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Alternative proteins: an innovative approach to dog food production

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In recent years, the search for alternative proteins for pet consumption has increased due to concerns about ingredient quality and the sustainability issues associated with traditional livestock-based protein farming, whose production has led to environmental contamination. Examples of alternative proteins include those produced through Cellular Agriculture, plant-based proteins, insects, and fungi. Cellular agriculture products are classified into two categories: cell-based, which include cultured meat and other foods produced from animal cells grown in culture, including insect cells; and acellular, which include recombinant animal proteins and other ingredients produced in safe microbial cell factories through microbial fermentation using genetic engineering or synthetic biology. In this review, we provide current information on the environmental impact of livestock farming, offer an overview of alternative proteins with a focus on dog food, and highlight the importance of proteins in dog health. Additionally, we analyze the significance of the palatability and digestibility of alternative proteins for dogs, assess their safety, and explore their potential market in Latin America, particularly in Mexico. Finally, we share our perspective on the potential and future research opportunities for Mexico in the field of dog food made from alternative proteins, mainly acellular products.

KEYWORDS

acellular agriculture, alternative proteins, Mexico, nutritious food, pets, dogs

1 Introduction

The global human population reached 8 billion in 2022 and is projected to rise to roughly 10 billion by 2060 (Worldometer, 2025). Dogs are the most widely kept omnivorous companion animal, and although the exact population is difficult to determine due to the lack of a global census and the existence of feral and free-roaming canines, world dog population has been estimated to be around 1 billion (Bryce, 2021; Sykes et al., 2020;

Belo et al., 2015). This increase in population of both humans and companion animals will lead to a higher demand for meat than we currently have (Komarek et al., 2021).

To meet the overall demand for animal proteins, it will be essential to develop innovative technological solutions for producing and processing nutritious food while also supporting the various goals of the United Nations' 2030 Agenda for Sustainable Development (UN, 2015). For example, ensuring food security, water availability, and combating climate change caused by traditional livestock practices. However, projections have accounted only for human needs and overlooked consumption by other carnivores and omnivores, such as cats and dogs, respectively, which could substantially increase global demand for livestock-derived ingredients if alternatives are not adopted. Livestock is not the only source of climate change. Still, it primarily harms the environment through greenhouse gas (GHG) emissions and the extensive use of resources, such as land and water (Bidoglio et al., 2024). This growth, combined with the expansion of carnivorous and omnivorous companion animal populations, such as dogs and cats, increases overall demand for animal-based proteins.

Alternative proteins for pet consumption have grown due to concerns about ingredient quality and the sustainability issues linked to traditional livestock-based protein farming. Examples include plant-based proteins, insect cells, and fungi (Kaur et al., 2025). They offer significant ethical advantages by promoting sustainability, enhancing food security, and most importantly, reducing animal suffering, the need for animal slaughter, and key animal welfare issues related to traditional meat production (Boukid et al., 2021; Tso et al., 2021). Recently, a new field called Cellular Agriculture (CellAg) has emerged, focusing on developing alternative proteins. New Harvest is a nonprofit research organization dedicated to advancing cellular agriculture (New Harvest, 2025), and the Good Food Institute, "a nonprofit think tank working to make the global food system better" (Good Food Institute, 2025), have played a decisive role in the global growth of CellAg. Products created through CellAg are categorized into two types: cellular and acellular (Figure 1). The first is cell-based, which includes cultured meat and other foods produced from animal cells grown in culture, including insect cells (Eibl et al., 2021; Onwezen et al., 2021). The second is acellular, consisting of animal proteins and other macromolecules produced by engineered, Generally Recognized as Safe (GRAS) microorganisms such as bacteria, yeast, and fungi. They are called acellular because the final product is a purified macromolecule that does not contain whole cells. Acellular production involves reprogramming metabolic pathways or the expression of specific genes in microorganisms using engineering tools, scaling up fermentation processes, and downstream processing to produce food ingredients such as animal

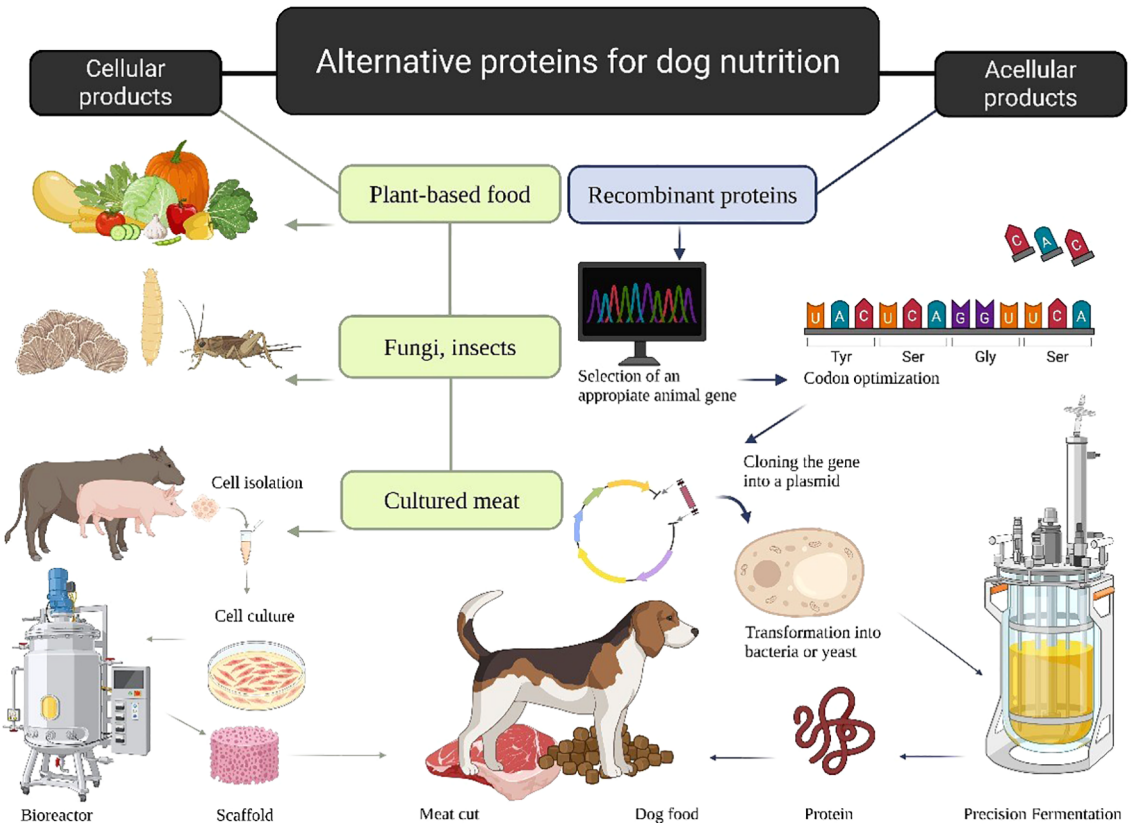

FIGURE 1
Schematic overview of products made by cellular agriculture. Left, cellular products, which can be derived from plants, fungi, insects, and cultured meat. Right, acellular products, where animal proteins are produced in microorganisms used as factories, scaled through precision fermentation. Created in BioRender. Carrillo, Y. (2025) https://BioRender.com/6veor0o.

proteins (Hilgendorf et al., 2024; Boukid et al., 2023). Proteins produced by precision fermentation are subsequently concentrated, semi-purified, and combined with suitable components to create products that resemble milk, meat, or eggs in taste and properties. Although these novel foods have experienced significant growth globally, and some are now commercially available, most are intended for human consumption, with few specifically designed for the pet market (Good Food Institute, 2025; New Harvest, 2025; Hoppenreijs et al., 2024).

On the other hand, the term "pet" encompasses a wide variety of animal species, including dogs, cats, small mammals (e.g., rabbits, ferrets, hedgehogs), reptiles, and other non-traditional companion animals (Cudworth, 2024; Pongrácz and Dobos, 2023). As pets exhibit significant physiological and nutritional differences (Bryce, 2021; Kirk, 2019), we consider it difficult to address all pets in a single review. In this work, we focused the manuscript on dogs, which are the most common companion animals in many countries, including Mexico (Peña-Corona et al., 2022). We present current information on the environmental impact of livestock farming, provide an overview of cellular agriculture with a focus on dog food, highlight the importance of proteins, and discuss their digestibility and palatability in dog nutrition. We also examine the regulatory aspects of alternative proteins, as well as their status in the Mexican and Latin American markets. Finally, we share our perspective on the potential and future research opportunities related to Mexico concerning dog food made from acellular proteins.

2 The importance of proteins in dog health

Any product used as dog food that is made from alternative proteins must meet the nutritional requirements for amino acid composition that pets need to stay healthy (Oberbauer and Larsen, 2021). Specifically, if the proteins are produced in microorganisms through precision fermentation, the proteins can be modified to meet all the essential amino acids for the dogs using genetic engineering or synthetic biology tools (French et al., 2025; Augustin et al., 2024; Proteins are biopolymeric structures composed of amino acids (AAs), which are essential for a dog's growth and health, extending lifespan and preventing malnutrition and deficiencies. They participate in numerous biochemical and physiological processes. Proteins serve many roles in organisms, including providing structural support, enabling enzymatic functions, transporting substances, defending against pathogens, and regulating body functions. Although many amino acids exist, most proteins are encoded by 20 that are specified in the universal genetic code (Wang et al., 2020). About half of these amino acids are produced naturally in a dog's metabolism through transamination, meaning they are non-essential amino acids, and are derived from different metabolic pathways. The other half are essential amino acids (EAAs), such as Arg, His, Ile, Leu, Lys, Met, Phe, Thr, Trp, and Val, which must be obtained through diet (Lopez and Mohiuddin, 2025; Oberbauer and Larsen, 2021). EAAs serve as building blocks for synthesizing new proteins, which are involved in creating many essential biomolecules within the dog's metabolism due to their complex nitrogen-containing structures.

AAs play critical roles in canine metabolism, neural health, and immune function (Huenerfauth et al., 2022; Chandel, 2021; Löscher and Schwartz-Porsche, 1986). Branched-chain AAs (Val, Leu, and Ile) contribute to metabolic regulation and support muscle protein synthesis; meanwhile, Leu and Arg influence nitrogen balance and hormonal signaling (Oberbauer and Larsen, 2021). Aromatic AAs (Tyr, Phe, and Trp) serve as precursors for hormones and neurotransmitters, and low levels are linked to cognitive and behavioral changes. Additionally, AAs like Trp, Arg, Leu, and Ile are essential for activating immune cells, which is especially important in aging dogs (Fretwell et al., 2006). Moreover, AAs such as Met, His, and Tau support methylation, inflammation control, and cardiovascular health. Moro et al., 2020.

3 Alternative proteins

Livestock not only accounts for about 15% of global GHG emissions (Gerssen-Gondelach et al., 2017) but also impacts public health due to the presence of antimicrobial and pesticide residues in food products (Tian et al., 2021; Chen et al., 2019; Menkem et al., 2019; Van Boeckel et al., 2017; WHO, 2014). In Mexico, it is estimated that 56% of the country's land is used for extensive farming, which contributes around 10% of the nation's total GHG emissions (IICA, 2021). Although limited information is available on the environmental impact of pet food, it has been reported that companion cats and dogs in Japan and the United States could consume approximately 15% and 20%, respectively of the food eaten by people, releasing almost 11 million, and to 64 million tons of greenhouse gases per year (Su and Martens, 2018; Okin, 2017).

Due to the negative impacts associated with livestock farming, alternatives to animal-derived proteins (alternative proteins) have grown and prospered in recent years, especially in the pet food industry, where their use is currently expanding (Kumar and Sharma, 2024). As previously mentioned, alternative proteins offer an alternative to traditional animal-based sources (Siegrist and Hartmann, 2023). In this section, we will briefly overview plant-based foods, fungi, insects, and products from cellular agriculture as innovative options for producing products like dog food.

3.1 Plant-based food

Plant-based foods are formulated to provide a complete nutritional profile using ingredients derived from plants, such as oats, almonds, soy, and nuts, rather than meat (Rini et al., 2022; Alcorta et al., 2021). In recent years, the market for plant-based foods has gained popularity overall due to its economic, social, and environmental advantages over animal-based ingredients (Weinrich, 2019), and this trend extends beyond human consumption. Various plant-based products and vegetarian formulas for dogs have been introduced to the market or

homemade, with their popularity growing especially in North America (Dodd et al., 2018).

Plant-based ingredients are primarily selected for their amino acid profiles; however, other bioactive compounds, such as flavonoids, phenolic acids, anthocyanins, carotenoids, and vitamins, are also considered during selection. These compounds are confirmed to benefit human health by supporting the maintenance and enhancement of cognitive functions and helping prevent chronic diseases such as diabetes, cardiovascular diseases, and certain types of cancer (Madhab et al., 2023; Baroni et al., 2021); nevertheless, more studies are currently needed to confirm a similar effect on canine health (Tanprasertsuk et al., 2022).

Although a plant-based diet offers an alternative to meat, it has limitations in protein quality, digestibility, and overall protein content. Legumes are among the richest plant sources of protein, containing 20% to 45% protein by weight (Zhang et al., 2024); however, they lack all the essential amino acids required for dogs (Table 1). One of the main challenges of plant-based ingredients is the reduction in bioavailability of their compounds after processing into final edible products. Therefore, different methods have been explored to enhance processing and preserve the benefits of these substances, such as lyophilization and non-thermal techniques like UV light irradiation, high hydrostatic pressure, and pulsed-electric fields (Tchonkouang et al., 2023; Bhatta et al., 2020; Al-juhaimi et al., 2018; Ribas-Agustí et al., 2018). Plant-based foods aim to develop products with optimal ingredient combinations to prevent deficiencies. Ingredients such as legumes (e.g., peas, soybeans), cereals (e.g., corn, rice), pulses, fruits, and other plant sources often contain limited amounts of certain essential amino acids (Table 1). Therefore, when using plant-based foods as dog food or other ingredients (e.g., yeast, insects) (Table 1), it is important to combine different plant protein sources to ensure a complete amino acid profile for dogs, which require ten essential amino acids (i.e., Arg, His, Ile, Leu, Lys, Met, Phe, Thr, Trp, Val) (Oberbauer and Larsen, 2021).

TABLE 1 Digestible indispensable amino acid score (DIAAS) of different ingredients used in dog diets, and the limit amino acids (AAs).

Product	Ingredients	Limiting AAs	DIAAS*
Plant-based food	Corn (whole)	Trp	40
	Rice (whole)	Trp	43
	Wheat (wholemeal)	Met	44
	Oat (whole)	Met	44
	Pea	Met	21
	Canola	Phe	40
	Soy	Met	39
Unconventional sources	Yeast (brewers)	AAA	29
	Insect (black soldier fly larvae)	Met	46
Animal-derived food	By-products (lung)	SAA	39
	Blood meal	Ile	9
	Bone meal	Trp	19
	Feather meal	Met	16
	Chicken meat	SAA	37
	Swine meat	SAA	40
	Bovine meat	SAA	54

*DIAAS values between 75–99 represent high-quality proteins, whereas values above 100 indicate proteins of excellent quality. Limiting amino acids with a DIAAS value higher than 100 indicate that they are not limiting. In the original manuscripts, protein quality was determined according to the Association of American Feed Control Officials nutrient profiles and the allowances for dogs recommended by the National Research Council. SAA: Sulfur amino acids (Met + Cys). AAA: Aromatic amino acids (Phe + Tyr). Information was obtained from Templeman and Shoveller (2022) and Do et al., 2020.

3.2 Insects and fungi

Insect protein meals have been shown to be a sustainable and nutritious alternative to traditional animal proteins, but there is still potential to increase consumer acceptance. Two main concerns about insect proteins are safety and entomophobia. Insect proteins can cause IgE cross-reactions with other arthropods; however, processing methods such as hydrolysis, microwaving, pressurization, and heating can reduce or eliminate the risks associated with allergenic proteins (Pan et al., 2022). Entomophobia, which involves feelings of worry, disgust, guilt, and anxiety about insects and their consumption, is the primary reason why people tend to be more cautious with this type of diet (Fantechi et al., 2024; Fernandes da Silva et al., 2023). Other alternative proteins used in diets include yeast and fungi, which are often included as dehydrated biomass (dead cells) derived from traditional fermentation, known as biomass fermentation or single-cell protein (Molfetta et al., 2022). Various products derived from medicinal fungi are marketed as food supplements for dogs (Los amigos de Firulais, 2025). To date, dog foods made from insects have been introduced to the market, which are supplemented with algae, glucosamine, and collagen, among other ingredients (Pet Fly, 2025). Additionally, chicken-based recipes for adult dogs containing insect protein are being marketed (Cooking, 2025).

3.3 Cellular agriculture

3.3.1 Cell-based products (cultured meat)

Cultured meat involves using only a few animal cells, rather than the entire animal, to grow them in a laboratory (*in vitro*). These cells are arranged systematically to mimic the structure of a traditional meat cut (Reis et al., 2020). Cultured meat offers several advantages, including positive environmental and animal welfare effects, as well as the potential to create products without substances that could harm consumer health, such as antibiotics, growth promoters, and N-nitrosamines, which have been linked to an increased risk of cancer. Similarly, cultured meat can be artificially modified to include compounds that make it more nutritious than ordinary meat (Fraeye et al., 2020). Its production involves isolating and growing animal cells *in vitro*, from mammals, birds, or fish. The types of cells used include embryonic stem cells

(ESCs), immortalized cell lines, pluripotent stem cells (iPSCs), and primary cells—each with different growth rates, differentiation procedures, and levels of consumer acceptance due to ethical concerns (Martins et al., 2024).

Alternatively, cultured meat often encounters greater challenges in gaining consumer acceptance (Bryant and Barnett, 2020). First, the cultured meat market mainly targets omnivores because vegan and vegetarian consumers avoid eating meat altogether. Potential consumers of cultured meat will choose it only if specific criteria are met, such as lower prices, transparent information about the process, flavor and texture are very similar (if not identical) to that of conventional meat (Post et al., 2020). After thorough evaluations, a few countries around the world have authorized cultured meat for human consumption, with Singapore leading the way, followed by the United States and the Middle East (Barrie, 2020). Currently, the companies at the forefront of authorized cultured meat available to consumers are GOOD Meat, Upside Foods, Aleph Farms, Wild Type, Mission Barns and Believer Meats (Coyne, 2025).

3.3.2 Acellular products

Although technologies for generating acellular products have existed for decades, their recent expansion into producing food-grade macromolecules, such as proteins, for use in new food products is a recent development in this field. Acellular products are animal proteins produced by genetically modified GRAS microorganisms (e.g., yeast, bacteria), which act as microbial cell factories that generate proteins. Their production can be scaled up through a process called "precision fermentation" (Linder, 2023; Tubb and Seba, 2021). Thanks to recombinant technology, there is no need for whole animals or their cells (Nielsen et al., 2024). When plants are used as factories instead of microorganisms, the process is known as "plant molecular farming" (Long et al., 2022). However, there are still challenges to overcome before this technology can be fully adopted and standardized within the alternative protein industry (Bobo, 2024). Compared to cellular products, acellular options are viewed as better by certain population groups because they do not involve animals. It has been estimated that recombinant protein production accounts for only 3% of the total GHG emissions from livestock farming (Knychala et al., 2024). Additionally, in terms of cost, recombinant proteins fall within a similar range compared to cultured meat, with an estimated price of $10 to $100 per kilogram of biomolecule, compared to $63 per kilogram of cultured meat (Garrison et al., 2022). Projections suggest that prices could drop below $10 per kilogram by 2030 (Tubb and Seba, 2021).

At a genetic level, recombination technology allows precise control over the traits of expressed proteins, which helps reduce risks related to zoonotic diseases and food allergies through genetic engineering. Recombinant proteins can also be modified to improve stability, enhance digestibility, facilitate protein interactions, and decrease allergenicity (Hoppenreijs et al., 2024; Boukid et al., 2023). Over the past decade, several recombinant protein companies have been established, mainly in the United States. These include The Every Company, Perfect Day, and Fybraworks Foods, which produce recombinant ovalbumin, casein, and muscle proteins, respectively. These proteins are combined with various animal-free, antibiotic-free, and sustainable ingredients to create final products such as bread and ice cream (GFI, 2025; Nielsen et al., 2024). Although around one hundred companies worldwide produce acellular products, only six are currently operating in Latin America (GFI, 2025).

4 Current status of alternative proteins in dog food

The popularity of plant-based dog food has increased not only among vegetarian and vegan guardians, but also among guardians who perceive health benefits for their dogs and the belief that these diets are produced without causing animal suffering (van Prooijen et al., 2024; Tanprasertsuk et al., 2022; Dodd et al., 2019). Products containing legumes and pulses are the main ingredients found in pet foods offered by market leaders such as Nestlé's Purina and Royal Canin. However, although some commercial diets have been successfully formulated to fulfill the requirements set by the National Research Council (NRC) (Linde et al., 2024; Cavanaugh et al., 2021), some brands still need supplementation of specific nutrients, such as amino acids, vitamins, and minerals (Brociek et al., 2025; Zafalon et al., 2020).

In Latin America, approximately 77 companies produce plant-based foods, primarily in Brazil, Mexico, Argentina, Chile, Peru, and Ecuador (GFI, 2025); however, none of these companies make dog food. The pet food industry is developing new formulations to address the current need for sustainability while meeting pets' nutritional requirements (Choi et al., 2023). Recently, proteins derived from unconventional sources, such as fungi and insects, have been leading the market for alternative dog foods, thanks to their high levels of micro- and macronutrients. From startups to established companies such as Nestlé's Purina and Colgate-Palmolive's Hill's Pet Nutrition Inc., the market has seen the launch of pet foods formulated with proteins from insects like black soldier fly larvae (*Hermetia illucens*) and mealworms (*Tenebrio molitor*) (DVM, 2023; Streisand, 2020). Insect meals have digestibility similar to that of animal-based proteins. Life cycle analyses have been done on insect protein production, consistently showing that this alternative uses less water, requires less land, and produces fewer greenhouse gas emissions than traditional livestock (Lisboa et al., 2024; Boakye-Yiadom et al., 2022; Halloran et al., 2016; Smetana et al., 2016). Additionally, insect proteins often exceed the minimum amino acid requirements according to NRC guidelines, with some exceptions, such as black soldier fly larvae and most plant and algal species, which have low levels of taurine (McCusker et al., 2014). Nevertheless, some studies have noted that the high protein content of insect meals is linked to chitin, a nitrogen-rich component of insect exoskeletons. This could complicate the availability of protein and may contribute to the nitrogen content attributed to proteins (Penazzi et al., 2021). Another disadvantage of this option is the significant price fluctuations, depending on the type of insect (Shah et al., 2022).

Therefore, in Latin America, the market for alternative proteins for dogs is led by companies that sell whole dehydrated insects, as supplement meals for animal nutrition; examples include IN Insect Nutrition (Mexico), which also sells dehydrated crickets (*Acheta domesticus*), Biofly (Colombia), and Futura (Venezuela) (APICAL, 2023). Companies like Wild Earth and Royal Canin currently offer these products on the market (Tyler, 2019).

In contrast, yeast and fungi offer several benefits for pets, including improving the gut microbiome, strengthening the immune system, enhancing the digestibility of the final product, and providing antioxidant effects (Davenport et al., 2023; Maturana et al., 2023; Van den Abbeele et al., 2020). *Saccharomyces cerevisiae* has been widely used in poultry and livestock nutrition, but its use in companion animals remains limited (Maturana et al., 2023). A dog diet containing 10% dried yeast (*S. cerevisiae*) showed improved palatability and digestibility compared to the control, indicating its potential as an alternative protein source for dogs (Davenport et al., 2023). The presence of yeast in a dog's diet helps suppress opportunistic pathogens (e.g., *E. coli*), stimulates microbiota activity, and increases the production of acetate, propionate, butyrate, ammonium, and branched short-chain fatty acids (Van den Abbeele et al., 2020).

Despite the challenges cultured meat faces in gaining full acceptance from consumers, pet owners are more willing to adopt it for feeding their pets (Oven et al., 2022). Some companies worldwide have taken advantage of this trend by developing products made from cultured meat, which can be sold as pet food. Examples include BioCraft, Meatly, and Bene Meat Technologies, with the latter two having received approval to sell cultured meat as dog food at the time of writing. Some Latin American companies and startups, such as Fazenda Futuro (Brazil), are working to introduce cultured meat to the regional market; however, many are still operating at a laboratory level, and none are yet focused on pet food (The Food Tech, 2024; Arratibel, 2023). Bond Pet Foods is currently developing acellular products for use as pet food (Wilbur-Elllis, 2024).

5 General consideration on protein content and quality in dog diets

The ideal quantity of proteins in dog diets remains a research topic. It's been shown that, when fed freely, dogs regulate their daily food intake in a way that results in consuming diets with approximately 21 to 27% protein, which corresponds to a nutrient density of 53–58 g/Mcal of ME (conversion based on tables from FEDIAF, 2024) (Tôrres et al., 2003; Roberts et al., 2018). Diets with protein contents outside this range have various effects on the dog's health: diets with low amounts of protein, less than 18% (45 g/Mcal ME, FEDIAF, 2024), lead to deficiencies not only of amino acids but also of vitamins. In comparison, diets with over 40% (100 g/Mcal ME, FEDIAF, 2024) of protein have been linked to increased inflammation and kidney dysfunction markers, even though they improve satiety and are used in weight-loss protocols (Ephraim et al., 2020; Weber et al., 2007).

There are four common types of foods included in various canine diets. They are categorized based on moisture content: (i) Dry, with 14% or less moisture, mainly extruded food; (ii) Wet, with 60% or more moisture, mostly canned food; (iii) Home-cooked, such as family leftovers; and (iv) Raw food, made from animal-based ingredients, with moisture levels that depend on the ingredients. Studies on dietary preferences show a weaker correlation with the income or educational level of guardians and a strong correlation with their age. Several studies have shown that younger populations prefer to feed their dogs dry and "premium" diets with higher quality levels (O'Brien et al., 2024; Kumcu and Woolverton, 2015). Although dry diets have been shown to reduce tooth plaque buildup, bad breath odor, and bacteria linked to poor oral health, wet diets have demonstrated better digestibility in older dogs (Oba et al., 2022; Kim et al., 2021). Raw diets have gained popularity among guardians who believe in feeding their dogs a diet similar to that of wolves (Morelli et al., 2019). Nevertheless, it has been demonstrated that raw diets often pose a higher risk of contamination with pathogenic and zoonotic microorganisms and that they may not meet dogs' nutritional requirements. It is interesting to note that over the years, dog domestication has led to natural genetic modifications, giving these animals omnivorous characteristics. In this sense, dogs can currently convert β-carotene to vitamin A, Cys to Tau, linoleic acid to arachidonic acid, and Trp to niacin (Tazerji et al., 2024; Davies et al., 2019; Nüesch-Inderbinen et al., 2019). Additionally, compared to carnivorous animals, dogs possess a microbiota that enables them to digest starches and cellulose (Li and Wu, 2023; Lyu et al., 2018).

Guidelines for formulating pet food are based on the NRC, which specifies recommended levels of nutrients such as protein, fat, minerals, and vitamins to meet the nutritional needs of dogs and cats (Figure 2) (FEDIAF, 2024; AAFCO, 2015). The most common diet for dogs is commercial dry food. Although they generally meet the minimum requirements specified by guidelines, several studies have found excessive levels of certain elements, such as fat and fiber, inconsistencies in labels, and varying levels of protein quality depending on the ingredients used, whether from plants, animals, or animal by-products, in different foods available on the market. A diet with more animal-based ingredients is linked to higher protein quality. In contrast, diets that include a significant amount of plant-based ingredients tend to have lower protein quality and digestibility (Geiger and Weber, 2022). In such cases, a plant-based product must be carefully formulated to achieve the appropriate quality levels. Formulating a dog diet that uses high-quality protein without harming the environment is a crucial issue that needs to be addressed.

6 Nutritional adequacy of alternative proteins for dogs

Plant-based commercial diets for dogs exhibit lower digestibility and suboptimal EAAs profiles, with reduced levels of Leu, Met, Tau, Lys, and Trp (Table 1) (Smola et al., 2024; Reilly et al., 2020; Kanakubo et al., 2015). Some vegan formulations for dogs have also

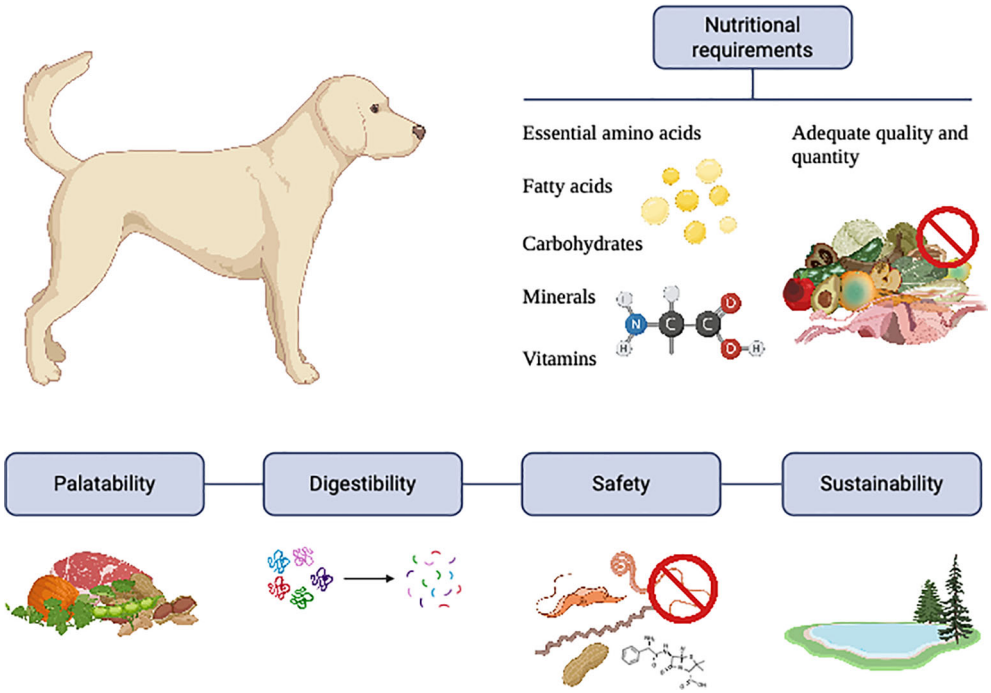

FIGURE 2
Schematic showing nutrients needed to make dog food. Besides the nutrients, the dog food should be appealing to the dog, free of pathogens, and help reduce environmental contamination. Created in BioRender. Carrillo, Y. (2025) https://BioRender.com/7mmbies.

been reported to lack sufficient Met and essential minerals, while containing excessive amounts of Zn, Cu, and Fe (Zafalon et al., 2020).

In recent years, there has been an increase in studies evaluating the nutritional adequacy of plant-based foods for both humans and dogs. Although several ingredients have been studied, most research reaches similar conclusions: plant-based foods need to be carefully formulated to avoid amino acid deficiencies. Unfortunately, grain-free pet foods (which replaces grains with pulses), now make up more than 40% of the dog and cat diets currently on the market. This is concerning because pulses are usually low in several EEAs for dogs, which means that poorly formulated grain-free diets might increase the risk of AA imbalances becoming more widespread as these diets grow more common (Banton et al., 2020).

Insect meals, considered one of the most promising alternatives to traditional proteins for dogs, show varying digestibility and amino acid levels depending on the specific ingredient. Some studies have indicated that insects, such as black soldier fly larvae, have Met and Cys as their primary limiting amino acids. Due to their high chitin content, food made from insects tends to be less digestible (Jacuńska et al., 2024).

Limited research is available on cultured meat and recombinant proteins for dog nutrition. Based on compositional analyses performed for human food products, cultured chicken has been reported to contain 9-16% less total protein and 5-24% less EAAs than conventional chicken meat, particularly His, Ile, Trp, and Val (Sikora and Rzymski, 2024). A study evaluating the safety and digestibility of food made with brewed recombinant lamb protein compared to a control containing egg protein found that dog food made with the recombinant protein leads to lower levels of serum chloride, cholesterol, homocysteine, and taurine in the blood compared to the control, but both showed similar digestibility. Data indicated that brewed recombinant lamb protein is safe for use in dog food (French et al., 2025).

7 Palatability and digestibility of alternative proteins in dogs

To improve the digestibility of alternative proteins, such as plant-based ingredients, various methods have been tested for use in dog food. The main goal of plant-based foods is to maintain the nutritional value of the ingredients while improving digestibility and palatability—the enjoyment of eating. Different enzymes, including acid-active proteases like phytases and xylanases (Carneiro et al., 2025; Mak et al., 2024; MaChado et al., 2021), have been used to achieve these goals. Some ingredients can either decrease or increase pet food palatability. For example, adding whole soybeans to dog diets reduces digestibility (Kamiloglu et al., 2024; Kim et al., 2023). However, incorporating micro- and macroalgae can improve both digestibility and palatability (Mota et al., 2024). Palatability ranks as the fourth most important factor in a pet owner's choice of food (Knight et al., 2023); nevertheless, only a few studies have explored dogs' preferences for these diets, with some indicating lower palatability than meat-based foods and others finding no significant differences (Le Guillas et al., 2024; Knight et al., 2023; Debnath, 2018).

Regarding the digestibility of unconventional protein sources such as insects and yeast, studies have shown high digestibility rates

in foods made with insects; however, digestibility tends to decrease as the insects age (Do et al., 2020; Mwaniki and Kiarie, 2019). Dog diets that include yeast as a protein source show higher digestibility, better taste, and other benefits such as improved gut microbiota, a stronger immune response, and reduced fecal odor, as demonstrated in several studies (Bastos et al., 2023; Davenport et al., 2023; Sampath et al., 2023; Soares et al., 2023; Bill Kaelle et al., 2022).

Palatability tests of cultured meat have been carried out on dogs by the company Meatly, reporting a strong preference for diets containing cultured meat over those without it (Meatly, 2024). Only a few tests have been performed on food containing recombinant proteins. A recent study involving dogs examined the digestibility of food made with "brewed lamb protein" expressed in *Saccharomyces cerevisiae*, and it found no significant difference compared to diets with traditional animal protein (French et al., 2025).

8 Safety aspects of alternative proteins

Although alternative proteins are an option for traditional animal protein, different safety considerations must be considered when using them as ingredients in dog food. Safety aspects can include nutritional factors (such as lack of all essential amino acids and digestibility), immunological factors (like anaphylactic reactions and allergenicity), and physiological factors (such as the possibility of urine alkalinization) (Jacuńska et al., 2023; Manning, 2024; Jappe, 2023; Knight and Leitsberger, 2016). Below, we will provide a brief explanation of each case.

It has been noted that the main issue with plant-based foods is their incomplete amino acid (AA) profiles, which can lead to malnutrition. However, other health risks should also be considered before adopting a vegetarian or vegan diet. Since plant-based ingredients such as wheat, oat, peas and soy have lower levels of acidifying amino acids, pets on these diets are at risk of urine alkalinization, which can often cause urolithiasis — the formation of bladder stones — that may completely block the urethra, posing a life-threatening medical emergency (Knight and Leitsberger, 2016). Additionally, plant-based foods may trigger anaphylactic reactions because many of the commonly used ingredients, such as soy, wheat, corn, rice, and legumes like peas, lentils, and chickpeas, are known food allergens and are often found in plant-based dog foods (Jappe, 2023; Präger et al., 2023; Zhang et al., 2023; Wehrmaker et al., 2022).

Although insects are high in protein, certain concerns need to be addressed, such as the increase in indigestible carbohydrates that can happen with diets made from them and the fact that insects may carry fungi, parasites, and bacteria (Jacuńska et al., 2024; Valdés et al., 2022). Another issue is allergenicity. It has been reported that edible insects contain IgE-binding allergens, which might cross-react with similar proteins found in various arthropods. Therefore, dogs allergic to dust mites might also react to insects like mealworms, where nine proteins have been identified as allergens (Barre et al., 2021; Premrov Bajuk et al., 2021). Additionally, edible insects are known to bioaccumulate heavy metals such as arsenic, cadmium, mercury, copper, and lead due to contaminated plants and soils (Meyer et al., 2021); however, strict monitoring of this contamination is being conducted to reduce potential health risks for consumers (Gori et al., 2025).

The safety assessment of cultured meat is closely linked to aseptic and controlled conditions during cultivation, including the culture media and cell manipulation techniques. However, other concerns exist, such as contamination from materials with allergenic properties, like scaffolds used to shape cultured meat, and biological hazards, including bacteria, endotoxins, viruses, and prions associated with the use of fetal bovine serum (Manning, 2024). However, most companies are removing the use of fetal bovine serum to make cultured meat because of the cost, limited supply chain, and ethical issues (Vegconomist, 2025). The safety of the cultured meat manufacturing process has been evaluated through comprehensive analyses based on Hazard Analysis and Critical Control Points (HACCP) strategies. The process of producing cultivated meat is divided into different stages, from collecting cell lines, through their proliferation and differentiation, to the formation of the final product (Zandonadi et al., 2025).

Studies assessing the safety of diets containing recombinant proteins, such as leghemoglobin, focus on the use of different expression vectors and their potential risks to consumer health. Using bioinformatics tools, studies have compared common expression vectors to databases to find similarities with known allergens. The popularity of *Komagataella phaffii* (formerly known as *P. pastoris*) as a microbial cell factory for producing recombinant proteins has led to research on its own proteins, its vulnerability to pepsin digestion in simulated gastric fluids, and sequence homology comparisons to known toxins and allergens. These studies have identified about twenty proteins with notable matches to environmental allergens and toxins. However, these proteins also match those found in *Saccharomyces cerevisiae*, which does not have allergenicity issues. Interesting, leghemoglobin expressed in *K. phaffii* has been shown to be safe and is intended for use as a flavor catalyst in plant-based food (Reyes et al., 2021; Fraser et al., 2018; Jin et al., 2018). In the pet food industry, using *K. phaffii* has proven to be safe and beneficial for animals, as it offers probiotic properties (Gil de los Santos et al., 2012).

To introduce alternative proteins to the market, final products must be approved by specialized agencies to ensure they comply with each country's regulations. The food regulatory framework in Mexico is overseen by COFEPRIS (Federal Committee for Protection against Sanitary Risks), but depending on the product type, other government agencies may also be involved. For example, products made from recombinant proteins must be regulated by agencies such as SEMARNAT (Ministry of the Environment and Natural Resources, in Spanish) and CIBIOGEM (Interministerial Commission on Biosafety and Genetically Modified Organisms) (SENASICA, 2024; CIBIOGEM, 2020). Regarding pet food, authorization for animal use or consumption must be obtained from SENASICA, following the SENASICA-01-024-A process, to market the products. A similar approval is expected for insect protein; however, this type of product is labeled as "novel," and it

needs to be thoroughly examined for safety and allergens. Pet food made with recombinant proteins also must be approved by CIBIOGEM before its release. Moreover, all products intended for pet consumption in Mexico must be regulated under the Federal Animal Health Act (2024).

9 The alternative proteins market in Mexico and Latin America

Latin America has significant potential to lead the global alternative protein market, primarily due to its biodiversity, which represents about one-third of the world's species (Neves et al., 2020; Raven et al., 2020). The diversity of vascular plants—444 species—and edible insects—735 species—found in this region are key advantages for the success of this market (Ulloa Ulloa et al., 2017; Costa-Neto, 2015). Latin America accounted for 9.25% of the global alternative protein market, valued at USD 1,413 million, and is projected to have the second-highest growth rate worldwide by 2030 (Figure 3) (Horizon, 2025). Another strength of Latin America is entomophagy, the practice of consuming insects, which is deeply rooted in the culture of many countries, especially Mexico, Brazil, Colombia, Venezuela, Ecuador, and Peru. Therefore, one of the biggest challenges for the alternative protein market is consumer acceptance, which tends to be lower in Latin America compared to other parts of the world. This also impacts the potential consumption of these products by pets in the region (Castro Delgado et al., 2020).

Although the market for alternative proteins is rapidly expanding worldwide, its focus on pet food remains relatively new, with only about 40 companies registered globally (Table 2); however, none of these companies are based in Latin America (GFI, 2025). It is worth noting that there are approximately 200 million dogs in Latin America, excluding strays. This large number is likely because dogs account for nearly 70% of the preferred companion animals (Statista, 2023; Coll Blanco and de la Rosa Blanco, 2019). In Mexico, the National Institute of Statistics and Geography (INEGI) reported that there are 43.8 million dogs in households nationwide (INEGI, 2021). The pet food market in Mexico has been growing, driven not only by population growth but also by a shift in how pet owners interact with their pets. They are now more engaged in their pets' health and nutrition, choosing high-quality pet food over homemade leftovers. In 2024, the market was valued at USD 3.29 billion, with USD 2.29 billion of that specifically for dog food (Mordor Intelligence, 2024). The international trade of Mexican pets was valued at USD 369 million in 2023 by the "Secretaría de Economía" (Mexican Economy Ministry) (SE, 2023). The economic outlook for the pet food industry in Mexico is promising for innovation and growth, creating opportunities for CellAg to develop diets that meet the nutritional needs of dogs in line with the UN's 2030 Agenda for Sustainable Development (UN, 2015).

Approximately 150 alternative protein companies are currently operating in Latin America, with 11 of them based in Mexico. However, it is important to note that some companies and startups are not registered with the Good Food Institute (GFI); therefore, the total number of alternative protein companies in Mexico might be underestimated. This becomes clearer when comparing its market size to that of the most representative countries in their regions (Table 3), where Mexico is close to reaching a market size comparable to that of higher-income countries (Horizon, 2025).

10 Outlook for acellular dog food in Mexico

Since livestock production is a significant source of greenhouse gases and pollution, various strategies should be implemented to reduce it. One such strategy involves producing eco-friendly protein sources that meet nutritional needs while also reducing greenhouse gas emissions. Mexico has pledged a 30% reduction in methane emissions by 2030, compared to 2020 levels. As livestock

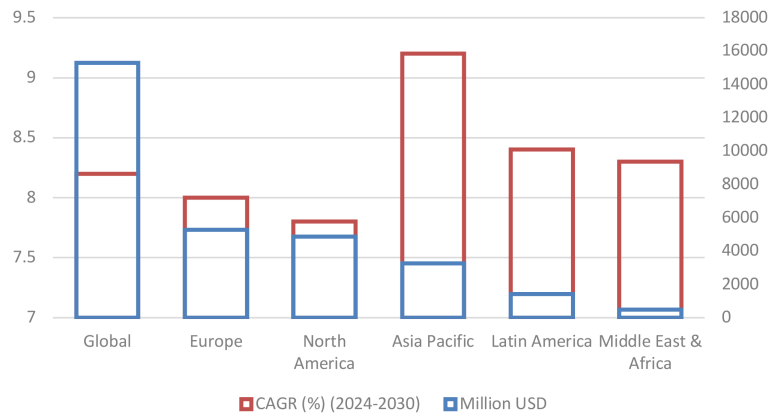

FIGURE 3
Alternative protein market size by region. CARG (red columns) indicates the Compound Annual Growth Rate. The market value is shown in millions of USD (blue). Data on alternative proteins include plant and insect proteins, as well as microbial proteins (including precision fermentation), sourced from Horizon, 2025.

TABLE 2 Alternative protein companies specializing in pet food worldwide.

Company	Operating regions	Type of product	Web page	Regulatory agency/status
Bene Meat Technologies	Europe	CM	https://www.benemeat.com/	Registered in EU Feed Materials Register
BioCraft Pet Nutrition	Europe, United States and Canada	CM	https://www.biocraftpet.com/	Registered with Austrian feed authorities (EU category 3 ABP use)
BioProcesia	Europe	MP	https://bioprocesia.com/	Regulated by EFSA
BondPet Foods	United States and Canada	Acell	https://www.bondpets.com/	Regulated by FDA
Bramble	United States and Canada	PB	https://bramblepets.com/	Regulated by FDA
Calidris Bio	Europe	MP	https://calidrisbio.com/en/	Regulated by EFSA
Calysta	United States	Microbial protein	https://calysta.com/	Approved for pet-food use by UK and EU feed authorities (multiple)
Cell AgriTech	Asia Pacific	CM	https://cell-agritech.com/	Regulated by SFA for SG market
Everything But	Asia Pacific	CM	https://www.linkedin.com/company/everything-but	Regulated by MAFRA
Faba Canada	United States and Canada	PB	https://fabacanada.com/	Regulated by CFIA for pet-food ingredient use
FlavingredProducts and Services	Asia Pacific	PB	https://www.flavingred.com/	Regulated by FSSAI (ingredients)
Freshwoof	Asia Pacific	PB	https://freshwoof.com/	Regulated by FDA
Friends & Family Pet Food Co.	United States, Canada, Asia Pacific	CM	https://friendsandfamily.pet/	Approved in Singapore by AVS
Kerry	United States, Canada, Latin America, Europe, Africa/Middle East, Asia Pacific, Australia/New Zealand	CM, PB, TF	https://www.kerry.com/	Regulated by FDA/EFSA
Kynda Biotech	Europe	MP	https://kyndatech.com/	Regulated by EU national feed authorities (multiple ingredients)
Manduca	Europe	PB, TF	https://manducaproteina.com/	Regulated by EU national pet-food authorities (unspecified)
Marsavet	Europe, United States and Canada	TF	https://marsavet.com/	Regulated by EFSA
Meatly	Europe	CM	https://meatly.pet/	Approved in UK by APHA/DEFRA/FSA
Moolec Science	Europe, Latin America, United States and Canada.	PMF	https://moolecscience.com/	Regulated by USDA/FDA for molecular-farming ingredients
Noochies!	United States and Canada	CM	https://www.noochies.co/	Regulated by FDA
Novel Farms	United States and Canada	CM	https://novelfarms.co/	Regulated by FDA
Oceanium	Europe	PB	https://oceanium.world/	Regulated by EFSA/FSA
Omni Pet	Europe	PB	https://omni.pet/	Regulated by FEDIAF
PawCo Foods	United States and Canada	PB	https://www.mypawco.com/	Regulated by FDA
Paws for Greens	Asia Pacific	PB	https://pawsforgreens.com/	Regulated by FSSAI
Pawsible Foods	Asia Pacific	TF	https://sg.linkedin.com/company/pawsiblefoods	Regulated by FDA
Petaluma Pet Food	United States and Canada	PB	https://www.feedpetaluma.com/	Regulated by FDA
Prefera Petfood	Europe	CM	https://www.preferapetfood.com/home	Regulated by national feed authority (multiple)
Simple Planet	Asia Pacific	CM	https://www.simpleplanet.io/	Regulated by MAFRA
Ten Lives	United States and Canada	TF	https://tenlivesfoods.com/	Regulated by FDA/CFIA

(Continued)

TABLE 2 Continued

Company	Operating regions	Type of product	Web page	Regulatory agency/status
Terramatter	Asia Pacific	Acell	https://terramatter.earth/home	Regulated by FSSAI
The Better Meat Co	United States and Canada	MP	https://www.bettermeat.co/	GRAS-pathway with FDA;
THE PACK	Europe	PB	https://thepackpet.com/	Regulated by national food authorities (multiple)
V-Dog, Inc.	Europe, United States and Canada, Asia Pacific	PB	https://v-dog.com/	Regulated by FDA
Vegancan	Latin America	PB	https://www.vegancan.com/	Regulated by COFEPRIS
Vestkorn	Europe	PB	https://vestkorn.com/	Regulated by multiple EU feed authorities (per ingredient)
Wild Earth	United States and Canada	PB, TF, CM	https://wildearth.com/	Regulated by FDA

*CM, cultured meat; PB, plant-based foods; MP, mycoprotein; TF, traditional fermentation; PMF, plant molecular farming; Acell, Acellular products (recombinant proteins). ABP, animal by-products; FDA, Food and Drug Administration; SFA, Singapore Food Agency; SG, Singapore, SE Asia, Southeast Asia; CFIA, Canadian Food Inspection Agency; AVS, Animal & Veterinary Service (Singapore); EFSA, European Food Safety Authority; APHA, Animal & Plant Health Agency (UK); DEFRA, Department for Environment, Food & Rural Affairs (UK); FSA, Food Standards Agency (UK); FSSAI, Food Safety and Standards Authority of India; MAFRA, Ministry of Agriculture, Food and Rural Affairs; USDA, United States Department of Agriculture; COFEPRIS, "Comisión Federal para la Protección contra Riesgos Sanitarios" (Mexico) With information from the Good Food Institute (2025), and companies' web pages.

contributes 13% of the GHGs in Mexico, some strategies have been implemented in this area, including the silvopastoral system, which integrates trees, legumes, and high-protein plants into the grazing area, and the use of biodigesters for manure management (Climate and Clean Air Coalition, 2025). Another approach is to reduce the use of livestock products, which serve as raw materials for dog food and other pet foods containing animal-derived meat. In this context, the Mexican pet food market is estimated to be worth USD 3.29 billion in 2024. It is projected to grow to USD 4.58 billion by 2029. Between 2024 and 2029, the highest value is expected to be for dog food, at around $3.2 billion (Mordor Intelligence, 2024).

Worldwide, companies mainly from the United States, Europe, and the Asia Pacific produce pet foods (e.g., dog food) based on cellular agriculture (e.g., cultured meat), and other alternative proteins, including plant-based proteins, mycoprotein, and microbial proteins (Table 2). The advantages and challenges of these products are described in previous sections. Some plant-based recipes for dogs, as well as those mixed with animal products (e.g., salmon), are sold in Mexico, although most are produced in other countries (Natural Balance, 2025; Bonza, 2025). It is worth noting that, worldwide, there is a limited number of dog foods based on acellular protein ingredients. To our knowledge, only Bond Pet Foods, a company based in the United States, produces and uses acellular proteins as supplements in both dry and wet pet foods. This company utilizes yeast as a microbial factory to create chicken protein and scales up protein production through precision fermentation (Bond Pet Foods, 2024).

TABLE 3 Alternative proteins market size by representative country.

Country	USD (million)	CAGR* 2024-2030
China	1106.1	9.8
Germany	1225.1	9.6
Mexico	753.7	9.2
India	795.9	9.1
South Africa	113.2	8.9
Brazil	361.9	8.6
UK	1151.8	8.2
Japan	397.8	8.2
France	752.8	7.6
USA	4464.5	7.5
Canada	409.7	7.4

*CAGR, compound Annual Growth Rate, with information from Horizon, 2025.

As the development of alternative proteins advances, new technologies offer opportunities to enhance their nutritional quality. One such technology is synthetic biology (synbio), an innovative approach that applies engineering principles such as design, testing, learning, and building to create or improve biological systems. Synbio allows the production of novel proteins with improved amino acid profiles. This technology has already been incorporated into the bioeconomy strategies of countries such as the United States and the United Kingdom, and it offers an opportunity to strengthen CellAg in Latin America. In Mexico and other Latin American countries such as Chile and Argentina, there are excellent research groups and talented human resources in biotechnology and synthetic biology capable of generating recombinant proteins with high nutritional value expressed in GRAS microorganisms, which can then be formulated for pet food development (Barboza-Pérez et al., 2025; Cisternas-Irrazábal et al., 2025; Liu et al., 2021).

On the other hand, the limited number of companies producing acellular dog food globally and the scarcity of these products in Mexico create a great opportunity to enter this market. Mexico has the necessary infrastructure, skilled labor, and advances in genetic engineering, biotechnology, and synthetic biology to make this

possible (Barboza-Pérez et al., 2025). Although some Mexican companies, such as Leaf Food and Heartbest Food, produce plant-based foods or plant-derived pigments for use as additives in the poultry and food industries, these products are only for human consumption (Figure 4). In this context, dog food enhanced with optimized animal proteins made in microbial factories could present a new opportunity for Mexican companies to develop a novel business model. It also offers a chance to reduce environmental pollution, as it does not involve livestock or land and lowers water use (Good Food Institute, 2025). Additionally, it supports sustainable processes, reduces reliance on traditional animal proteins for pets, and encourages significant bioeconomic growth. Recently, dogs (*Canis lupus familiaris*) have become important members of Mexican families, and they need food that meets their nutritional needs. Acellular foods have several advantages over cellular products, such as allowing more precise control of protein composition, enabling functional modifications, and removing zoonotic and allergenic risks associated with them. Through Synthetic Biology, we can engineer a microbial cell factory to produce an animal protein of interest, such as from cow, goat, chicken, or salmon, that satisfies nutritional requirements (Figure 1).

Finally, Mexico faces several challenges that could hinder the development of acellular protein-based dog foods and the growth of the acellular industry. One of the main issues is the ambiguity in the Mexican Biosafety Law regarding new biotechnological applications, synthetic biology, and other emerging biotechnologies, including cellular meat culture, acellular products, agriculture, and bioengineered microorganisms (Barboza-Pérez et al., 2025). It will be essential to invest in research and development to identify or create new proteins that can be scaled up and adapted to the Mexican or Latin American market, ensuring economic viability. Although technological advances in cellular agriculture offer several benefits, it is important to continue research and invest in training human resources in emerging areas such as synthetic biology, which will help develop more nutritious products for pets, particularly dogs, that involve sustainable processes. Lastly, outreach for these products will be key to increasing public awareness about their use.

11 Conclusions

Reducing the consumption of livestock products is essential due to their significant greenhouse gas emissions that contribute to environmental pollution. As pets, especially dogs, have become a central part of families, there is a growing demand for dog food that meets nutritional needs, tastes good, and is easy to digest. Alternative proteins are excellent options for making dog food in various forms, such as plant-based, insect-based, fungal-based, cultured meat, microbial protein, and acellular protein, which are mainly produced by companies outside Mexico. The development of alternative protein sources, especially cellular agriculture companies within Mexico that produce and sell dog food, presents a great opportunity to enter this rapidly growing market. Producing animal proteins in microbial cell factories for dog food can also be a valuable opportunity for Mexican investors, as the country has the necessary resources, such as skilled workers and infrastructure, to support these advancements. However, for these proteins to become mainstream in pet food, challenges like lowering costs, increasing acceptance among pet owners, and establishing clear regulatory pathways need to be addressed. While this review mainly focuses on dogs, many of these alternative proteins could also be used for other pets, such as cats, once species-specific research is completed. Overall, continued investment in both scientific and industrial fields will be necessary to make alternative proteins a significant complement or even a substitute for traditional animal-based ingredients in pet food.

FIGURE 4
Alternative protein companies based in Mexico. Leaf Food, plant-based food (https://leaf-foods.com/); VELOZBIO, animal-free protein, multiprotein platform, plant molecular farming (https://www.velozbio.com/); DProtein, mycoprotein; Heartbest Food, plant-based (https://heartbest.me/); Vepinsa Foods, sells and distributes naturally derived pigments from plants, primarily for the poultry and food industries (https://vepinsa.com.mx/). Part of the information was taken from the Good Food Institute, 2025.

Author contributions

YC: Conceptualization, Formal Analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing. AG: Conceptualization, Investigation, Supervision, Writing – review & editing. MP: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. LC: Formal Analysis, Investigation, Methodology, Writing – review & editing. JB: Conceptualization, Funding acquisition, Investigation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

AAFCO (2015). Association of America Feed Control Officials. Dog and cat food nutrient profiles. Available online at: https://www.chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.aafco.org/wp-content/uploads/2023/01/Model_Bills_and_Regulations_Agenda_Midyear_2015_Final_Attachment_A.: Proposed_revisions_to_AAFCO_Nutrient_Profiles_PFC_Final_070214.pdf (Accessed August 21, 2025).

Alcorta, A., Porta, A., Tárrega, A., Álvarez, M. D., and Vaquero, M. P. (2021). Foods for plant-based diets: Challenges and innovations. *Foods* 10, 293. doi: 10.3390/foods10020293

Al-juhaimi, F., Ghafoor, K., Özcan, M. M., Jahurul, M. H. A., Babiker, E. E., Jinap, S., et al. (2018). Effect of various food processing and handling methods on preservation of natural antioxidants in fruits and vegetables. *J. Food Sci. Technol.* 55, 3872–3880. doi: 10.1007/s13197-018-3370-0

APICAL (2023). *Alianza de la Industria de Insectos Comestibles de América Latina*. Available online at: https://www.apical.la/ (Accessed August 21, 2025).

Arratibel, A. J. (2023) in *El laboratorio mexicano que elabora carne bovina: ¿La alternativa del futuro?*, El País México. Available online at: https://www.elpais.com/Mexico/actualidad/2023-07-27/el-laboratorio-mexicano-que-elabora-carne-bovina-la-alternativa-del-futuro.html (Accessed August 21, 2025).

Augustin, M. A., Hartley, C. J., Maloney, G., and Tyndall, S. (2024). Innovation in precision fermentation for food ingredients. *Crit. Rev. Food Sci. Nutr.* 64, 6218–6238. doi: 10.1080/10408398.2023.2166014

Banton, S., Pezzali, J., Donadelli, R., Bakovic, M., Wood, K., Verbrugghe, A., et al. (2020). The acute effects of feeding a grain-free diet with or without methionine, taurine or methyl donor/acceptor supplementation on plasma and whole blood amino acid concentrations in dogs. *J. Anim. Sci.* 98, 62. doi: 10.1093/jas/skaa278.112

Barboza-Pérez, U. E., Pérez-Zavala, M. D. L., and Barboza-Corona, J. E. (2025). Synthetic biology in Mexico: Brief history, current landscape, and perspectives towards a bio-based economy. *Eng. Biol.* 9, e12037. doi: 10.1049/enb2.12037

Baroni, L., Sarni, A. R., and Zuliani, C. (2021). Plant foods rich in antioxidants and human cognition: A systematic review. *Antioxidants* 10, 714. doi: 10.3390/antiox10050714

Barre, A., Pichereaux, C., Simplicien, M., Burlet-Schiltz, O., Benoist, H., and Rougé, P. (2021). A proteomic- and bioinformatic-based identification of specific allergens from edible insects: Probes for future detection as food ingredients. *Foods* 10, 280. doi: 10.3390/foods10020280

Barrie, L. (2020). "Singapore gives green light to cell-based meat," in *Just Food*. Available online at: https://www.just-food.com/news/singapore-gives-green-light-to-cell-based-meat/ (Accessed August 21, 2025).

Bastos, T. S., Souza, C. M.-M., Kaelle, G. C. B., do Nascimento, M. Q., de Oliveira, S. G., and Félix, A. P. (2023). Diet supplemented with Saccharomyces cerevisiae from different fermentation media modulates the faecal microbiota and the intestinal fermentative products in dogs. *J. Anim. Physiol. Anim. Nutr.* 107, 30–40. doi: 10.1111/jpn.13824

Belo, V. S., Werneck, G. L., da Silva, E. S., Barbosa, D. S., and Struchiner, C. J. (2015). Population estimation methods for free-ranging dogs: A systematic review. *PloS One* 10, e0144830. doi: 10.1371/journal.pone.0144830

Bhatta, S., Stevanovic-Janezic, T., and Ratti, C. (2020). Freeze-drying of plant-based foods. *Fooods* 9, 87. doi: 10.3390/foods9010087

Bidoglio, G. A., Shwarzmueller, F., and Kastner, T. (2024). A global multi-indicator assessment of the environmental impact of livestock products. *Glob Environ. Change.* 87, 102853. doi: 10.1016/j.gloenvcha.2024.102853

Bill Kaelle, G. C., Menezes Souza, C. M., Bastos, T. S., Souza Vasconcellos, R., de Oliveira, S. G., and Félix, A. P. (2022). Diet digestibility and palatability and intestinal fermentative products in dogs fed yeast extract. *Ital J. Anim. Sci.* 21, 802–810. doi: 10.1080/1828051X.2022.2054733

Boakye-Yiadom, K. A., Ilari, A., and Duca, D. (2022). Greenhouse gas emissions and life cycle assessment on the black soldier fly (*Hermetia illucens* L.). *Sustainability* 14, 10456. doi: 10.3390/su141610456

Bobo, J. (2024). Molecular farming navigates a complex regulatory landscape. *Front. Plant Sci.* 15. doi: 10.3389/fpls.2024.1411943

Bond Pet Foods (2024).Meat protein for the pet food world. Available online at: https://www.bondpets.com/ (Accessed August 21, 2025).

Bonza (2025).La mejor comida vegetal para perros. Available online at: https://www.bonza.dog/es/ (Accessed August 21, 2025).

Boukid, F., Ganeshan, S., Wang, Y., Tülbek, M.Ç., and Nickerson, M. T. (2023). Bioengineered enzymes and precision fermentation in the food industry. *Int. J. Mol. Sci.* 24, 10156. doi: 10.3390/ijms241210156

Boukid, F., Rosell, C., Rosene, S., Bover-Cid, S., and Castellari, M. (2021). Non-animal proteins as cutting-edge ingredients to reformulate animal-free foodstuffs: Present status and future perspectives. *Crit. Rev. Food Sci. Nutr.* 62, 6390–6420. doi: 10.1080/10408398.2021.1901649

Brociek, R. A., Li, D., Broughton, R., and Gardner, D. S. (2025). Nutritional analysis of commercially available, complete plant- and meat-based dry dog foods in the UK. *PLOS ONE*. 20, e0328506. doi: 10.1371/journal.pone.0328506

Bryant, C., and Barnett, J. (2020). Consumer acceptance of cultured meat: An updated review, (2018-2020). *Appl. Sci.* 10, 5201. doi: 10.3390/app10155201

Bryce, C. M. (2021). Dogs as pets and pests: Global patterns of canine abundance, activity, and health. *Integr. Comp. Biol.* 61, 154–165. doi: 10.1093/icb/icab046

Carneiro, N. O., Souza, C. M. M., Bastos, T. S., Maiorka, A., Félix, A. P., and de Oliveira, S. G. (2025). Addition of xylanase to high and low nutrient density diets on nutrient digestibility and palatability, fecal characteristics, fermentation products and intestinal permeability in dogs. *Anim. Feed Sci. Technol.* 320, 1–10. doi: 10.1016/j.anifeedsci.2024.116192

Castro Delgado, M., Chambers, E., Carbonell-BarraChina, A., Noguera Artiaga, L., Vidal Quintanar, R., and Burgos Hernández, A. (2020). Consumer acceptability in the USA, Mexico, and Spain of chocolate chip cookies made with partial insect powder replacement. *J. Food Sci.* 85, 1621–1628. doi: 10.1111/1750-3841.15175

Cavanaugh, S. M., Cavanaugh, R. P., Gilbert, G. E., Leavitt, E. L., Ketzis, J. K., and Vieira, A. B. (2021). Short-term amino acid, clinicopathologic, and echocardiographic findings in healthy dogs fed a commercial plant-based diet. *PloS One* 16, e0258044. doi: 10.1371/journal.pone.0258044

Chandel, N. S. (2021). Amino acid metabolism. *Cold Spring Harb. Perspect. Biol.* 13, a040584. doi: 10.1101/cshperspect.a040584

Chen, J., Ying, G. G., and Deng, W. J. (2019). Atibiotic residues in food: Extraction, analysis, and human health concerns. *J. Agric. Food Chem.* 67, 7569–7586. doi: 10.1021/acs.jafc.9b01334

Choi, B., Kim, S., and Jang, G. (2023). Nutritional evaluation of new alternative types of dog foods including raw and cooked homemade-style diets. *J. Veterinary Sci.* 24, e63. doi: 10.4142/jvs.23037

CIBIOGEM (2020).Comisión Intersecretarial de Bioseguridad y Organismos Genéticamente Modificados. Available online at: http://www.gob.mx/senasica/acciones-y-programas/comision-intersecretarial-de-bioseguridad-y-organismos-geneticamente-modificados (Accessed August 21, 2025).

Cisternas-Irrazábal, C., Vallejos-Romero, A., Chauvet, M., García-Ojeda, M., Cordovés-Sánchez, M., and Sáez-Ardura, F. (2025). Mapa científico de un campo emergente en un país periférico: Análisis de redes del campo de la biología sintética en Chile. *Redes. Rev. Hisp. Anal. redes Soc* 37, 59–77. doi: 10.5565/rev/redes.1140

Climate and Clean Air Coalition (2025).Mexico-Develop methane roadmap for the livestock sub-sector and inclusion of agricultural livestock methane in Mexico´s NDC 3.0. Available online at: https://www.ccacoalition.org/projects/mexico-develop-methane-roadmap-livestock-sub-sector-and-inclusion-agricultural-livestock-methane-mexicos-ndc-30 (Accessed October 14, 2025).

Coll Blanco, C., and de la Rosa Blanco, S. (2019). Comportamiento de compra del consumidor de productos para mascotas en Latinoamérica. *Ad-gnosis* 7, 29–48. doi: 10.21803/adgnosis.v7i7.291

Cooking (2025).Premium dog food, insect proteins. Available online at: https://www.cookingChile.cl/alimentos-para-perros/insect-protein/ (Accessed October 14, 2025).

Costa-Neto, E. M. (2015). Anthropo-entomophagy in Latin America: An overview of the importance of edible insects to local communities. *J. Insects Food Feed.* 1, 17–24. doi: 10.3920/JIFF2014.0015

Coyne, A. (2025). "Protein pioneers: The countries that have approved cultivated meat," in *Just Food*. Available online at: https://www.just-food.com/features/protein-pioneers-the-countries-which-have-approved-cultivated-meat/ (Accessed November 22, 2025).

Cudworth, E. (2024). Companions, captives, kin: Domination and affection in the conceptualizing of pets'. *Pets* 1, 182–200. doi: 10.3390/pets1020014

Davenport, G. M., Block, S. S., and Adolphe, J. L. (2023). Effects of extruded pet foods containing dried yeast (Saccharomyces cerevisiae) on palatability, nutrient digestibility, and fecal quality in dogs and cats. *Transl. Anim. Sci.* 7, txad107. doi: 10.1093/tas/txad107

Davies, R. H., Lawes, J. R., and Wales, A. D. (2019). Raw diets for dogs and cats: A review, with particular reference to microbiological hazards. *J. Small Anim. Pract.* 60, 329–339. doi: 10.1111/jsap.13000

Debnath, B. (2018). Comparative evaluation of vegetarian and meat based dry pet food on palatability, food intake and growth performance in growing nondescript female dogs. *J. Anim. Res.* 8, 1015–1019. doi: 10.30954/2277-940X.12.2018.11

Do, S., Koutsos, L., Utterback, P. L., Parsons, C. M., de Godoy, M. R. C., and Swanson, K. S. (2020). Nutrient and AA digestibility of black soldier fly larvae differing in age using the precision-fed cecectomized rooster assay. *J. Anim. Sci.* 98, skz363. doi: 10.1093/jas/skz363

Dodd, S. A. S., Adolphe, J. L., and Verbrugghe, A. (2018). Plant-based diets for dogs. *J. Am. Vet. Med. Assoc.* 253, 1425–1432. doi: 10.2460/javma.253.11.1425

Dodd, S. A. S., Cave, N. J., Adolphe, J. L., Shoveller, A. K., and Verbrugghe, A. (2019). Plant-based (vegan) diets for pets: A survey of pet owner attitudes and feeding practices. *PLoS One* 14, e0210806. doi: 10.1371/journal.pone.0210806

DVM (2023).Hill's releases new sustainable fish and innovative insect protein products. Dvm360. Available online at: https://www.dvm360.com/view/hill-s-releases-new-sustainable-fish-and-innovative-insect-protein-products (Accessed August 21, 2025).

Eibl, R., Senn, Y., Gubser, G., Jossen, V., van den Bos, C., and Eibl, D. (2021). Cellular agriculture: Opportunities and challenges. *Annu. Rev. Food Sci. Technol.* 12, 51–73. doi: 10.1146/annurev-food-063020-123940

Ephraim, E., Cochrane, C. Y., and Jewell, D. E. (2020). Varying protein levels influence metabolomics and the gut microbiome in healthy adult dogs. *Toxins* 12, 8. doi: 10.3390/toxins12080517

Fantechi, T., Califano, G., Caracciolo, F., and Contini, C. (2024). Puppy power: How neophobia, attitude towards sustainability, and animal empathy affect the demand for insect-based pet food. *Food Res. Int.* 177, 113879. doi: 10.1016/j.foodres.2023.113879

Federal Animal Health Act (2024).DOF-21-05-2024. Available online at: https://www.chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.diputados.gob.mx/LeyesBiblio/pdf/LFSA.pdf (Accessed August 21, 2025).

FEDIAF (European Pet Food) (2024). *Nutritional Guidelines for complete and complementary pet food for cats and dogs 2024*. Brussel. Available online at: https://europeanpetfood.org/self-regulation/nutritional-guidelines/ (Accessed August 21, 2025).

Fernandes da Silva, C. B., Tavares Filho, E. R., Pimentel, T. C., Pagani, M. M., Márisco, E. T., Cruz, A. G., et al. (2023). The impact of information on the perception, emotional profile, and insights of Brazilian pet owners with different degrees of entomophobia. *Food Qual Prefer.* 110, 104967. doi: 10.1016/j.foodqual.2023.104967

Fraeye, I., Kratka, M., Vandenburgh, H., and Thorrez, L. (2020). Sensorial and nutritional aspects of cultured meat in comparison to traditional meat: Much to be inferred. *Front. Nutr.* 7. doi: 10.3389/fnut.2020.00035

Fraser, R. Z., Shitut, M., Agrawal, P., Mendes, O., and Klapholz, S. (2018). Safety evaluation of soy leghemoglobin protein preparation derived from Pichia pastoris, intended for use as flavor catalyst in plant-based meat. *Int. J. Toxicol.* 37, 241–262. doi: 10.1177/1091581818766318

French, S., Cochrane, C. Y., Faurot, M., Audibert, P., Belloso, T., and Badri, D. V. (2025). Safety and digestibility of a novel ingredient, brewed lamb protein, in healthy adult dogs. *Animals* 15, 3. doi: 10.3390/ani15030427

Fretwell, L. K., McCune, S., Fone, J. V., and Yates, D. J. (2006). The effect of supplementation with branched-chain amino acids on cognitive function in active dogs. *J. Nutr.* 136, 2069S–2071S. doi: 10.1093/jn/136.7.2069S

Garrison, G. L., Biermacher, J. T., and Brorsen, B. W. (2022). How much will large-scale production of cell-cultured meat cost? *J. Agric. Food Res.* 10, 100358. doi: 10.1016/j.jafr.2022.100358

Geiger, A. K., and Weber, L. P. (2022). Assessing non-protein nitrogen sources in commercial dry dog foods. *Transl. Anim. Sci.* 6, txac009. doi: 10.1093/tas/txac009

Gerssen-Gondelach, S. J., Wicke, B., and Faaij, A. P. C. (2017). GHG emissions and other environmental impacts of indirect land use change mitigation. *GCB Bioenergy* 9, 725–742. doi: 10.1111/gcbb.12394

Gil de los Santos, J. R., Storch, O. B., Fernandes, C. G., and Gil-Turnes, C. (2012). Evaluation in broilers of the probiotic properties of Pichia pastoris and a recombinant P. pastoris containing the Clostridium perfringens alpha toxin gene. *Vet. Microbiol.* 156, 448–451. doi: 10.1016/j.vetmic.2011.11.019

Gori, A., Armani, A., Pedonese, F., Benini, O., Mancini, S., and Nuvoloni, R. (2025). Heavy metals (Pb, Cd, Ni) in insect-based products for human consumption sold by e-commerce in the EU market: Occurrence and potential health risk associated with dietary exposure. *Food Control.* 167, 110781. doi: 10.1016/j.foodcont.2024.110781

Halloran, A., Roos, N., Eilenberg, J., Cerutti, A., and Bruun, S. (2016). Life cycle assessment of edible insects for food protein: A review. *Agron. Sustain. Dev.* 36, 57. doi: 10.1007/s13593-016-0392-8

Hilgendorf, K., Wang, Y., Miller, M. J., and Jin, Y. S. (2024). Precision fermentation for improving the quality, flavor, safety, and sustainability of foods. *Curr. Opin. Biotechnol.* 86, 103084. doi: 10.1016/j.copbio.2024.103084

Hoppenreijs, L. J. G., Annibal, A., Vreeke, G. J. C., Boom, R. M., and Keppler, J. K. (2024). Food proteins from yeast-based precision fermentation: Simple purification of recombinant β-lactoglobulin using polyphosphate. *Food Res. Int.* 176, 113801. doi: 10.1016/j.foodres.2023.113801

Horizon (2025). "Alternative protein market size & outlook 2030," in *Horizon Databook: The World's Largest Portal for Market Reports & Statistics* (San Francisco: Grandview Research). Available online at: https://www.grandviewresearch.com/industry-analysis/alternative-protein-market-report.

Huenerfauth, E. I., Bien, C. G., Bien, C., Volk, H. A., and Meyerhoff, N. (2022). Case report: Anti-GABAA receptor encephalitis in a dog. *Front. Vet. Sci.* 9. doi: 10.3389/fvets.2022.886711

IICA (Instituto Interamericano de Cooperación para la Agricultura) (2021). *La ganadería en México tiene amplio potencial para contribuir a la mitigación y la adaptación al cambio climático*. Ciudad de México, México. Available online at: https://www.omecega.org.mx/noticias/la-ganaderia-en-mexico-tiene-amplio-

potencial-para-contribuir-a-la-mitigacion-yla-adaptacion-al-cambio-climatico (Accessed August 21, 2025).

INEGI (Instituto Nacional de Estadística y Geografía) (2021). *Primera encuesta nacional de bienestar autorreportado (ENBIARE) 2021*. Aguascalientes, Aguascalientes. Available online at: https://www.inegi.org.mx/app/saladeprensa/noticia/7021 (Accessed August 21, 2025).

Jacuńska, W., Biel, W., Witkowicz, R., Maciejewska-Markiewicz, D., and Piatkowska, E. (2023). Comparison of key nutrient content of commercial puppy foods with canine dietary requirements. *Appl. Sci.* 13, 11791. doi: 10.3390/app132111791

Jacuńska, W., Biel, W., and Zych, K. (2024). Evaluation of the nutritional value of insect-based complete pet foods. *App. Sci.* 14, 22. doi: 10.3390/app142210258

Jappe, U. (2023). Vegan diet-alternative protein sources as potentially allergy risk. *Allergo J. Int.* 32, 251–257. doi: 10.1007/s40629-023-00248-7

Jin, Y., He, X., Andoh-Kumi, K., Fraser, R. Z., Lu, M., and Goodman, R. E. (2018). Evaluating potential risks of food allergy and toxicity of soy leghemoglobin expressed in Pichia pastoris. *Mol. Nutr. Food Res.* 62, 1700297. doi: 10.1002/mnfr.201700297

Kamiloglu, S., Tomas, M., Ozkan, G., Ozdal, T., and Capanoglu, E. (2024). *In vitro* digestibility of plant proteins: Strategies for improvement and health implications. *Curr. Opin. Food Sci.* 57, 101148. doi: 10.1016/j.cofs.2024.101148

Kanakubo, K., Fascetti, A. J., and Larsen, J. A. (2015). Assessment of protein and amino acid concentrations and labeling adequacy of commercial vegetarian diets formulated for dogs and cats. *J. Am. Vet. Med. Assoc.* 247, 385–392. doi: 10.2460/javma.247.4.385

Kaur, S. P., Sagar, N. A., and Rani, N. (2025). Alternative proteins: Innovation in sources, processing, and consumption. *Front. Sustain Food Syst.* 9. doi: 10.3389/fsufs.2025.1641712

Kim, H. S., Li, S., Zheng, Y., and Aldrich, C. G. (2023). Apparent total tract digestibility and palatability of extruded diets with graded levels of whole soybeans by dogs. *Front. Vet. Sci.* 10. doi: 10.3389/fvets.2023.1137788

Kim, K. H., Seo, K., Cho, H. W., Jeon, J. H., Kim, C. H., Jung, J., et al. (2021). Age-related digestibility of nutrients depending on the moisture content in aged dogs. *J. Anim. Sci. Technol.* 63, 1355–1361. doi: 10.5187/jast.2021.e116

Kirk, C. P. (2019). Dogs have masters, cats have staff: Consumers' psychological ownership and their economic valuation of pets. *J. Bus Res.* 99, 306–318. doi: 10.1016/j.jbusres.2019.02.057

Knight, A., Huang, E., Rai, N., and Brown, H. (2023). Correction: vegan versus meat-based dog food: Guardian-reported indicators of health. *PloS One* 18, e0291214. doi: 10.1371/journal.pone.0291214

Knight, A., and Leitsberger, M. (2016). Vegetarian versus meat-based diets for companion animals. *Animals* 6, 57. doi: 10.3390/ani6090057

Knychala, M. M., Boing, L. A., Ienczak, J. L., Trichez, D., and Stambuk, B. U. (2024). Precision fermentation as an alternative to animal protein, a review. *Fermentation* 10, 315. doi: 10.3390/fermentation10060315

Komarek, A. M., Dunston, S., Enahoro, D., Godfray, H. C. J., Herrero, M., Mason-D'Croz, D., et al. (2021). Income, consumer preferences, and the future of livestock-derived food demand. *Glob Environ. Change.* 70, 102343. doi: 10.1016/j.gloenvcha.2021.102343

Kumar, R., and Sharma, A. (2024). Emerging innovations in pet food industry sustainability, nutrition, and consumer trends in 2024. *JATU* 146, 132–139. doi: 10.48184/2304-568X-2024-4-132-139

Kumcu, A., and Woolverton, A. E. (2015). Feeding Fido: changing consumer food preferences bring pets to the table. *J. Food Prod. Mark.* 21, 213–230. doi: 10.1080/10454446.2012.715575

Le Guillas, G., Vanacker, P., Salles, C., and Labouré, H. (2024). Insights to study, understand and manage extruded dry pet food palatability. *Animals* 14, 7. doi: 10.3390/ani14071095

Li, P., and Wu, G. (2023). Amino acid nutrition and metabolism in domestic cats and dogs. *J. Anim. Sci. Biotechnol.* 14, 19. doi: 10.1186/s40104-022-00827-8

Linde, A., Lahiff, M., Krantz, A., Sharp, N., Ng, T. T., and Melgarejo, T. (2024). Domestic dogs maintain clinical, nutritional, and hematological health outcomes when fed a commercial plant-based diet for a year. *PloS One* 19, e0298942. doi: 10.1371/journal.pone.0298942

Linder, T. (2023). Beyond agriculture—How microorganisms can revolutionize global food production. *ACS Food Sci. Technol.* 3, 1144–1152. doi: 10.1021/acsfoodscitech.3c00099

Lisboa, H. M., Nascimento, A., Arruda, A., Sarinho, A., Lima, J., Batista, L., et al. (2024). Unlocking the potential of insect-based proteins: Sustainable solutions for global food security and nutrition. *Foods* 13, 1846. doi: 10.3390/foods13121846

Liu, Y., Dong, X., Wang, B., Tian, R., Li, J., Liu, L., et al. (2021). Food synthetic biology-driven protein supply transition: From animal-derived production to microbial fermentation. *Chin. J. Chem. Eng.* 30, 29–36. doi: 10.1016/j.cjche.2020.11.014

Long, Y., Wei, X., Wu, S., Wu, N., Li, Q. X., Tan, B., et al. (2022). Plant molecular farming, a tool for functional food production. *J. Agric. Food Chem.* 70, 2108–2116. doi: 10.1021/acs.jafc.1c07185

Lopez, M. J., and Mohiuddin, S. S. (2025). *Biochemistry, Essential Amino Acids* (StatPearls Publishing). Available online at: http://www.ncbi.nlm.nih.gov/books/NBK557845/.

Los amigos de Firulais (2025).Hongos medicinales para perros. Available online at: https://losamigosdefirulais.com/hongos-medicinales-para-perros/ (Accessed October 14, 2025).

Löscher, W., and Schwartz-Porsche, D. (1986). Low levels of γ-aminobutyric acid in cerebrospinal fluid of dogs with epilepsy. *J. Neurochem.* 46, 1322–1325. doi: 10.1111/j.1471-4159.1986.tb00658.x

Lyu, T., Liu, G., Zhang, H., Wang, L., Zhou, S., Dou, H., et al. (2018). Changes in feeding habits promoted the differentiation of the composition and function of gut microbiotas between domestic dogs (Canis lupus familiaris) and gray wolves (Canis lupus). *AMB Express.* 8, 123. doi: 10.1186/s13568-018-0652-x

MaChado, M. F., Bastos, T. S., Souza, C. M. M., Félix, A. P., Maiorka, A., and Oliveira, S. G. (2021). Effect of phytase and carbohydrases supplementation on digestibility, palatability, fecal characteristics and fecal fermentation products in dogs fed plant-protein diet. *Anim. Feed Sci. Technol.* 279, 115032. doi: 10.1016/j.anifeedsci.2021.115032

Madhab, M., Mangla, C., Vijaya, S., Patil, D. N., Joseph, R. A., Anuradha, S., et al. (2023). Different biological activities especially antioxidant activity of plant based functional foods for human health. *Int. J. Membr. Sci. Technol.* 10, 2419–2423. doi: 10.15379/ijmst.v10i4.3507

Mak, W. S., Jones, C. P., McBride, K. E., Fritz, E. A. P., Hirsch, J., German, J. B., et al. (2024). Acid-active proteases to optimize dietary protein digestibility: A step towards sustainable nutrition. *Front. Nutr.* 11. doi: 10.3389/fnut.2024.1291685

Manning, L. (2024). Responsible innovation: Mitigating the food safety aspects of cultured meat production. *J. Food Sci.* 89, 4638–4659. doi: 10.1111/1750-3841.17228

Martins, B., Bister, A., Dohmen, R. G. J., Gouveia, M. A., Hueber, R., Melzener, L., et al. (2024). Advances and challenges in cell biology for cultured meat. *Annu. Rev. Anim. Biosci.* 12, 345–368. doi: 10.1146/annurev-animal-021022-055132

Maturana, M., Castillejos, L., Martin-Orue, S. M., Minel, A., Chetty, O., Felix, A. P., et al. (2023). Potential benefits of yeast Saccharomyces and their derivatives in dogs and cats: A review. *Front. Vet. Sci.* 10. doi: 10.3389/fvets.2023.1279506

McCusker, S., Buff, P. R., Yu, Z., and Fascetti, A. J. (2014). Amino acid content of selected plant, algae and insect species: A search for alternative protein sources for use in pet foods. *J. Nutr. Sci.* 3, e39. doi: 10.1017/jns.2014.33

Meatly (2024). *The Webinar Vet* (Meatly). Available online at: https://meatly.pet/the-webinar-vet/ (Accessed May 28, 2025).

Menkem, Z. E., Ngangom, B. L., Tamunjoh, S. S. A., and Boyom, F. F. (2019). Antibiotic residues in food animals: Public health concern. *Acta Ecologica Sinica.* 39, 411–415. doi: 10.1016/j.chnaes.2018.10.004

Meyer, A. M., Meijer, N., Hoek-van den Hil, E. F., and van der Fels-Klerx, H. J. (2021). Chemical food safety hazards of insects reared for food and feed. *J. Insects as Food Feed* 7, 823–831. doi: 10.3920/JIFF2020.00857

Molfetta, M., Morais, E. G., Barreira, L., Bruno, G. L., Porcelli, F., Dugat-Bony, E., et al. (2022). Protein sources alternative to meat: state of the art and involvement of fermentation. *Foods* 11, 2065. doi: 10.3390/foods11142065

Mordor Intelligence (2024).Mexico pet food market size & share analysis - growth trends & forecasts up to 2029. Available online at: https://www.mordorintelligence.com/industry-reports/Mexico-pet-food-market (Accessed January 14, 2025).

Morelli, G., Bastianello, S., Catellani, P., and Ricci, R. (2019). Raw meat-based diets for dogs: survey of owners' motivations, attitudes and practices. *BMC Vet. Res.* 15, 74. doi: 10.1186/s12917-019-1824-x

Moro, J., Tomé, D., Schmidely, P., Demersay, T.-C., and Azzout-Marniche, D. (2020). Histidine: A systematic review on metabolism and physiological effects in human and different animal species. *Nutrients* 12, 1414. doi: 10.3390/nu12051414

Mota, C. S. C., Cabrita, A. R. J., Yergaliyev, T., Camarinha-Silva, A., Almeida, A., Abreu, H., et al. (2024). Macroalgae and microalga blend in dogs' food: Effects on palatability, digestibility, and fecal metabolites and microbiota. *Algal Res.* 84, 103775. doi: 10.1016/j.algal.2024.103775

Mwaniki, Z. N., and Kiarie, E. (2019). Standardized ileal digestible amino acids and apparent metabolizable energy content in defatted black soldier fly larvae meal fed to broiler chickens. *Can. J. Anim. Sci.* 99, 211–217. doi: 10.1139/cjas-2018-0111

Natural Balance (2025). Available online at: https://www.naturalbalanceinc.com/ (Accessed August 21, 2025).

Neves, D. M., Dexter, K. G., Baker, T. R., Coelho de Souza, F., Oliveira-Filho, A. T., Queiroz, L. P., et al. (2020). Evolutionary diversity in tropical tree communities peaks at intermediate precipitation. *Sci. Rep.* 10, 1188. doi: 10.1038/s41598-019-55621-w

New Harvest (2025).Cellular agriculture for the public good. Available online at: https://www.new-harvest.org/ (Accessed August 21, 2025).

Nielsen, M. B., Meyer, A. S., and Arnau, J. (2024). The next food revolution is here: recombinant microbial production of milk and egg proteins by precision fermentation. *Annu. Rev. Food Sci. Technol.* 15, 173–187. doi: 10.1146/annurev-food-072023-034256

Nüesch-Inderbinen, M., Treier, A., Zurfluh, K., and Stephan, R. (2019). Raw meat-based diets for companion animals: a potential source of transmission of pathogenic and antimicrobial-resistant Enterobacteriaceae. *R Soc. Open Sci.* 6, 191170. doi: 10.1098/rsos.191170

O'Brien, J. S., Tolbert, M. K., and Ruple, A. (2024). Dog and owner demographics impact dietary choices in Dog Aging Project cohort. *J. Am. Vet. Med. Assooc* 262, 1–9. doi: 10.2460/javma.24.05.0358

Oba, P. M., Sieja, K. M., Keating, S. C. J., Hristova, T., Somrak, A. J., and Swanson, K. S. (2022). Oral microbiota populations of adult dogs consuming wet or dry foods. *J. 5Anim. Sci.* 100, skac200. doi: 10.1093/jas/skac200

Oberbauer, A. M., and Larsen, J. A. (2021). "Amino acids in dog nutrition and health," in *Amino Acids in Nutrition and Health, Advances in Experimental Medicine and Biology*. Ed. G. Wu (Springer International Publishing, Cham), 199–216. doi: 10.1007/978-3-030-54462-1_10

Okin, G. S. (2017). Environmental impacts of food consumption by dogs and cats. *PloS One* 12, e0181301. doi: 10.1371/journal.pone.0181301

Onwezen, M. C., Bouwman, E. P., Reinders, M. J., and Dagevos, H. (2021). A systematic review on consumer acceptance of alternative proteins: Pulses, algae, insects, plant-based meat alternatives, and cultured meat. *Appetite* 159, 105058. doi: 10.1016/j.appet.2020.105058

Oven, A., Yoxon, B., and Milburn, J. (2022). Investigating the market for cultivated meat as pet food: A survey analysis. *PloS One* 32, 17. doi: 10.1371/journal.pone.0275009

Pan, J., Xu, H., Cheng, Y., Mintah, B. K., Dabbour, M., Yang, F., et al. (2022). Recent insight on edible insect protein: extraction, functional properties, allergenicity, bioactivity, and applications. *Foods* 11, 2931. doi: 10.3390/foods11192931

Peña-Corona, S. I., Gomez-Vazquez, J. P., López-Flores, E. A., Vargas Estrada, D., Arvizu-Tovar, L., Pérez-Rivero, J. J., et al. (2022). Use of an extrapolation method to estimate the population of cats and dogs living at homes in Mexico in 2022. *Veterinaria México OA*. 9, 1–10. doi: 10.22201/fmvz.24486760e.2022.1001

Penazzi, L., Schiavone, A., Russo, N., Nery, J., Valle, E., Madrid, J., et al. (2021). *In vivo* and *in vitro* digestibility of an extruded complete dog food containing black soldier fly (hermetia illucens) larvae meal as protein source. *Front. Vet. Sci.* 8. doi: 10.3389/fvets.2021.653411

Pet Fly (2025).Superfood, superalimentos funcionales a base de insectos. Available online at: https://www.petfly.co/ (Accessed October 14, 2025).

Pongrácz, P., and Dobos, P. (2023). What is a companion animal? An ethological approach based on Tinbergen's four questions. Critical review. *Appl. Anim. Behav. Sci.* 267, 106055. doi: 10.1016/j.applanim.2023.106055

Post, M. J., Levenberg, S., Kaplan, D. L., Genovese, N., Fu, J., Bryant, C. J., et al. (2020). Scientific, sustainability and regulatory challenges of cultured meat. *Nat. Food.* 1, 403–415. doi: 10.1038/s43016-020-0112-z

Präger, L., Simon, J. C., and Treudler, R. (2023). Food allergy - New risks through vegan diet? Overview of new allergen sources and current data on the potential risk of anaphylaxis. *J. Dtsch Dermatol. Ges.* 21, 1308–1313. doi: 10.1111/ddg.15157

Premrov Bajuk, B., Zrimšek, P., Kotnik, T., Leonardi, A., Križaj, I., and Jakovac Strajn, B. (2021). Insect protein-based diet as potential risk of allergy in dogs. *Animals* 11, 1942. doi: 10.3390/ani11071942

Raven, P. H., Gereau, R. E., Phillipson, P. B., Chatelain, C., Jenkins, C. N., and Ulloa Ulloa, C. (2020). The distribution of biodiversity richness in the tropics. *Sci. Adv.* 6, eabc6228. doi: 10.1126/sciadv.abc6228

Reilly, L. M., von Schaumburg, P. C., Hoke, J. M., Davenport, G. M., Utterback, P. L., Parsons, C. M., et al. (2020). Macronutrient composition, true metabolizable energy and amino acid digestibility, and indispensable amino acid scoring of pulse ingredients for use in canine and feline diets. *J. Anim. Sci.* 98, skaa149. doi: 10.1093/jas/skaa149

Reis, G. G., Heidemann, M. S., Borini, F. M., and Molento, C. F. M. (2020). Livestock value chain in transition: Cultivated (cell-based) meat and the need for breakthrough capabilities. *Technol. Soc* 62, 101286. doi: 10.1016/j.techsoc.2020.101286

Reyes, T. F., Chen, Y., Fraser, R. Z., Chan, T., and Li, X. (2021). Assessment of the potential allergenicity and toxicity of Pichia proteins in a novel leghemoglobin preparation. *Regul. Toxicol. Pharmacol.* 119, 104817. doi: 10.1016/j.yrtph.2020.104817

Ribas-Agustí, A., Martín-Belloso, O., Soliva-Fortuny, R., and Elez-Martínez, P. (2018). Food processing strategies to enhance phenolic compounds bioaccessibility and bioavailability in plant-based foods. *Crit. Rev. Food Sci. Nutr.* 58, 2531–2548. doi: 10.1080/10408398.2017.1331200

Rini, L., Schouteten, J. J., Faber, I., Bechtold, K.-B., Perez-Cueto, F. J. A., Gellynck, X., et al. (2022). Identifying the key success factors of plant-based food brands in Europe. *Sustainability* 15, 306. doi: 10.3390/su15010306

Roberts, M. T., Bermingham, E. N., Cave, N. J., Young, W., McKenzie, C. M., and Thomas, D. G. (2018). Macronutrient intake of dogs, self-selecting diets varying in composition offered ad libitum. *J. Anim. Physiol. Anim. Nutr.* 102, 568–575. doi: 10.1111/jpn.12794

Sampath, V., Sureshkumar, S., and Kim, I. H. (2023). The efficacy of yeast supplementation on monogastric animal performance—A short review. *Life* 13, 2037. doi: 10.3390/life13102037

Secretaría de Economía (SE) (2023). "Alimentos para Perros o Gatos, Acondicionados para la Venta al por Menor: Intercambio comercial, compras y ventas internacionales, mercado y especialización," in *Data México, Gobierno de México*. Available online at: https://www.economia.gob.mx/dataMexico/es/profile/product/dog-or-cat-food-put-up-for-retail (Accessed February 12, 2025).

SENASICA (2024).SENASICA-01-024-A Autorización de productos para uso o consumo animal. Available online at: http://www.gob.mx/senasica/documentos/senasica-01-024-a-autorizacion-de-productos-para-uso-o-consumo-animal?state=published (Accessed Junuary 5, 2025).

Shah, A. A., Totakul, P., Matra, M., Cherdthong, A., Harnboonsong, Y., and Wanapat, M. (2022). Nutritional composition of various insects and potential uses as alternative protein sources in animal diets. *Anim. Bioscience.* 35, 317–331. doi: 10.5713/ab.21.0447

Siegrist, M., and Hartmann, C. (2023). Why alternative proteins will not disrupt the meat industry. *Meat Sci.* 203, 109223. doi: 10.1016/j.meatsci.2023.109223

Sikora, D., and Rzymski, P. (2024). Assessment of the potential nutritional value of cell-cultured chicken meat in light of European dietary recommendations. *J. Food Compos Anal.* 135, 106663. doi: 10.1016/j.jfca.2024.106663

Smetana, S., Palanisamy, M., Mathys, A., and Heinz, V. (2016). Sustainability of insect use for feed and food: Life cycle assessment perspective. *J. Cleaner Production.* 137, 741–751. doi: 10.1016/j.jclepro.2016.07.148

Smola, M., Utterback, P., Parsons, C. M., Liu, Y., Chen, Z., Ng, P., et al. (2024). 304 Amino acid digestibility and protein quality of fermented soybean-based ingredients using the precision-fed cecectomized rooster assay. *J. Anim. Sci.* 102, 120–121. doi: 10.1093/jas/skae234.140

Soares, N. M. M., Bastos, T. S., Kaelle, G. C. B., de Souza, R. B. M., dos, S., de Oliveira, S. G., et al. (2023). Digestibility and palatability of the diet and intestinal functionality of dogs fed a blend of yeast cell wall and oregano essential oil. *Animals* 13, 2527. doi: 10.3390/ani13152527

Statista (2023). Growth pet population in Latin America 2022. (New York, United States: Statista Inc.). Available online at: https://www.statista.com/statistics/1185191/latin-america-pet-population/ (Accessed January 02, 2025).

Streisand, N. (2020). Nestlé thinks your cat (or dog) will eat insects and fava beans. (London: CCN Business). Available online at: https://www.ukpetfood.org/resource/purina-launches-pet-food-with-plant-and-insect-protein.html (Accessed January 17, 2025).

Su, B., and Martens, P. (2018). Environmental impacts of food consumption by companion dogs and cats in Japan. *Ecol. Indic.* 93, 1043–1049. doi: 10.1016/j.ecolind.2018.06.015

Sykes, N., Beirne, P., Horowitz, A., Jones, I., Kalof, L., Karlsson, E., et al. (2020). Humanity's best friend: A dog-centric approach to addressing global challenges. *Animals* 10, 502. doi: 10.3390/ani10030502

Tanprasertsuk, J., Tate, D. E., and Shmalberg, J. (2022). Roles of plant-based ingredients and phytonutrients in canine nutrition and health. *J. Anim. Physiol. Anim. Nutr.* 106, 586–613. doi: 10.1111/jpn.13626

Tazerji, S., Elahinia, A., Akhtardanesh, B., Kabir, F., Vazir, B., Duarte, P. M., et al. (2024). Nutritional risks and consequences of meat-only diets for dogs and cats. *Ger. J. Vet. Res.* 4, 62–76. doi: 10.51585/gjvr.2024.1.0076

Tchonkouang, R. D., Lima, A. R., Quintino, A. C., Cristofoli, N. L., and Vieira, M. C. (2023). UV-C light: a promising preservation technology for vegetable-based nonsolid food products. *Foods* 12, 3227. doi: 10.3390/foods12173227

Templeman, J. R., and Shoveller, A. K. (2022). Digestible indispensable amino acid scores of animal and plant ingredients potentially used in dog diet formulation: How this protein quality metric is affected by ingredient characteristics and reference amino acid profile. *J. Anim. Sci.* 100, skac279. doi: 10.1093/jas/skac279

The Food Tech (2024). "Carne alternativa en Latam: innovaciones que están cambiando a la industria de alimentos," in *THE FOOD TECH - Medio de noticias líder en la Industria de Alimentos y Bebidas*. Available online at: https://thefoodtech.com/tecnologia-de-los-alimentos/carne-alternativa-en-latam-plant-based-carne-cultivada/ (Accessed January 27, 2025).

The Good Food Institute (GFI) (2025). *Alternative protein company database, (2025)* (GFI). Available online at: https://gfi.org/resource/alternative-protein-company-database/ (Accessed August 21, 2025).

Tian, M., He, X., Feng, Y., Wang, W., Chen, H., Gong, M., et al. (2021). Pollution by antibiotics and antimicrobial resistance in livestock and poultry manure in China, and countermeasures. *Antibiotics.* 10, 539. doi: 10.3390/antibiotics10050539

Tôrres, C. L., Hickenbottom, S. J., and Rogers, Q. R. (2003). Palatability affects the percentage of metabolizable energy as protein selected by adult beagles. *J. Nutr.* 133, 3516–3522. doi: 10.1093/jn/133.11.3516

Tso, R., Lim, A. J., and Forde, C. G. (2021). A critical appraisal of the evidence supporting consumer motivations for alternative proteins. *Foods* 10, 1–28. doi: 10.3390/foods10010024

Tubb, C., and Seba, T. (2021). "Rethinking food and agriculture 2020-2030: the second domestication of plants and animals, the disruption of the cow, and the collapse of industrial livestock farming," in *Rethinking Food and Agriculture* (London: RethinkX). Available online at: https://www.rethinkx.com/publications/rethinkingfoodandagriculture2019.en.

Tyler, J. (2019). "Wild Earth pioneers vegan dog diet, fungal yeast rises to the occasion | 2019-08-19 | Pet Food Processing," in *Pet food processing*. (Kansas city, MO, United States: Sosland Publishing). Available online at: https://www.petfoodprocessing.net/articles/13292-wild-earth-pioneers-vegan-dog-diet-fungal-yeast-rises-to-the-occasion (Accessed February 4, 2025).

Ulloa Ulloa, C., Acevedo-Rodríguez, P., Beck, S., Belgrano, M. J., Bernal, R., Berry, P. E., et al. (2017). An integrated assessment of the vascular plant species of the Americas. *Science* 358, 1614–1617. doi: 10.1126/science.aao0398

UN (2015). Transforming our world: the 2030 Agenda for Sustainable Development. Available online at: https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf (Accessed August 21, 2025).

Valdés, F., Villanueva, V., Durán, E., Campos, F., Avendaño, C., Sánchez, M., et al. (2022). Insects as feed for companion and exotic pets: A current trend. *Animals* 12, 1450. doi: 10.3390/ani12111450

Van Boeckel, T. P., Glennon, E. E., Chen, D., Gilbert, M., Robinson, T. P., Grenfell, B. T., et al. (2017). Reducing antimicrobial use in food animals. *Science* 351, 1350–1352. doi: 10.1126/science.aao1495

Van den Abbeele, P., Moens, F., Pignataro, G., Schnurr, J., Ribecco, C., Gramenzi, A., et al. (2020). Yeast-derived formulations are differentially fermented by the canine and feline microbiome as assessed in a novel *in vitro* colonic fermentation model. *J. Agric. Food Chem.* 68, 13102–13110. doi: 10.1021/acs.jafc.9b05085

van Prooijen, A.-M., Smeets, A. E. M. J., Yang, K. X., and Hoppezak, P. (2024). Consumer considerations of carbon paw prints in evaluations of dog food products. *Soc. Anim.* 1–22. doi: 10.1163/15685306-bja10184

Vegconomist, the vegan business magazine (2023).The companies removing fetal bovine serum to make ethical, slaughter-free meat. Available online at: https://vegconomist.com/cultivated-cell-cultured-biotechnology/companies-removing-fetal-bovine-serum-slaughter-free-meat/ (Accessed November 26, 2025).

Wang, Q., Zhong, C., and Xiao, H. (2020). Genetic engineering of filamentous fungi for efficient protein expression and secretion. *Front. Bioeng. Biotechnol.* 8. doi: 10.3389/fbioe.2020.00293

Weber, M., Bissot, T., Servet, E., Sergheraert, R., Biourge, V., and German, A. J. (2007). A high-protein, high-fiber diet designed for weight loss improves satiety in dogs. *J. Vet. Intern. Med.* 21, 1203–1208. doi: 10.1892/07-016.1

Wehrmaker, A. M., Draijer, N., Bosch, G., and van der Goot, A. J. (2022). Evaluation of plant-based recipes meeting nutritional requirements for dog food: The effect of fractionation and ingredient constraints. *Anim. Feed Sci. Technol.* 290, 115345. doi: 10.1016/j.anifeedsci.2022.115345

Weinrich, R. (2019). Opportunities for the adoption of health-based sustainable dietary patterns: a review on consumer research of meat substitutes. *Sustainability* 11, 4028. doi: 10.3390/su11154028

WHO (2014). *Antimicrobial resistance: Global report on surveillance* (World Health Organization). Available online at: https://iris.who.int/handle/10665/112642 (Accessed January 27, 2025).

Wilbur-Elllis (2024).Wilbur-Ellis nutrition and bond pet foods enter into partnership to develop ingredients through precision fermentation. Available online at: https://www.prnewswire.com/news-releases/wilbur-ellis-nutrition-and-bond-pet-foods-enter-into-partnership-to-develop-ingredients-through-precision-fermentation-302124008.html (Accessed January 29, 2025).

Worldometer (2025). *World population clock: 8.2 billion people (LIVE 2025)* (Worldometer). Available online at: http://www.worldometers.info/world-population/ (Accessed June 18 2025).

Zafalon, R. V. A., Risolia, L. W., Vendramini, T. H. A., Rodrigues, R. B. A., Pedrinelli, V., Teixeira, F. A., et al. (2020). Nutritional inadequacies in commercial vegan foods for dogs and cats. *PloS One* 15, e0227046. doi: 10.1371/journal.pone.0227046

Zandonadi, R. P., Ramos, M. C., Elias, F. T. S., and Guimarães, N. S. (2025). Global insights into cultured meat: uncovering production processes, potential hazards, regulatory frameworks, and key challenges—a scoping review. *Foods* 14, 129. doi: 10.3390/foods14010129

Zhang, Y., Che, H., Li, C., and Jin, T. (2023). Food allergens of plant origin. *Foods* 12, 2232. doi: 10.3390/foods12112232

Zhang, X., Zhang, Z., Shen, A., Zhang, T., Jiang, L., El-Seedi, H., et al. (2024). Legumes as an alternative protein source in plant-based foods: Applications, challenges and strategies. *Curr. Res. Food Sci.* 9, 100876. doi: 10.1016/j.crfs.2024.100876