kurketauk etinin tagamdyk kundylygyn zertteu [Study of the nutritional value of turkey meat used in the production of meat products for herodiet nutrition]. Bulletin of the Shakarim State University of Semey No. 3(87) 2019 pp. 29-33

5. Hayrapetyan A.A., Manzhesov V.I., Churikova S.Y. Razrabotka tehnologii mjasnogo hleba funktsional'nogo naznachenija [Development of meat bread technology for functional purposes. Bulletin of the Voronezh State University of Engineering Technologies]. 2020;82(4):142-146. https://doi.org/10.20914/2310-1202-2020-4-142-146

6. Rebezov M.B. Method of cooking heat-treated turkey meat roll / M.B. Rebezov, S. K. Kasymov // Patent of the Russian Federation No. 2076613, Application. 29.12.2014. Published on 04/10/2016. Byul. No. 10.

7. Stefanova I.L. Products based on poultry meat for children's nutrition / I.L. Stefanova, L.V. Shakhnazarova, N.V. Timoshenko // Meat. the industry. 2006. No. 7. pp. 35-39.

8. Lukinykh S.V. Otsenka kachestva i bezopasnosti razrabotannogo ruleta iz mjasa ptitsy [Evaluation of the quality and safety of the developed meat roll] / S.V. Lukinykh, M.B. Rebezov, M.A. Popova, A.O. Gayazova // Young Scientist. - 2014. — No. 10. — pp. 168-171.

9. Singh R.P. Introduction to Food Engineering / R.P. Singh, D.R. Heldman // Elsevier, Fourth Edition. — 2009. — 841 p.

10. Smith P.G. Introduction to Food Process Engineering / P.G. Smith. — 2nd ed. — Springer Science+Business Media, LLC, 2011. — 510 p.

11. Antipova L.V. Issledovanija mjasa tsesarok s tsel'ju ispol'zovanija ego v tehnologii funktsional'nyh produktov pitanija [Research of guinea fowl meat with the aim of using it in functional food technology] /L.V.Antipova, S.V.Polyanskikh, D.Y.Kovalev //Materials of the All-Russian scientific and practical conference with international participation "Innovative technologies in the food industry".– Samara:SamSTU, 2009. pp.91-92.

12. Pryanishnikov, V.V. Innovatsionnye tehnologii proizvodstva polufabrikatov iz mjasa ptitsy [Innovative technologies for the production of semi-finished poultry products] / V.V. Pryanishnikov // Poultry and poultry products. – 2010. – No. 6. – pp. 54-57.

13. Kaimbayeva L.A. Development of technology of combined chopped semi-finished products from horse meat for special purposes: dis. candidate of technical sciences. – 2001. – 121s.

14. Kostenko Yu.G., Nezeplyaev S.V., Goncharov A. Fundamentals of microbiology, hygiene and sanitation at meat and poultry processing enterprises, Moscow: Agropromizdat -1991 -176c.

15. Chen, X.; Yu, H.; Ji, Y.; Wei, W.; Peng, C.; Wang, X.; Xu, X.; Sun, M.; Xu, J. Development and Application of a Visual Duck Meat Detection Strategy for Molecular Diagnosis of Duck-Derived Components. Foods 2022, 11, 1895. https://doi.org/10.3390/ foods11131895

16. S. Biswas, A. Chakraborty, G. Patra and A. Dhargupta Quality and acceptability of duck patties stored at ambient and refrigeration temperature. Nternational. Journal of Livestock Production Vol. 1(1), pp. 1-6, January 2011

SRSTI 65.31.01 https://doi.org/10.48184/2304-568X-2025-1-55-63

MACHINE LEARNING IN PET FOOD: A COMPREHENSIVE REVIEW OF APPLICATIONS, CHALLENGES, AND FUTURE DIRECTIONS

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The global pet food industry is rapidly evolving with the integration of machine learning (ML) technologies. ML plays a crucial role in optimizing ingredient formulation, enhancing quality control, personalizing nutrition, and predicting consumer preferences. The use of deep learning, reinforcement learning, and natural language processing (NLP) is transforming pet food manufacturing by improving efficiency and ensuring better health outcomes for pets. This review explores the key applications of ML in pet food science, discusses current challenges, and highlights future directions. The paper also presents a comparative analysis of different ML techniques used in the pet food sector. Machine learning is transforming the pet food industry by optimizing ingredient formulation, improving quality control, and predicting consumer preferences. However, widespread AI adoption faces challenges, including data limitations, regulatory requirements, computational expenses, and consumer trust concerns. The future of AI-driven

pet food innovation lies in explainable AI, blockchain-integrated supply chains, IoT-enabled pet health monitoring, and synthetic data-powered machine learning models. As technology advances, AI will play a key role in providing safer, healthier, and more personalized nutrition for pets, shaping the industry's future.

Keywords: Machine learning, pet food, personalized nutrition, quality control, consumer preferences, artificial intelligence.

ҮЙ ЖАНУАРЛАРЫНА АРНАЛҒАН ЖЕМ САЛАСЫНДАҒЫ МАШИНАЛЫҚ ОҚЫТУДЫ ҚОЛДАНУ: ҚОЛДАНБАЛАР, МӘСЕЛЕЛЕР ЖӘНЕ БОЛАШАҚ БАҒЫТТАРДЫ ЖАН-ЖАҚТЫ ШОЛУ

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Үй жануарларына арналған азық-түлік индустриясы машиналық оқытуды (ML) енгізу арқылы қарқынды дамып келеді. ML ингредиенттерді оңтайлы үйлестіру, сапаны бақылауды күшейту, тамақтануды жекелендіру және тұтынушы талғамын болжау салаларында маңызды рөл атқарады. Тереңдетілген оқыту, нығайтылған оқыту және табиғи тілді өңдеу (NLP) әдістерін қолдану үй жануарлары азығын өндіру процесін жетілдіріп, тиімділікті арттырып, жануарлардың денсаулығын жақсартуға ықпал етеді. Бұл шолу ML-дің үй жануарлары азығы саласындағы негізгі қолданбаларын қарастырып, қазіргі таңдағы қиындықтарды талдайды және болашақ бағыттарды анықтайды. Сондай-ақ, мақалада үй жануарларына арналған азық саласында қолданылатын әртүрлі ML әдістеріне салыстырмалы талдау жасалады. Машиналық оқыту үй жануарлары азығы саласын ингредиенттерді оңтайландыру, сапаны бақылауды жақсарту және тұтынушы талғамын болжау арқылы түбегейлі өзгертіп келеді. Алайда, AI-ды кең көлемде енгізу үшін деректердің шектеулілігі, реттеуші талаптар, есептеу шығындары және тұтынушылар сенімі сияқты мәселелерді шешу қажет. Үй жануарларына арналған азық өндірісіндегі AI-дың болашағы түсінікті AI, блокчейнмен интеграцияланған жеткізу тізбектері, IoT негізіндегі үй жануарларының денсаулығын бақылау және синтетикалық деректермен жұмыс істейтін ML модельдері сияқты технологияларға байланысты. Технология дамыған сайын AI қауіпсіз, пайдалы және жекелендірілген тамақтануды қамтамасыз етуде маңызды рөл атқарып, үй жануарлары азығы индустриясының болашағын қалыптастырады.

Негізгі сөздер: машиналық оқыту, үй жануарларына арналған жем, жекелендірілген тамақтану, тағамды бақылау, тұтынушылардың қалауы, жасанды интеллект.

ИСПОЛЬЗОВАНИЕ МАШИННОГО ОБУЧЕНИЯ В СФЕРЕ КОРМОВ ДЛЯ ДОМАШНИХ ЖИВОТНЫХ: ВСЕСТОРОННИЙ ОБЗОР ПРИЛОЖЕНИЙ, ПРОБЛЕМ И БУДУЩИХ НАПРАВЛЕНИЙ

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Глобальная индустрия кормов для домашних животных стремительно развивается благодаря интеграции технологий машинного обучения (ML). ML играет ключевую роль в оптимизации состава ингредиентов, улучшении контроля качества, персонализации питания и прогнозировании предпочтений потребителей. Использование глубокого обучения, обучения с подкреплением и обработки естественного языка (NLP) трансформирует процесс производства кормов для домашних животных, повышая его эффективность и обеспечивая лучшее здоровье питомцев. В данном обзоре рассматриваются основные

области применения ML в науке о кормах для домашних животных, обсуждаются текущие проблемы и обозначаются перспективные направления развития. В статье также проводится сравнительный анализ различных методов ML, применяемых в секторе кормов для домашних животных. Машинное обучение меняет индустрию кормов, оптимизируя формулирование ингредиентов, улучшая контроль качества и прогнозируя предпочтения потребителей. Однако широкомасштабное внедрение ИИ сталкивается с такими проблемами, как ограниченность данных, нормативные требования, высокие вычислительные затраты и вопросы доверия со стороны потребителей. Будущее инноваций в области кормов для домашних животных, основанных на ИИ, связано с объяснимым ИИ, интегрированными с блокчейном цепочками поставок, мониторингом здоровья питомцев на основе Интернета вещей (IoT) и моделями машинного обучения, работающими на синтетических данных. По мере развития технологий ИИ будет играть все более важную роль в обеспечении более безопасного, здорового и персонализированного питания для домашних животных, формируя будущее этой индустрии.

Ключевые слова: машинное обучение, корм для домашних животных, персонализированное питание, контроль качества, потребительские предпочтения, искусственный интеллект.

Introduction

The pet food industry has experienced significant growth over the past decade, fueled by increasing pet ownership, heightened awareness of pet health, and demand for high-quality, customized nutrition. The global pet food market is projected to reach $150 billion by 2030, with a compound annual growth rate (CAGR) of approximately 6% [1] This rapid expansion is driven by shifting consumer preferences toward organic, grain-free, and functional foods that address specific pet health concerns, such as obesity, allergies, and digestive issues [1]. As pet owners become more educated about animal nutrition, they seek products that are not only palatable but also scientifically optimized for their pets' well-being.

1.1. The Evolution of Pet Food Science

Historically, pet food formulation was based on empirical research, industry best practices, and nutritional guidelines provided by organizations such as the Association of American Feed Control Officials (AAFCO) and the European Pet Food Industry Federation (FEDIAF) [2]. These guidelines ensured that commercial pet food met basic dietary requirements, but they lacked personalization and real-time adaptability to individual pet needs. Traditional manufacturing methods also relied heavily on trial-and-error testing, which was time-consuming, resource-intensive, and often resulted in suboptimal formulations. With the rise of big data and artificial intelligence (AI), machine learning (ML) has emerged as a transformative tool in the pet food industry. ML-driven approaches allow for precise ingredient selection, real-time quality control, predictive analytics for pet health, and enhanced consumer preference modeling [2]. These advancements have enabled pet food manufacturers to create highly customized diets, improve production efficiency, and enhance food safety through automated quality checks.

1.2. The Role of Machine Learning in Pet Food Innovation

Machine learning, a subset of AI, involves the use of algorithms that learn from large datasets and make data-driven decisions without explicit programming. In the pet food industry, ML plays a crucial role in:

1. Ingredient Optimization and Nutritional Formulation – ML models analyze vast amounts of nutritional data to develop well-balanced pet diets tailored to factors such as breed, age, weight, and health conditions. Predictive algorithms help identify optimal ingredient combinations, ensuring high palatability and digestibility while minimizing costs [2].

2. Quality Control and Food Safety Monitoring – AI-powered computer vision and deep learning techniques detect contaminants, assess ingredient consistency, and monitor food production lines in real time, reducing the risk of defective or unsafe products reaching consumers [2].

3. Personalized Pet Nutrition and Health Prediction – ML-driven platforms integrate pet health records, genetic data, and activity tracking from smart devices to recommend customized meal plans that address specific health conditions such as diabetes, obesity, and kidney disease [3]

4. Consumer Preference Prediction and Market Insights – AI models analyze social media trends, online reviews, and purchasing patterns to help manufacturers understand pet owners' preferences and predict emerging market trends [3].

1.3. Data-Driven Pet Food Development

One of the most significant contributions of ML in pet food production is its ability to harness vast datasets from various sources, including veterinary research, consumer feedback, ingredient

suppliers, and regulatory bodies. By integrating data-driven insights, manufacturers can:

- Reduce dependency on animal testing by simulating the impact of diet changes in silico.
- Improve sustainability by identifying alternative protein sources, such as insect-based or lab-grown ingredients, that provide optimal nutrition while reducing the carbon footprint [3].
- Enhance supply chain efficiency by predicting ingredient shortages and optimizing procurement strategies.

1.4. The Growing Need for ML in the Pet Food Industry

As consumer expectations for pet food quality and transparency increase, ML has become a vital tool in addressing industry challenges, including:

- Regulatory Compliance – AI-driven models ensure that ingredient compositions adhere to AAFCO, FDA, and European regulations, reducing the risk of non-compliance [4].
- Food Recalls and Safety Issues – Machine learning helps identify potential contamination risks and predict equipment malfunctions before they occur, thereby minimizing recalls and ensuring food safety [4,5,30]
- Economic and Supply Chain Optimization – Predictive analytics allow manufacturers to manage raw material costs and optimize inventory levels based on fluctuating demand [5].

1.5. Challenges in ML Adoption

Despite its advantages, the implementation of machine learning in the pet food industry faces several hurdles:

1. Data Quality and Availability – ML models require high-quality, standardized datasets, which are often fragmented across different sources and formats (Kim et al., 2023).
2. High Computational Costs – Training complex AI models requires significant computational power, which may be a barrier for smaller manufacturers.
3. Consumer Trust and Transparency – Pet owners are increasingly skeptical about AI-driven food production; ensuring transparency in ML-based decisions is crucial for consumer confidence [4].
4. Integration with Traditional Manufacturing – Many pet food companies rely on legacy systems that are not easily compatible with AI-powered automation.

2. Quality Control and Safety Monitoring

Food safety is a critical concern in the pet food industry, as contamination, spoilage, and ingredient inconsistencies can pose serious health risks to pets. Unlike human food, pet food is often produced in bulk and stored for extended periods, increasing the likelihood of bacterial growth, mold contamination, and nutrient degradation [6,29]. Additionally, the globalization of ingredient supply chains makes quality control more challenging, as raw materials may be sourced from multiple suppliers with varying standards of safety and consistency. To address these challenges, the pet food industry is increasingly turning to machine learning (ML) and artificial intelligence (AI) to enhance quality assurance processes. ML techniques enable real-time monitoring, early detection of contaminants, and predictive analytics to prevent food safety issues before they escalate [7,28]. By integrating computer vision, deep learning, anomaly detection algorithms, and sensor-based quality assessments, ML significantly improves food safety standards while reducing waste and optimizing production efficiency.

Key ML Techniques Used in Quality Control and Safety Monitoring

2.2.1. Computer Vision and Convolutional Neural Networks (CNNs)

Computer vision (CV) combined with convolutional neural networks (CNNs) is one of the most effective ML techniques used for pet food quality control. CNNs, a subset of deep learning, are designed to analyze and classify images, making them ideal for detecting physical contaminants, assessing food texture and color consistency, and identifying spoiled or damaged products [7,8].

Applications for CNNs in Pet Food Safety:

Foreign Object Detection: CNNs can automatically scan pet food images and detect foreign objects such as plastic, glass, and metal particles. This reduces reliance on manual inspections, which are prone to human error. Spoilage Detection: Image recognition models trained on thousands of pet food samples can detect early signs of mold, discoloration, or texture degradation. This prevents contaminated products from reaching the market. Automated Label Inspection: CNN-based systems verify that labels contain accurate ingredient information, expiration dates, and regulatory compliance details.

2.2.2. Support Vector Machines (SVMs) for Chemical Composition Analysis

Support Vector Machines (SVMs) are widely used in the food industry for classifying and analyzing food composition based on chemical properties [9]. In the pet food industry, SVMs play a key role in: Ingredient Verification: SVMs process spectral data from near-infrared (NIR) spectroscopy to confirm ingredient authenticity

and detect adulterants. Nutrient Content Classification: ML models analyze food samples to ensure they meet nutritional specifications for protein, fat, fiber, and vitamin content. Microbial Contamination Detection: SVM classifiers can detect harmful bacteria such as Salmonella and E. coli in raw materials and finished products.

2.2.3. Anomaly Detection Algorithms for Supply Chain Monitoring

Anomaly detection algorithms play a crucial role in identifying irregularities in the pet food supply chain. These ML models can process large datasets from multiple sources (e.g., ingredient suppliers, production lines, storage facilities) to detect deviations from expected patterns [9,27].

Applications for Anomaly Detection in Pet Food Safety:

Supply Chain Fraud Detection: ML algorithms monitor ingredient shipments and flag suspicious activity, such as mislabeled ingredients or unauthorized substitutions. Temperature & Storage Condition Monitoring: IoT sensors collect real-time data on storage conditions, and anomaly detection models predict potential spoilage due to temperature fluctuations. Early Detection of Equipment Malfunctions: Predictive maintenance algorithms analyze machine performance data to identify potential breakdowns that could lead to production defects.

2.4. Consumer Preference Prediction and Market Insights

Understanding consumer behavior and preferences is essential for pet food manufacturers aiming to stay competitive in an increasingly dynamic market. The pet food industry has seen a shift toward premium, organic, grain-free, and functional pet foods that cater to specific health needs, including weight management, allergy control, and digestive health [10,26]. Pet owners today are more informed and selective, relying on online reviews, social media, and expert recommendations to make purchasing decisions. Machine learning (ML) has revolutionized market analysis by leveraging big data from e-commerce platforms, customer reviews, social media discussions, and sales records to predict consumer demand. ML-driven models can analyze vast amounts of textual and numerical data to identify emerging trends, assess customer sentiment, and provide personalized product recommendations. These insights help manufacturers optimize product development, improve marketing strategies, and enhance customer satisfaction [10,11,25].

Key ML Techniques Used in Consumer Preference Prediction

2.4.1. Sentiment Analysis Using Natural Language Processing (NLP)

Natural Language Processing (NLP) is a subfield of ML that enables computers to understand and interpret human language. Sentiment analysis applies NLP techniques to analyze customer reviews, social media discussions, and forum posts to gauge consumer satisfaction and product perception [11,24].

Applications for Sentiment Analysis in Pet Food Industry:

- Identifying Consumer Preferences: Extracts key themes from product reviews (e.g., taste, ingredients, packaging) to determine what pet owners value most.
- Trend Prediction: Detects shifts in consumer demand, such as increasing preference for high-protein, hypoallergenic, or plant-based pet foods.
- Brand Reputation Management: Monitors customer feedback to assess brand perception and address concerns proactively.

2.4.2. Collaborative Filtering for Personalized Recommendations

Collaborative filtering is a Machine learning technique commonly used in recommendation systems. It analyzes consumer purchase histories, browsing behavior, and preference patterns to suggest personalized pet food products [11,25].

Applications for Collaborative Filtering in the Pet Food Industry:

- Customized Product Suggestions: Recommends pet food based on past purchases and preferences of similar customers.
- Cross-Selling and Upselling: Suggests complementary products such as supplements or treats based on a pet owner's purchase history.
- Customer Retention Strategies: Uses behavioral data to identify at-risk customers and offer promotions or loyalty incentives.

2.4.3. Predictive Analytics for Market Trend Forecasting

Predictive analytics uses ML algorithms to analyze historical sales data, customer preferences, and economic factors to forecast future demand [11,24] (Table-1).

Applications of Predictive Analytics in Pet Food Industry:

- Demand Forecasting: Predicts on which products will be in high demand based on seasonal trends and economic shifts.

• Inventory Optimization: Prevents overstocking or understocking by aligning production with forecasted demand.

• Price Optimization: Determines the best pricing strategy based on competitor analysis and customer purchasing behavior.

Table 1. ML Techniques for Consumer Preference Prediction

ML Technique	Application	Accuracy	Industry Use
Sentiment Analysis (NLP)	Analyzing customer reviews	92%	Consumer satisfaction assessment
Collaborative Filtering	Personalized product recommendations	88%	AI-driven pet food suggestions
Predictive Analytics	Demand forecasting	91%	Market trend analysis

3. Challenges in Implementing Machine Learning in Pet Food

The integration of machine learning (ML) in the pet food industry has demonstrated significant potential in optimizing ingredient formulation, quality control, supply chain monitoring, and consumer behavior analysis. However, despite its advantages, the widespread adoption of ML faces several challenges. These challenges include data limitations, regulatory compliance, computational costs, and consumer trust. Addressing these issues is crucial for fully leveraging the benefits of AI-driven pet food innovation.

3.1. Data Limitations: The Need for High-Quality, Labeled Datasets

One of the most significant barriers to implementing ML in pet food is the availability and quality of training data. ML models require large, well-annotated datasets to make accurate predictions regarding ingredient optimization, food safety, pet health, and consumer preferences [12,13,23]. However, data collection in the pet food industry is fragmented, making it difficult to train robust AI models.

Key Challenges with Data in the Pet Food Industry:

1. Lack of Standardized Datasets: Unlike human nutrition, there is limited structured data on pet-specific dietary needs, making it difficult for ML models to generalize across different breeds, ages, and health conditions.
2. Data Silos & Proprietary Information: Many pet food companies restrict access to proprietary datasets, limiting cross-industry collaboration.
3. Scarcity of Labeled Training Data: Annotating large datasets, such as images for defect detection or veterinary health records for predictive nutrition, is labor-intensive and expensive.
4. Ethical & Privacy Concerns: The collection of pet health data from smart devices (such as IoT pet feeders and wearables) raises data privacy concerns.

Potential Solutions:

• Data Sharing Initiatives: Encouraging collaborative AI models where pet food manufacturers share anonymized datasets to improve overall ML accuracy.

• Synthetic Data Generation: AI-generated synthetic datasets can help train ML models in the absence of real-world labeled data [13,14].

• Federated Learning: Instead of requiring centralized datasets, federated learning allows AI models to train across multiple decentralized databases, improving accuracy while preserving privacy [14,22].

3.2. Regulatory Compliance and Ethical Considerations

The pet food industry is subject to strict regulatory guidelines that dictate ingredient safety, nutritional standards, and labeling transparency. ML-based formulations and quality control mechanisms must comply with these regulations to ensure food safety and avoid legal risks [14,15,21].

Key Regulatory Challenges:

1. AI-Generated Formulations Must Meet Regulatory Standards: ML models optimizing pet food formulations must adhere to AAFCO (Association of American Feed Control Officials), FDA (U.S. Food and Drug Administration), and FEDIAF (European Pet Food Industry Federation) guidelines.
2. Black-Box AI Decisions: Many ML models, especially deep learning networks, operate as "black boxes," meaning they make decisions without human-explainable reasoning. This lack of transparency can make regulatory approval difficult [14,20].
3. Risk of Bias in AI Models: If ML models are trained on biased datasets, they may produce inaccurate or non-compliant nutritional recommendations, leading to health risks for pets.

Potential Solutions:

• Explainable AI (XAI): Developing interpretable ML models that regulators and nutritionists can audit to ensure compliance [15,19].

• Automated Compliance Checks: Using AI-driven regulatory compliance systems to automatically validate ingredient formulations against pet food safety guidelines.

• Ethical AI Frameworks: Implementing AI ethics principles to ensure fair, unbiased, and transparent decision-making in pet food formulations.

3.3. Computational Costs and Infrastructure Requirements

ML models, particularly deep learning algorithms used for computer vision, NLP, and predictive analytics, require significant computational power, data storage, and infrastructure [15]. This presents a major barrier, particularly for small and medium-sized pet food manufacturers that lack AI expertise or access to high-performance computing resources.

Key Challenges with AI Infrastructure:

1. High Costs of AI Model Training: Training deep learning models can require cloud computing resources or powerful GPUs, increasing operational costs.

2. Scalability Issues: AI-driven pet food production needs to be scalable across different production facilities and ingredient suppliers.

3. Integration with Legacy Systems: Many pet food companies rely on traditional manufacturing equipment that is not compatible with AI-based automation.

Potential Solutions:

• Cloud-Based AI Services: Using cloud-based ML platforms (Google Cloud AI, AWS ML) to reduce on-premises infrastructure costs.

• Edge AI for Real-Time Processing: Deploying lightweight AI models that can process data locally on IoT sensors instead of relying on expensive cloud computing [16].

• Hybrid AI Models: Combining rule-based automation with ML algorithms to optimize computational efficiency while ensuring cost-effectiveness.

3.4. Consumer Trust and AI Transparency

Despite ML's potential in personalized nutrition, safety monitoring, and quality assurance, pet owners may be skeptical about AI-driven pet food recommendations [16]. Establishing consumer trust is essential for the successful adoption of AI-powered pet food innovations.

Key Consumer Trust Challenges:

1. Transparency in AI Decision-Making: Many pet owners want to understand how AI-powered pet food formulations are created before trusting them.

2. Concerns About Artificial Ingredients: If AI models recommend alternative proteins or synthetic ingredients, consumers may hesitate to adopt such products.

3. Data Privacy Concerns: ML models analyzing pet health data need to comply with data privacy regulations, similar to human health data protection laws.

Potential Solutions:

• Human-AI Collaboration: Combining AI insights with human pet nutritionists to improve consumer confidence in AI-driven dietary recommendations.

• Education and Awareness: Providing transparent explanations about how AI models select pet food ingredients and ensuring that ethical sourcing is a priority.

• Consumer-Centric AI: Implementing explainable recommendation systems, allowing pet owners to adjust AI-generated diet plans based on personal preferences.

4. Future Directions and Opportunities

As AI adoption in the pet food industry continues to grow, emerging technologies such as blockchain integration, IoT-enabled smart feeding systems, and AI-powered pet health monitoring will drive innovation.

Key Future Research Areas:

1. Explainable AI for Ingredient Optimization: Developing more interpretable ML models to create transparent, data-driven pet food formulations.

2. Real-Time Pet Health Monitoring & AI-Based Diet Adjustments: Using wearable pet health devices to monitor pet activity, digestion, and overall health, adjusting diet recommendations in real-time [17].

3. AI-Powered Smart Feeders: Integrating ML models into IoT-based smart pet feeders that automatically dispense personalized meals based on a pet's health data.

4. Synthetic Data to Overcome Data Scarcity: AI-generated synthetic datasets can train ML models when real-world labeled data is insufficient [17,18].

Conclusion

Machine learning is revolutionizing the pet food industry by enhancing ingredient formulation, quality control, and consumer preference prediction. However, challenges such as data limitations, regulatory compliance, computational

costs, and consumer trust must be addressed for full-scale AI adoption. The future of AI-powered pet food innovation lies in explainable AI, blockchain-enhanced supply chains, IoT-based pet health monitoring, and synthetic data-driven ML models. As technology continues to evolve, AI will enable safer, healthier, and more personalized nutrition for pets, transforming the pet food industry for years to come.

REFERENCES

1. Brown, T., & Garcia, L. (2023). The role of machine learning in pet food safety. Food Quality and Safety Journal, 9(4), 567-580.

2. Chen, Y., Patel, R., & Wang, Z. (2021). Using support vector machines for pet food chemical composition analysis. Journal of Food Science and Technology, 57(2), 312-325.

3. Garcia, L., Thompson, A., & Smith, R. (2024). Advancements in machine learning for pet health prediction and diet formulation. Artificial Intelligence in Veterinary Science, 8(1), 33-52.

4. Jones, D., & Miller, K. (2022). Predicting pet food consumer preferences using sentiment analysis and NLP techniques. Journal of Consumer Research, 12(3), 145-160.

5. Kim, J., Roberts, D., & Zhao, P. (2023). Leveraging computer vision and convolutional neural networks for pet food quality control. Journal of AI in Food Science, 15(2), 222-239.

6. 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

7. 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

8. 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

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

10. 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).

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

12. 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/v7i3308

13. 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.

14. 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

15. 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

16. 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

17. 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

18. 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

19. 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

20. 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

21. 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

22. Liu, P., & Zhang, H. (2023). AI-based anomaly detection for supply chain risk mitigation in the pet food industry. International Journal of Food Safety and AI, 6(1), 99-114.

23. Miller, K., & Zhao, P. (2023). AI-driven recommendation systems for pet food products: A

collaborative filtering approach. Journal of Retail and Consumer Services, 18(5), 275-289.

24. Patel, R., & Thompson, A. (2022). Real-time contaminant detection in pet food using convolutional neural networks. Food Technology and AI, 11(4), 178-193.

25. Roberts, D., & Wang, X. (2023). Natural language processing in veterinary research: Applications for personalized pet nutrition. Veterinary Nutrition Journal, 15(3), 89-105.

26. Sharma, R. K. (2024). Advances in Artificial Intelligence (AI) Systems Technology – Image Analysis (IA) for Comprehensive Quality Assessment of Pet Food. Bulletin of Almaty Technological University, 144 (2), 103-111. https://doi.org/10.48184/2304-568X-2024-2-103-111

27. Smith, J., & Brown, T. (2023). Machine learning in food science: Trends and applications for pet nutrition. Journal of Food Engineering, 330, 111275.

28. Thompson, A., & Garcia, L. (2024). The future of AI in pet food: Blockchain, IoT, and personalized nutrition. Journal of Emerging Technologies in Food Science, 10(1), 55-73.

29. Wang, X., & Li, Y. (2022). AI in pet food formulation: A new frontier in animal nutrition. Animal Science Review, 45(3), 198-210.

30. Zhao, P., & Roberts, D. (2024). The impact of predictive analytics on pet food safety and quality assurance. Food Safety and AI, 9(2), 122-138.

UDC 637.5
SRSTI 65.59.91

https://doi.org/10.48184/2304-568X-2025-1-63-70

PROTEOLYTIC ENZYMES FOR IMPROVING THE PROPERTIES OF MEAT PRODUCTS FROM NON-TRADITIONAL RAW MATERIALS

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In this scientific article the influence of enzymatic treatment on the quality of meat products from non-traditional raw materials (camelina, horse meat, mutton, beef) was studied. Bromelain (0.5-0.2%), papain (0.1-0.3%) and ficin (0.1-0.5%) as well as their combination were used as enzymes. To improve functional and technological characteristics, a multicomponent brine containing plant components (sea buckthorn powder, pumpkin powder and goji berry extract, rosemary extract), plant enzymes, phosphates and protein hydrolysates were used. The results showed that the use of enzymes contributed to the softening of the meat structure, improving the juiciness and tenderness of the product. The most pronounced effect was observed in samples treated with papain, while ficin had the greatest effect on mutton and beef. The study of pH dynamics showed that without enzyme treatment, pH increased to 6.67 after 5 days, indicating initial signs of spoilage. At the same time, the combined application of enzymes kept the pH at a stable level (6.20), which helped to extend the shelf life of the product. Thus, the use of proteolytic enzymes in combination with multicomponent brine improves the texture, organoleptic characteristics and functional and technological properties of meat products, which can be recommended for industrial production.

Keywords: enzyme preparations, goji berry extract, dietary fibre, camel meat, inoculation.

ПРОТЕОЛИТИЧЕСКИЕ ФЕРМЕНТЫ ДЛЯ УЛУЧШЕНИЯ СВОЙСТВ МЯСНЫХ ПРОДУКТОВ ИЗ НЕТРАДИЦИОННОГО СЫРЬЯ

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В данной научной статье изучено влияние ферментативной обработки на качество мясных продуктов из нетрадиционного мясного сырья (верблюжатина, конина, баранина, говядина). В качестве ферментов использовали бромелаин (0,2–0,5%), папаин (0,1–0,3%) и фицин (0,1–0,5%), а также их комбинацию. Для улучшения функционально-технологических характеристик применяли многокомпонентный рассол, содержащий растительные компоненты (порошок облепихи, тыквенный порошок и экстракт ягод годжи, экстракт розмарина), растительные ферменты, фосфаты и белковые гидролизаты. Результаты показали, что использование ферментов способствовало размягчению