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Review Article

Valorization of Agri by-products for Animal Feeds and Pet Food: Advances, Mechanisms, and Future Prospects

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ABSTRACT

The valorization of agri-food and agro-industrial by-products has emerged as a cornerstone of sustainable food and feed production systems. Traditionally considered waste, these by-products are now recognized as valuable resources rich in proteins, fibers, lipids, minerals, and bioactive compounds. Their strategic incorporation into livestock and pet food formulations enhances nutritional quality, gut health, and overall animal performance while contributing to resource efficiency and circular economy objectives. Technological innovations in rendering, extrusion, fermentation, and bioprocessing have enabled the transformation of heterogeneous by-products into safe, functional, and nutritionally standardized feed ingredients. Mechanistic insights from recent studies highlight improved nutrient digestibility, antioxidant potential, and modulation of the gut microbiota, thereby linking compositional attributes with measurable physiological and productive outcomes in animals. From an environmental perspective, valorization substantially reduces waste generation, greenhouse gas emissions, and the environmental footprint of food production by diverting organic residues from landfills. Economically, it decreases feed formulation costs and opens novel market opportunities through the development of eco-labeled, sustainable pet food and livestock feed products. However, challenges such as compositional variability, regulatory compliance, and consumer perception remain barriers to large-scale adoption. Ongoing research into nutrient standardization, traceability, and green processing technologies continues to bridge these gaps. The efficient utilization of agri-food and agro-industrial by-products exemplifies the convergence of sustainability, technology, and innovation. It represents a viable pathway toward resilient, cost-effective, and environmentally responsible food and feed systems aligned with global sustainability goals.

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INTRODUCTION

Any animal kept by humans for companionship or pleasure rather than for utility known as pet animal. The main distinction between pets and domesticated livestock is the degree of contact between owner and animal. Another distinction is the owner's affection for the animal, which is often returned. According to Statistic report, there are 471 million pet dogs worldwide in 2018. According to industry estimates, at present there are over 31 million pets in India, with a growth rate of approximately 11%, implying an addition of almost 3 million pets per year. According to Statistic report, there are 471 million pet dogs worldwide in 2018. According to industry estimates, at present there are over 31 million pets in India, with a growth rate of approximately 11%, implying an addition of almost 3 million pets per year.

The commercially available animal feeds intended for consumption by pets, usually specific to the type of animal, such as dog food or cat food is termed as pet food. It may be broadly classified into dry type, semi moist type and moist type according to the processing methods applied, ingredients used and moisture content. As per National Research Council (2006) dry type pet food should contain moisture 6-10 per cent, fat 7-20 per cent, protein 16-30 per cent, carbohydrate 41-70 per cent and energy 2800-4050 Kcal ME/ kg feed. The moisture content of semi-moist pet foods has an intermediate water content of 25- 35 per cent and a moist food varies from 60 to more than 87 per cent (Pame K. *et al.,).*

Agri-food byproducts are derived during various phases of agricultural and food processing operations, innovative food products are developed by using this and it help to reduce waste, and improve the overall sustainability of our food systems due to its nutritional, functional, and bioactive components. Agri-food byproducts is capable of enhancing sustainability, minimizing waste disposal, and creating value-added products within the food industry (Vastolo A. *et al*). Plant-based products are highly perishable and require appropriate post-harvest practices to maintain their quality, leading to high wastage rates (FAO, 2019). plant-based agricultural by-products are one of the major sources for extracting different bioactive compounds over the past few decades.

The global growth of agriculture and food processing industries has generated massive quantities of by-products including fruit pomaces, cereal co-products, oilseed cakes, and animal-derived materials. These by-products have shifted from being waste management concerns to valuable inputs in feed and food systems, particularly within the frameworks of circular economy and sustainability. Their use aligns with global strategies for resource recovery, reducing environmental impact, and increasing the functional attributes of animal-derived foods. Modern research underscores their capacity to enhance product nutritional value, improve gut health, mitigate costs, and provide bioactive compounds.

Nutritional requirement of pet

The term nutrient requirement is generally used to refer to the quantity of an essential nutrient needed to be absorbed by an animal for a physiological state (Morris and Rogers 1994). A healthy pet nutrition plan consists of balanced meals that include proteins, carbohydrates, fats, vitamins, and minerals tailored to your pet's specific needs. Water intake is crucial, along with portion control to maintain a healthy weight and prevent obesity-related health issues in pets.

Dogs and cats require specific dietary nutrient concentrations based on their life stage. The Association of American Feed Control Officials (AAFCO) publishes nutrient profiles for dogs and cats in the two main life stage categories of nutritional requirements: Adult Maintenance and Growth and Reproduction. NRC uses the following life stages when listing nutrient requirements:

- Growth after weaning
- Adult maintenance
- Late gestation
- Peak lactation

For growing pup pies and kittens were determined as the minimal intake of an amino acid that supported maximal rate of

body weight gain or nitrogen balance. This technique gives valid estimates when the diet contains excess levels of all essential nutrients other than the one being studied and body weight gain and nitrogen balance have the same maxima (Morris and Rogers1994)

Ingredient in pet food

Ingredient is a general term used for raw materials and additives used in pet foods. Typical pet food ingredients include protein sources such as poultry, beef and fish, vegetables, cereals, vitamins and minerals, combined for a balanced diet. Every ingredient has to be safe and result in a safe finished product. Every ingredient in a pet food is included for a purpose. The ingredient has to deliver the right nutrition with the right functionality (Thompson, 2008). The pet food industry uses two main categories of primary ingredients: grains and milling byproducts such as corn gluten meal and animal tissue byproducts from the meat-packing, poultry-processing and fish-canning industries. grains is minor compared with animal tissue

Classification of By-Products

Plant-Based By-Products

Plant-derived by-products such as cereal brans (corn gluten, wheat bran), fruit and vegetable pomaces (apple, citrus, tomato), and oilseed cakes (sunflower, canola, hemp) are rich sources of proteins, fibers, phytochemicals, and antioxidants, with demonstrated applications in both livestock and pet food industries. These by-products can modulate fiber content, potentiate antioxidant capacity through polyphenols and carotenoids, and offer proteins essential for growth and maintenance.

Animal-Based By-Products

Processed animal tissues including meat-cum-bone meal, blood meal, rendered fats, gelatin, and spray-dried plasma are high in protein and minerals, useful substrates for pet and farm animal feeds. Their inclusion offers essential amino acids, supports palatability, enhances shelf life, and contributes to sustainability by recycling slaughterhouse outputs.

Nutritional and Functional Value

Proteins, Fibers, and Bioactive CompoundsBy-products serve as concentrated sources of high-quality proteins, digestible fibers, fatty acids, vitamins, and minerals. For example, corn gluten meal provides >70% protein with low fat, while oilseed cakes and fruit pomaces deliver unique fiber blends supporting gut health. Bioactives include phenolic acids, carotenoids, and saponins, conferring antioxidant, anti-inflammatory, and immunomodulatory actions. Starch and Resistant CarbohydratesCereal co-products improve the textural and processing properties of extruded pet food, supply fermentable carbohydrates for gut microbiota, and can increase colonic butyrate via resistant starch fermentation, supporting mucosal and immune health.

Processing Technologies and Effects

Industrial Processing-Rendering, drying, irradiation, and extrusion are critical in transforming animal and plant by-products into safe, shelf-stable, and functional feed ingredients. Proper processing ensures microbial inactivation, minimizes allergenicity, and optimizes protein bioavailability.

Technological and Functional Applications- In pet food formulation, by-products add structure (through starch/fiber in extrusion), adjust palatability, and control moisture analogs for shelf-stable products. By-products can replace primary grains, reducing food-feed competition between animal and humans.

Effects on Animal Health and Product Quality

Digestibility and Gastrointestinal Effects- By-products, especially from cereals and oilseeds, provide fermentable fibers that modulate colonic microbiota, increase fecal short-chain fatty acid production, and enhance gut function. Resistant starch and fiber-rich pomaces support stool quality, reduce pathogenic putrefaction, and may decrease fecal ammonia and pH.

Metabolic and Immune Effects-Carotenoids and polyphenols from plant by-products can support immune function, reduce oxidative stress, and potentially protect against chronic conditions. High-protein animal by-products safely deliver essential nutrients when processed appropriately, without increasing risks of prion or allergen transmission under modern standards.

Safety, Quality Control, and Regulatory Aspects

Modern industrial practices maintain food and feed safety by controlling pathogens

(via rendering, irradiation), mycotoxins (by screening cereal by-products), and allergenicity (by formulating with knowledge of animal-specific sensitivities).

Regulatory agencies (US FDA, EU EFSA) establish composition, inclusion, and quality parameters to safeguard both animals and end-consumers.

Environmental and Economic Impact

By valorizing food industry by-products, substantial reductions in landfill waste, greenhouse gas emissions, and waste management costs are achieved. Incorporation of by-products in animal feeds decreases dependency on arable land, supports rural economies, and aligns with United Nations Sustainable Development Goals.

The global market share for by-product-based feeds is steadily increasing, supported by growth in the pet food industry.

Challenges and Future Directions

It includes variability in chemical composition (due to source and seasonal variability), consumer skepticism regarding by-product use in pet food, and regulatory complexities. Future prospects involve novel processing (enzymatic hydrolysis, green extraction), enhanced traceability, improved nutrient standardization, and targeted communication to build acceptance and maximize sustainability impacts. Systems biology and nanotechnology offer new strategies for bioactive extraction and functionalization.

CONCLUSION

Valorizing agri-food and agro-industrial by-products presents a sustainable and practical strategy to enhance feed and pet food systems. These by-products, once perceived as waste, now provide valuable sources of proteins, fibers, and bioactive compounds that improve nutrition, gut health, and overall animal performance. Technological advancements in rendering, extrusion, and bioprocessing have transformed by-products into safe, functional, and nutritionally consistent feed ingredients.Their utilization supports circular economy goals by minimizing waste, lowering production costs, and reducing environmental burdens such as greenhouse gas emissions and landfill use. Despite challenges in compositional variability and consumer acceptance, continued innovation in nutrient standardization, traceability, and green processing holds great promise. In essence, by-product valorization merges economic efficiency with ecological responsibility, empowering the development of resilient and sustainable food and feed industries.

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