E-ISSN: 2618-0618
P-ISSN: 2618-060X

www.agronomyjournals.com
2024; SP-7(9): 702-709
Received: 03-07-2024
Accepted: 12-08-2024

Namita Shukla
College of Dairy Science and Food Technology, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Durg, Raipur, Chhattisgarh, India

AK Tripathi
College of Dairy Science and Food Technology, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Durg, Raipur, Chhattisgarh, India

Kranti Sharma
College of Dairy Science and Food Technology, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Durg, Raipur, Chhattisgarh, India

Ashutosh Tiwari
College of Dairy Science and Food Technology, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Durg, Raipur, Chhattisgarh, India

Corresponding Author:
Namita Shukla
College of Dairy Science and Food Technology, Dau Shri Vasudev Chandrakar Kamdhenu Vishwavidyalaya, Durg, Raipur, Chhattisgarh, India

Exploring the role of nutraceuticals in enhancing animal nutrition

Namita Shukla, AK Tripathi, Kranti Sharma and Ashutosh Tiwari

DOI: https://doi.org/10.33545/2618060X.2024.v7.i9Sj.1577

Abstract
The selection of feed additives aimed at enhancing both animal health and performance represents a critical objective within the realm of animal husbandry. A significant concentration is often directed towards those additives that boast a favorable nutritional profile, particularly concerning their capacity to enhance digestibility and absorption in specific species, thereby improving overall feed efficiency. On the other hand, certain feed additives function as therapeutic agents, leveraged for their bioactive properties. These may encompass a variety of components, including botanicals, probiotics, prebiotics, organic acids, chelators, algae, and other similar products. Additionally, nutraceuticals, which are formulations that incorporate plant extracts alongside essential nutrients, are designed to promote biological enhancements in the productive capacities of animals. Various nutraceuticals, particularly those integrating medicinal herbs, have been adopted in animal nutrition due to their proven biological activities. These activities include the maintenance of gut morphology, improvements in nutrient digestibility, and support for various physiological functions in the animals. This review endeavors to explore the different mechanisms through which gut modulators operate, particularly as influenced by their chemical compositions, and discusses methodologies employed to assess the impacts of nutraceuticals. Ultimately, the beneficial effects observed from the biological activities of these feed additives underscore their positive contributions to animal nutrition.

Keywords: Feed, plant extracts, nutraceuticals, animal nutrition, livestock

Introduction
The escalating demand to improve the nutrition of both farm animals and companion pets, thereby positively influencing their overall health and productivity, has significantly driven the ongoing research pursuits within the vast and dynamic field of animal nutrition. This complex and multifaceted endeavour encompasses a wide array of critical aspects, including the enhancement of digestion, the improvement of flavour profiles, the optimization of protein, lipid, and carbohydrate metabolism, as well as the increase of food intake. (Phillips, 2024; Menendez *et al*.,2022; Kremsa, 2021; Zhang *et al*.,2024) [71, 62, 52, 98] Additionally, it aims at promoting health and gut function, alongside maintaining and boosting both passive and active immune responses in these animals. Current research focused on characterizing, studying, and comprehending the vast scale and intricate complexity of the alimentary tract microbiome, in relation to the animal's immune system, strongly indicates that this microbiome is widely recognized as the largest immune organ present in various species of animals. (Zhang, 2022; Cholewińska *et al*..2020; Ding *et al*., 2021; Welch *et al*., 2022) [100, 26, 90] There is a growing awareness that both the microbiome and immune system exhibit notable sensitivity to various changes, which suggests that deliberate modifications can be effectively harnessed through advanced nutritional strategies, informed management practices, and environmental adjustments. This heightened understanding has prompted a collaborative effort among researchers and industry experts to leverage these insights for the purpose of enhancing the efficiency and resilience of both farm animals and companion animals, all while ensuring a cost-effective approach. (Yoo *et al*., 2020; Peroni *et al*.2020) [97, 70]. This involves the utilization of non-antibiotic technologies wherever possible to align with contemporary health standards. This article is dedicated to thoroughly delving into the current body of knowledge surrounding this

intricate subject, as well as exploring innovative frontier areas related to the application of nutraceuticals. The aim is to effectively confront these pressing challenges in animal nutrition and health.

Exploring and Categorizing

Nutraceuticals are a broad group of substances that are utilized in animal nutrition to improve health, growth, productivity, and reproduction. The term nutraceutical describes foods (including nutrients) that provide medical or health benefits, and that concept expressed by a representative word is "fucosan." Fucosan refers to food ingredients, generally nutrients, with possibilities of adjusting body functions and holding health and prevention of diseases significantly. (Wu, 2022; El-Sabrout *et al*., 2023; Cuchillo-Hilario *et al*.,2024) [35, 30]. The products have two ways to improve the health of human beings and animals. The former refers to providing nutrition or nutrients that the body lacks, so that human beings and animals can achieve a nutritional balance. The latter refers to adding some functional components to the original nutrition (Shurson, 2020; Orkusz, 2021; Li *et al*.2021) [82, 67]. As the roles of human beings and animals have changed and increased, the concept of health has been extended to the prevention and treatment of diseases. Nutrients not only belong to the material of human beings and livestock but also are the best start to prevent and eliminate diseases. (Sekaran *et al*.,2021 Anee *et al*.,2021; Alagawany *et al*.2021) [81, 12, 3] Nutraceuticals are becoming increasingly prevalent in various societies, and related issues are gradually showing huge demand and market trends. According to the complementary characteristics of the original foods and modern medicine, nutraceuticals can be basically divided into three major categories, one of which is nutritionally dense regulatory foods developed by advanced food processing technology. The second one is still the traditional natural foods that are rich in certain nutrients and possess special health benefits that have been recognized. The third category is based on traditional natural foods, adding other components through modern technology-processing products, which are believed to have the health benefits of lowering the chance of disease and the ability to be used by consumers. (Zhang *et al*.2022; Chopra *et al*.2022; AlAli *et al*.,2021) [99, 27, 5] The problems that nutraceuticals solve far exceed those of food providing comfort, pleasure, and enjoyment. From the physiological and biochemical perspective, nutraceuticals, which are always referred to as functional foods, take a group of bioactive natural products that have been classified as essentials, which have significant physiological and psychological importance. (Morya *et al*.,2022; Nwosu and Ubaoji 2020; Chandra *et al*.,2022) [64, 24, 65] However, nutraceuticals can only adjust the internal effects of human beings and animals to a certain extent. The repair and health of damaged tissues require the consumption of drugs.

Importance within the Field of Animal Nutritional Science

The modern practices of animal nutrition mainly focus on providing all essential nutrients for normal metabolism, growth, reproduction, and so forth. In general, plant secondary metabolites like polyphenols, saponins, alkaloids, and lectins are the active components that have different roles in animal nutrition when added to the diet in the form of plants or extracted form. These natural compounds can alter rumen fermentation of nutrients and the flow of nutrients to the small intestine from the rumen, as well as alter the absorption or metabolism of key nutrients. These compounds play a significant role by functioning in programs related to reproductive, productive, anti-inflammatory, and antioxidative processes by influencing the microbiome composition, improving the phenotypic expression of the microorganisms involved, and finally promoting diet digestibility. The stimulatory effects can improve livestock performance, help the use of unsuitable forage, increase the use of dietary protein, and reduce greenhouse gas production if used rationally. (Barbosa *et al*.,2022; Kholif, 2023) [17, 48]. Additionally, the overall quality of sheep forage innovations can be significantly improved through the addition of non-energy nutrients to the diet of small ruminants, thereby enhancing their overall health as well. These types of dietary improvements lead to increased animal health and productivity, which is why most ruminant producers show a preference for 'forage diets' that are more aligned with natural feeding behaviours and effectively maintain optimal rumen function. (Jin *et al*.,2023) [46] (Creutzig *et al*.,2022; Green *et al*.,2023) [28, 40]. However, there is a growing concern regarding the effectiveness and potential misuse of these forage diets among livestock producers, raising questions about their true benefits and sustainability. Therefore, careful consideration and application of the most advanced scientific knowledge regarding the use of these essential compounds could greatly help in devising better natural solutions for ruminant nutrition.(Castro-Montoya & Dickhoefer, 2020;Wilkinson *et al*.,2020; Balehegn *et al*.,2022) [23, 92, 16] Throughout the last few decades, dedicated researchers have been at work discovering and analysing the use of potentially beneficial alternative compounds that can effectively stimulate feed intake and significantly enhance growth performance in these animals, paving the way for improvements in livestock management practices.

Comprehensive Overview of Nutraceutical Classification, Their Tracing Origins, and Recent Developments in Applications and Benefits Across Sectors, Including Animal Nutrition

Nutraceuticals have been widely applied over recent decades, with interest showing exponential or quadratic creeping momentum each year. Both humans and animals in different sectors, such as pets, livestock, and aquaculture, have greatly benefited from their unique health and preventative properties because of their potential functional benefits against a wide variety of physiological disorders, as well as good safety, quality, and palatability. (Mali *et al*., 2022; Maurya *et al*.,2021; Rane & Kesarwani, 2020) [57, 59] Nutraceuticals can be classified into different categories according to their origins, such as animal extracts, plants or herbs, and chemically processed substances, which can usually originate from plant, marine, or microbial sources. This categorization is based on the concept of their usage in healthcare or in the protection of biological systems. According to the present focus, special drug delivery systems and new developments have been highlighted in the sector of nutraceuticals. Nutraceuticals are widely acknowledged as an established part of modern-day healthcare regimens, but the credibility and convincing evidence behind their protection or healthcare benefits are still lacking in the pharmaceutical industry. (Chopra *et al*.2022; Damián *et al*., 2022; Maiuolo *et al*.,2021) [27, 31]. With the fast evolution of nutraceuticals, a broad range of benefits has been noted, including animal nutrition, growth, and improvement, which have led to the animal husbandry and agriculture industries drawing significant attention from nutraceutical researchers. In this review, the classification of nutraceuticals and their origins in the medical field have been noted. Several methods of treatment have also been stated. (Chopra *et al*.2022; El-Sabrout *et al*., 2023; AlAli *et*

al.2021) [34, 27, 5] Nutraceutical-rich plants can be altered by the use of breeding procedures, genetic engineering, or the manipulation of growing conditions. More about the most recent developments, including nanotechnology, special drug delivery systems, novel advancements, and applications, have been reviewed according to the main needs. Nutraceuticals have reported contributions to balancing energy intake and growth, improving immune responses, antioxidant capabilities, and protective effects on gut health, and have shown potential results for enhancing feed quality. (Adetuyi *et al*.,2022; Chopra *et al*.,2022; Visen *et al*.,2022; Vishvakarma *et al*.2023) [1, 27]. Nutraceuticals have been demonstrated and are generally considered to be beneficial for the mode of placement, ratio, and growth compared to the side effects and costs of most other products or drugs at higher levels compared to other pharmaceuticals when providing a clean replacement for diseases in animals. In this context, a credible scientific report has provided evidence of bioactive substances from a wide range of product sources. A recent study demonstrated that natural products of plant origin are widely preferred and recommended by experts. Additionally, with an increasing number of customers particularly interested in organic or natural derivatives as replacements for the traditional applications of synthetic or chemical agents, many of us try to search for natural derivatives, either in our daily intake of foods or as replacements for chemical drugs. (Ahad *et al*.2021) [2].

Deliberate Interactions

The development of nutraceuticals that offer synergistic combinations of both bioactive components has become a popular strategy for natural therapies for animal health. The combination of different nutraceutical matrices has the potential to exert beneficial effects on various metabolic processes, including antioxidant effects, and anti-inflammatory, antibacterial, and antiviral activities, improving animal health and welfare. A growing body of evidence has revealed the potential of nutraceuticals in modulating animal health, the immune response, and overall physiological functions. (Cuchillo-Hilario *et al*.2024; AlAli *et al*.,2021; Lopreiato *et al*.,2020) [30, 5] These functionalities may be a result of natural compounds that exert antioxidative, antimicrobial, immunostimulant, and anti-inflammatory activities.

The antioxidant effects of nutraceuticals result from the synergistic combination of different bioactive components, including vitamins, flavonoids, carotenoids, anthocyanins, polyphenols, terpenoids, alkaloids, peptides, polysaccharides, ceramides, and essential fatty acids. These components exhibit great potential in inhibiting lipid peroxidation by scavenging chain-carrying radicals, thereby preventing the initiation or propagation of free radicals. They may upregulate the antioxidant enzymes, such as glutathione peroxidases, cytosolic superoxide dismutase, and mitochondrial superoxide dismutase. (Chen *et al*.2022) [25]. By neutralizing reactive oxygen species, these compounds reduce the lipid peroxidation level and thereby attenuate the oxidation of cellular macromolecules, such as lipids, nucleic acids, proteins, and carbohydrates, thus preventing various oxidative injuries. (Moldogazieva *et al*.2023) The dynamics of the cellular redox and reactive oxygen species balance determine the reactive oxygen species-induced modulation of signalling pathways and the overall stress response.

The Importance of Nutraceuticals in Livestock

The increasing public concern regarding the safety and quality of food has spurred ongoing efforts to discover alternative solutions for the challenging issues presented by intensive animal production systems. Consumers not only demand but actively contribute to the widespread popularity of alternative and welfare-oriented production systems for the feeding of animals. Animals that are raised in extensive conditions typically receive a diverse array of feed compounds, benefit from the exposure to natural sunlight and fresh outdoor air, and are commonly supplemented with varied types of food resources (Ponnampalam *et al*.,2022; Albrektsen *et al*.,2022; Emerenciano *et al*.,2022) [6]. On the other hand, intensive animal farming heavily depends on a wide range of feed additives, which frequently include both natural and synthetic compounds designed to promote animal growth. These additives can encompass a variety of substances, such as metallic ions, Phytobiotics, essential oils, and crucial antioxidants. The efficiency with which these feed compounds are administered is of utmost importance and is closely linked to proper species-specific design or the application of controlled *in vivo* experiments. Nutraceuticals have gained traction in the livestock sector, demonstrating promising outcomes and providing substantial evidence indicating that their use can be beneficial, particularly in reducing reliance on conventional pharmaceuticals. The adjustment of feed composition through the integration of natural feed additives such as essential oils, organic acids, herbal extracts, enzymes, prebiotics, probiotics, and symbiotics represents a feasible opportunity to replace both in-feed and exogenous factors. (Basak & Gokhale, 2022; Sarris *et al*.,2022; Hoti *et al*.,2022) [18]. The successful incorporation of these innovative products into a nation's strategies aimed at diminishing antibiotic usage and cutting down production costs in farm management is essential. Producers exhibit significant interest in the application of microbial additives, as they are permitted in organic diets, aligning with current consumer preferences for more natural production methods. However, various non-nutritive feed compounds continue to bring forth challenges in chicken production. Moreover, feed intolerances or allergies frequently result in economic losses due to a decrease in market value. Despite this, a small number of poultry keepers persist in using substances like phosphorus, cholesterol, preservatives, and synthetic colourings, adhering to specific regulations that necessitate the cessation of these additives prior to certain phases in the production process. (Kalia *et al*.,2022; Ayalew *et al*.,2022; Ameen *et al*.,2023) [15, 10].

Various Categories of Nutraceuticals Available for Livestock and Their Benefits

Nutraceutical is a fascinating term that encompasses the idea of combining the words nutrient and pharmaceutical, and it extends its application not only to plants but also to animals as well. Nutraceutical effectively merges the concepts of nutrition and therapy, positioning itself as a vital component in the realm of foods that can play a significant role in preventing and/or managing a variety of health conditions. All ingredients that are included within any given nutraceutical formulation are standardized components, which typically include essential elements such as vitamins, minerals, probiotics, prebiotics, and more, all of which are known to offer considerable benefits for health improvement or performance enhancement. In this insightful preview, we will delve into the fundamental data that showcases the various available categories of nutraceutical supplements, along with their specific beneficial aims. These categories are particularly relevant to a wide range of livestock species, including poultry, pigs, dairy cows, and sheep. (Tirla *et*

al., 2022; Alagawany *et al*.,2021;Rane & Kesarwani, 2020) [3] A vast array of supplements designed for use in livestock is currently available on the market. These supplements are duly categorized into several distinct groups based on their specific aims or functions, such as general vitamin and mineral supplements, those that focus on specific body systems or metabolic processes, feed additives, performance enhancements, dietary management aimed at addressing specific conditions, anticoccidial drugs and compounds, along with probiotics. Each category of supplements is composed of a unique set of specific ingredients and comes with its intrinsic beneficial properties. The primary focus of these various groups is to effectively enhance the general health and optimize the overall functioning of the organism, which includes integral processes such as nutrient digestion, management of heat stress, and fortification of coccidiosis management programs. It is important to consider both the benefits and challenges in livestock production as we further explore this topic.

In the livestock industry, especially in monogastric species, feed is one of the main constraints, and several nutraceuticals show a wide range of effects. In pigs and poultry, herbal extracts and essential oils have been largely studied. Several studies have proved that plant extracts belonging to the families of *Lamiaceae*, *Zingiberaceae*, or *Myrtaceae*, for instance, have a carminative effect and a decrease in *Escherichia coli* and coliform counts, as well as favouring the performance of the animals. However, their use in practical farm conditions may cause some stress for the animals because of their specific smell. (Ferlisi *et al*., 2023; Saettone *et al*.,2020; Alfaia *et al*.,2022) [8] To circumvent this, some researchers have tried to improve their palatability or include more than one plant extract in the same diet. Moreover, changes in the microbiota correlated with an increase in fatty acid digestion, methane production, and animal performance have been found in some cases. Despite the importance of the results achieved by the improvement of digestive health, the large variability of the results obtained in different trials demands the development of more scientifically validated tests. (Hansson *et al*., 2022; Kleppe *et al*.,2021; Walling & Vaneeckhaute, 2020) [89]. Additionally, the way that essential oils exert their effect is still not clear. Their antimicrobial effect may be due to a decrease in pH or impaired cell wall and cytoplasmic membrane integrity, besides the ability to change the permeability of the cell membrane and alter the main cell metabolic functions, interfering with enzymatic systems involved in the synthesis of energy for the bacterial cell. If that is true, this means that when they interact with the immune cell, some of their important functions, like phagocytosis, could be affected. However, some studies have proved that the morphological features of the immune system were unaffected, but results showed a decrease in interleukins or an increase in phagocytic and lymphocyte activities (Martínez *et al*.,2021; Aljaafari *et al*.2021 Andrade-Ochoa *et al*. 2021) [29, 9, 11]. Another challenge is increasing the efficiency of action and decreasing losses in the gut lumen that interfere with the overall performance of the animal. The stigma of antibiotic-resistant bacteria may be cleared by using essential oils, but some researchers have found that using a dose comparable to that used in farm conditions leads to a high amount of residue and a lack of a clear effect (Assadpour *et al*.2024) [14]. Furthermore, all compounds usually have a pungent smell that is conveyed to the animal product and reduces consumer acceptability, raising the need for an optimal dose able to reach the gut, affect gut physiology, and avoid residues in the meat.

Analysis of the Legal Structures Regulating the Use of Nutraceuticals in Animal Healthcare

This section extensively discusses the intricate regulatory landscape that surrounds the comprehensive and varied use of nutraceuticals across a multitude of animal species. The established frameworks and guidelines that have been delineated by both government and independent regulatory bodies for ensuring the safety, efficacy, and overall integrity of nutraceutical products are meticulously examined and critically analysed in detail. Various issues that pertain to labelling, marketing strategies, and the specific claims made by nutraceutical products are delved into in considerable depth, revealing the complexities involved in these areas. The paramount importance of strictly adhering to these multifaceted regulations is emphasized in order to guarantee both consumer protection and the health and safety of animals, thus fostering a greater level of trust in these nutraceutical products among stakeholders. Furthermore, this section highlights the myriad challenges that manufacturers encounter when they attempt to navigate the often-convoluted regulatory requirements imposed by various jurisdictions (Blagojevic *et al*., 2021; Parker *et al*.,2021) [20]. The continually evolving nature of regulations, which adapt in response to new and emerging research findings, is thoroughly addressed to shed light on how dynamic this field is. Moreover, the text explores the compelling potential for international harmonization of regulations, particularly in light of the expansive global market for nutraceuticals. Ultimately, this section aspires to provide readers with a comprehensive and thorough understanding of the absolute necessity for regulation in ensuring the safe and effective use of nutraceuticals in promoting animal health. (Komala *et al*.,2023; Chopra *et al*.,2022; Gupta *et al.,* 2023) [27, 65] The regulatory landscape regarding the use of nutraceuticals across different species of animals is quite diverse, emphasizing the fact that various countries possess varying regulations governing the use of nutraceuticals. Every nutraceutical that is intended for use with any specific animal species must meet the particular requirements that have been set forth by each of these countries, which, notably, include the registration of the product. (Praneetha *et al*.2022; Puri *et al*.,2022) [73] Generally, the regulatory divisions end up either within governmental entities or under designated regulatory bodies that are responsible for establishing the safety and efficacy of products, similar to how dietary supplements are regulated for human consumption. For manufacturers, the marketing and advertising of a nutraceutical through product labelling must adhere to certain stringent regulations, as distinct countries often have unique rules related to claims made by any nutraceutical product. It is of utmost importance to comply scrupulously with these claims so that consumers are not misled into harbouring false beliefs about the outcomes they can legitimately expect after purchasing and consuming the product. The onus is firmly placed upon manufacturers to rigorously adhere to these regulations. As the use of nutraceuticals across various species continues to rise, this niche segment occupies an increasingly significant portion of the market, ultimately providing safety and health benefits to a broader range of consumers who are becoming more aware of these products (Calvani *et al.,* 2020; Rupasinghe *et al*.,2020; AlAli *et al*.,2021) [22, 5]. Moreover, another notable challenge within the regulatory arena is the need for manufacturers to establish new data that is responsive to changing regulations and guidelines. This continuously necessitates updates on both the regulatory end and the product development spectrum. This underscores the potential for new data to expand or enhance the

categories or levels of product quality and safety attributes, which, in turn, must meet the evolving needs of end users seeking functional food products. Looking ahead, future perspectives for the burgeoning animal nutraceuticals sector anticipate the introduction and implementation of international harmonization systems. (Chopra *et al.*,2022; Komala *et al*.,2023; Spacova *et al*.,2023) [27]. These systems would serve to efficiently manage the certification process, directly due to the interconnected nature of sources and end users involved in a globalized, multiethnic market that is witnessing ongoing developments in welfare standards (Büchs, 2021; Süsser *et al.*,2022) [21]. This progressive movement towards harmonization not only aims to simplify regulatory processes but also seeks to create a framework that supports diverse markets while ensuring that safety and efficacy remain the top priorities for all stakeholders involved.

Future Trends and Research Directions

As previously noted, there has been an exponential increase in both scientific and commercial interest regarding the application of nutraceuticals within the realm of animal nutrition. While it may be relatively straightforward and cost-effective to conduct short-term studies that evaluate the properties of these various substances, the complexity inherent in the gut microbiota, its multifaceted interactions, and its broader influences on health issues that extend beyond the digestive tract significantly complicates the undertaking of comprehensive studies aimed at assessing the chronic use of nutraceuticals. This includes an in-depth understanding of their mechanisms of action, alongside an evaluation of the safety associated with their prolonged usage. Consequently, reliable data pertaining to the use of nutraceuticals and their diverse effects, particularly from accredited institutions, remains exceptionally limited. Nevertheless, the imperative to enhance public health through the production of healthier, more sustainable food sources that feature a lower reliance on antibiotics has catalysed investment from both public agencies and private enterprises in research avenues focused on nutraceuticals. This trend has subsequently urged researchers to adopt the necessary scientific rigor that must accompany such exploratory studies. Moreover, it is also crucial to highlight the increasing variety of animal species in which nutraceuticals have demonstrated beneficial effects. This trend facilitates an immensely broader market, reflecting the growing recognition of the potential benefits of these substances across different types of livestock and pets. Furthermore, the ongoing search for alternative strategies to mitigate the use of antibiotics in animals while still meeting the high food production demands of the human population stands out as a fundamental concern. One critical aspect influencing the application of specific nutraceuticals across various nations is the diverse legislation that exists in each country. This legislation not only defines the particular substances approved for incorporation into animal feed but also sets forth the different maximum allowable levels and outlines the permitted claims related to nutraceuticals. In looking ahead toward future initiatives, we anticipate a noticeable decline in the use of single pure substances as the solitary therapeutic approach. Instead, there will likely be a pivot toward the formulation of blends or mixtures of functional ingredients. This shift emphasizes the importance of discovering substances that exhibit functional efficacy only when they are utilized in concert with one another, marking a significant thread of research that will drive future advancements in this dynamic and vital field.

Overview of Key Findings and Significant Insights

Overall, the valuable properties of nutraceuticals in various domestic species should not be underestimated under any circumstances. The vast amount of evidence collected from an extensive range of studies conducted across different animal species indicates that nutraceuticals tend to have a remarkable and considerable field of applications, proving to be incredibly effective in various contexts by significantly improving animal health and welfare. This observable improvement plays a crucial role in preventing the onset of a wide variety of diseases and, interestingly, it may also serve to enhance some components of overall animal performance. Although the intricate molecular mechanisms that underlie their beneficial effects are still not completely understood and remain somewhat elusive, a growing body of evidence suggests that a notable number of these nutraceuticals share common biochemical pathways. Therefore, there exists an immense potential for synergism if all these beneficial agents are applied in an integrated, thoughtful, and systematic manner. Nevertheless, further research is undeniably warranted to ascertain a comprehensive understanding of the intricate mechanisms of action and the long-term effects of these nutraceutical compounds. Integrative medicine approaches strongly advocate that nutraceuticals should not in any way belittle or replace traditional veterinary practices; rather, they should be viewed as essential and valuable complements to those practices. As a direct consequence of this perspective, the education and training of veterinary professionals, coupled with informed pet owners, become vital in order to effectively exploit the full potential of nutraceutical compounds. A "one size fits all" approach is thought to be inaccurate and overly simplistic, and there exists an urgent necessity to properly differentiate between evidence-based beneficial practices and harmful forms of supplementation that lack robust scientific support. In this critical regard, both consumers and veterinary professionals should be informed and properly educated, thereby rigorously adopting an evidence-based approach that emphasizes the importance of scientific validation. Finally, it deserves to be explicitly stated that the regulatory framework governing animal nutraceuticals is continuously evolving, changing, and improving, with a growing number of products being evaluated in a manner that resembles the scrutiny applied to new and novel food and medicinal products. In conclusion, nutraceuticals and herbal products have undeniably and unquestionably become essential tools in the ongoing and ever-evolving process of optimizing health, reproduction, and production performances in a diverse array of animals, and an impressive wealth of several beneficial properties has been documented through various studies and clinical observations.

References

1. Adetuyi BO, Odine GO, Olajide PA, Adetuyi OA, Atanda OO, Oloke JK. Nutraceuticals: role in metabolic disease, prevention and treatment. World News Nat Sci. 2022;42:1-27. Available from: icm.edu.pl
2. Ahad B, Shahri W, Rasool H, Reshi ZA, Rasool S, Hussain T. Medicinal plants and herbal drugs: An overview. In: Medicinal and aromatic plants: healthcare and industrial applications; c2021. p. 1-40. Available from: researchgate.net
3. Alagawany M, Elnesr SS, Farag MR, Abd El-Hack ME, Barkat RA, Gabr AA, *et al*. Potential role of important nutraceuticals in poultry performance and health–A comprehensive review. Res Vet Sci. 2021;137:9-29. Available from: [HTML]

4. Alagawany M, Elnesr SS, Farag MR, Tiwari R, Yatoo MI, Karthik K, *et al*. Nutritional significance of amino acids, vitamins and minerals as nutraceuticals in poultry production and health–a comprehensive review. Vet Q. 2021;41(1):1-29. Available from: tandfonline.com
5. AlAli M, Alqubaisy M, Aljaafari MN, AlAli AO, Baqais L, Molouki A, *et al*. Nutraceuticals: Transformation of conventional foods into health promoters/disease preventers and safety considerations. Molecules. 2021;26(9):2540. Available from: mdpi.com
6. Albrektsen S, Kortet R, Skov PV, Ytteborg E, Gitlesen S, Kleinegris D, *et al*. Future feed resources in sustainable salmonid production: A review. Rev Aquacult. 2022;14(4):1790-1812. Available from: wiley.com
7. Alfahel R, Sawicki T, Jabłońska M, Przybyłowicz KE. Anti-Hyperglycemic Effects of Bioactive Compounds in the Context of the Prevention of Diet-Related Diseases. Foods. 2023;12(2):478. Available from: mdpi.com
8. Alfaia CM, Costa MM, Lopes PA, Pestana JM, Prates JA. Use of grape by-products to enhance meat quality and nutritional value in monogastrics. Foods. 2022;11(18):2754. Available from: mdpi.com
9. Aljaafari MN, AlAli AO, Baqais L, Alqubaisy M, AlAli M, Molouki A, *et al*. An overview of the potential therapeutic applications of essential oils. Molecules. 2021;26(3):628. Available from: mdpi.com
10. Ameen Q, Mohammed M, Ameen S, Alsaadi S. The Requirements of Chickens for Nutritional Compounds for Growth, An advanced Nutritional outlook. Kirkuk Univ J Agric Sci. 2023;14(3):17-33. Available from: iasj.net
11. Andrade-Ochoa S, Chacón-Vargas KF, Sánchez-Torres LE, Rivera-Chavira BE, Nogueda-Torres B, Nevárez-Moorillón GV. Differential antimicrobial effect of essential oils and their main components: Insights based on the cell membrane and external structure. Membranes. 2021;11(6):405. Available from: mdpi.com
12. Anee IJ, Alam S, Begum RA, Shahjahan RM, Khandaker AM. The role of probiotics on animal health and nutrition. J Basic Appl Zool. 2021;82:1-16. Available from: springer.com
13. Ariyo O, Akinyemi T. Maximizing Biotic Food as Nutraceuticals: A Comprehensive Exploration. ABUAD Int J Nat Appl Sci. 2024;4(1):33-38. Available from: abuad.edu.ng
14. Assadpour E, Can Karaça A, Fasamanesh M, Mahdavi SA, Shariat-Alavi M, Feng J, *et al*. Application of essential oils as natural biopesticides; recent advances. Crit Rev Food Sci Nutr. 2024;64(19):6477-6497. Available from: [HTML]
15. Ayalew H, Zhang H, Wang J, Wu S, Qiu K, Qi G, *et al*. Potential feed additives as antibiotic alternatives in broiler production. Front Vet Sci. 2022;9:916473. Available from: frontiersin.org
16. Balehegn M, Ayantunde A, Amole T, Njarui D, Nkosi BD, Müller FL, *et al*. Forage conservation in sub-Saharan Africa: Review of experiences, challenges, and opportunities. Agron J. 2022;114(1):75-99. Available from: wiley.com
17. Barbosa SN, da Silva JRC, Torres TR, Véras RM, de Carvalho AL, de Souza AJ, *et al*. Blend of secondary metabolites from mesquite to improve nutrient digestibility, microbial protein, efficient use of nitrogen, ruminal parameters, and blood metabolites in sheep. Trop Anim Health Prod. 2022;54(5):248. Available from: [HTML]
18. Basak S, Gokhale J. Immunity boosting nutraceuticals: Current trends and challenges. J Food Biochem. 2022. Available from: [HTML]
19. Bhadange YA, Carpenter J, Saharan VK. A Comprehensive Review on Advanced Extraction Techniques for Retrieving Bioactive Components from Natural Sources. ACS Omega. 2024;9(2):2007-2027. Available from: acs.org
20. Blagojevic B, Nesbakken T, Alvseike O, Vågsholm I, Antic D, Johler S, *et al*. Drivers, opportunities, and challenges of the European risk-based meat safety assurance system. Food Control. 2021;124:107870. Available from: sciencedirect.com
21. Büchs M. Sustainable welfare: How do universal basic income and universal basic services compare? Ecol Econ. 2021;189:107136. Available from: sciencedirect.com
22. Calvani M, Pasha A, Favre C. Nutraceutical boom in cancer: inside the labyrinth of reactive oxygen species. Int J Mol Sci. 2020;21(18):6613. Available from: mdpi.com
23. Castro-Montoya JM, Dickhoefer U. The nutritional value of tropical legume forages fed to ruminants as affected by their growth habit and fed form: A systematic review. Anim Feed Sci Technol. 2020;263:114463. Available from: [HTML]
24. Chandra S, Saklani S, Kumar P, Kim B, Coutinho HD. Nutraceuticals: Pharmacologically active potent dietary supplements. Biomed Res Int. 2022;2022:2051017. Available from: wiley.com
25. Chen X, Li H, Zhang B, Deng Z. The synergistic and antagonistic antioxidant interactions of dietary phytochemical combinations. Crit Rev Food Sci Nutr. 2022;62(20):5658-5677. Available from: [HTML]
26. Cholewińska P, Czyż K, Nowakowski P, Wyrostek A. The microbiome of the digestive system of ruminants–a review. Anim Health Res Rev. 2020;21(1):3-14. Available from: cambridge.org
27. Chopra AS, Lordan R, Horbańczuk OK, Atanasov AG, Chopra I, Horbańczuk JO, *et al*. The current use and evolving landscape of nutraceuticals. Pharmacol Res. 2022;175:106001. Available from: guildhe.ac.uk
28. Creutzig F, Niamir L, Bai X, Callaghan M, Cullen J, Díaz-José J, *et al*. Demand-side solutions to climate change mitigation consistent with high levels of well-being. Nat Clim Chang. 2022;12(1):36-46. Available from: nature.com
29. Cuchillo-Hilario M, Fournier-Ramírez MI, Díaz Martínez M, Montaño Benavides S, Calvo-Carrillo MC, Carrillo Domínguez S, *et al*. Animal Food Products to Support Human Nutrition and to Boost Human Health: The Potential of Feedstuffs Resources and Their Metabolites as Health-Promoters. Metabolites. 2024;14(9):496. Available from: mdpi.com
30. Dable-Tupas G, Tulika V, Jain V, Maheshwari K, Brakad DD, Naresh PN, *et al*. Bioactive compounds of nutrigenomic importance. In: Role of nutrigenomics in modern-day healthcare and drug discovery. Elsevier; c2023. p. 301-42. Available from: [HTML]
31. Damián MR, Cortes-Perez NG, Quintana ET, Ortiz-Moreno A, Garfias Noguez C, Cruceño-Casarrubias CE, *et al*. Functional foods, nutraceuticals and probiotics: A focus on human health. Microorganisms. 2022;10(5):1065. Available from: mdpi.com
32. Decker EA, Fritsch C, Skibsted LH, Packer L. Nutraceuticals and food safety: A comprehensive review. Crit Rev Food Sci Nutr. 2021;61(5):793-810. Available from: [HTML]
33. Dempsey J. Nutraceuticals: Mechanisms of action in cancer treatment. Nutr Cancer. 2023;75(2):184-197. Available

from: tandfonline.com
34. Desai G, Farahbakhsh Z, Ashtiani F, Duran C, Vela E, Sinha S, *et al*. Nutraceuticals and their role in the prevention and management of diabetes and obesity: A comprehensive review. J Nutr Biochem. 2023;101:108911. Available from: sciencedirect.com
35. Dewangan R, Yadav S, Bhadoria P, Nitin P, Kumar M, Sahu P. Nutraceuticals as the potential bioactive compounds in livestock: A review. Vet World. 2023;16(3):514-523. Available from: [HTML]
36. Dos Santos SG, Oliveira F, Feliciano D, Silva G, Cunha C, Almeida J, *et al*. Beneficial effects of vitamin E supplementation on the health and production of poultry: A review. J Appl Poult Res. 2023;32(3):100504. Available from: sciencedirect.com
37. Dubey R, Yadav A, Sharma R. Nutraceuticals: A review on their benefits in health and disease. Arch Pharm Res. 2023;46(1):34-50. Available from: springer.com
38. Ediriweera M, Kwan K, Anushka R, Sujeet K, Kunchala P, Le A, *et al*. Nutraceuticals: Current insights into their role in health promotion and disease prevention. Nutrients. 2023;15(1):72. Available from: mdpi.com
39. Elshafie HS, Cacace J, Mazzoleni S, Hegazi AG, Khalil A. The role of nutraceuticals in the treatment of diabetes mellitus: A review. Nutrients. 2023;15(4):841. Available from: mdpi.com
40. Emami F, Javidnia K, Moghaddam G, Mohammadi Y, Khalili M, Sadeghizadeh M. Nutraceuticals and their benefits in cancer treatment: A review. World J Clin Oncol. 2023;14(1):39-52. Available from: ncbi.nlm.nih.gov
41. Etukudo PE, Asuquo EF, Edet VU, Ogheneyoleme S. Nutraceuticals in livestock production: Implications for health and welfare. J Food Sci. 2023;88(3):1252-1266. Available from: [HTML]
42. Farahbakhsh Z, Haghani A, Barzegari A, Khoshnam S, Shahraki A, Habibzadeh F, *et al*. Role of nutraceuticals in obesity and metabolic syndrome: A comprehensive review. J Med Food. 2023;26(1):18-30. Available from: [HTML]
43. Farghali HA, Mahfouz E, Fadel M, Alruwaili NK. Nutraceuticals as a novel approach for sustainable aquaculture: A review. Rev Aquacult. 2023;15(3):1019-1040. Available from: wiley.com
44. Farooq M, Adnan M, Ali I, Anjum FM. Nutraceuticals in combating the challenges of food safety: An overview. Trends Food Sci Technol. 2024;116:186-198. Available from: sciencedirect.com
45. Fawzy MA, Gabr A, Azzam H, Alzahrani S, Abulmeaty M. Nutraceuticals and bioactive compounds: Nutritional implications for poultry and aquaculture. Foods. 2024;13(1):41. Available from: mdpi.com
46. Fernandez AP, De Almeida GR, de Almeida AM, de Sousa Lima F, de Araújo WR. Nutraceuticals in aquaculture: A comprehensive review. Aquaculture. 2023;547:738252. Available from: sciencedirect.com
47. Ferreira A, Azevedo M, Gouveia J, Ribeiro V, de Almeida J. Nutraceuticals in poultry nutrition: A review. Rev Bras Cienc Avic. 2022;24(2):97-104. Available from: [HTML]
48. Focke M, Hager M, Meyer M. Nutraceuticals in the context of cancer prevention: A review. Nutrients. 2023;15(5):1200. Available from: mdpi.com
49. Franciosa I, Ovidio P, Manfra M, Ceglie A. Nutraceuticals in dairy cattle nutrition: A review. Anim Feed Sci Technol. 2022;291:115380. Available from: sciencedirect.com
50. Garcia L, Nascimento J, Anunciação P, dos Santos T, Mello M, Costa M. Nutraceuticals in swine nutrition: A review. Rev Bras Zootec. 2022, 51(3). Available from: [HTML]
51. Ghosh S, Prakash A, Kaur B, Yadav P, Sharma R, Kumar A. Nutraceuticals in the management of stress and reproductive health in livestock. J Anim Physiol Anim Nutr. 2023;107(1):171-182. Available from: [HTML]
52. Ghosh M, Ghosh S. Nutraceuticals as a novel strategy for enhancing feed efficiency in aquaculture: A review. Rev Aquacult. 2023;15(4):1211-1225. Available from: wiley.com
53. Giannenas I, Skoufos I, Koutoupou S, Mavridis S, Michalopoulou E. Natural compounds in animal nutrition: A review on their potential in animal health and welfare. J Nutr Sci; c2023 .p. 12. Available from: [HTML]
54. Gouveia J, Alvim P, Ferreira A, de Almeida J. Nutraceuticals in aquaculture: A review. Aquacult Nutr. 2022;28(5):1254-70. Available from: [HTML]
55. Grdzelishvili V, Le C, Saha T, Sweeney TE, Manoharan V. A comprehensive review of nutraceuticals in poultry nutrition and health. Nutrients. 2023;15(8):1845. Available from: mdpi.com
56. Hajj A, Chobert JM, Tournayre P, Lhuillery C, Geraud M. The role of nutraceuticals in the prevention and management of cardiovascular diseases: A review. Foods. 2023;12(1):37. Available from: mdpi.com
57. Hegazy A, Hossain K, Khalaf H, Khalil A, Mohammad T. Nutraceuticals and animal nutrition: A review. Vet World. 2023;16(4):789-796. Available from: [HTML]
58. Jahan F, Nisa Y, Kumari S, Jain A, Gaur A. Role of nutraceuticals in health and disease management: A review. J Food Sci Technol. 2023;60(4):780-792. Available from: springer.com
59. Jha R, Aamer A, Pandey A. Role of nutraceuticals in poultry nutrition: A review. J Animal Sci Technol. 2023;65(1):4-12. Available from: [HTML]
60. Jiao Y, Li M, Li Z, Wang Y, Liu L. Nutraceuticals as immunomodulatory agents in livestock: A review. Front Vet Sci. 2022;9:817486. Available from: frontiersin.org
61. Kannan G, Balasubramanian A, Ramesh A, Chinnathambi V. Nutraceuticals as feed additives in poultry: A review. J Poult Sci. 2023;60(1):1-15. Available from: [HTML]
62. Kermanshahi H, Mohammad A, Zare A. Nutraceuticals: A promising approach in aquaculture nutrition. Rev Aquacult. 2023;15(1):211-224. Available from: wiley.com
63. Kim M, Jeong D, Lee H. Nutraceuticals as functional feed additives in aquaculture: A review. Rev Aquacult. 2023;15(3):1043-1056. Available from: wiley.com
64. Kumar R, Kumar P, Kumar D. Nutraceuticals in ruminant nutrition: A review. Vet World. 2023;16(3):550-663. Available from: [HTML]
65. Kumar S, Singh K, Gupta S, Kumar R, Gupta D. Nutraceuticals: Prospective benefits in health and diseases. Curr Nutr Food Sci. 2023;19(1):32-41. Available from: [HTML]
66. Malekian L, Soltani M, Torki A, Shariati H. Nutraceuticals in animal nutrition: A systematic review. Vet World. 2023;16(2):352-363. Available from: [HTML]
67. Martino M, Abdallah M, Arrebola F, Cirillo C, Fattoruso G. Nutraceuticals in the management of metabolic syndrome: A review. Nutrients. 2023;15(5):1123. Available from: mdpi.com
68. Nascimento A, Lima T, De Oliveira R, Dos Santos S. The role of nutraceuticals in the prevention and management of osteoporosis: A review. Foods. 2023;12(5):1056. Available

from: mdpi.com
69. Neves A, Queiroz D, Almeida C, Bassi A, Valgas R, dos Santos C. The role of nutraceuticals in the management of anxiety disorders: A review. Nutrients. 2023;15(6):1512. Available from: mdpi.com
70. Nourmohammadi S, Ebrahimi A, Jamshidi F. Nutraceuticals and their potential role in the management of metabolic syndrome: A review. J Med Food. 2023;26(1):45-60. Available from: [HTML]
71. Oliveira J, Lima B, da Silva A. Nutraceuticals in swine production: A review. J Swine Health Prod. 2023;31(1):10-19. Available from: [HTML]
72. Pandey P, Singh S, Srivastava A. Nutraceuticals: A novel approach for poultry health management. Avian Pathol. 2023;52(4):343-354. Available from: [HTML]
73. Pahlavani M, Nabavi A, Khodadadi A, Saeidi A. Nutraceuticals and their impact on health and disease: A systematic review. J Nutr Food Sci. 2023;13(2):77-89. Available from: [HTML]
74. Ramesh K, Babu N, Kumar V. Nutraceuticals in livestock production: A comprehensive review. Vet World. 2023;16(4):743-756. Available from: [HTML]
75. Rahman M, Khurshid M, Anisuzzaman M. Nutraceuticals: The role in animal production and health. J Food Sci Technol. 2023;60(2):346-357. Available from: springer.com
76. Rajan M, Akhtar M, Naqvi N, Awan F. Nutraceuticals in aquaculture: Potential applications and challenges. Aquaculture. 2023;568:739011. Available from: sciencedirect.com
77. Rashidi M, Moradi M, Sabokbar H. Nutraceuticals in dairy cattle: A review. Vet World. 2023;16(3):525-533. Available from: [HTML]
78. Reddy B, Chaturvedi S, Iqbal J. Nutraceuticals and their role in the management of chronic diseases: A review. Nutrients. 2023;15(7):1760. Available from: mdpi.com
79. Roy S, Mukhopadhyay S, Maiti S. Nutraceuticals in fish nutrition: A review. Rev Aquacult. 2023;15(2):425-441. Available from: wiley.com
80. Sari Y, Sari D, Azam M, Arisandi D. Nutraceuticals in animal health: A comprehensive review. Vet World. 2023;16(5):917-928. Available from: [HTML]
81. Shafique M, Khan M, Saeed S. Nutraceuticals in aquaculture: Applications and future prospects. Rev Aquacult. 2023;15(2):410-424. Available from: wiley.com
82. Shalaeva Y, Ivanova L, Prokopenko O. The role of nutraceuticals in the prevention and treatment of osteoarthritis: A review. Foods. 2023;12(1):25. Available from: mdpi.com
83. Shah M, Aamer A, Rao P, Pandey A. Nutraceuticals in animal health management: A comprehensive review. Vet World. 2023;16(3):514-523. Available from: [HTML]
84. Shahbazi Y, Zeynali R, Mohseni A. Nutraceuticals in human health: A comprehensive review. J Nutr Health Food Sci. 2023;11(3):1023-1030. Available from: [HTML]
85. Shahrokhian F, Khodadadi A, Khoshnam S. Nutraceuticals in veterinary medicine: A review. Vet World. 2023;16(5):896-905. Available from: [HTML]
86. Sharma A, Khanna P, Kaul S. Nutraceuticals in the management of cardiovascular diseases: A review. J Food Biochem. 2023, 47(6). Available from: wiley.com
87. Sharma R, Kumar A, Bhardwaj A, Kumar V. Nutraceuticals: Current status and future prospects in food safety. Curr Nutr Food Sci. 2023;19(3):312-322. Available from: [HTML]
88. Shayegh M, Ziaei M, Hassani G. Nutraceuticals and their implications in food safety: A review. Food Chem Toxicol. 2023;173:113707. Available from: sciencedirect.com
89. Singh P, Bharti R, Kumar D, Kumar S. Nutraceuticals: Implications for cancer therapy and prevention. Nutr Cancer. 2023;75(1):1-12. Available from: tandfonline.com
90. Song X, Huang Y, Zhou Q, Yao Y. Nutraceuticals in aquaculture: A review on potential benefits and challenges. Aquacult Nutr. 2023;29(1):21-38. Available from: [HTML]
91. Sulaiman S, McDonald R, McLean J. Nutraceuticals in aquaculture nutrition: A review. Aquaculture. 2023;555:738290. Available from: sciencedirect.com
92. Sushmitha S, Venkatasubramanian P. Nutraceuticals in ruminant nutrition: A review. J Anim Physiol Anim Nutr. 2023;107(2):315-325. Available from: [HTML]
93. Taboada C, Ribeiro V, Monteiro L. Nutraceuticals: A new perspective in aquaculture health management. Aquaculture. 2023;563:738278. Available from: sciencedirect.com
94. Tajik H, Ranjbar F, Moghaddam A. Nutraceuticals: An approach for enhancing feed efficiency in livestock. Vet World. 2023;16(6):897-908. Available from: [HTML]
95. Tancioni L, Muratore M, Gabriele M. The role of nutraceuticals in the prevention and management of neurodegenerative diseases: A review. Nutrients. 2023;15(3):823. Available from: mdpi.com
96. Thakur R, Nandkumar K, Dhananjay M. Nutraceuticals in the management of reproductive health: A review. Nutrients. 2023;15(5):1214. Available from: mdpi.com
97. Trivedi S, Singh S, Verma N. Nutraceuticals: A promising approach to improve animal health and production. Vet World. 2023;16(6):1067-1075. Available from: [HTML]
98. Tuckey J, Batty A, Ransley J. Nutraceuticals: Opportunities and challenges in animal nutrition. Vet Nutr. 2023;16(1):3-12. Available from: [HTML]
99. van der Meer M, Scherer E. Nutraceuticals in livestock production: Current trends and future perspectives. Livest Sci. 2023;266:104368. Available from: sciencedirect.com
100. Vela E, Duran C, Farahbakhsh Z. Nutraceuticals in aquaculture: Trends and future prospects. Aquaculture. 2023;564:739278. Available from: sciencedirect.com
101. Wagle R, Dewangan R, Kumar N. Nutraceuticals as feed additives for improving livestock performance: A review. J Anim Sci Technol. 2023;65(1):3-10. Available from: [HTML]
102. Wadhwa M, Tiwari M, Mukhopadhyay S. Nutraceuticals in the management of obesity: A review. Crit Rev Food Sci Nutr. 2023;63(8):1139-1154. Available from: tandfonline.com
103. Wong E, Chan D. Nutraceuticals in veterinary medicine: Current applications and future prospects. Vet World. 2023;16(7):953-962. Available from: [HTML]
104. Xu W, Guo X, Yang Y, Wang Y. Nutraceuticals in aquaculture: Opportunities and challenges. Aquacult Res. 2023;54(1):1-15. Available from: [HTML]
105. Zaytseva A, Vlasenko E, Kalinina N. Nutraceuticals and their role in the management of metabolic syndrome: A review. Nutrients. 2023;15(5):1147. Available from: mdpi.com
106. Zheng M, Liu T, Wei X, Zhan Q. The role of nutraceuticals in the prevention and treatment of chronic diseases: A review. Foods. 2023;12(4):907. Available from: mdpi.com