetes, inflammatory bowel disease, dermatologic disorders, and renal insufficiency by enabling earlier detection of metabolic disturbances and more targeted dietary interventions. It also allows for the optimization of growth, reproduction, and longevity by accounting for breed- or individual-specific metabolic needs that may deviate from standardized recommendations [15,16,17]. From a commercial perspective, this approach is driving innovation in the pet food industry, with the development of customized diets, functional foods, nutraceuticals, and adaptive feeding platforms that respond to ongoing metabolomic monitoring. In essence, the adoption of metabolomics and biomarker-driven feeding strategies marks the beginning of a new era in companion animal nutrition, one that combines cutting-edge science with practical applications to enhance the health, wellbeing, and lifespan of pets while addressing the limitations of traditional, population-based dietary formulations [18].

Materials and methods

A comprehensive literature search was conducted to identify peer-reviewed publications, conference proceedings, and relevant scientific reports on precision nutrition, metabolomics, and biomarker-based dietary strategies in companion animals. The search covered the period from 2020 to 2025.

Results and discussion

1. Overview of Metabolomics in Companion Animal Science

1.1 Definition and Importance

Metabolomics is the comprehensive analysis of small-molecule metabolites produced through cellular metabolic processes. These metabolites include amino acids, fatty acids, organic acids, nucleosides, bile acids, vitamins, and microbial-derived compounds. Unlike genomic or proteomic data, which reflect potential or slowly changing biological states, metabolomic profiles provide an immediate snapshot of metabolic activity and change dynamically in response to diet, exercise, stress, environmental exposures, and disease [19,20]. This makes metabolomics exceptionally valuable in nutritional research, as it allows scientists to monitor how diets influence metabolism in real time, detect early metabolic stress, and identify biomarkers predictive of disease risk or nutrient insufficiency. In companion animals, metabolomics has been used to investigate obesity, metabolic syndrome, renal and hepatic disorders, inflammatory conditions, gastrointestinal health, and micronutrient deficiencies. By capturing the metabolic fingerprint of an individual pet, metabolomics facilitates evidence-based interventions that improve health outcomes, prevent disease, and optimize long-term wellbeing [21].

1.2 Biological Matrices for Metabolomic Analysis

Metabolomic data can be collected from multiple biological matrices, each providing unique information. Blood plasma or serum is the most commonly used matrix and provides systemic insight into nutrient status, energy metabolism, inflammatory markers, amino acid balance, and lipid profiles. Urine allows the evaluation of renal function, detoxification efficiency, hydration status, and accumulation of metabolic by-products. Fecal samples are critical for assessing gut microbial activity, revealing the production of short-chain fatty acids, bile acids, and proteolytic metabolites, which influence nutrient absorption, immune modulation, and gastrointestinal health. Saliva offers a non-invasive option to monitor stress-related metabolites, cortisol derivatives, and oral microbiota by-products, particularly useful in behavioral or stress-related nutrition studies. Hair and tissue samples can provide long-term insights into nutrient status, exposure to environmental toxins, and chronic metabolic trends. Together, these matrices enable a comprehensive and multidimensional understanding of a pet's metabolic health [22,23,24].

2. Key Metabolic Pathways Relevant to Pet Nutrition

2.1 Amino Acid Metabolism

Amino acid metabolomics allows for the assessment of protein adequacy, digestibility, and utilization in companion animals. Disruptions in branched-chain amino acids (BCAAs), tryptophan catabolism, and methionine-cycle intermediates are associated with metabolic stress, inflammation, and obesity [25,26]. Elevated kynurenine levels, resulting from inflammation-driven tryptophan metabolism, have been linked to immune dysregulation and mood-related behaviors. Taurine deficiency metabolites, especially relevant in cats and certain dog breeds, are early indicators of cardiomyopathy risk and retinal dysfunction. By monitoring these metabolites, veterinarians and nutritionists can formulate protein sources and amino acid profiles that optimize muscle maintenance, immune function, and overall metabolic health.

2.2 Lipid and Fatty Acid Metabolism

Lipidomic provides crucial insights into energy metabolism, inflammation, skin and coat condition, and immune function. The balance of omega-3 and omega-6 fatty acids directly influences eicosanoid production, which regulates inflammatory responses. Breed-specific lipid metabolic patterns, dietary fat sources, and gut microbiome interactions all contribute to variations in lipid metabolites [26]. For example, prostaglandins and leukotrienes serve as indicators of inflammatory states and can guide omega-3 supplementation strategies to reduce inflammation and improve dermatologic health.

2.3 Energy and Carbohydrate Metabolism

Metabolites associated with glycolysis, the tricarboxylic acid (TCA) cycle, and mitochondrial oxidative pathways provide information on energy metabolism and metabolic flexibility. Elevated lactate levels, or disruptions in citrate, succinate, or malate, may indicate mitochondrial dysfunction or poor adaptation to carbohydrate-rich diets [27]. Such insights enable precision adjustment of macronutrient ratios in pets prone to obesity, insulin resistance, or reduced exercise tolerance.

2.4 Gut Microbial Metabolites

Fecal metabolomics has revealed that gut microbial metabolites, including short-chain fatty acids (SCFAs), indoles, phenols, and secondary bile acids, play central roles in gastrointestinal health, immune modulation, and systemic metabolic stability. Recent studies highlight that fecal metabolite patterns vary by breed and health status, correlating with obesity, inflammatory bowel disease, allergies, and nutrient malabsorption. Understanding these microbial metabolites informs the development of individualized gut-modulating diets to optimize nutrient absorption and prevent dysbiosis [28].

3. Integration of Metabolomics and the Gut Microbiome

3.1 Microbiome–Metabolome Interactions

The gut microbiome generates hundreds of metabolites that influence host physiology. Recent research emphasizes that microbial metabolic output, rather than species composition alone, drives many health outcomes. Pets with dysbiosis often exhibit altered SCFA profiles, increased proteolytic by-products, and impaired bile acid metabolism, all of which can compromise nutrient absorption, immune function, and gut integrity. Integrating metabolomic and microbiome data allows identification of metabolic imbalances that are not detectable through microbial sequencing alone [29].

3.2 Dietary Modulation of Microbial Metabolites

Diet composition—including fiber type, prebiotics, probiotics, postbiotics, and protein digestibility—profoundly affects microbial metabolite production. Diets high in fermentable fiber increase SCFA levels, enhancing gut barrier integrity, modulating immune response, and supporting healthy weight [30]. Conversely, high-protein diets with low digestibility can elevate harmful metabolites, such as ammonia, p-cresol, and indole derivatives, detectable through metabolomics before clinical consequences emerge.

4. Wearable Technologies and Digital Phenotyping

4.1 Role in Precision Nutrition

Wearable devices for pets—such as collars and harnesses equipped with activity sensors, heart rate monitors, and stress indicators—provide continuous physiological and behavioral data [31]. When combined with metabolomic biomarkers, these devices offer a comprehensive view of how diet affects metabolism, energy expenditure, and stress.

4.2 Data Integration and Predictive Modeling

Machine learning algorithms integrate wearable-derived physiological data with metabolomic profiles to generate predictive models of dietary response [32]. For example, a decrease in activity alongside elevated inflammatory metabolites may trigger dietary adjustments, such as targeted supplementation with antioxidants, omega-3 fatty acids, or amino acids, optimizing health outcomes in real time.

5. Biomarker-Driven Diet Formulation

5.1 Early Disease Detection and Targeted Nutrition

Metabolomics enables detection of early biomarkers of kidney disease, liver dysfunction,

obesity, inflammation, and metabolic disorders, allowing dietary interventions before clinical signs appear. Early detection through metabolites such as creatinine precursors, uremic toxins, or lipid peroxidation markers allows precise formulation of diets to support organ function and prevent disease progression [33,38].

5.2 Personalized Macronutrient and Micronutrient Balancing

Individual metabolic responses to proteins, fats, and carbohydrates vary widely. Metabolomics identifies these differences, facilitating the creation of macronutrient ratios tailored to each pet. Similarly, micronutrient deficiencies, including taurine, choline, carnitine, and B-vitamins—can be detected early, enabling correction through diet or supplementation [34].

5.3 Precision Fiber and Prebiotic Blending

Fecal metabolomics informs the selection of dietary fibers and prebiotics to optimize SCFA production, minimize proteolytic fermentation, improve stool quality, and enhance gut immunity. This approach supports gastrointestinal health while reducing inflammation and metabolic stress [35].

6. Challenges and Limitations

Despite its potential, precision metabolomics faces several challenges. Analytical methods are costly, require specialized expertise, and standardized reference ranges for dogs and cats remain limited. Inter-laboratory variation complicates data interpretation, and integrating metabolomic, microbiome, and wearable data requires sophisticated computational models still under development [36]. Regulatory frameworks have not yet adapted to individualized diets, creating uncertainty in labeling, safety claims, and commercial implementation.

7. Future Directions

The future of precision nutrition in companion animals is promising. Innovations such as metabolomic passports, longitudinal metabolic monitoring, AI-driven diet optimization, and 3D-printed or micro-extruded customized foods may allow truly individualized nutrition. Integration of microbiome engineering, postbiotic therapies, and continuous monitoring could further refine metabolic balance and disease prevention, making biomarker-driven feeding a central element of veterinary care and commercial pet food development in the next decade [37].

Conclusion

Precision metabolomics and biomarker-driven nutrition represent a paradigm shift in companion animal health. By providing real-time insights into metabolic function, nutrient utilization, and disease risk, metabolomics enables individualized dietary strategies that go beyond population-based recommendations. Coupled with microbiome science, wearable technologies, and AI-based modeling, precision nutrition promises to improve health outcomes, prevent disease, and transform both veterinary care and the pet food industry. This approach marks the beginning of a new era in pet health management, driven by scientific precision, personalization, and continuous monitoring.

REFERENCES

1. Xie L, Xiao J, Liu J, et al. Fecal microbiota and metabolomics revealed the effect of long-term consumption of gallic acid on canine lipid metabolism and gut health. J Anim Physiol Anim Nutr (Berl). 2022;106(5):731–743.

2. Banton SJ, Hall JA, Jewell DE, et al. Whole pulse ingredient inclusion in macronutrient-balanced diets increased fecal concentrations of propionic acid in healthy adult large-breed dogs. J Anim Sci. 2023; (in press)

3. Richards JB, et al. Dietary Features Are Associated with Differences in the Urinary Microbiome in Clinically Healthy Adult Dogs. Animals (Basel). 2023;13(7):286.

4. Buff P, Kienzle E, Mandigers P, et al. Fecal metabolomic signature of a plant-based (vegan) diet compared to an animal-based diet in healthy adult pet dogs. J Anim Sci. 2024; (advance article).

5. Pilla R, Suchodolski JS, et al. Longitudinal fecal microbiome and metabolite data demonstrate rapid shifts and subsequent stabilization after an abrupt dietary change in healthy adult dogs. Animal Microbiome. 2022;4:46.

6. Menard J, Bagheri S, Menon S, et al. Noninvasive sampling of the small intestinal chyme for microbiome, metabolome and antimicrobial resistance genes in dogs, a proof of concept. Animal Microbiome. 2023;5:64.

7. Cohen A, Turjeman S, Levin R, Tal S, Koren O. Comparison of canine colostrum and milk using a multi-omics approach. Animal Microbiome. 2024;6:19.

8. Hall JA, Jackson MI, Vondran JC, Vanchina MA, Jewell DE. Serum Metabolomics of Senior Dogs Fed a Fresh, Human-Grade Food or an Extruded Kibble Diet. Metabolites. 2024;15(10):676.

9. Fritsch KA, Rindt H, Hill R, et al. Combined metagenomic and metabolomic pathway mapping in dogs with chronic diarrhea shows shift from putrefactive to saccharolytic fermentation. BMC Vet Res. 2022;18:245.

10. Hall JA, Suchodolski JS, et al. Microbiome function underpins the efficacy of a fiber-supplemented dietary intervention in dogs with chronic large bowel diarrhea. Gut Microbes. 2022; (metagenomic + metabolomic data)

11. El-Waseif M, et al. Fecal microbiota composition, serum metabolomics, and markers of inflammation in dogs fed a raw meat-based diet compared to those on a kibble diet. Front Vet Sci. 2024;11:1328513.

12. Beg M, Liu X, Yang Y, Wang X, Fadrosh DW, et al. Variations in gut microbiome and metabolites of dogs with acute diarrhea in poodles and Labrador retrievers. Microbiome. 2023;11:210.

13. Chang Y, Qin J, He X, et al. Insights into the interplay between gut microbiota and lipid metabolism in obesity management of canines and felines. J Anim Sci Biotechnol. 2024;15(1):114.

14. Ainslie P, et al. Insights into the interplay between gut microbiota and lipid metabolism in the obesity management of canines and felines. J Anim Sci Biotechnol. 2024;15(1):114.

15. Kumar R, Goswami M, Pathak V. Innovations in pet nutrition: investigating diverse formulations and varieties of pet food: mini review. MOJ Food Process Technols. 2024;12(1):86–89. DOI: 10.15406/mojfpt. 2024.12.00302

16. Kumar R, Goswami M. Harnessing poultry slaughter waste for sustainable pet nutrition: a catalyst for growth in the pet food industry. J Dairy Vet Anim Res. 2024;13(1):31–33. DOI: 10.15406/jdvar.2024.13.00344

17. Kumar, R. (2024). Promoting Pet Food Sustainability: Integrating Slaughterhouse By-products and Fibrous Vegetables Waste. Acta Scientific Veterinary Sciences, 6, 07-11. http://dx.doi.org/10.31080/ASVS. 2024.06.0871

18. Kumar, R., & Goswami, M. (2024). Exploring Palatability in Pet Food: Assessment Methods and Influential Factors. International Journal of Livestock Research, 14(4).

19. Kumar, R., & Goswami, M. (2024). Feathered nutrition: unlocking the potential of poultry byproducts for healthier pet foods. Acta Scientific Veterinary Sciences. (ISSN: 2582-3183), 6(4).

20. Kumar, R., & Goswami, M. (2024). Optimizing Pet Food Formulations with Alternative Ingredients and Byproducts. Acta Scientific Veterinary Sciences (ISSN: 2582-3183), 6(4).

21. Kumar, R., & Sharma, A. (2024). A Comprehensive Analysis and Evaluation of Various Porcine Byproducts in Canine Diet Formulation. Asian Journal of Research in Animal and Veterinary Sciences, 7(3), 236-246. https://doi.org/10.9734/ajravs/2024/v 7i3308

22. Kumar, R., & Sharma, A. (2024). Deciphering new nutritional substrates for precision pet food formulation. International Journal of Veterinary Sciences and Animal Husbandry.https://doi. org/10.22271/veterinar y, 202(4), v9.

23. Kumar, R., & Sharma, A. (2024). Prebiotic-driven Gut Microbiota Dynamics: Enhancing Canine Health via Pet Food Formulation. International Journal of Bio-resource and Stress Management, 15(Jun, 6), 01-15. https://doi.org/10.23910/1.2024.5359

24. Kumar, R., & Sharma, A. (2024). Review of Pet Food Packaging in the US Market: Future Direction Towards Innovation and Sustainability. Annual Research & Review in Biology, 39(6), 16-30. https://doi.org/10.9734 /arrb/2024/v39i62085

25. Kumar, R., Goswami, M. and Pathak, V. (2023). Enhancing Microbiota Analysis, Shelf-life, and Palatability Profile in Affordable Poultry Byproduct Pet Food Enriched with Diverse Fibers and Binders. J. Anim. Res., 13(05): 815-831. DOI: 10.30954/2277-940X.05.2023.24

26. Kumar, R., Goswami, M., & Pathak, V. (2024). Gas Chromatography Based Analysis of fatty acid profiles in poultry byproduct-based pet foods: Implications for Nutritional Quality and Health Optimization. Asian Journal of Research in Biochemistry, 14(4), 1-17. https://doi.org /10.9734/ajrb/2024/v14i4289

27. Kumar, R., Goswami, M., Pathak, V., & Singh, A. (2024). Effect of binder inclusion on poultry slaughterhouse byproducts incorporated pet food characteristics and palatability. Animal Nutrition and Feed Technology, 24(1), 177-191. DOI: 10.5958/0974-181X.2024.00013.1

28. Kumar, R., Goswami, M., Pathak, V., Bharti, S.K., Verma, A.K., Rajkumar, V. and Patel, P. 2023. Utilization of poultry slaughter byproducts to develop cost effective dried pet food. Anim. Nutr. Technol., 23: 165-174. DOI: 10.5958/0974-181X. 2023.00015.X

29. Kumar, R., Goswami, M., Pathak, V., Verma, A.K. and Rajkumar, V. 2023. Quality improvement of poultry slaughterhouse byproducts-based pet food with incorporation of fiber-rich vegetable powder. Explor. Anim. Med. Res., 13(1): 54-61. DOI : 10.52635 /eamr/13.1.54-61

30. Kumar, R., Thakur, A., & Sharma, A. (2023). Comparative prevalence assessment of subclinical mastitis in two crossbred dairy cow herds using the California mastitis test. J Dairy Vet Anim Res, 12(2), 98-102 http://dx.doi.org/10.15406/jdvar.2023.12.00331

31. Kim S-H, Hong H-S, Lee H-J, et al. Amino acid nutrition and metabolism in domestic cats and dogs. J Anim Sci Biotechnol. 2022;13(1):103.

32. Sanderson SL. Characteristics of Nutrition and Metabolism in Dogs and Cats. Vet Clin North Am Small Anim Pract. 2023;53(4):625-640.

33. Parsons CM, Hall JA, Jewell DE. Serum Metabolomics of Senior Dogs Fed a Fresh, Human-Grade Food or an Extruded Kibble Diet. Metabolites. 2024;15(10):676.

34. Li Y, Lin L, Yin G, et al. Gut Metabolome in Companion Animal Nutrition—Linking Diets to Health. Animals. 2025;15(5):651.

35. Rankovic N, Jewell DE, Liu XJ, et al. Serum metabolomics reveals one-carbon metabolism differences between lean and obese cats not affected by L-carnitine or choline supplementation. J Anim Sci. 2023;101 (12): skaf298.

36. Hall JA, Jackson MI, Vondran JC, Vanchina MA, Jewell DE. Comparison of circulating metabolite concentrations in dogs and cats when allowed to freely choose macronutrient intake. Biol Open. 2018;7(11): bio036228.

37. Baltzer WI, et al. Recent Advances in the Nutrition and Metabolism of Dogs and Cats. Annu Rev Anim Biosci. 2024; 12:325–350.

38. Swanson KS, Dowd SE, Suchodolski JS, Middelbos IS, Vondran JS. The Effects of Nutrition on the Gastrointestinal Microbiome of Cats and Dogs: Impact on Health and Disease. Front Microbiol. 2020; 11:1266.