

Review

Potentials and Applications of Microalgae and *Spirulina* (*Cyanobacterium*) in Pet Nutrition and Health: A Comprehensive Review with a Special Focus on *Euglena gracilis*

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Abstract

The pet food industry is undergoing a significant transformation, driven by the growing trend of companion animal humanization and increasing concerns over the environmental sustainability of conventional protein and lipid sources. Consumers now seek diets that not only meet basic nutritional requirements but also offer preventive health benefits. Microalgae, including *Arthrospira* (*Spirulina*, a kind of *cyanobacterium*), *Chlorella*, *Schizochytrium*, and *Euglena gracilis*, have emerged as versatile biological platforms capable of addressing both functional and sustainability challenges. These microorganisms produce high-quality proteins, omega-3 long-chain polyunsaturated fatty acids (particularly docosahexaenoic acid, DHA), natural pigments, and immunomodulatory polysaccharides. This review synthesizes findings from peer-reviewed studies on the application of microalgae in pet nutrition, covering dogs, cats, and aquatic companion animals. We examine how algal ingredients influence gut microbiota, for instance, by enriching beneficial genera such as *Turicibacter* and *Peptococcus*, enhance vaccine responses and mucosal immunity, support cognitive function in aging pets, and contribute to weight management. Particular attention is given to *Euglena gracilis* and its paramylon (β -1,3-glucan), a pathogen-associated molecular pattern that engages the Dectin-1 pathway to train innate immunity and has demonstrated antiviral activity through host defense mechanisms. The review also surveys the patent landscape, highlighting trends in palatability enhancement, hypoallergenic formulations, and novel delivery formats. Key challenges remain, including ingredient standardization, safety validation, palatability optimization, and consumer acceptance. We outline a translational roadmap that prioritizes well-designed clinical trials in target species and processing methods that preserve bioactivity. Collectively, the evidence positions microalgae, and *Euglena gracilis* in particular, as promising candidates for next-generation functional pet foods that deliver health benefits alongside ecological sustainability.

Keywords: microalgae; paramylon; pet food; functional nutrition; omega-3 DHA; immunity; palatability



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1. Introduction

Over the past decade, the global pet care market has undergone a profound shift in consumer attitudes. Companion animals are increasingly regarded as family members, a cultural change often described as the humanization of pet ownership. This shift has

redefined expectations for pet food: owners now look for products that go beyond basic nutrition to support preventive health and manage chronic conditions such as obesity, cognitive decline, allergies, and dermatological issues. A recent survey of Chinese consumers found that perceived health benefits and safety assurances are the strongest predictors of purchase intentions for pet nutritional products [1].

At the same time, the pet food industry faces mounting pressure to improve the sustainability of its supply chains. Traditional sources of key nutrients, particularly fishmeal and fish oil, are under severe ecological strain. Roughly 90% of global fisheries are now classified as overexploited or fully depleted, yet aquaculture, which is projected to supply 60% of global fish consumption by 2030, remains heavily dependent on these same marine ingredients [2]. This paradox has driven researchers and manufacturers to explore alternative, low-footprint sources of high-quality protein and essential fatty acids [3].

Microalgae have re-emerged as highly promising candidates in this context. Unlike conventional terrestrial crops or animal-based ingredients, microalgae can be cultivated on non-arable land using brackish water or even wastewater, with rapid growth rates and a favorable carbon footprint [4]. Different species offer distinct nutritional profiles: *Arthrospira* provides protein concentrations up to 70% dry weight along with phycobiliproteins; *Schizochytrium* (*Labyrinthulomycetes*) is an industrial source of docosahexaenoic acid (DHA); and green microalgae such as *Chlorella* and *Tetrademus* deliver balanced amino acid profiles and dietary fiber [5,6]. Beyond macronutrients, microalgae synthesize a range of bioactive compounds, including carotenoids with antioxidant properties and β -glucans that can modulate innate immune responses.

Industry interest has accelerated in recent years, reflected in a surge of patent filings covering algal ingredients for pet food applications. Innovations now span palatability enhancement, hypoallergenic formulations, life-stage-specific diets, and novel processing methods such as cold-pressing to preserve heat-sensitive bioactives [7,8]. Circular economy models are also emerging: one study showed that poultry and fish processing by-products could be upcycled with *Spirulina* (*cyanobacterium*) into nutritious pet biscuits with significant antimicrobial properties and low water activity for extended shelf life [9]. These developments suggest that microalgae are transitioning from niche ingredients toward mainstream components of sustainable pet nutrition.

Among the diverse microalgae under investigation, *Euglena gracilis* occupies a distinctive position. This eukaryotic microalga lacks a rigid cellulosic wall, which may enhance nutrient digestibility relative to many other algae. More importantly, it accumulates paramylon, a crystalline β -1,3-glucan that functions as a pathogen-associated molecular pattern capable of training innate immunity via the Dectin-1 receptor pathway [10]. These features position *E. gracilis* as a candidate ingredient for next-generation functional pet foods, particularly for immune support, antiviral defense, and metabolic recovery.

This review synthesizes evidence from the peer-reviewed literature and recent patent filings on the use of microalgae in pet nutrition. We cover applications in dogs, cats, and aquatic companion animals, with special emphasis on *Euglena gracilis* and its paramylon-based mechanisms. We also discuss the translational gap between scientific findings and commercial products, identify key barriers to adoption, and propose priorities for future research.

2. Nutritional Profiles and Functional Ingredients

Microalgae are not a single nutritional entity. Different taxonomic groups produce markedly different compositions of protein, lipid, fiber, and bioactive metabolites, which directly influences their suitability for specific pet applications. Understanding these differences is essential for rational formulation.

Protein is one of the most frequently cited reasons for including microalgae in pet foods. Some species, particularly *Arthrospira platensis* (*Spirulina*, *cyanobacterium*) and *Chlorella vulgaris*, contain protein levels exceeding 50% of dry weight, with amino acid profiles comparable to conventional animal proteins [5]. A detailed metabolomic analysis of three microalgae grown in industrial photobioreactors—*Tetradasmus obliquus*, *Chlorella vulgaris*, and *Nannochloropsis oceanica*—found that all three exceeded the essential amino acid requirements for dogs at all life stages, with the exception of methionine and cysteine. This suggests that while these microalgae can serve as valuable protein sources, they are best combined with other ingredients to achieve a complete amino acid balance [5].

Fatty acid profiles vary even more dramatically across species. *Schizochytrium* sp. is cultivated commercially for its high DHA content. In aged beagle dogs, supplementation with whole-cell *Schizochytrium* significantly improved plasma DHA status and enhanced performance in visual discrimination learning tasks, indicating that algal DHA is bioavailable and functionally effective in the canine brain [11]. By contrast, *N. oceanica* is richer in eicosapentaenoic acid (EPA), while *T. obliquus* contains linolenic acid but lacks arachidonic acid as a fatty acid that cats cannot synthesize endogenously and must obtain from their diet. Microalgal blends for feline nutrition therefore require careful design to avoid deficiencies [12].

Beyond protein and fatty acids, microalgae contribute important micronutrients and bioactive compounds. Taurine is an essential amino acid for cats; its deficiency causes dilated cardiomyopathy and retinal degeneration. Traditionally obtained from animal tissues, taurine has now been quantified in several red and green macroalgae as well as in microalgae-enriched food products. An analysis of 26 commercial algae species found that some algae-based pastas contained levels of taurine and its derivatives (hypotaurine and homotaurine) comparable to those found in foods of animal origin, suggesting that microalgae could help support taurine requirements in plant-forward pet diets [6].

Microalgae also contribute a range of vitamins that support companion animal health. *Spirulina* and *Chlorella* are rich sources of B-complex vitamins, including B₁ (thiamine), B₂ (riboflavin), B₆, and B₁₂, as well as provitamin A (β -carotene), vitamin E (tocopherols), and vitamin K [13]. The vitamin B₁₂ content of certain microalgae is of particular interest for plant-forward pet diets, as this vitamin is naturally absent from most plant ingredients [14]. However, it should be noted that the bioactivity of algal vitamin B₁₂ in mammals remains a subject of ongoing investigation, as some algal forms may include inactive analogs [13].

Digestibility is a critical practical consideration. Algal cell walls differ in composition and rigidity, affecting the release of intracellular nutrients during digestion. *Chlorella* possesses a tough cellulose-rich wall that may limit nutrient availability unless the biomass is processed (e.g., by mechanical disruption or enzymatic treatment). *Euglena gracilis*, by contrast, lacks a cell wall entirely, which may enhance digestibility and palatability. A feeding trial in adult Beagle dogs evaluated an algal blend containing two macroalgae (*Ulva rigida* and *Fucus vesiculosus*) and one microalga (*Chlorella vulgaris*) at inclusion levels of 0.5%, 1.0%, and 1.5%. The highest inclusion level increased the digestibility of organic matter, fiber, and energy, and raised fecal total short-chain fatty acids and acetate content, indicating improved colonic fermentation. Dogs showed no reduction in food intake, although they preferred the control diet when given a direct choice [15].

However, not all products deliver what their labels promise. A survey of European dog foods conducted between 2020 and 2024 revealed that plant-based and hybrid diets often contained higher fiber and ash but lower protein and fat than animal-based diets [16]. More concerning, a study on commercial puppy foods found that none of the tested diets fully met their label claims for EPA and DHA levels, pointing to significant gaps in quality control and ingredient specification [17]. For microalgae-enriched products, this issue

may be particularly acute because algal oils are prone to oxidation and because analytical methods for quantifying DHA in complex feed matrices are not always standardized.

A final point concerns sulfonic acid derivatives. In addition to taurine, microalgae contain hypotaurine and homotaurine, compounds with antioxidant and neuroprotective properties. The green alga *Ulva lactuca* (macrophyte), for example, showed relatively high concentrations of homotaurine, while *Chlorella vulgaris* and *Nannochloropsis* species were among the richest in total protein [6]. These findings suggest that microalgae could contribute not only to basic nutrition but also to functional outcomes related to oxidative stress and neural health, though direct evidence in pets remains limited. Table 1 summarizes the nutritional components and functional positioning of major microalgae used in pet foods and supplements.

The processing of microalgal biomass for pet food applications significantly influences nutrient bioavailability, palatability, and functional efficacy [18,19]. Commercially, microalgae are most commonly supplied as dried biomass, achieved via spray-drying or drum-drying, which preserves protein and lipid content while extending shelf life [19]. Freeze-drying is occasionally used for high-value bioactive ingredients (e.g., phycocyanin, astaxanthin) to minimize thermal degradation, though its higher cost limits widespread adoption [19]. Live microalgae are rarely used in companion animal diets due to storage and consistency challenges, except in aquaculture settings where live feeds remain standard for larval stages [20]. Extrusion cooking—the predominant manufacturing process for dry kibble—exposes algal biomass to high temperature and pressure, which may reduce the bioactivity of heat-labile compounds such as DHA and certain pigments [21,22]. Cold-pressing and low-temperature extrusion represent emerging alternatives to preserve thermosensitive bioactives. For *Euglena gracilis*, the absence of a rigid cell wall may reduce the need for mechanical disruption, potentially preserving paramylon integrity during processing [20].

Table 1. Nutritional components and functional positioning of major microalgae and Spirulina (cyanobacterium) used in pet foods and supplements.

Microalga	Primary Nutrients/Actives	Functional Positioning in Pets	Typical Inclusion/Dose Range	Key Measurable Endpoints	Evidence Level	References
<i>Euglena gracilis</i> (<i>Euglena</i>)	Paramylon (β -1,3-glucan); wall-less biomass; micronutrients	Immune modulation (innate training/antiviral defense); recovery support; gut-immune axis	The concentration of <i>Euglena</i> powder is 2–5% and the extract is 0.11 mg/mL and for 12 h.	Immune markers (cytokines/IgA); infection outcomes; GI tolerance; palatability	E3, E4	[10,23]
<i>Arthrospira platensis</i> (<i>Spirulina</i> , <i>cyanobacterium</i>)	High protein; phycocyanin; carotenoids; antioxidants	Immune support; antioxidant/anti-inflammatory; skin/coat; palatability	The daily amount (g/kg BW) of <i>Spirulina</i> ranged from 0.08 to 0.25 for cats, from 0.06 to 0.19 for small-sized dogs, from 0.05 to 0.15 for medium-sized dogs, and from 0.04 to 0.12 for large-sized dogs	Food intake/palatability; fecal quality; inflammatory/oxidative biomarkers	E1, E4	[24–26]
<i>Chlorella vulgaris</i> (<i>Chlorella</i>)	Protein; cell-wall components/fiber; pigments; micronutrients	GI health (microbiota/SCFA); digestibility; antioxidant support	Three algal blend supplementation levels (0.5, 1.0, and 1.5%)	Apparent digestibility; fecal SCFA; microbiota profiles; fecal quality	E1	[15,27]
<i>Schizochytrium</i> sp. (DHA microalga, <i>Labyrinthulomycetes</i>)	DHA-rich oil; omega-3 lipids	Cognition/aging; skin/coat; anti-inflammatory lipid support	Two diets containing 0 and 0.4% of <i>Schizochytrium</i> sp. were evaluated in three experiments	Serum/plasma DHA; inflammatory markers; cognitive endpoints; coat scores	E1	[28]
<i>Haematococcus pluvialis</i>	Astaxanthin; carotenoids	Antioxidant; skin/coat pigmentation; aging support	<i>H. pluvialis</i> biomass (BHP; 450 mg/kg; o.p.), its polar fraction (PHP; 30 mg/kg; p.o.)	Oxidative stress markers; coat color; immune parameters	E2	[29,30]
<i>Tetrademus obliquus</i>	Protein; essential amino acids; fiber	Protein supplementation; gut health	0.5–1.5% in dog diets	Amino acid digestibility; fecal microbiota	E1	[5,27]
<i>Nannochloropsis oceanica</i>	EPA; protein; carotenoids	Omega-3 support; antioxidant	0.5–1.5% in dog diets	EPA status; oxidative stress markers	E1	[5,27]

Evidence levels: E1 = in vivo in target pets (dog/cat/fish); E2 = in vivo in non-pet animal models; E3 = in vitro/ex vivo (including canine/feline gut models); E4 = patent/industrial disclosure; E5 = narrative review or general background. Abbreviations: SCFA, short-chain fatty acids; bw, body weight; GI, gastrointestinal.

3. Canine Health Applications

Dogs represent the largest market segment for functional pet foods, and most published research on microalgae in companion animals has been conducted in canines. The evidence base has matured from simple ingredient characterization to controlled feeding trials measuring physiological outcomes such as immune markers, gut microbiota composition, cognitive performance, and serum lipid profiles.

The relationship between microalgae consumption and immune function has been investigated in both in vitro and in vivo settings. In an in vitro canine gut model using four microalgae species—*Arthrospira platensis*, *Haematococcus pluvialis*, *Phaeodactylum tricornutum*, and *Chlorella vulgaris*—researchers observed species-specific effects on fermentation and microbial populations. *P. tricornutum* increased propionate by 36% and butyrate by 24% after six hours of incubation, while reducing branched-chain fatty acids. *Chlorella vulgaris* decreased the abundance of *Clostridium coccooides* and *Enterococcus* spp. after 24 h [31]. These findings suggest that certain microalgae can shift canine gut fermentation toward a more saccharolytic profile, generally considered beneficial for colon health.

In vivo evidence comes from a 42-week feeding study in adult dogs. Animals receiving a diet supplemented with dried *Arthrospira platensis* showed significantly higher antibody responses to rabies vaccination and elevated fecal immunoglobulin A levels—a marker of mucosal immune competence—compared to controls. Gut microbiota stability was also improved in the supplemented dogs [32]. These results align with earlier frameworks positioning *Spirulina* as an immunomodulator in canine and feline health [33].

More recent work extended these observations to other species. A digestibility and palatability study in Beagle dogs compared diets supplemented with 0.5%, 1.0%, and 1.5% of *Chlorella vulgaris*, *Nannochloropsis oceanica*, or *Tetrademus obliquus*. Microalgae inclusion did not negatively affect food intake or overall digestibility; *C. vulgaris* actually increased protein digestibility. Fecal microbiota analysis revealed enrichment of *Turicibacter* and *Peptococcus* in dogs fed algae-supplemented diets. Both genera have been associated with gut health and immune activation in other species, suggesting prebiotic-like effects [27]. Similar findings were reported with an algal blend containing macroalgae and *C. vulgaris*, where increased fecal short-chain fatty acids and acetate were observed without major shifts in overall microbial diversity [15].

Cognitive decline in aging dogs shares pathological features with human Alzheimer's disease, including oxidative stress, inflammation, and neuronal membrane deterioration. DHA is a structural component of neuronal membranes, and its dietary supply declines with age. In a controlled trial using aged Beagle dogs, supplementation with whole-cell *Schizochytrium* sp. for 25 weeks significantly improved plasma DHA status and enhanced initial learning of visual object discrimination tasks. The animals performed better on shape discrimination and variable contrast discrimination protocols compared to controls, although long-term memory consolidation was not significantly affected [11]. These results indicate that algal DHA can support specific domains of cognitive function in senior dogs.

Safety is a prerequisite for any long-term nutritional intervention. A nine-month toxicity study in Beagle dogs administered DHA ethyl ester (90% concentrate from microalgal oil) at doses of 150, 1000, and 2000 mg/kg body weight per day via oral gavage. The treatment was well tolerated at all doses. Dry, flaky skin occurred only at the two highest doses and reversed completely during a two-month recovery period, with no microscopic correlates. Dose-related decreases in serum cholesterol and triglycerides were noted, reflecting the known lipid-lowering effects of DHA. No other adverse findings were attributed to the test article, establishing a no-observable-adverse-effect level of 2000 mg/kg body weight per day for both sexes [34]. This safety window is substantially wider than typical inclusion levels in commercial pet foods.

Canine obesity has reached epidemic proportions in many countries. A double-blind, placebo-controlled trial in overweight dogs compared a high-protein, high-fiber weight-loss diet with or without *Spirulina* supplementation over 12 weeks. Both groups lost approximately 11% of initial body weight and showed significant improvements in serum total cholesterol, glucose, alkaline phosphatase, and paraoxonase-1. However, dogs receiving *Spirulina* exhibited a more rapid reduction in serum triglycerides: by week 6, the *Spirulina* group had a significant decrease from baseline while the placebo group did not. A significantly higher percentage of dogs in the *Spirulina* group achieved a triglyceride reduction exceeding 15% at week 6 and 30% at week 12. Bilirubin decreased only in the *Spirulina* group, hinting at possible hepatoprotective effects [35].

Palatability remains a potential hurdle at higher inclusion levels. A study evaluating increasing amounts of *Spirulina* tablets in healthy dogs and cats found that most animals accepted the tablets either alone or mixed with food, with no significant changes in fecal score, defecation frequency, vomiting, scratching, or general health over six weeks. Inclusion levels ranged from 0.04 to 0.19 g/kg body weight per day [25]. These data suggest moderate supplementation is well tolerated, but higher levels intended for therapeutic effects may require palatability masking strategies such as microencapsulation or flavor coating [7]. Table 2 summarizes in vivo studies of microalgae and *Spirulina* used in dogs and cats.

Table 2. Summary of in vivo evidence for microalgae (or algal-derived ingredients) and *Spirulina* in dogs and cats.

Ingredient/Microalga	Target Animal	Study Design (n; Duration)	Dose/Inclusion	Primary Outcomes (Quantitative Where Available)	Safety/Tolerability	Evidence Level	References
<i>Schizochytrium</i> sp. (DHA source, <i>Labyrinthulomycetes</i>)	Dogs (aged Beagle)	Randomized controlled; n = 12; 25 weeks	The dehydrated single-cell algal (DHA) biomass comprised 0.4% of the experimental diet	Improved shape discrimination learning ($p < 0.05$); ↑ plasma DHA ($p < 0.001$)	No adverse effects reported	E1	[11]
DHA ethyl ester (microalgal oil)	Dogs (Beagle)	9-month toxicity + 2-month recovery; n = not specified	150, 1000, 2000 mg/kg bw/day	Dry flaky skin at ≥ 1000 mg/kg (reversible); ↓ cholesterol & triglycerides; NOAEL 2000 mg/kg	Well tolerated; no histopathology findings	E1	[34]
<i>Arthrospira platensis</i> (<i>Spirulina</i> , <i>cyanobacterium</i>)	Dogs (adult, mixed breed)	42-week feeding + vaccine response; n = 30	Pre-test diet supplemented with 0.2% spray-dried <i>Spirulina</i>	↑ rabies vaccine titers; ↑ fecal IgA; ↑ gut microbiota stability ($p < 0.05$)	No adverse effects reported	E1	[32]
<i>Arthrospira platensis</i> (<i>Spirulina</i> tablets)	Dogs and cats (healthy cohort)	Owner-perceived palatability; 6 weeks	Escalating: cats 0.08–0.25; small dogs 0.06–0.19; medium 0.05–0.15; large 0.04–0.12 g/kg bw/day	Palatable; no change in fecal score, vomiting, scratching, behavior	Well tolerated	E1	[25]
<i>Spirulina</i> (<i>cyanobacterium</i>) (in weight loss diet)	Overweight dogs	Double-blind, placebo-controlled; 12 weeks; n = 32	The amount ranging between 0.06 g/kg/day and 0.08 g/kg/day was established for the study. (Dose dependent on body weight)	Triglycerides ↓ more rapidly in <i>Spirulina</i> group; bilirubin ↓ only in <i>Spirulina</i> group	No safety concerns	E1	[35]
<i>Chlorella vulgaris</i> <i>N. oceanica</i> <i>T. obliquus</i>	Healthy Beagle dogs	Palatability + digestibility (Latin square); 10 d periods; n = 6 per trial	0.5%, 1.0%, 1.5% of diet	↑ protein digestibility (<i>C. vulgaris</i>); ↑ <i>Turicibacter</i> & <i>Peptococcus</i> ; no negative intake effects	Well tolerated	E1	[27]
Macroalgae + microalga blend (<i>Ulva</i> , <i>Fucus</i> , <i>Chlorella</i>)	Adult Beagle dogs	Palatability + digestibility (replicated Latin square); 10 d periods; n = 6	0.5%, 1.0%, 1.5% of diet	1.5% ↑ OM/fiber/energy digestibility; ↑ fecal total SCFA & acetate; ↓ propionate; improved fecal quality	No intake impact; dogs preferred control diet	E1	[15]
<i>Schizochytrium</i> spp. (DHA, <i>Labyrinthulomycetes</i>)	Domestic cats	62 d feeding + neutering; n = 37	4.0, 8.0, 12.0, 16.0 g/kg diet	Post-surgery PGE2 ↓ linearly ($R^2 = 0.8706$); DHA deposited in gonads	No adverse effects reported	E1	[36]

Notes: Standardize dosing as % of complete diet (w/w) for food-format interventions and as mg/kg bw/day for extracts/oils. NOAEL: no-observed-adverse-effect level; PGE2: prostaglandin E2; SCFA: short-chain fatty acids; n denotes the number of samples; ↑ means increase and ↓ means decrease.

4. Feline Health Applications

Compared to dogs, published research on microalgae in cats is more limited but growing in specific therapeutic directions. Cats are obligate carnivores with unique nutritional requirements, including a dietary need for preformed arachidonic acid and taurine, and a lower capacity for synthesizing certain long-chain polyunsaturated fatty acids from plant-based precursors. These metabolic particularities mean that microalgae cannot simply be transferred from canine formulations without careful consideration.

The anti-inflammatory potential of microalgal DHA has been evaluated in domestic cats using *Schizochytrium* spp. biomass. In a study involving 37 young cats (approximately 11.5 months of age), animals were fed diets containing algal biomass at 4.0, 8.0, 12.0, or 16.0 g/kg, replacing poultry fat as the primary omega-6 source. After 62 days, the cats were neutered, and inflammatory markers were measured before and after surgery. Prostaglandin E2 concentrations after surgery decreased linearly with increasing microalgal inclusion ($R^2 = 0.8706$), indicating that DHA from *Schizochytrium* can modulate the acute inflammatory response to surgical trauma. The study also documented DHA deposition in gonadal tissues—both testes and ovaries—following supplementation [36].

Viral infections pose significant health challenges in multi-cat environments. Monogalactosyl diacylglyceride isolated from the green microalga *Coccomyxa* sp. KJ demonstrated virucidal activity against feline calicivirus, a common cause of upper respiratory disease in cats that also serves as a surrogate for human norovirus. At 100 µg/mL, the compound reduced viral infectivity to approximately 10% after 60 min of incubation. In animal experiments, intraoral administration at 1 mg per day suppressed viral shedding in feces and produced higher neutralizing antibody titers compared to controls [37]. While this work was conducted in mice rather than cats, the specific testing against feline calicivirus makes the findings directly relevant to feline health.

Palatability is often cited as a barrier to microalgal use in cats. However, a study providing increasing amounts of *Spirulina* tablets to healthy cats over six weeks found that most cats accepted the tablets either alone or mixed with food. Daily amounts ranged from 0.08 to 0.25 g/kg body weight. Owners reported no significant adverse effects on fecal score, defecation frequency, vomiting, scratching, lacrimation, general health status, or behavioral attitudes [25]. These findings suggest that at moderate inclusion levels, *Spirulina* is palatable and well tolerated in cats.

Feline research clearly lags behind canine research in gut microbiota modulation. While several well-controlled trials have examined microalgae effects on the canine intestinal ecosystem, comparable studies in cats are scarce. Given the importance of the gut microbiome for feline health—particularly in managing inflammatory bowel disease and chronic diarrhea—this is a priority for future research. Similarly, the potential for microalgae to contribute to taurine nutrition in cats has been suggested by compositional analyses, but direct feeding studies measuring taurine status are lacking [6].

5. Aquatic Companion Animals and Ornamental Fish

Although the primary focus is on dogs and cats, microalgae have a long history of use in aquatic animal nutrition, including ornamental fish and other aquatic pets. This body of work provides valuable proof-of-concept data for immune enhancement, pigmentation, stress resistance, and detoxification.

One of the most visible applications is pigmentation enhancement. Consumers of ornamental fish place high value on bright, stable body colors, and natural pigments from microalgae are preferred over synthetic alternatives. Studies in goldfish (*Carassius auratus*) found that dietary *Spirulina* significantly improves skin pigmentation and growth performance [38]. For the ornamental shrimp industry, astaxanthin-rich *Haematococcus*

pluvialis is a standard ingredient for enhancing red coloration; recent work in Pacific white shrimp (*Litopenaeus vannamei*) confirmed that dietary inclusion at 1.2 g/kg feed optimizes growth, pigmentation, and disease resistance [29].

Growth promotion is another well-established effect. In *Nile tilapia*, dietary *Spirulina* at 1% inclusion significantly improved growth performance, feed utilization, and immune responses while reducing oxidative stress following challenge with *Pseudomonas fluorescens* [39]. A mixture of *Dunaliella salina* and *Spirulina* (1:1) at 1.0–1.5 g/kg diet in broiler chicks—a model for small pet birds—improved body weight gain, feed conversion ratio, lipid profiles, and immune parameters [40]. In hybrid yellow catfish, 1% *Arthrospira platensis* increased food intake, growth performance, and antioxidant capacity while reducing whole-body lipid content [41].

Disease resistance has been tested against a range of aquatic pathogens. In *Nile tilapia*, dietary *Amphora coffeaeformis* at 2–3% significantly improved survival following challenge with *Aeromonas hydrophila* [42]. Dietary *Pediastrum boryanum* extract at 1.5 mg/kg increased IgM levels, lysozyme activity, and expression of immune-related genes while improving intestinal villus height and surface area [43]. In rainbow trout, a combination of *Chlorella* sp. and *Schizochytrium* sp. extracts upregulated genes for growth hormone, digestive enzymes, antioxidant enzymes, and immune mediators [44]. In Pacific white shrimp, a microalgal meal containing *Phaeodactylum tricornutum* and *Tetraselmis* sp. reduced mortality after *Vibrio parahaemolyticus* challenge to one-sixth of that in controls [45].

A particularly important function is protection against environmental toxins. Fish and ornamental aquatic animals are often exposed to heavy metals and pesticides in captive environments. Dietary *Chlorella vulgaris* at 15 g/kg effectively alleviated cadmium-induced oxidative stress and immunosuppression in *Nile tilapia* [46]. In common carp exposed to imidacloprid, 10% *Chlorella vulgaris* dry powder improved growth, reduced serum cortisol and liver enzymes, enhanced immune parameters, and increased antioxidant enzyme activities [47]. Mercury toxicity in *Nile tilapia* was mitigated by *Nannochloropsis oculata* at 5–10% of the diet [48]. For ornamental species kept in small water volumes, these detoxification effects may be particularly valuable.

6. *Euglena gracilis* and Paramylon: A Distinctive Functional Platform

Among the diverse microalgae being developed for pet nutrition, *Euglena gracilis* occupies an unusual and potentially valuable position. This freshwater eukaryotic microalga has several features that set it apart from more commonly used species such as *Chlorella* or *Spirulina* [23]. Most notably, *E. gracilis* lacks a rigid cellulosic cell wall. Instead, it is surrounded by a proteinaceous pellicle that allows flexibility and motility. From a nutritional perspective, the absence of a tough cell wall means that cellular contents—including proteins, lipids, and the characteristic storage polysaccharide—may be more readily accessible to digestive enzymes, potentially translating into higher digestibility and improved bioavailability.

What truly distinguishes *E. gracilis* is its accumulation of paramylon, a high-molecular-weight linear β -1,3-glucan. Paramylon is synthesized in the cytoplasm and stored as semicrystalline granules ranging from 0.2 to 20 μ m. Structurally, paramylon differs from yeast or cereal β -glucans: yeast β -glucans typically contain β -1,3 linkages with β -1,6 branches, while paramylon is unbranched. This structural simplicity may influence receptor binding specificity and downstream immune effects.

As shown in Figure 1, the immunological relevance of paramylon stems from its recognition as a pathogen-associated molecular pattern. β -glucans bind to the Dectin-1 receptor on macrophages and dendritic cells, leading to NF- κ B activation and cytokine production [33]. Studies using *Euglena* extracts have demonstrated antiviral activity against

influenza virus, mediated through host cell defense mechanisms rather than direct virucidal action [10]. In the context of gut health, microalgae including *Euglena* have been shown to modulate short-chain fatty acid production and beneficial bacterial populations in canine gut models [31].

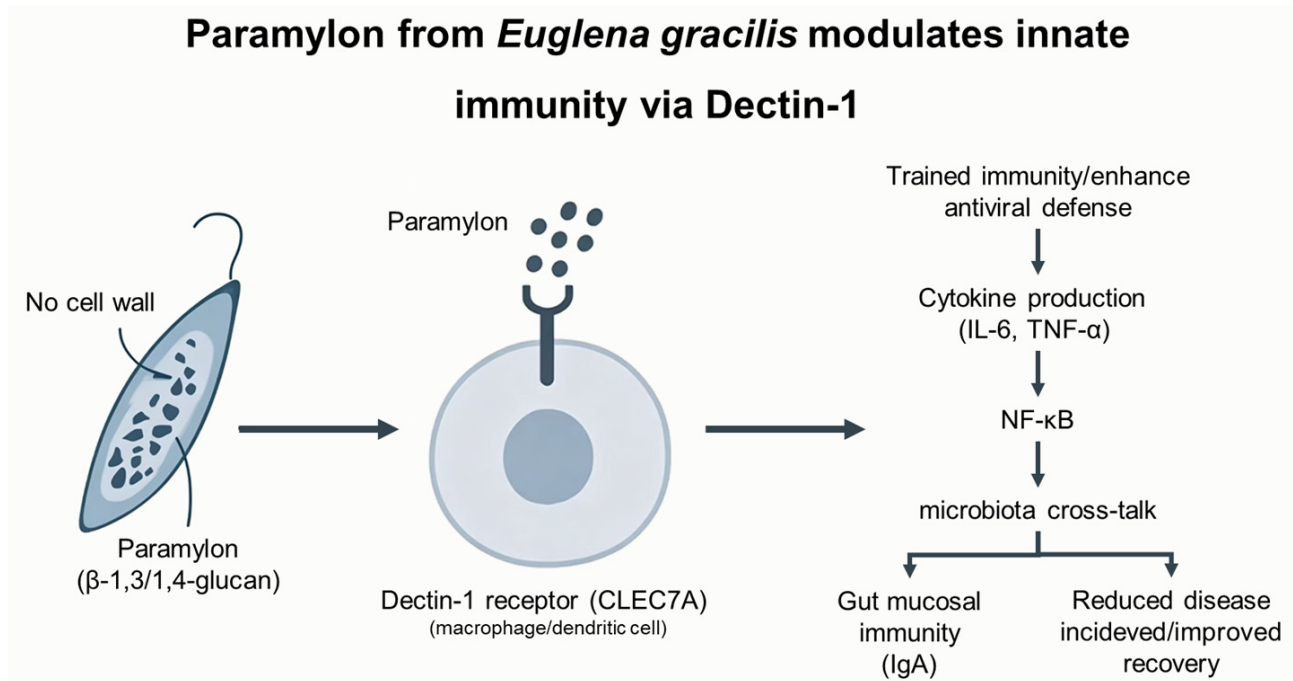


Figure 1. Mechanistic pathway of paramylon-induced innate immune training.

The translational potential of *Euglena* has not gone unnoticed by the pet food industry. A nutritional formulation combining *Euglena* powder, *Spirulina* powder, glucose, functional oligosaccharides, and L-glutamine has been proposed to confer multiple health benefits: reducing disease susceptibility, alleviating gastrointestinal distress, promoting recovery following surgical intervention or antibiotic therapy, and enhancing immunocompetence [4]. The pairing of *Euglena* with *Spirulina* reflects a market hypothesis that paramylon's immune-training effect may synergize with phycocyanin- and antioxidant-mediated effects of *Spirulina*.

It is worth comparing *Euglena* paramylon with β -glucans from other sources already established in pet nutrition. Yeast-derived β -glucans have been used for decades as immune modulators, with substantial evidence supporting their safety and efficacy. Paramylon offers potential advantages: the unbranched β -1,3 structure may present a different epitope to Dectin-1, potentially altering the cytokine profile of the immune response. Moreover, because paramylon is produced intracellularly in crystalline form, it may be protected from degradation during feed processing and gastrointestinal transit. However, direct comparative studies in pets have not been conducted.

7. Broader Evidence from Non-Target Animal Models

Substantial research on microalgae has been conducted in rabbits, birds, and rodents, providing supporting evidence for safety, antioxidant activity, immune modulation, and tissue protection that is mechanistically relevant to companion animals.

Rabbits, kept as companion animals in many households, have been used in several feeding trials. In New Zealand White rabbits, dietary *Chlorella vulgaris* at 300–500 mg/kg improved body weight gain and feed conversion while increasing serum total protein and decreasing total cholesterol. Antioxidant enzyme activities were enhanced, and intestinal

morphology remained normal [49]. Another study found that *Chlorella vulgaris* at 500 mg per animal per day increased final body weight and carcass yield, reduced malondialdehyde, and upregulated *SOD1* and *GPX1* expression in liver and ovaries [50]. In dwarf rabbits, a diet containing 3% *Spirulina* was well tolerated over 14 weeks [51].

While the majority of microalgae feeding studies have been conducted in rats, a smaller but significant body of evidence exists for the golden Syrian hamster (*Mesocricetus auratus*), a species widely used as a model for human lipid metabolism. Cherng and Shih demonstrated that dietary supplementation with *Chlorella pyrenoidosa* significantly decreased serum triglycerides, total cholesterol, and LDL cholesterol in hamsters fed a high-fat diet for up to eight weeks, while also reducing the total cholesterol/HDL ratio, an indicator of coronary heart disease risk [52]. In hypercholesterolemic hamsters, red algal biomass from *Porphyridium cruentum* was found to dose-dependently lower circulating cholesterol, highlighting its potential as a functional ingredient for blood cholesterol management [52,53]. Furthermore, a *Spirulina* liquid extract (SLE) enriched in phycocyanin was shown to protect against high-fat diet-induced metabolic disturbances in hamsters, lowering glycemia and reducing lipid accumulation (cholesterol and glucosylceramide) in the liver and aorta, alongside decreased hepatic expression of HMGCoA reductase and TGF- β 1 [54]. Another study reported that dietary *Spirulina* inhibited oxidative stress and increased antioxidant status in hypercholesterolemic hamsters, with combination therapy of fish oil and *Spirulina* also proving beneficial [55]. Collectively, these findings in hamsters corroborate the lipid-lowering, antioxidant, and metabolic benefits observed in rat studies, reinforcing the translational potential of microalgae as functional feed additives.

In avian species, a mixture of *Dunaliella salina* and *Spirulina* (1:1) at 1.0–1.5 g/kg diet in broiler chicks improved body weight gain, feed conversion ratio, lipid profile, and immune markers [40]. Laying hens fed 2% *Chlorella vulgaris* or *Spirulina* platensis showed increased egg yolk pigmentation, antioxidant capacity, and beta-carotene content [56].

Rodent models have provided the deepest mechanistic insights. In a rat model of D-galactosamine-induced hepatotoxicity, *Spirulina* aqueous extract (9% in diet) reversed liver enzyme elevations, reduced TNF- α , IL-6, and IL-1 β , and restored antioxidant enzyme activities [57]. *Spirulina* also protected against aflatoxin B1-induced hepatic oxidative stress and DNA damage [58], and against methotrexate-induced neurotoxicity [59]. Astaxanthin-rich *Haematococcus pluvialis* ameliorated age-related hepatic changes in D-galactose-treated rats via the Nrf2/Keap1 pathway [30]. In mice, *Spirulina* phycobiliproteins protected against cadmium-induced reproductive toxicity [60]. In dogs themselves, *Spirulina* polysaccharide showed chemo- and radioprotective effects on the hematopoietic system [61].

8. Industrial Translation and Patent Landscape

The growing scientific interest in microalgae for pet nutrition is matched by intense commercial activity documented in the patent literature (shown in Figure 2). Patents provide a window into near-term product strategies, formulation technologies, and claimed health benefits that have not yet appeared in peer-reviewed journals.

A substantial number of Chinese patents describe dog and cat foods containing *Spirulina* in multi-ingredient formulas, often combined with traditional Chinese medicine ingredients such as hawthorn, medlar, or Astragalus. However, clinical evidence supporting these combinations is generally not provided in the patent documents.

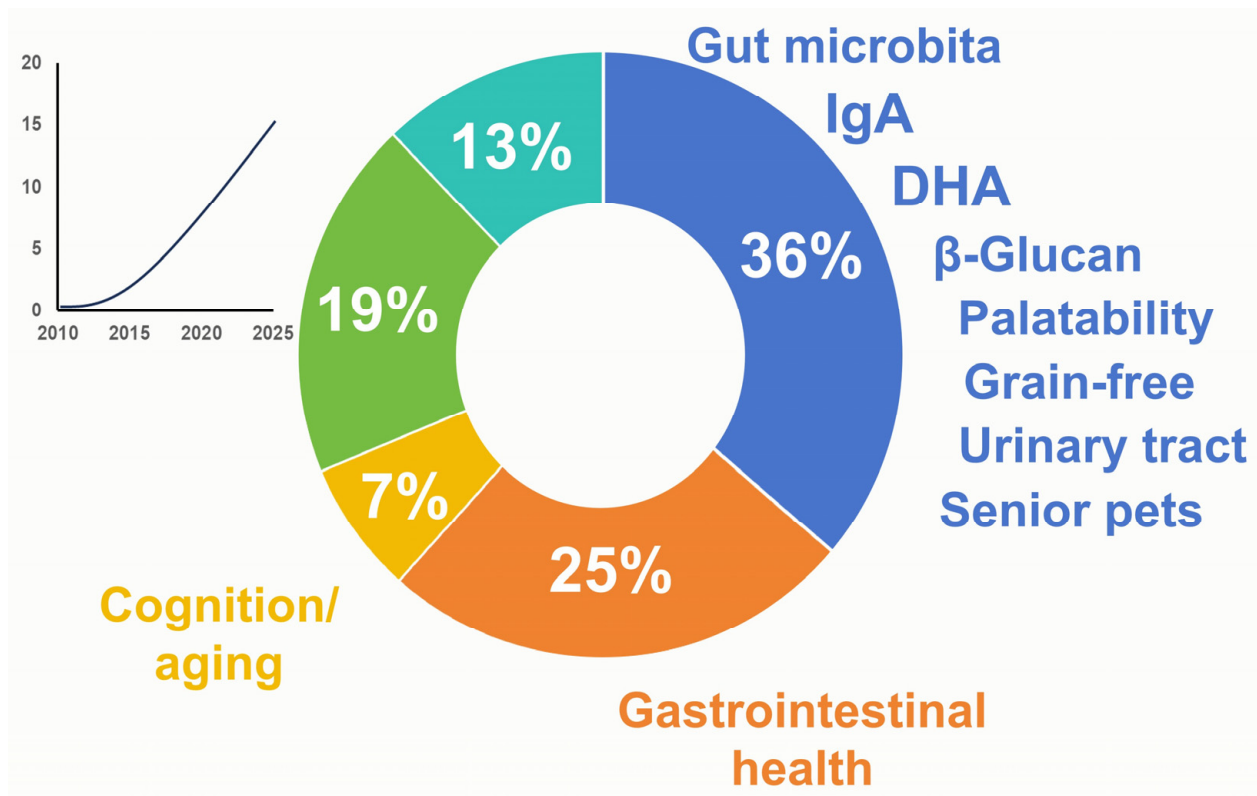


Figure 2. Patent landscape of algal ingredients for pet health. The donut chart shows the distribution of patent application categories (weight management, gastrointestinal health, skin/coat, immunity, palatability, processing). The line graph on the left displays the cumulative annual trend of patent publications from 2010 to 2025, showing a steady increase in patenting activity over this period, with a notable acceleration after 2020. The word cloud displays frequently occurring claim keywords extracted from the patent corpus. The data are from [3,62].

Palatability remains a central challenge. One early innovation described a palatability-enhancing composition using delipidated microbial biomeal, a by-product of DHA extraction from microalgae, as a flavor substrate [63]. More recent work has focused on microencapsulation and Maillard reaction enhancement to mask off-notes and improve aromatic compound retention [7].

Beyond palatability, patents cover weight management [64,65], gastrointestinal health [66], hypoallergenic formulations [67], and urinary tract health [68]. Notably, several recent patents explicitly mention *Euglena gracilis* alongside *Spirulina* in multi-ingredient formulations for immune support and gastrointestinal recovery [23,65].

From a regulatory perspective, patent claims must be viewed with caution. Many patents use language implying therapeutic effects—"treating obesity," "preventing allergy," "protecting intestine"—which may not be permissible for pet foods under regulatory frameworks such as the European Union's nutritional claims regulation or The Association of American Feed Control Officials (AAFCO) guidelines. Patent examiners do not enforce pet food labeling regulations, so the existence of a patent claim does not guarantee it can be lawfully used on a product label. The patent landscape and translational innovations of microalgae-based pet foods/treats/supplements was summarized in Table 3.

Table 3. Patent landscape and translational innovations of microalgae-based pet foods/treats/supplements.

Patent ID	Core Technical Concept	Format/Dosage Form	Claim Category	Regulatory/Scientific Risk Notes	References
CN109527208-A	Pet nutritional supplement combining <i>Euglena</i> powder with <i>Spirulina</i> powder, probiotics, oligosaccharides; positioned for disease prevention and recovery	Supplement (powder/treat)	Immune support; GI health	Claims imply therapeutic effects (“reduce disease incidence”); reframe as “supports immune function” for pet food compliance	[23]
CN111202164-A	Soft capsule containing microalgae powder (<i>Euglena</i> , <i>Haematococcus</i> , <i>Chlorella</i> , <i>Spirulina</i>) with insect repellent herbs	Soft capsule	GI health; insect repellent	Novel delivery format; requires stability and efficacy data	[69]
US2019307822-A1	Oral composition of honey + <i>Spirulina</i> for reducing bad breath (halitosis)	Treat/oral-care supplement	Oral health	Halitosis claims may be regulated as therapeutic; need microbiome/odor metrics	[70]
WO2008039911-A1	Palatability enhancer using delipidated microbial biomeal (DHA extraction by-product)	Palatant/flavor coating	Palatability	Low risk; process innovation	[63]
CN109315626-A	Grain-free cat food with <i>Spirulina</i> , potato, pea protein, pumpkin, probiotics; positioned for allergy prevention	Cat food (kibble/wet)	Allergy/sensitive digestion	“Prevent allergy” is high-risk wording; reframe as “hypoallergenic support”	[67]
CN107865237-A	Dog food for obesity containing <i>Spirulina</i> , carp, barley, hawthorn	Dog food (kibble/wet)	Weight management/lipid metabolism	Weight claims require controlled trials; avoid “anti-obesity” wording	[65]
CN105211554-A	High-protein low-calorie dog food with <i>Spirulina</i> , snail, coix seed	Dog food (kibble/wet)	Weight management	Same as above	[64]
KR2020079460-A	Anti-obesity agent for pet food comprising microalgae extracts (<i>Isochrysis</i> , <i>Phaeodactylum</i> , <i>Odontella</i>)	Additive/extract	Weight management	Strongly evidence-dependent; avoid “anti-obesity agent” phrasing	[71]
KR2020066535-A	Agent for treating obesity and diabetes in companion cats using microalgae extract	Additive/extract	Weight management/metabolic	High regulatory risk; would need veterinary drug pathway	[72]
CN113367245-A	Cold-pressed dog food manufacturing with <i>Spirulina</i> and fresh meats	Cold-pressed kibble	General functional nutrition	Processing claim; need validation of microbial safety and shelf life	[73]
CN108936031-A	Elderly cat food with <i>Spirulina</i> , probiotics, yeast, herbs (<i>Astragalus</i> , <i>Pseudoginseng</i>)	Cat food (kibble/wet)	Immune support; anti-aging	“Delay senescence” is strong claim; reframe as “supports healthy aging”	[74]
CN112273534-A	Urinary tract care cat food with <i>Spirulina</i> , plantain, chicory, yam, licorice	Cat food (kibble/wet)	Urinary health	Claims require clinical data; avoid “treat FLUTD (Feline lower urinary tract diseases)” wording	[68]
CN108783002-A	Nutrient particle (premix) with <i>Spirulina</i> , spinach, apple, carrot powders; positioned for immunity	Premix/granule	Immune support	Immune claims require careful wording and biomarker evidence	[75]
CN105394329-A	Dog food for brightening fur with salmon, lecithin, fish oil, <i>Spirulina</i> .	Dog food (kibble/wet)	Skin & coat	Coat claims feasible with objective scoring (e.g., coat score, fatty acid profile)	[76]

9. Challenges and Future Perspectives

Despite considerable promise, several barriers must be overcome before microalgae can achieve their full potential in pet nutrition.

Standardization and quality control are immediate technical hurdles. Microalgal biomass composition varies with species, strain, cultivation conditions, harvesting methods, and post-harvest processing. Without robust specifications and validated analytical methods, consistent nutritional and functional performance is difficult to ensure. A survey of commercial puppy foods found that none met their label claims for EPA and DHA [17]. For microalgae-enriched products, manufacturers should specify species, protein and lipid content, fatty acid profile, pigment levels, and contaminant limits. Third-party certification and batch-specific certificates of analysis are becoming industry norms. Figure 3 summarizes key points, against which the practical hurdles of specification and analytical validation will be discussed next.

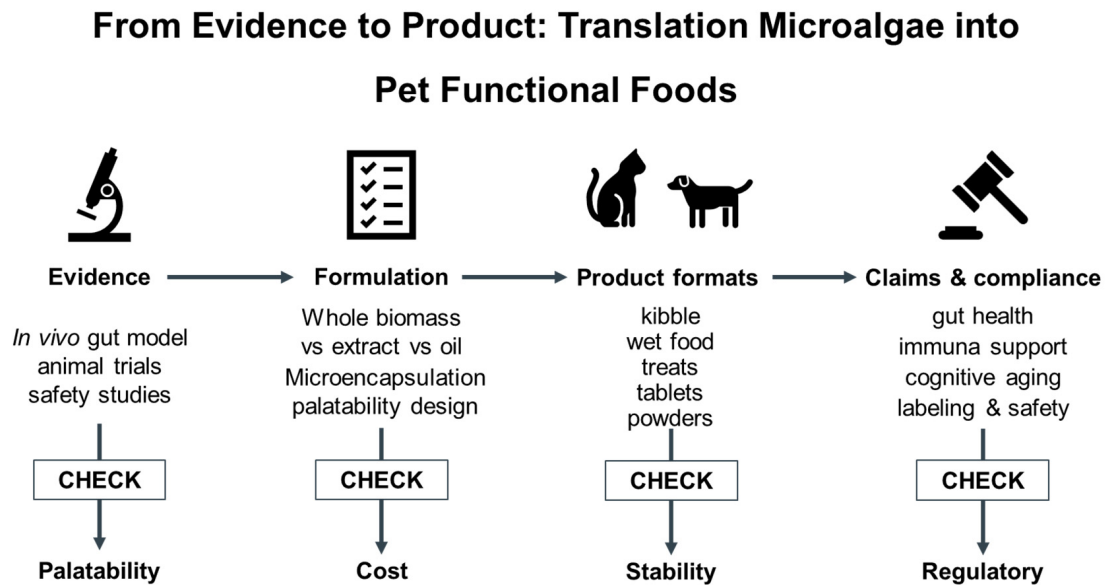


Figure 3. Translational roadmap from evidence to product for microalgae-based pet functional foods.

Safety monitoring requires ongoing attention. Microalgae can accumulate heavy metals if not properly controlled. Some *cyanobacteria* produce cyanotoxins, though commercial strains are generally non-toxicogenic. Microalgal oils are highly unsaturated and prone to oxidation, generating off-flavors and potentially harmful lipid peroxides. The nine-month toxicity study on DHA ethyl ester established a broad safety margin [34], but less refined whole biomass products may have different profiles.

Palatability remains a practical constraint. While dogs and cats accept moderate levels, higher inclusions can reduce food intake due to grassy or fishy off-notes. Dogs preferred the control diet over diets containing 1.5% *Chlorella vulgaris* or *Nannochloropsis oceanica*, though they accepted *Tetrademus obliquus* at the same level without preference difference [15]. Palatant technologies including microencapsulation, flavor coating, and Maillard reaction enhancement are under development [7].

Cost is a perennial barrier. Microalgal production in closed photobioreactors is more expensive than conventional ingredients. However, costs are declining as production scales up and lower-cost cultivation methods improve. Circular economy approaches, using distillery co-products as feedstock or upcycling processing by-products with *Spirulina*, offer promising strategies [2,9]. For pet foods, microalgae are most likely positioned as functional ingredients at 0.5–2% inclusion, where cost impact is manageable.

Consumer acceptance and regulatory compliance are closely linked. Pet owners may be unfamiliar with microalgae or associate them with pond scum. Educational marketing emphasizing species, cultivation method, and evidence-based benefits can overcome skepticism. Regulatory frameworks vary: the EU requires novel food authorizations; the US uses GRAS notifications; China approved *Euglena gracilis* as a new resource food ingredient in 2013. Manufacturers must ensure claims comply with local regulations.

Research priorities include: (1) large-scale randomized controlled trials in dogs and cats measuring vaccine antibody titers, fecal IgA, gut microbiota composition, cognitive performance, and coat scoring; (2) dose–response studies to establish optimal inclusion levels; (3) comparative studies between *Euglena* paramylon and other β -glucan sources; (4) processing studies examining extrusion, retorting, and cold-pressing effects on bioactivity; and (5) long-term safety studies including reproductive and multigenerational assessments.

10. Conclusions

Microalgae have moved beyond their traditional role as alternative protein sources and are now recognized as multifunctional ingredients capable of supporting companion animal health across the entire life cycle. The evidence synthesized in this review demonstrates that microalgae such as *Spirulina*, *Chlorella*, *Schizochytrium*, and *Euglena gracilis* can deliver high-quality proteins, omega-3 DHA, natural pigments, and immunomodulatory polysaccharides in forms that are digestible, safe, and increasingly palatable to dogs, cats, and aquatic pets.

Among these, *Euglena gracilis* stands out as a particularly distinctive functional platform. Its wall-less cell structure may enhance nutrient bioavailability, while its paramylon β -1,3-glucan offers a mechanism for training innate immunity through the Dectin-1 pathway. Emerging evidence of antiviral activity via host–cell defense mechanisms, coupled with explicit industrial interest in combining *Euglena* with *Spirulina* in patented supplements, positions this microalga as a promising candidate for next-generation functional pet foods aimed at immune resilience, recovery support, and metabolic health.

However, the gap between scientific evidence and commercial claims remains substantial. Rigorous, well-powered clinical trials in target species are needed to confirm functional benefits. Dose–response relationships, long-term safety, and the effects of food processing on bioactivity require systematic investigation. Standardization of algal biomass and transparent quality control are essential for building consumer trust and meeting regulatory expectations.

The convergence of nutritional functionality, sustainability advantages, and industrial innovation suggests that microalgae will play an increasingly important role in the future of pet food. For *E. gracilis* in particular, the path forward is clear: move from mechanistic plausibility and patent claims to published, peer-reviewed evidence in dogs and cats.

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Abbreviations

The following abbreviations are used in this manuscript:

DHA	docosahexaenoic acid
EPA	eicosapentaenoic acid
SCFA	short-chain fatty acids
bw	body weight
GI	gastrointestinal

NOAEL	no-observed-adverse-effect level
PGE2	prostaglandin E2
SCFA	short-chain fatty acids.
AAFCO	Association of American Feed Control Officials
FLUTD	Feline lower urinary tract diseases

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