THE SUSTAINABLE INTEGRATION OF ANIMAL BY-PRODUCTS INTO THE CIRCULAR BIOECONOMY OF PET FOOD

S. I. Petrescu*, M. Matei, C. G. Radu Rusu, D. Simeanu, D. Lăpușneanu, I. M. Pop

Faculty of Food and Animal Sciences, "Ion Ionescu de la Brad" Iasi University of Life Sciences, 8 Mihail Sadoveanu Alley, 700489 Iasi, Romania

Abstract

Anthropogenic activities, particularly those associated with the rearing and slaughter of animals for human and animal consumption, generate a carbon footprint with a significant environmental impact. At European Union level, the food sector and the animal feed industry are recognised as being among the main contributors to global greenhouse gas emissions.

This study aims to explore the applicability of the concept of the circular bioeconomy in the pet food industry. The research analyses the need for and viability of utilising animal by-products not intended or unsuitable for human consumption as a sustainable alternative to 'human-grade' ingredients and assesses the current legislative framework (FEDIAF, AAFCO), the digestibility parameters of these by-products, as well as the barriers arising from perceptions and trends towards humanisation amongst pet owners.

Key words: *animal by-products, circular bioeconomy, pet owners, pet food industry.*

INTRODUCTION

Exponential population growth and the meat industry generate massive greenhouse gas emissions, placing significant pressure on resources and highlighting the need for sustainable food systems.

Pet food accounts for between 1.1% and 2.9% of global agricultural emissions [1], with a single dog generating approximately 630 kg of CO_2 equivalent annually [2]. According to recent FEDIAF statistics from 2022, the pet population in Europe has reached 352 million, comprising 129 million cats and 106 million dogs.

The use of animal by-products (ABPs) not intended for human consumption is an alternative in animal nutrition. This makes efficient use of resources, reduces waste and prevents direct competition with the production of food intended for human consumption [1].

The global pet food market is experiencing rapid expansion, with its value estimated to reach 136.5 billion euros by 2026, driven by an increase in the global pet ownership rate, as shown in Table 1 [3]. This growth is directly reflected in investors' interest in emerging markets; the specialist press [4] highlights South-Eastern Europe as a major magnet for new investment in production facilities.

MATERIAL AND METHOD

This study applied a methodology based on documentary research and a narrative synthesis of the information available in the scientific literature and in sources relevant to the pet food industry. The analysis examined the intersection between pet owners' behaviour and preferences, the dynamics of the pet food market, sustainability trends,

* Corresponding author: silvia.petrescu@iuls.ro
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and scientifically-based nutritional requirements.

Scientific articles published in specialist journals were analysed, with a focus on recent literature from the period 2020–2026, supplemented by earlier works relevant to the topic. Academic sources included studies on pet owners' preferences, the perceived quality of pet food, pet parenting, the acceptance of alternative protein sources, the sustainability of diets and the nutritional composition of ingredients.

To characterise market trends, information from specialist sources such as Euromonitor International, Petfood Industry and FEDIAF was utilised, whilst data on pet ownership was sourced from the World Population Review (2026). In the case of commercial sources, the analysis was based on publicly available information, namely articles, abstracts and press releases, without access to the full commercial reports.

Legislative aspects concerning the use of animal by-products were analysed with reference to Regulation (EC) No 1069/2009, whilst information on the nutritional requirements of dogs and cats was cross-referenced with specialist veterinary and scientific sources.

The data were summarised narratively and organised thematically, with the aim of identifying similarities and differences between consumer perceptions, commercial trends and scientific evidence regarding the nutritional value, safety and sustainability of the ingredients used in pet food. This approach has made it possible to highlight the main criteria influencing the choice of pet food and the potential differences between the quality perceived by owners and the scientifically demonstrated nutritional and functional quality.

RESULTS AND DISCUSSIONS

A survey-based study analysing the responses of over 8,000 dog and cat owners in German-speaking countries shows that conventional meat-based pet food remains the predominant choice, but acceptance of alternatives is influenced by the owner's own diet, demographic characteristics and their perception of what is biologically appropriate for the animal. The pet's health was the main criterion for choosing food, whereas sustainability played a secondary role; of these owners, the overwhelming majority cited the internet as their main source of information regarding their pet's nutritional needs, whilst only 14 per cent cited their vet's recommendation as a source of information [2].

Table 1. Pet ownership statistics in the world, 2026

Country	Dogs (million)	Cats (million)
United States	69.9	74.1
China	27.4	53.1
Russia	17.6	23.3
United Kingdom	12.7	11.9
Germany	10.6	15.2
Spain	9.3	5.9
Italy	8.8	10.2
Poland	8.1	7.3
France	7.6	14.9
Ukraine	4.9	7.6
Romania	4.2	4.4
Portugal	2.8	2.0
Hungary	2.8	2.4

Source: World Population Review, 2026 [3]

Furthermore, another study, with a smaller sample size comprising over 2,600 dog owners – the majority of whom, over 80 per cent, were in the UK – showed that 84 per cent of owners fed their dogs conventional food or raw meat, and of those who assessed more sustainable alternatives, 43 per cent considered at least one to be acceptable. Over 80 per cent identified optimal nutritional content or nutritional balance as a decisive factor in their purchasing decision [5].

There is also direct evidence that the humanisation of pets alters the way owners evaluate pet food. A study carried out in Italy involving 935 respondents, dog and cat owners, found that the phrase 'contains natural ingredients' received the highest

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score amongst the quality characteristics assessed [6].

With regard to environmental concerns, amongst the studies cited, in German-speaking countries, only 800 of the more than 6,000 respondents selected environmental sustainability as important when choosing a type of pet food for their pet, whilst concern for health, nutrition, quality, naturalness and the freshness of ingredients ranked among the top most important aspects of dog and cat food, as highlighted in Figure 1 [2].

In Italy, young people under 35 were more concerned about recyclable packaging; even so, the greatest priority for them remained their pets' digestive health and food made from 'natural' ingredients [6].

Scientific literature frequently describes the phenomenon of 'pet humanisation', characterised by the integration of the companion animal into a social and family role similar to that attributed to a human family member. This trend is particularly relevant amongst younger generations, including Millennials and Generation Z [7,8], for whom the relationship with a pet may involve high levels of attachment, empathy and concern for the animal's well-being. This development has numerous positive implications, as it increases the attention paid to the animal's health, comfort and individual needs. However, when the physiological and nutritional characteristics of a dog or cat are interpreted predominantly through the lens of human values, preferences and dietary practices, this phenomenon can lead to the transfer of certain concepts specific to human nutrition to pet nutrition.

In this context, the term 'pet parent' has become increasingly common, reflecting the conceptual similarity between the owner–pet relationship and that between a parent and a child [9]. The humanisation of pets can therefore influence not only the way in which they are cared for and perceived, but also decisions regarding diet, ingredient profiles and the criteria used to define what constitutes 'high-quality' pet food. These trends are exerting increasing pressure on the pet food industry [10,11, 12] and, indirectly, on veterinary practice, through the diversification of owners' expectations and the growing demand for products that meet criteria inspired by human nutrition.

From a sustainability perspective, this transformation is significant because the choice of ingredients for dog and cat food can influence the environmental footprint of the final product. In particular, a preference for ingredients perceived as more natural, fresh, premium or 'human-grade' may favour the use of raw materials which, in certain production systems, have a value and a use that competes with human food [13]. In contrast, the utilisation of animal by-products eligible for use in pet food could represent an alternative compatible with the principles of the circular bioeconomy, provided that safety, nutritional value, acceptability and environmental impact are demonstrated.

Animal by-products (ABP), however, are a cause for concern amongst some pet owners, particularly when they are perceived as an indication of poor-quality pet food.

Studies on consumer behaviour [14] have shown that stating the absence of by-products can influence purchasing decisions, suggesting that negative perceptions of these ingredients may contribute to a preference for products promoted as containing fresh meat, 'natural' ingredients or raw materials perceived as being of superior quality [15]. However, these perceptions must be distinguished from the nutritional characteristics and the legal status of ABP. The term 'animal by-product' encompasses a broad and heterogeneous category of materials, and their exact composition depends on the applicable legal definition

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and the category of ingredients under consideration.

In the United States, for example, the AAFCO defines 'meat by-products' as clean, non-rendered parts derived from slaughtered mammals, other than meat itself, including organs such as the liver, kidneys, spleen and blood, whilst hair, horns, teeth and hooves are excluded from this definition [16]. In the European Union, however, the legislative concept of animal by-products is broader, and certain materials such as horns, feet, feathers, hair and other materials of animal origin may be classified as Category 3, subject to the conditions laid down in the legislation in force.

Regulation (EC) No 1069/2009 [17] provides a strict definition of animal by-products. Category 3 by-products are low-risk and are used legally and safely in pet food, in accordance with sterilisation and processing standards.

Therefore, the term 'by-product' should not be interpreted as synonymous with either 'low quality' or 'unsuitable for use in animal feed'.

From a nutritional point of view, certain animal tissues classified as by-products can provide valuable nutrients, which are found in lower concentrations in skeletal muscle tissue. Internal organs are particularly important as sources of specific micronutrients, including vitamin A, vitamin B12, iron, zinc and copper, although their composition varies considerably depending on the organ, species and processing method [18]. Similarly, ingredients of animal origin can provide significant amounts of taurine, an essential nutrient for cats, with measurable concentrations of taurine reported in ingredients such as chicken by-product meal and other protein products derived from poultry [19]. However, the nutritional value of ABP should not be generalised to all materials in this category, as differences in tissue composition, mineral content and processing can significantly influence nutrient concentration, amino acid availability and digestibility.

Distinguishing between the perception of ingredients and nutritional adequacy is particularly important when comparing meat derived exclusively from muscle tissue with diets that include offal or processed animal proteins. Feed consisting predominantly or exclusively of skeletal muscle tissue, when not properly balanced, may provide insufficient quantities or inappropriate ratios of certain essential nutrients, particularly with regard to calcium and phosphorus [20, 21]. Consequently, the completeness and balance of a type of feed must be assessed at the level of the final formulated product and not inferred solely from the presence or absence of a particular category of ingredients.

In this context, a clinical and nutritional approach is essential for assessing the suitability of a particular type of feed, as it involves correlating the nutritional composition and bioavailability of nutrients with the specific requirements of the animal's species, age, physiological condition and clinical status. The assessment must take into account not only energy intake and the balance of essential nutrients, but also the digestibility of ingredients, individual tolerance and any metabolic changes associated with medical conditions [22]. In the case of animals with medical conditions requiring dietary intervention, feed selection must be guided by specific clinical objectives, and its efficacy must be assessed by monitoring the clinical response and relevant nutritional parameters [23]. Therefore, the value of an ingredient cannot be determined solely on the basis of its origin or consumer perception, but must be analysed in relation to its role within the complete formulation and its effects on the animal's health.

From the perspective of the circular bioeconomy, the utilisation of suitable

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animal by-products can represent an opportunity to retain nutrients and energy within the food system, rather than directing them towards disposal or uses with lower added value. Rendering and the subsequent use of the resulting protein, lipid and mineral ingredients in pet food have been proposed as resource-efficient utilisation pathways. However, increasing competition for Category 3 animal by-products from sectors such as biofuel and biogas production may put pressure on their future availability [15]. Consequently, the sustainability potential of ABP should be assessed not only from the perspective of waste reduction, but also in relation to alternative uses, processing requirements, nutrient replacement and the environmental consequences associated with different utilisation pathways [24].



Figure 1. Key pet food attributes prioritized by pet owners, ranked according to their perceived importance [7, 25, 26].

CONCLUSIONS

The pet food industry lies at the intersection of sustainability and the phenomenon of 'pet humanisation'. Pet owners' preference for 'natural', premium or 'human-grade' ingredients favours the use of raw materials that compete directly with human food, thereby increasing the sector's environmental footprint. Although the studies mentioned show that owners prioritise health, ingredient quality and nutritional balance, their purchasing decisions are strongly influenced by subjective perceptions and information found online, only a small proportion of them (approximately 14 per cent) rely on recommendations from vets or pet nutrition specialists.

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This is why studies highlight the importance of educating pet owners ('pet parents') to correct negative perceptions of animal by-products, emphasising their nutritional value in an accurate and transparent manner.

The pet food of the future will need to strike a balance between meeting the emotional expectations of younger generations (Millennials and Generation Z) and reducing the environmental impact (carbon footprint) generated by the pet food industry.

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