

Functional Nutritional Supplementation in Companion Animals: A Clinical Review of Bioactive Ingredients and Physiological Outcomes

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Abstract

Nutritional supplementation in companion animals has progressed from basic dietary fortification to the development of highly targeted, function-driven formulations designed to influence complex physiological systems. Modern nutraceutical strategies extend beyond the prevention of overt deficiencies, focusing instead on optimizing biological function at both the cellular and systemic levels. These formulations are increasingly designed to support immune regulation, metabolic efficiency, gastrointestinal balance, and integumentary integrity through the incorporation of bioactive and synergistic compounds.

This paper presents a comprehensive synthesis of current evidence surrounding key nutraceutical ingredients utilized in veterinary supplementation, including trace minerals, antioxidants, collagen peptides, prebiotic fibers, phytochemicals, and metabolic cofactors such as nicotinamide adenine dinucleotide (NAD⁺). Particular attention is given to the mechanistic pathways through which these compounds exert their effects, as well as their clinical relevance in supporting health across different life stages. The integration of these ingredients reflects a broader shift toward precision nutrition and preventative care in companion animal health, where targeted supplementation plays a role in maintaining long-term physiological balance.

Introduction

The role of nutrition in companion animal health has expanded significantly, with increasing recognition that optimal health extends beyond meeting minimum dietary requirements. While commercial pet foods are formulated to provide baseline nutrition, multiple factors can influence the quality and availability of nutrients within these diets. Processing methods such as high-heat extrusion, as well as storage conditions and ingredient variability, may contribute to the degradation or reduced bioavailability of essential micronutrients (Freeman et al., 2013). As a result, animals may experience subtle nutritional imbalances that do not present as acute deficiencies but can influence long-term physiological function.

In response to these limitations, nutraceutical supplementation has emerged as a targeted strategy to support systemic health. Unlike traditional supplementation approaches, which primarily address deficiencies, functional nutraceuticals are designed to interact with specific biological pathways. This

includes modulation of immune responses, stabilization of oxidative processes, and support for tissue regeneration and repair. As veterinary science continues to adopt more integrative and preventative approaches, nutraceuticals are increasingly positioned as tools for enhancing resilience, supporting recovery, and maintaining physiological equilibrium across the lifespan of companion animals.

Trace Minerals and Bioavailable Silicon

Trace minerals play a foundational role in maintaining cellular and systemic function, acting as essential cofactors in enzymatic reactions that govern metabolism, immune responses, and intracellular signaling. Even minor disruptions in trace mineral balance can have widespread physiological consequences, affecting neurological function, digestive processes, and immune competence (Rondanelli et al., 2021). In companion animals, the challenge often lies not in the presence of these minerals within the diet, but in their bioavailability and efficient utilization at the cellular level.

Among emerging areas of interest is the role of bioavailable silicon, particularly in the form of orthosilicic acid. Silicon contributes to the structural integrity of connective tissues by supporting collagen synthesis and cross-linking, which are essential for maintaining the strength and elasticity of skin, cartilage, and bone (Jugdaohsingh, 2007). In addition to its structural functions, silicon has been investigated for its potential involvement in detoxification processes. Its interaction with certain metal ions suggests a role in supporting the body's natural ability to manage environmental exposures, further positioning it as a multifunctional component within advanced nutraceutical formulations.

Immune Modulation and Antioxidant Defense

The balance between oxidative stress and antioxidant defense is a critical determinant of cellular health and immune function. Reactive oxygen species are generated as a natural byproduct of metabolism but can accumulate under conditions of stress, inflammation, or environmental exposure. When not adequately neutralized, these molecules can damage lipids, proteins, and DNA, contributing to the progression of chronic conditions. Antioxidants serve as a primary defense mechanism, helping to maintain redox balance and protect cellular integrity.

Vitamin C remains one of the most well-characterized antioxidants in both human and veterinary nutrition. Although endogenous synthesis occurs in dogs and cats, physiological demands may exceed production capacity during periods of stress, illness, or aging (Freeman et al., 2013). Supplementation in these contexts may support immune responsiveness and reduce oxidative burden. Complementing this, plant-derived flavonoids such as quercetin provide additional immunomodulatory effects through their ability to regulate inflammatory pathways and histamine release (Li et al., 2016). Carotenoids further contribute to immune and ocular health, illustrating the layered and synergistic nature of antioxidant systems within nutraceutical formulations.

Collagen Peptides and Connective Tissue Integrity

Connective tissue health is central to mobility, structural stability, and overall quality of life in companion animals. Collagen, as the primary structural protein in these tissues, provides the framework necessary for maintaining joint function, skin elasticity, and musculoskeletal integrity. With age or increased physical demand, the natural synthesis of collagen may decline, leading to reduced resilience and increased susceptibility to degenerative changes.

Collagen peptides offer a bioavailable source of key amino acids required for the maintenance and repair of connective tissues. Beyond serving as building blocks, these peptides may also stimulate endogenous collagen production, contributing to improved structural integrity over time. Clinical observations have demonstrated that collagen supplementation can support joint mobility and may reduce discomfort associated with degenerative conditions such as osteoarthritis (Rondanelli et al., 2021). This dual role in both structural support and functional improvement underscores the value of collagen peptides in formulations targeting both preventative and supportive care.

Prebiotic Fibers and Gastrointestinal Health

The gastrointestinal system is increasingly recognized as a central regulator of overall health, influencing not only digestion but also immune function, metabolic processes, and even neurological signaling. At the core of this system is the gut microbiome, a complex and dynamic community of microorganisms that interact closely with the host. The composition and activity of this microbial ecosystem are heavily influenced by dietary inputs, particularly the presence of prebiotic fibers.

Prebiotic compounds such as inulin, psyllium, and fruit-derived fibers serve as substrates for beneficial bacteria, promoting their growth and metabolic activity (Rondanelli et al., 2021). This supports the production of short-chain fatty acids and other metabolites that contribute to intestinal health and systemic immune signaling. Additional fiber sources, including banana flour and barley grass, provide resistant starches and micronutrients that further enhance microbial diversity and stability. By supporting a balanced and resilient microbiome, prebiotic fibers contribute to improved nutrient absorption, strengthened intestinal barrier function, and broader systemic health.

Phytochemical-Rich Greens and Micronutrient Density

Phytochemical-rich greens provide a concentrated source of biologically active compounds that support cellular protection and metabolic efficiency. Ingredients such as spirulina, alfalfa, spinach, and parsley are rich in antioxidants, chlorophyll, vitamins, and trace minerals, all of which contribute to maintaining cellular homeostasis. These compounds play a role in neutralizing oxidative stress, supporting detoxification pathways, and enhancing overall metabolic performance (Karkos et al., 2011).

In addition to their antioxidant capacity, certain plant-derived compounds influence vascular and metabolic processes through mechanisms such as nitric oxide production. Beetroot-derived nitrates, for example, are converted into nitric oxide within the body, promoting vasodilation and improving circulation. Enhanced blood flow supports the delivery of oxygen and nutrients to tissues, which is essential for maintaining energy levels and organ function. The integration of these phytochemicals into nutraceutical formulations provides a multifaceted approach to supporting both cellular and systemic health.

Cellular Energy and Longevity Pathways

Cellular energy production underpins all biological processes, making mitochondrial function a central focus in both human and veterinary health. Nicotinamide adenine dinucleotide (NAD⁺) is a key cofactor in this process, facilitating the transfer of electrons during metabolic reactions that generate ATP. Beyond its role in energy metabolism, NAD⁺ is also involved in DNA repair and the regulation of cellular stress responses, linking it to broader longevity pathways.

Declining NAD⁺ levels have been associated with aging and metabolic dysfunction, highlighting the importance of maintaining adequate availability of this cofactor (Rondanelli et al., 2021). Nutraceutical strategies that support NAD⁺ levels are being explored for their potential to enhance cellular resilience, improve metabolic efficiency, and support healthy aging. By targeting fundamental processes at the cellular level, these approaches represent a shift toward interventions that address the root mechanisms of physiological decline rather than solely managing outward symptoms.

Topical Barrier Support and Dermatological Health

The integumentary system serves as a protective interface between the body and the external environment, making its integrity essential for overall health. Skin and coat condition are influenced by both internal and external factors, including nutrition, environmental exposure, and microbial interactions. Topical bioactive compounds provide targeted support for maintaining barrier function and protecting against external stressors.

Hypochlorous acid (HOCl) is a notable example, offering antimicrobial and anti-inflammatory properties that support skin health without disrupting the natural microbiome (Block and Rowan, 2020). Niacinamide contributes to improved barrier function by en-

hancing lipid synthesis and moisture retention, while botanical agents such as aloe vera provide soothing and reparative effects. When combined with internal nutritional support, these topical interventions contribute to a comprehensive approach to maintaining dermatological health and resilience.

Clinical Implications

The integration of nutraceuticals into companion animal care reflects a shift toward systems-based and preventative approaches to health management. By addressing multiple physiological pathways simultaneously, these formulations offer a more holistic strategy for supporting overall well-being. The combined effects of minerals, antioxidants, fibers, and bioactive compounds contribute to maintaining immune balance, gastrointestinal stability, connective tissue integrity, and efficient cellular metabolism.

This approach is particularly valuable in populations with increased physiological demands, including aging animals, those with chronic conditions, and individuals exposed to environmental stressors. In these contexts, maintaining homeostasis becomes increasingly complex, and targeted nutritional support can play a critical role in preserving function and quality of life. As the body of clinical evidence continues to grow, nutraceuticals are becoming an increasingly important component of individualized care strategies within veterinary practice.

Conclusion

Functional nutraceutical supplementation represents an advanced, evidence-informed approach to supporting companion animal health. By targeting key physiological systems and underlying cellular processes, these formulations extend beyond traditional nutrition to promote resilience, balance, and long-term well-being. The synergistic interaction of trace minerals, antioxidants, prebiotic fibers, collagen peptides, and metabolic cofactors highlights the importance of integrated approaches in modern veterinary nutrition.

While current research provides a strong foundation for the use of these compounds, continued investigation is necessary to refine dosing strategies, evaluate long-term safety, and further elucidate mechanisms of action. As scientific understanding advances, nutraceuticals are expected to play an increasingly central role in shaping the future of companion animal health, bridging the gap between nutrition, prevention, and therapeutic support.

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