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REVIEW ARTICLE

# Utilization of Fruit and Vegetable Pomace in Pet Food Formulation: A Sustainable Approach

**Mahsa Hallaj Salahipour[a], Sajjad Valinezhad[b,*]**

[a] Department of Basic Sciences, Faculty of Veterinary Medicine, Urmia University, Urmia, Iran.
[b] Product Developer-Arat Food Industries, Safadasht, Tehran, Iran.

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**Abstract**

Pet owners and researchers are increasingly looking for sustainable and healthy options in animal nutrition. Fruit and vegetable pomace, the solid material left after juice or puree extraction, is one promising ingredient. Pomace from apples, tomatoes, grapes, carrots, and spinach contains useful nutrients such as fiber, pectin, polyphenols, vitamins, and natural sugars. Studies show that including moderate amounts of pomace (about 2.5–10% of the diet) can improve digestion, support beneficial gut bacteria, enhance antioxidant activity, and lead to better stool quality in dogs and cats. Processing methods like drying, fermentation, and extrusion help make pomace safer, more stable, and easier to digest. At the same time, using pomace reduces food waste, lowers disposal costs, and supports environmental sustainability. Safety and regulatory guidelines from organizations such as AAFCO and FEDIAF ensure proper use in pet food. This review summarizes current knowledge about pomace composition, benefits, processing, and safety, and highlights future research needs for making pomace a reliable ingredient in sustainable pet diets.

## 1. Introduction

The global pet food industry has witnessed remarkable growth over the past two decades, driven by rising pet ownership, the humanization of pets, and increasing demand for premium, health-oriented products (Alexander et al., 2020). As consumers become more conscious of sustainability and nutrition, there is a growing interest in alternative ingredients that are both functional and environmentally responsible (Alexander et al., 2020). One such promising category is fruit and vegetable pomace—the fibrous, nutrient-rich by-product left after juice extraction or food processing.

Pomace typically includes peels, pulp, seeds, and stems, and is often discarded or underutilized despite its valuable nutritional profile. Fruit and vegetable waste can account for up to 30–50% of the original raw material, representing a significant loss of potential feedstock (Nagarajaiah and Prakash, 2016). In the context of pet food formulation, these by-products offer a unique opportunity to enhance dietary fiber, introduce natural antioxidants, and reduce reliance on synthetic additives—all while contributing to circular economy goals (Lu et al., 2022).

From a compositional perspective, pomace is a concentrated source of dietary fiber (including pectin and fermentable fibers), bioactive compounds such as polyphenols, flavonoids, and carotenoids, as well as residual simple sugars, vitamins, and minerals (Granucci et al., 2023, Mnisi et al., 2022). These components have been associated with improved gas-

*Corresponding author: S. Valinezhad
E-mail address: sajad@aratcompany.com
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trointestinal health, modulation of gut microbiota, enhanced antioxidant status, and potential immune support in companion animals (Lu et al., 2022, Mnisi et al., 2022). For example, moderate inclusion of tomato pomace in dog diets has been shown to maintain digestibility and meet safety standards when appropriately processed (Lu et al., 2022).

Beyond nutritional benefits, the incorporation of pomace into pet food aligns with global sustainability frameworks such as the United Nations Sustainable Development Goals (SDGs), particularly SDG 12: Responsible Consumption and Production (Alexander et al., 2020). By valorizing agro-industrial by-products, manufacturers can reduce environmental burdens associated with waste disposal, lower feed production costs, and decrease dependence on resource-intensive raw materials (Alexander et al., 2020, Lu et al., 2022)

Despite these advantages, the use of pomace in pet food remains underexplored compared to its application in livestock and poultry nutrition (Mnisi et al., 2022). Challenges such as variability in composition, microbial stability, palatability, and compliance with regulatory standards (e.g., guidelines from the Association of American Feed Control Officials and the European Pet Food Industry Federation) must be addressed through targeted research and innovative processing techniques (Granucci et al., 2023, Lu et al., 2022).

This review synthesizes current knowledge on the nutritional composition, functional properties, processing methods, safety considerations, and regulatory frameworks related to the use of fruit and vegetable pomace in pet food. It also identifies research gaps and future directions to support the integration of pomace as a sustainable, functional ingredient in the evolving pet food market.

## 2. Nutritional Composition of Fruit and Vegetable Pomace

Fruit and vegetable pomace, the solid residue remaining after juice or puree extraction, is a nutrient-dense by-product containing substantial amounts of dietary fiber, residual sugars, vitamins, minerals, and bioactive compounds (Granucci et al., 2023, Nagarajaiah and Prakash, 2016). Although the primary extraction process removes most juice and soluble nutrients, the remaining pulp, skins, and seeds retain significant nutritional value that can be harnessed in pet food formulations.

Dietary fiber is the predominant component of pomace, with insoluble fractions such as cellulose, hemicellulose, and lignin contributing to fecal bulk and bowel regularity, and soluble fractions such as pectin and gums providing fermentable substrates for beneficial gut microbiota (Mnisi et al., 2022, Nagarajaiah and Prakash, 2016). Apple pomace typically contains around 30% total dietary fiber, rich in pectin, while carrot pomace can exceed 50%, dominated by cellulose and pectin (de Brito et al., 2021, Granucci et al., 2023, Sagar et al., 2018). Adequate inclusion of these fibers in pet diets can improve stool quality, promote satiety, and support colonic health (Mnisi et al., 2022, Valinezhad and Hallaj-Salahipour, 2025).

Polyphenols and antioxidants are abundant in many fruit pomaces, particularly grape, apple, and berry residues. These include flavonoids (e.g., quercetin, catechins), anthocyanins, resveratrol, and carotenoids such as lycopene in tomato pomace (Nagarajaiah and Prakash, 2016, Singh et al., 2020), Such compounds exhibit antioxidant, anti-inflammatory, and antimicrobial activities, potentially supporting immune function, skin health, and mitigating oxidative stress in companion animals (Mnisi et al., 2022, Singh et al., 2020).

Vitamins and minerals are retained in varying amounts depending on the source and processing method. Common micronutrients include vitamin C (notably in citrus and apple pomace), vitamin A precursors such as beta-carotene (in carrot and spinach pomace), B-complex vitamins, and minerals like potassium, calcium, magnesium, and iron (Lu et al., 2022, Nagarajaiah and Prakash, 2016).

Residual sugars and organic acids persist in pomace despite juice extraction. Apple pomace may contain 8–14% sugars depending on pressing method, while tomato pomace contains glucose, fructose, and malic acid (Kengoo et al., 2023, Valinezhad and Hallaj-Salahipour, 2025, Kumar et al., 2024a). These components can enhance palatability and, in moderation, serve as fermentable energy sources or prebiotics for gut microbiota (Mnisi et al., 2022).

Protein and lipids are present in modest amounts, with vegetable pomaces such as tomato containing up to 15–20% crude protein and 3–5% lipids, and grape pomace containing $\sim$10% protein and $\sim$5% lipids (Granucci et al., 2023, Singh et al., 2020). While insufficient as primary protein or fat sources, they contribute to the overall nutrient profile when combined with other ingredients (de Brito et al., 2021).

Values are approximate and may vary depending on cultivar, growing conditions, and processing methods. Fiber values represent total dietary fiber content, including both soluble and insoluble fractions. Protein and lipid contents are expressed on a dry matter basis. Functional benefits are based on reported bioactive properties and observed effects in animal nutrition studies.

**Table 1**
Comparative nutritional composition and functional benefits of selected fruit and vegetable pomaces (de Brito et al., 2021, Granucci et al., 2023, Mnisi et al., 2022, Sagar et al., 2018, Singh et al., 2020).

| Pomace type | Fiber (%) | Key bio actives | Vitamins / Minerals | Protein (%) | Lipids (%) | Functional benefits in pets |
|---|---|---|---|---|---|---|
| Apple | ∼30 | Polyphenols, pectin | Vitamin C, potassium | ∼5 | <2 | Gut health, antioxidant support |
| Carrot | >50 | Beta-carotene, pectin | Vitamin A, calcium | ∼6 | <1 | Vision support, digestive regulation |
| Grape | ∼40 | Resveratrol, tannins | Iron, magnesium | ∼10 | ∼5 | Anti-inflammatory, cardiovascular health |
| Tomato | ∼45 | Lycopene, flavonoids | Vitamin A, potassium | 15–20 | 3–5 | Antioxidant, skin and coat health |
| Spinach | ∼35 | Chlorophyll, flavonoids | Folate, iron | ∼8 | 2–4 | Blood health, immune support |

## 3. Benefits and Challenges of Using Pomace in Pet Food

The incorporation of fruit and vegetable pomace into pet food formulations offers a diverse range of nutritional, economic, and environmental benefits, but also presents certain limitations that require careful consideration to ensure safety, palatability, and nutritional adequacy for companion animals.

### *3.1. Benefits*

**Environmental sustainability** – Pomace utilization supports circular economy principles by diverting food processing waste from landfills and reducing greenhouse gas emissions. For example, apple pomace can account for up to 25% of the original fruit mass during juice production, and its disposal poses environmental challenges unless repurposed (Sagar et al., 2018).
**Cost-effectiveness** – Pomace is often available at low or no cost from juice and food manufacturers, making it an economical alternative to conventional fiber sources such as beet pulp or cellulose. Tomato pomace, for instance, has been incorporated into dog diets at 2.5–5% without compromising digestibility, offering a cost-effective ingredient option (Singh et al., 2020).
**Digestive health** – Rich in both soluble and insoluble fiber, pomace can promote gut motility, improve stool consistency, and support beneficial gut microbiota in dogs and cats (Moreno et al., 2022).
**Functional properties** – Bioactive compounds such as polyphenols, flavonoids, and carotenoids present in pomace exhibit antioxidant, anti-inflammatory, and antimicrobial effects. Blueberry and cranberry pomace, for example, are rich in flavonoids that may aid DNA repair and cellular health in dogs (Xu et al., 2021).
**Weight management and special diets** – The high fiber and low caloric density of pomace can increase satiety and reduce energy intake, making it suitable for diets targeting overweight, diabetic, or senior pets (Kumar et al., 2024a).

### *3.2. Challenges*

**Anti-nutritional factors** – Some pomaces contain tannins, oxalates, or phytates that can interfere with nutrient absorption or cause gastrointestinal discomfort. High inclusion levels of certain flavonoids may also negatively affect digestibility or cause toxicity (Erinle and Adewole, 2022).
**Microbial contamination** – Due to high moisture content, fresh pomace is susceptible to microbial spoilage. Without proper drying or preservation, it may harbor molds or pathogens. Extrusion processing has been shown to improve microbial stability compared to raw or boiled forms (Singh et al., 2020).
**Palatability issues** – Certain pomaces impart bitter or sour flavors that can reduce feed acceptance, particularly in selective eaters. Flavor masking or blending with more palatable ingredients may be necessary (Marti et al., 2024).
**Nutrient imbalance** – Pomace alone cannot meet the complete nutritional requirements of pets and must be balanced with adequate protein, fat, and micronutrients. Substituting corn starch with tomato pomace, for example, reduced protein digestibility in dog diets (Singh et al., 2020).
**Regulatory constraints** – Pet food regulations in some regions restrict the use of certain by-products or require extensive safety validation. AAFCO and FEDIAF currently recognize apple and tomato pomace for pet food use, while other pomace types may require separate approval (AAFCO, 2015).

## 4. Review of Existing Studies and Experimental Findings

Over the past decade, the nutritional and functional potential of fruit and vegetable pomace has been investigated in a variety of animal diets, including poultry, livestock, and, more recently, companion animals. These studies provide important insights into the feasibility, benefits, and limitations of pomace inclusion in pet food formulations.

## 5. Studies in Companion Animals

**Apple pomace in dog diets** Brito et al. (2021) evaluated the inclusion of dried apple pomace at 3–9% in dry dog food. The results showed improved fecal consistency, increased fecal butyrate concentrations, and enrichment of beneficial gut bacteria (e.g., *Faecalibacterium*, *Bacteroides*, *Blautia*), without adverse effects on feed acceptance, although protein digestibility declined slightly at higher inclusion levels (de Brito et al., 2021).

**Tomato pomace in canine nutrition** – Singh et al. (2020) supplemented raw, boiled, and extruded dog diets with 2.5% and 5% tomato pomace. Extruded diets showed the highest digestibility, with 2.5% inclusion performing better than 5%. No significant changes in crude protein digestibility were observed, and all diets met safety standards. Improvements in skin and coat condition were attributed to lycopene and vitamin A precursor (Singh et al., 2020).

**Grape pomace potential** – Although more extensively studied in poultry, grape pomace is rich in polyphenols and has demonstrated anti-inflammatory and antimicrobial effects in animals (Mnisi et al., 2022), suggesting possible immune-support benefits in pets.

**Carrot and spinach pomace in treats** – (Sagar et al., 2018) reported that incorporating carrot and spinach pomace into pet treats increased fiber content and antioxidant capacity. These formulations were well accepted by dogs, indicating good palatability.

## 6. Comparative Studies in Livestock and Poultry

While direct research on pets remains limited, findings from livestock and poultry nutrition support the potential value of pomace. Mnisi et al. (2022) reviewed the use of grape, apple, and citrus pomace in poultry diets, noting improvements in gut morphology, feed efficiency, and immune response, alongside reduced ammonia emissions and oxidative stress. Colombino et al. (2020) found that berry pomace (apple, blackcurrant, strawberry) in broiler diets increased ileum and ceca weight, enhanced digesta viscosity, boosted short-chain fatty acid production, and altered microbiota composition (Colombino et al., 2020). Granucci et al. (2023) analyzed beverage industry pomaces and confirmed their high fiber and antioxidant content, supporting their suitability for animal feed (Granucci et al., 2023).

## 7. Identified Research Gaps and Priority Areas for Future Investigation

Despite promising findings, several important gaps remain in the current body of research on the use of fruit and vegetable pomace in pet nutrition. There is a clear need for more species-specific trials, particularly involving cats and exotic companion animals, as most existing studies focus on dogs or extrapolate from livestock and poultry data (de Brito et al., 2021, Mnisi et al., 2022). Long-term investigations are lacking, especially those assessing the effects of pomace inclusion on metabolic health, healthy ageing, and the management of chronic conditions in pets (de Brito et al., 2021, Singh et al., 2020). Considerable variability in pomace composition between different fruit and vegetable sources, as well as across processing methods, highlights the necessity for standardization in both raw material quality and processing protocols (Granucci et al., 2023, Sagar et al., 2018). Finally, consumer acceptance and market feasibility studies are limited, yet they are essential for understanding how pet owners perceive pomace-based products and for ensuring successful commercial adoption (Kumar et al., 2024a).

## 8. Processing Techniques and Formulation Strategies

The safe and effective use of fruit and vegetable pomace in pet food requires processing and formulation approaches that preserve nutritional value, enhance palatability, and minimize anti-nutritional or microbial risks (Granucci et al., 2023, Sagar et al., 2018).

### *8.1. Processing Techniques*

**Drying and dehydration** – Reducing moisture content is essential for extending shelf life and preventing microbial spoilage. Methods include low-cost but weather-dependent sun drying, controlled hot-air drying, and freeze-drying, which best preserves bioactive compounds but is costly (Sagar et al., 2018).

**Grinding and milling** – Once dried, pomace is milled into a fine powder to ensure uniform mixing in formulations. Particle size influences both digestibility and texture (Granucci et al., 2023).

**Fermentation and enzymatic treatment** – Fermentation with lactic acid bacteria or enzymatic hydrolysis can reduce anti-nutritional factors, improve nutrient bioavailability, and enhance flavor while supporting gut health (Mnisi et al., 2022).

**Extrusion and palletization** – Incorporating pomace into extruded kibble or pelleted treats improves digestibility and allows for the inclusion of complementary proteins, fats, and micronutrients (Singh et al., 2020).

### *8.2. Formulation Strategies*

**Inclusion levels** – Pomace is typically included at 2.5–10% of the total diet, with lower levels (2.5–5%) suited for treats or sensitive pets, and higher levels (up to 10%) for fiber-rich or weight-control diets (Singh et al., 2020).

**Complementary ingredients** – To achieve complete nutrition, pomace is combined with protein sources (e.g., chicken meal, fish meal, soybean meal), fat sources (e.g., fish oil, flaxseed), carbohydrate sources (e.g., rice, oats, sweet potatoes), and vitamin–mineral premixes (Kumar et al., 2024b, Sagar et al., 2018).

**Functional additives** – Prebiotics (e.g., inulin), probiotics (*Lactobacillus*, *Bifidobacterium*), antioxidants (e.g., blueberry extract, citrus bioflavonoids), and flavor enhancers (e.g., natural meat flavors, yeast extracts) can be incorporated to improve gut health, oxidative stability, and palatability (Atuahene et al., 2024).

**Product types** – Pomace can be used in dry kibble, semi-moist treats, dental chews, and supplement powders, with processing tailored to the intended format (FEDIAF, 2021).

## 9. Regulatory and Labelling Considerations

In the USA, AAFCO requires clear ingredient definitions and nutritional adequacy statements, while in the EU, FEDIAF recommends accounting for rehydration factors when using dehydrated ingredients. Functional claims such as "supports digestion" or "rich in antioxidants" must be substantiated by scientific evidence and comply with labelling laws (AAFCO, 2015).

## 10. Example Formulations Reported in the Literature

Several studies have described complete or partial pet food formulations incorporating fruit and vegetable pomace for specific nutritional goals. For instance, De brito et al. (2021) and Singh et al. (2020) reported diets for senior dogs that included blends of apple, carrot, and spinach pomace (5–10% of the formulation) alongside high-quality protein sources, omega-3 fatty acids, and joint-support additives such as glucosamine and chondroitin. These diets aimed to enhance fiber intake, antioxidant status, and joint health while maintaining palatability and digestibility (de Brito et al., 2021, Singh et al., 2020).

## 11. Safety Considerations and Regulatory Frameworks

The incorporation of fruit and vegetable pomace into pet food must comply with stringent safety standards to protect the health and well-being of companion animals. While pomace offers recognized nutritional and functional benefits, its use is subject to regulatory oversight and rigorous quality control measures (Mnisi et al., 2022, Sagar et al., 2018).

From a safety perspective, fresh pomace is highly perishable due to its moisture, sugar, and organic acid content, making it susceptible to microbial contamination by molds (*Aspergillus*, *Penicillium*), yeasts, and pathogenic bacteria such as *Salmonella* and *E. coli*. Appropriate mitigation strategies include hot-air or freeze-drying, extrusion cooking, and fermentation, which can reduce microbial load and extend shelf life (Singh et al., 2020). In addition, pomace from conventionally grown produce may contain pesticide residues or heavy metals (e.g., lead, cadmium, mercury), necessitating sourcing from certified suppliers and batch-level contaminant testing (Kumar et al., 2019).

Certain pomaces also contain anti-nutritional factors such as tannins, oxalates, phytates, and saponins, which can impair nutrient absorption or cause gastrointestinal irritation. Processing methods including enzymatic hydrolysis, fermentation, and blending with protein-rich ingredients can help reduce these compounds (Mnisi et al., 2022). Furthermore, some pets may exhibit sensitivities or allergic reactions to specific fruit proteins or fibers, highlighting the importance of digestibility trials and careful monitoring during product development (de Brito et al., 2021).

Regulatory frameworks vary by region but share common principles of safety, nutritional adequacy, and truthful labelling. In the United States, the Food and Drug Administration (FDA) enforces safety under the Federal Food, Drug, and Cosmetic Act, while the Association of American Feed Control Officials (AAFCO) defines approved feed ingredients, sets nutritional standards, and requires that pomace be listed under recognized feed materials (AAFCO, 2015). In the European Union, the European Pet Food Industry Federation (FEDIAF) regulates safety, composition, labelling, and functional claims (FEDIAF, 2021).

## 12. Conclusion and Future Perspectives

The integration of fruit and vegetable pomace into pet food emerges as a scientifically supported and practically viable approach to advancing sustainability, nutritional innovation, and waste valorization in the pet food industry. Across the reviewed literature, pomace—particularly from apples, tomatoes, grapes, and carrots—has consistently demonstrated its value as a rich source of dietary fiber, polyphenols, vitamins, and residual sugars. When incorporated at moderate inclusion levels (typically 2.5–10%), it can improve gut health, modulate microbiota, enhance antioxidant status, and support overall well-being in companion animals, without compromising palatability or nutrient digestibility (de Brito et al., 2021, Singh et al., 2020)

Beyond its nutritional merits, pomace utilization directly addresses environmental and economic challenges. By diverting millions of tonnes of by-products from landfill and reducing disposal costs, it supports circular economy principles and lowers the carbon footprint of pet food production (Alexander et al., 2020, Kumar et al., 2019). Life cycle assessments indicate that diets incorporating such by-products can have substantially lower greenhouse gas emissions compared to premium meat-based formulations.

However, realizing the full potential of pomace in pet nutrition requires addressing key challenges. Antinutritional factors, microbial contamination risks, and variability in composition must be managed through advanced processing methods such as extrusion, fermentation, and enzymatic hydrolysis. Regulatory compliance with frameworks such as AAFCO and FEDIAF remains essential to ensure safety, labelling accuracy, and consumer trust (AAFCO, 2015, FEDIAF, 2021).

Looking ahead, five priority areas stand out for future research and industry development:

1. **Species-specific trials** – Controlled, long-term studies in dogs, cats, and other companion animals to determine optimal inclusion rates and health outcomes.

2. **Functional formulations** – Targeted diets for senior pets, weight management, gastrointestinal health, and metabolic disorders, leveraging specific pomace types.

3. **Processing innovations** – Novel techniques to enhance nutrient bioavailability, reduce antinutritional compounds, and improve shelf life.

4. **Consumer perception** – Market research to understand pet owner attitudes toward pomace-based products and the influence of sustainability claims on purchasing decisions.

5. **Policy harmonization** – Development of unified global standards for by-product use in pet food, including inclusion in authorized feed material registries (Kita et al., 2024).

By bridging nutritional science, sustainable resource management, and product innovation, fruit and vegetable pomace can transition from an underutilized by-product to a cornerstone ingredient in next-generation pet foods. Its adoption offers a rare convergence of benefits—supporting animal health, reducing environmental impact, and enhancing economic efficiency—positioning it as a transformative element in the future of companion animal nutrition.

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