Review Paper:

Plant Biodiversity and Nano-Herbal Applications: Enhancing Sustainability in Agriculture and Veterinary Medicine

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Abstract

Plant biodiversity underpins the resilience and sustainability of agricultural and veterinary systems by providing food, fodder, medicine and essential ecosystem services. As global agriculture faces challenges from climate change, soil degradation and livestock health issues, harnessing plant diversity emerges as a crucial strategy for achieving sustainability. Diverse plant species contribute directly to crop productivity, soil fertility and climate resilience while simultaneously ensuring high-quality fodder and natural therapeutics for livestock. Phytochemicals derived from medicinal plants serve as eco-friendly alternatives to synthetic drugs, thereby reducing antimicrobial resistance and supporting animal health.

Furthermore, ecosystem services provided by plant biodiversity including pollination, carbon sequestration and water regulation strengthen agro-ecosystems and livestock systems alike. This study reviews the central role of plant biodiversity in sustainable agriculture and veterinary medicine, emphasizing its ecological, nutritional and therapeutic significance. By integrating botanical knowledge into agro-veterinary practices, biodiversity conservation can be aligned with productivity and animal health, offering pathways toward resilient food systems and sustainable development.

Keywords: Sustainable agriculture, Agro-ecosystem services, Fodder plants, Plant biodiversity, Climate resilience.

Introduction

Plant biodiversity represents one of the most valuable natural resources sustaining life on Earth, forming the basis of food security, ecosystem balance and human as well as animal health. In the modern era of agriculture and veterinary medicine, the conservation and sustainable utilization of plant diversity have become cornerstones for meeting the rising global demand for food, fodder and natural therapeutics[7,27]. The interconnection between plants, agriculture and livestock health underscores the importance of a botanical perspective in agro-veterinary sciences. From a global perspective, more than 30,000 plant species are known to be edible, of which around 7,000 are traditionally cultivated for food and fodder[6]. A significant fraction of these plants not only provide nutritional support to humans but also serve as essential fodder for livestock.

Furthermore, medicinal plants and their phytochemicals are increasingly gaining attention as natural alternatives to synthetic drugs in veterinary practice, especially for controlling parasitic infections, enhancing immunity and improving overall livestock productivity[8,20]. The agricultural sector has long relied on plant diversity to enhance crop productivity, resilience to stress and soil health. Traditional cropping systems such as mixed farming, agroforestry and intercropping highlight the age-old wisdom of integrating plant biodiversity for sustainable agricultural practices[1].

However, with intensification of monocultures and the heavy use of chemical inputs, biodiversity is increasingly under threat, leading to ecosystem imbalances that negatively affect both crops and livestock. Similarly, veterinary medicine has traditionally used plants as sources of natural remedies. For example, *Azadirachta indica* (neem)**,** *Withania somnifera* (ashwagandha) and *Moringa oleifera* (moringa) have been widely documented for their roles in controlling animal diseases, promoting growth and serving as immune boosters[13]. Such applications not only reduce dependency on synthetic antibiotics and anthelmintics but also align with the One Health approach that emphasizes sustainable solutions for both humans and animals. The significance of harnessing plant biodiversity extends beyond food and medicine.

Plant diversity contributes to ecosystem services such as pollination, carbon sequestration, soil fertility enhancement and regulation of water cycles all of which directly and indirectly impact agriculture and livestock systems[16]. As climate change intensifies, these ecosystem services become even more critical for ensuring resilient farming systems.

Thus, the intersection of botany, agriculture and veterinary sciences is a fertile ground for research and innovation. By recognizing plants not merely as passive resources but as active contributors to sustainability, this review highlights the central role of plant biodiversity in agro-veterinary systems. It lays the foundation for exploring how biodiversity can be harnessed for sustainable agriculture and veterinary applications, with a focus on phytochemical, nutritional, ecological and therapeutic dimensions (Fig. 1).

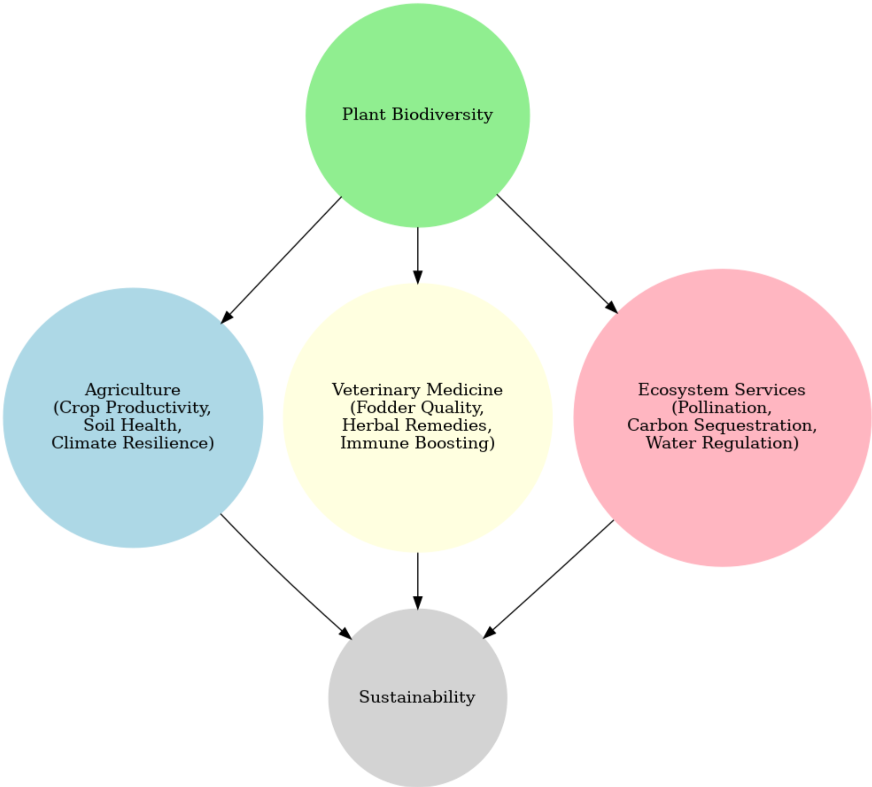

Fig. 1: Conceptual framework of the role of plant biodiversity in agriculture and veterinary medicine

Plant Biodiversity and Agricultural Sustainability

Plant biodiversity plays a pivotal role in agricultural sustainability by ensuring the availability of diverse genetic, nutritional and ecological resources that support farming systems. Traditional agriculture was inherently biodiversity-rich, relying on diverse crop varieties, mixed farming and agroforestry practices, which collectively provided stability against pests, diseases and unpredictable climatic conditions. However, the rise of industrial agriculture has resulted in monocultures, narrowing genetic bases and dependence on chemical fertilizers and pesticides, thereby threatening long-term sustainability[1]. Conservation and strategic utilization of plant biodiversity is therefore essential to restore ecological balance, to enhance food security and build to resilience in agricultural landscapes.

One of the most important contributions of plant biodiversity to agriculture is in crop productivity and soil fertility**.** Leguminous species such as *Cajanus cajan* (pigeon pea) and *Vigna radiata* (green gram) are widely used in intercropping systems due to their ability to fix atmospheric nitrogen, thus reducing the dependence on synthetic nitrogen fertilizers and improving soil fertility.

Peoples and Craswell[22] highlighted that biological nitrogen fixation through legumes can significantly contribute to sustainable crop production. Similarly, cover crops and green manures, including *Sesbania* and *Trifolium* species, improve soil organic matter content, promote beneficial microbial activity and regulate soil nutrient cycling, thereby enhancing soil health[3]. These practices exemplify how biodiversity-driven agricultural inputs contribute to productivity while maintaining ecological balance.

Plant biodiversity also strengthens climate resilience in farming systems. Traditional landraces of crops such as *Oryza sativa* (rice) and *Zea mays* (maize) possess genetic traits that confer resistance to drought, pests and salinity, making them valuable resources in climate adaptation programs[27]. Perennial trees used in agroforestry systems not only provide shade and regulate microclimates but also act as significant carbon sinks, contributing to global climate change mitigation. The integration of such species into farming systems ensures stable yields under environmental stress, providing a strong argument for conserving and reintroducing traditional cultivars into modern agriculture.

Another crucial role of plant biodiversity is in pollination services. A wide range of flowering plants provides nectar and habitats for pollinators such as bees, butterflies and birds, which are indispensable for the fertilization and fruit set of many agricultural crops. The Millennium Ecosystem Assessment[16] reported that approximately 35% of global crop production depends on pollinators, a service largely sustained by biodiverse ecosystems. Loss of plant diversity thus translates directly into declining pollinator populations and reduced crop productivity.

The collective contributions of diverse plant groups to agriculture are summarized in table 1 which highlight selected examples of species and their roles in sustainable farming systems.

Table 1
Examples of Plant Biodiversity Utilized in Sustainable Agriculture

Plant Group/Species	Agricultural Role	Example Application
Cajanus cajan (Pigeon pea)[22]	Nitrogen fixation, soil fertility improvement	Intercropping with cereals for enhanced soil nitrogen
Oryza sativa (Traditional landraces)[27]	Climate resilience, stress tolerance	Drought-resistant rice cultivation in marginal areas
Trifolium spp.[1] (Clovers)	Green manure, soil organic matter enrichment	Cover cropping in rotation systems
Azadirachta indica[23] (Neem)	Biopesticide source, soil health regulation	Organic pest management
Sesbania spp.[3]	Green manure, soil fertility	Incorporated into soil before sowing major crops
Leucaena leucocephala[17] (Agroforestry tree)	Carbon sequestration, microclimate regulation	Shelterbelts, alley cropping for sustainable farming

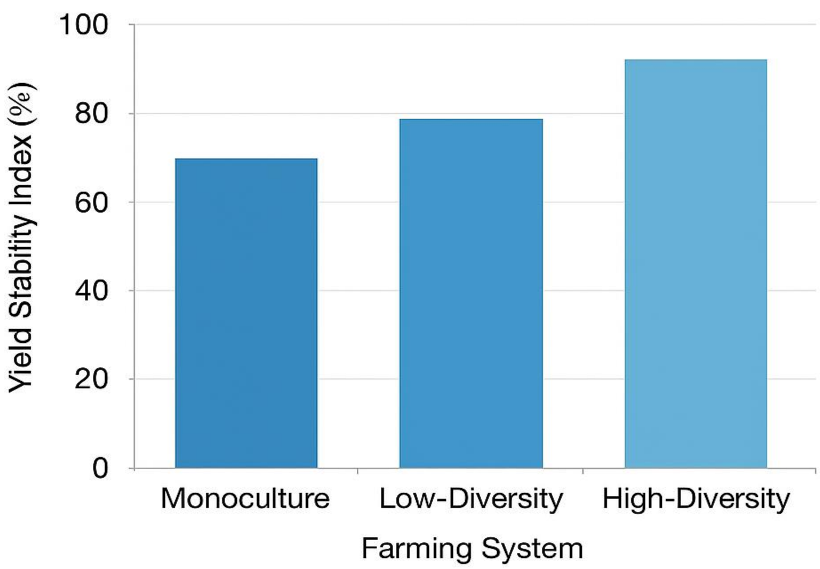

Fig. 2: Role of Plant Biodiversity in Agricultural Sustainability[1,10,12]

Figure 2 illustrates that yield stability increases with greater crop density highlighting the ecological benefits of biodiversity in sustaining agricultural production. Plant biodiversity is not just a passive background element in agriculture but rather the active driver of soil fertility, resilience, productivity and ecological balance. Strengthening conservation and utilization of this biodiversity is therefore fundamental to building sustainable agricultural systems capable of withstanding the pressures of climate change and growing food demands.

Role of Plants in Veterinary Medicine and Animal Nutrition

Plants have been integral to veterinary medicine and animal nutrition since ancient times, serving as sources of fodder, nutraceuticals and therapeutic compounds. Traditional livestock-rearing communities have relied heavily on locally available plant resources to enhance animal health, to prevent diseases and to improve productivity. In modern veterinary science, there is a growing shift towards botanical alternatives to synthetic drugs due to rising concerns over antimicrobial resistance, drug residues in animal products and the need for eco-friendly, sustainable practices[8,20].

One of the most significant roles of plants in veterinary science is their contribution to fodder and nutrition. Nutrient-rich plants such as *Medicago sativa* (alfalfa), *Moringa oleifera* (moringa) and *Leucaena leucocephala* provide high protein content, essential amino acids, vitamins and minerals that improve livestock growth, milk yield and reproductive efficiency. Moringa, for example, has been described as a "miracle tree" due to its exceptionally high levels of protein, carotenoids and calcium, which enhance weight gain and immunity in cattle and goats[26].

Similarly, *Medicago sativa* has long been recognized as a high-protein forage crop that enhances rumen microbial activity and improves digestibility[28].

The inclusion of diverse fodder plants in animal diets reduces the reliance on expensive commercial feeds, making livestock farming more sustainable, especially in low-input systems. Beyond nutrition, plants are extensively used as ethnoveterinary medicines for the prevention and treatment of animal diseases. For example, *Azadirachta indica* (neem) is employed for its antimicrobial, antiparasitic and immunostimulatory properties in cattle and poultry. *Withania somnifera* (ashwagandha) has adaptogenic effects that help livestock cope with stress, while *Allium sativum* (garlic) is widely used to control gastrointestinal parasites in ruminants[13]. The ethnoveterinary use of these plants highlights their potential as cost-effective alternatives to synthetic drugs, particularly in rural areas where modern veterinary services are limited.

Phytochemicals present in plants such as alkaloids, tannins, flavonoids and essential oils, play diverse pharmacological roles in veterinary health. Tannins derived from fodder trees such as *Acacia nilotica* have been shown to reduce methane emissions from ruminants by altering rumen fermentation patterns, thus contributing to both animal health and climate change mitigation[19]. Essential oils from plants such as *Thymus vulgaris* (thyme) and *Cymbopogon citratus* (lemongrass) have been reported to act as natural growth promoters and immune enhancers in poultry production[4]. Table 2 provides examples of fodder and medicinal plants widely used in veterinary medicine and animal nutrition, along with their key roles.

To illustrate the integration of plants in veterinary systems, figure 3 overviews how fodder plants and medicinal plants contribute to livestock productivity, disease management and sustainability.

Table 2
Examples of Plant Resources in Veterinary Medicine and Animal Nutrition

Plant Species	Role in Veterinary/Animal Nutrition	Application/Effect
Medicago sativa (Alfalfa)[28]	High-protein forage, improved digestibility	Enhances rumen microbial activity and milk yield
Moringa oleifera (Moringa)[26]	Nutrient-rich fodder, immune booster	Improves weight gain, enhances immunity in cattle and goats
Leucaena leucocephala[24]	Protein-rich fodder tree, anti-methanogenic effect	Enhances growth and reduces methane emissions in ruminants
Azadirachta indica[23] (Neem)	Antimicrobial, antiparasitic, immunostimulant	Used for controlling ectoparasites and bacterial infections
Withania somnifera[13] (Ashwagandha)	Adaptogenic, stress relief, immune enhancer	Enhances resilience in stressed cattle
Allium sativum[2] (Garlic)	Anthelmintic, antimicrobial	Controls gastrointestinal parasites in ruminants
Acacia nilotica[19]	Source of tannins, methane reduction	Improves rumen fermentation and reduces greenhouse gases
Thymus vulgaris[4] (Thyme)	Essential oil with antimicrobial and growth-promoting effects	Used as feed additive in poultry production

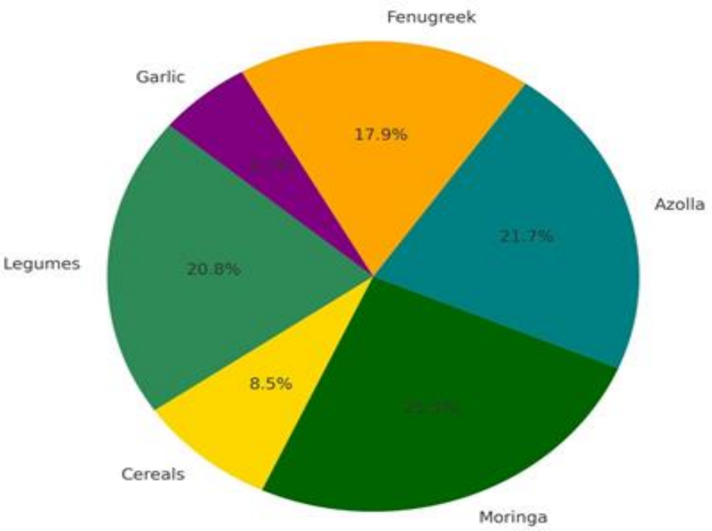

Fig. 3: Role of Plants in Veterinary Medicine and Animal Nutrition[9,11,15]

Thus, plants not only serve as the foundation of animal nutrition but also as natural remedies that bridge traditional ethnoveterinary knowledge with modern sustainable livestock practices. By integrating diverse fodder species and medicinal plants into animal health systems, veterinary science can reduce its dependency on synthetic drugs, enhance animal welfare and contribute to sustainable livestock production.

Phytochemicals as Alternatives to Synthetic Drugs in Livestock Care

The widespread use of synthetic drugs in livestock has led to growing concerns regarding antimicrobial resistance, drug residues in animal products and environmental contamination. Consequently, plant-derived phytochemicals have emerged as promising natural alternatives in livestock care. Phytochemicals, which include alkaloids, tannins, flavonoids, saponins and essential oils, are bioactive secondary metabolites that exhibit antimicrobial, antiparasitic, antioxidant and immunomodulatory activities. Incorporating these compounds into livestock management systems enhances animal health, improves productivity and reduces dependence on synthetic chemicals[8,19].

Alkaloids, a diverse class of nitrogen-containing compounds, are widely utilized for their pharmacological effects in livestock. Species such as *Moringa oleifera*, *Azadirachta indica* (neem) and *Erythrina spp.* contain alkaloids that have demonstrated antimicrobial and antiparasitic activities. Neem-derived alkaloids, for example, are effective against ectoparasites and gastrointestinal parasites in cattle and poultry, providing an environmentally friendly alternative to conventional anthelmintics. Tannins, polyphenolic compounds present in plants like *Acacia nilotica* and *Leucaena leucocephala*, contribute to improved protein utilization in ruminants by binding dietary proteins and modifying rumen fermentation patterns. These effects not only enhance nutrient efficiency but also reduce methane emissions, offering environmental and health benefits[19].

Additionally, tannin-rich plant extracts have shown antiparasitic properties against nematodes and other gastrointestinal parasites, reducing the reliance on synthetic anthelmintics. Flavonoids and saponins provide antioxidant, immunomodulatory and growth-promoting effects. Flavonoid-rich plants such as *Glycyrrhiza glabra* (licorice) and *Allium sativum* (garlic) strengthen antioxidant defenses in livestock, protecting cells from oxidative stress. Saponins from *Yucca schidigera* enhance nutrient digestibility and reduce ammonia emissions in poultry and ruminants, thereby improving feed efficiency and supporting environmental sustainability[4,20]. Table 3 summarizes key phytochemical classes, their plant sources and their documented effects in livestock care.

To visualize the mechanisms of action, figure 4 illustrates how phytochemicals interact with livestock systems. “Phytochemicals” connect to effects such as antimicrobial activity, antiparasitic effects, immunomodulation, antioxidant protection and nutrient efficiency. These effects collectively contribute to sustainable livestock health and reduced dependence on synthetic drugs.

The integration of phytochemicals in livestock care represents a sustainable strategy that bridges traditional ethnoveterinary practices with modern animal husbandry. Utilizing bioactive compounds from plants not only enhances animal health and productivity but also minimizes the environmental impact of synthetic drugs, supporting the development of resilient and sustainable livestock production systems.

Nanoformulated Herbal Extracts in Veterinary and Agricultural Applications: Nanoformulation of herbal extracts represents a transformative approach in both agricultural and veterinary sciences, offering enhanced bioavailability, controlled release and targeted delivery of bioactive compounds. Unlike conventional herbal extracts, nanoformulations improve solubility, stability and efficacy of phytochemicals, reducing dosage requirements and minimizing environmental impact[18,25].

Case studies from recent research illustrate the practical applications of nano-herbal technologies in improving plant health, animal nutrition and disease management. In agriculture, nano-encapsulated plant extracts such as *Azadirachta indica* (neem) nanoparticles have been used effectively as biopesticides.

Studies show that neem nanoemulsions demonstrate higher pest mortality rates and longer residual activity compared to traditional neem extracts, while reducing phytotoxicity and environmental contamination[4]. Similarly, nanoformulations of *Curcuma longa* (turmeric) and *Ocimum sanctum* (holy basil) have been applied to crops to enhance resistance against fungal and bacterial pathogens, showing promising antifungal and antibacterial activity while supporting plant growth promotion. In veterinary applications, nanoformulated herbal compounds offer enhanced therapeutic outcomes in livestock care.

For instance, nanoencapsulated *Moringa oleifera* leaf extracts have been used as a dietary supplement in poultry, improving feed efficiency, immune response and antioxidant status[21]. Likewise, nanoparticles containing *Azadirachta indica* or *Allium sativum* extracts have been applied to control gastrointestinal parasites and ectoparasites in cattle and goats, demonstrating higher bioavailability and sustained release compared to conventional formulations[25].

A representative table (Table 4) of recent case studies of nanoformulated herbal extracts is provided summarizing plant sources, types of nanoformulations, target applications and observed benefits.

Table 3
Major Phytochemical Classes Used in Livestock Care

Phytochemical Class	Plant Source(s)	Reported Effects in Livestock
Alkaloids[8,23]	*Azadirachta indica, Moringa oleifera, Erythrina spp.*	Antimicrobial, antiparasitic, immune-enhancing
Tannins[19]	*Acacia nilotica, Leucaena leucocephala*	Antiparasitic, improved nitrogen utilization, reduced methane
Flavonoids[4,20]	*Glycyrrhiza glabra, Allium sativum*	Antioxidant, immunomodulatory, growth-promoting
Saponins[20]	*Yucca schidigera, Quillaja saponaria*	Enhanced nutrient digestibility, reduced ammonia emissions
Essential Oils[4]	*Thymus vulgaris, Cymbopogon citratus*	Antimicrobial, growth-promoting, immune-enhancing

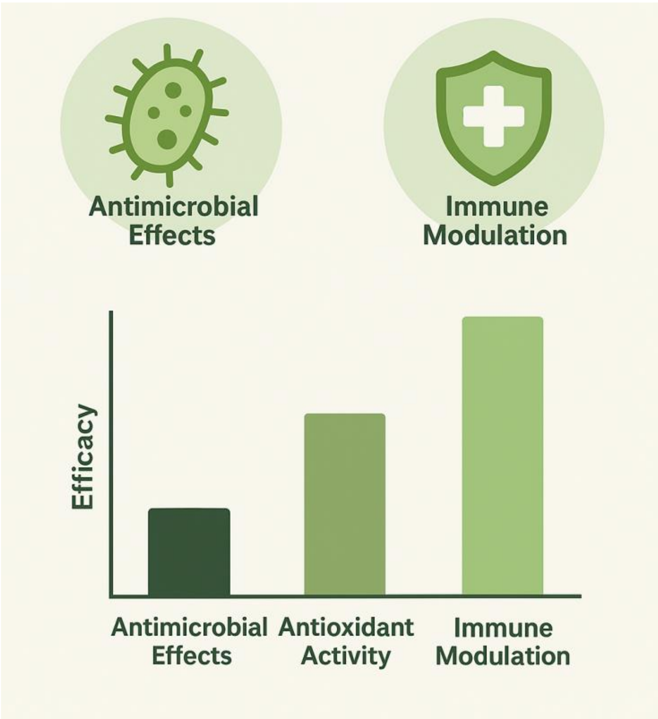

Fig. 4: Mechanisms of Action of Phytochemicals in Livestock Care

Table 4
Case Studies of Nanoformulated Herbal Extracts

Plant Source	Type of Nanoformulation	Target Application	Observed Benefits
Azadirachta indica[14] (Neem)	Nanoemulsion	Biopesticide for crops	Enhanced pest mortality, longer residual effect, reduced phytotoxicity
Curcuma longa[25] (Turmeric)	Nanoencapsulated extract	Fungal pathogen control in crops	Antifungal activity, improved plant growth
Ocimum sanctum[25] (Holy Basil)	Nanoparticles	Bacterial pathogen suppression	Enhanced antibacterial activity, plant protection
Moringa oleifera[21]	Nanoencapsulated powder	Poultry feed supplement	Improved feed efficiency, antioxidant status, immune response
Allium sativum[25] (Garlic)	Nanoformulation	Ectoparasite control in livestock	Higher bioavailability, sustained release, reduced parasite load

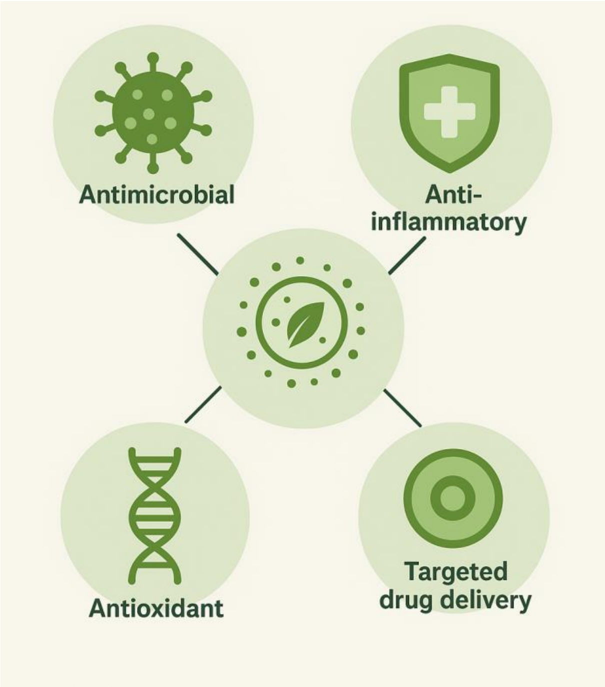

Fig. 5: Mechanism of Action of Nanoformulated Herbal Extracts

To illustrate the mechanism of action, figure 5 depicts how nanoformulated herbal extracts enhance delivery, stability and bioactivity in both plants and animals. The schematic shows the nanoformulation encapsulating bioactive compounds, targeting specific pests, pathogens, or livestock systems, resulting in improved efficacy and reduced environmental impact.

Overall, these case studies demonstrate the potential of nano-herbal technologies in bridging traditional plant-based remedies with modern nanotechnology, achieving sustainable and efficient solutions in agriculture and livestock management. Ongoing research and field trials are critical to standardize formulations, assess long-term safety and scale up applications for commercial use.

Safety, Toxicology and Regulatory Aspects of Plant-based and Nano-Herbal Products

While plant-based and nano-herbal products offer significant benefits in agriculture and veterinary applications, safety and regulatory considerations are paramount. The bioactive compounds in plants, although natural, can exhibit toxic effects at high concentrations or with prolonged exposure. Alkaloids, saponins, tannins and essential oils, when overused, may cause organ toxicity, gastrointestinal disturbances, or reproductive effects in livestock[8,19]. Therefore, establishing safe dosage ranges, standardizing extracts and conducting thorough toxicological evaluations are essential before commercial application. Nanoformulations, although enhancing efficacy and bioavailability, introduce additional safety concerns.

The small size and high surface area of nanoparticles may lead to unforeseen interactions at the cellular level, including oxidative stress, cytotoxicity, or accumulation in animal tissues[18]. Studies have shown that while nanoencapsulated herbal extracts generally reduce environmental contamination and chemical load, chronic exposure at high concentrations can alter liver and kidney function in experimental animals, necessitating careful monitoring and regulatory oversight[21]. Regulatory frameworks for plant-based and nano-herbal products are still evolving.

Agencies such as the Food and Agriculture Organization (FAO), World Health Organization (WHO) and regional authorities like the European Food Safety Authority (EFSA) have issued guidelines for herbal feed additives, emphasizing safety, quality and efficacy[5]. Nanoformulations require additional scrutiny due to their novel physicochemical properties, with regulatory recommendations including characterization of particle size, release kinetics, residual solvents and long-term toxicological studies[25]. To provide a concise overview, table 5 lists key safety considerations, potential toxicities and recommended regulatory practices for plant-based and nano-herbal products.

Figure 6 presents a diagram summarizing the safety evaluation and regulatory framework for plant-based and nano-herbal products. It shows the flow from product development, toxicological assessment, regulatory compliance to safe application in agriculture and veterinary practices.

Ensuring the safety and regulatory compliance of plant-based and nano-herbal products is essential to prevent adverse effects on livestock, crops and the environment. Continuous research, standardized quality control and adherence to international regulatory guidelines are vital for the sustainable and responsible use of these products.

Table 5
Safety and Regulatory Considerations of Plant-Based and Nano-Herbal Products

Aspect	Consideration/Concern	Recommended Practice/Regulation
Plant-Based Extracts[8,19]	Alkaloid, tannin, saponin toxicity	Standardized dosing, toxicological evaluation
Nanoformulations[18,21]	Cellular uptake, bioaccumulation, oxidative stress	Particle characterization, *in vivo* safety studies
Residue in Animal Products[5]	Drug/metabolite residues in milk, meat, eggs	Maximum residue limits (MRLs) establishment
Environmental Impact[18]	Persistence, runoff, soil accumulation	Environmental risk assessment
Regulatory Compliance[5]	Lack of standardized guidelines	Follow FAO/WHO/EFSA recommendations

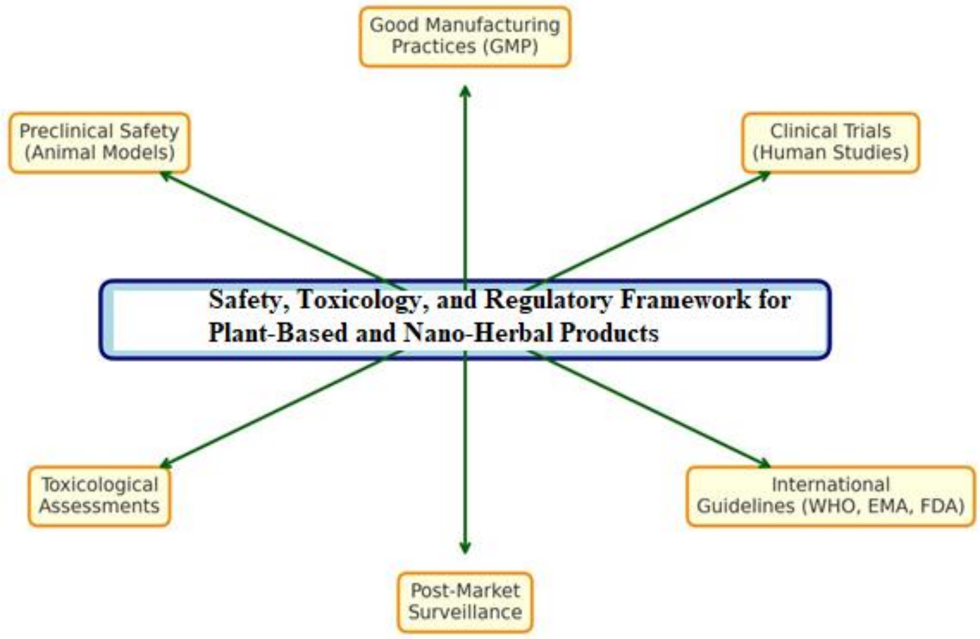

Fig. 6: Safety, Toxicology and Regulatory Framework for Plant-Based and Nano-Herbal Products

Future Prospects and Challenges in Plant-Based and Nano-Herbal Applications

The future of plant-based and nano-herbal products in agriculture and veterinary medicine is highly promising, offering sustainable alternatives to chemical fertilizers, pesticides and synthetic drugs. Advances in nanotechnology, biotechnology and plant metabolomics have expanded opportunities for improving the efficacy, stability and targeted delivery of phytochemicals. For instance, the development of smart nano-carriers allows controlled release of bioactive compounds, enhancing plant growth, pest resistance and animal health while minimizing environmental contamination[18,25].

Emerging research focuses on integrated agro-veterinary systems where plant biodiversity, nanoformulations and conventional farming are combined to optimize productivity, resilience and ecological balance. Crops enriched with bioactive nanoparticles can reduce pest outbreaks, while nano-herbal supplements in livestock feed improve immunity and nutrient utilization. This convergence of plant science and nanotechnology opens avenues for precision agriculture and sustainable livestock management. Despite the potential, several challenges must be addressed. Standardization of plant extracts and nanoformulations remains a major hurdle, as variations in phytochemical content due to species, cultivation conditions and extraction methods can affect efficacy and safety.

Regulatory frameworks for nano-herbal products are still evolving, requiring robust toxicological, environmental and residue studies before widespread adoption[5,21]. Additionally, cost-effective scaling of nanoformulations and ensuring farmer adoption, particularly in developing regions, are significant practical challenges. Table 6 summarizes the key future prospects and associated challenges of plant-based and nano-herbal applications in agriculture and veterinary science.

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Table 6
Future Prospects and Challenges of Plant-Based and Nano-Herbal Applications

Aspect	Future Prospect	Challenge/Barrier
Nanoformulations[18,25]	Controlled release, targeted delivery	Standardization, cost-effective production
Agro-Veterinary Integration[25]	Improved crop protection and livestock health	Farmer adoption, practical implementation
Plant Metabolomics and Biotechnology[18]	Enhanced phytochemical profiling, metabolite optimization	Variation in phytochemical content, consistency issues
Environmental Sustainability[5]	Reduced chemical inputs, eco-friendly practices	Regulatory compliance, long-term ecological impact
Precision Agriculture[25]	Smart delivery systems, optimized resource use	Technology cost, training, monitoring systems

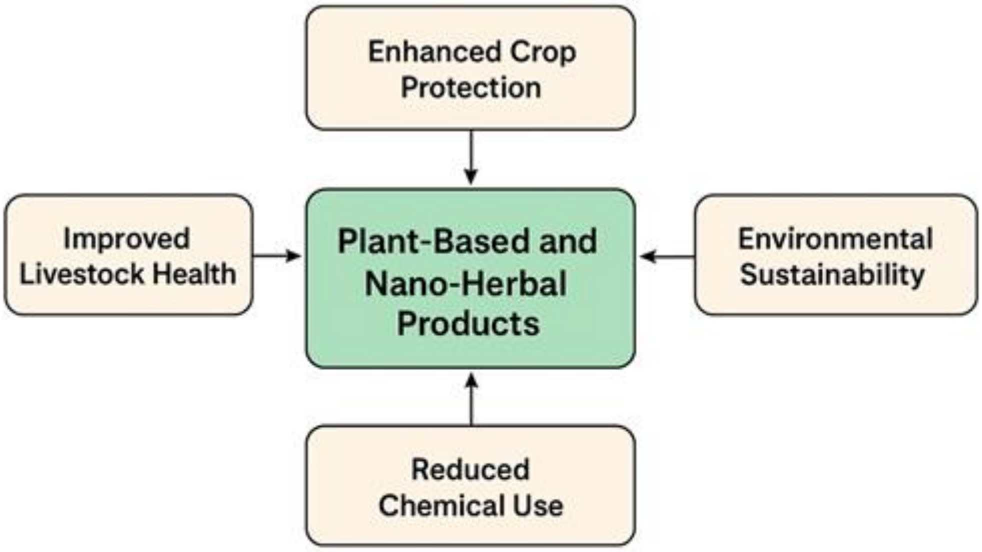

Fig. 7: Framework of Future Integration of Plant-Based and Nano-Herbal Products

Figure 7 illustrates a framework for the future integration of plant-based and nano-herbal products in agriculture and veterinary systems. The diagram highlights synergistic pathways between plant biodiversity, nanoformulations and livestock feed, leading to sustainable production, enhanced productivity and reduced environmental impact. The prospects of plant-based and nano-herbal products are immense, but their success depends on addressing standardization, regulatory and adoption challenges.

Multidisciplinary research, farmer training and supportive policy frameworks will be essential for translating scientific advances into practical, large-scale applications, thereby promoting sustainable agriculture and livestock management globally.

Conclusion

Plant biodiversity and phytochemicals play a pivotal role in enhancing agricultural productivity and livestock health, offering sustainable and eco-friendly alternatives to synthetic chemicals. The integration of plant-based products into farming and veterinary practices not only supports disease prevention and improved nutrition but also contributes to environmental conservation by reducing chemical residues and mitigating ecological risks.

Nanoformulations of herbal extracts have emerged as a transformative technology, providing enhanced solubility, stability, bioavailability and targeted delivery of bioactive compounds. Case studies demonstrate their efficacy in pest management, disease control and nutritional supplementation, both in crops and livestock systems. The use of nano-herbal technologies bridges traditional ethnoveterinary knowledge with modern scientific advancements, offering precise and efficient solutions for contemporary agricultural and veterinary challenges.

Despite these promising developments, safety, toxicology and regulatory considerations remain critical. Standardization of extracts, thorough toxicological evaluation and adherence to international regulatory frameworks are essential to ensure the safe and effective application of both plant-based and nano-herbal products. Moreover, challenges such as cost, scalability and farmer adoption must be addressed to facilitate widespread implementation. Looking forward, multidisciplinary research integrating plant science, nanotechnology, metabolomics and veterinary science is essential for optimizing the use of phytochemicals and nanoformulations. With appropriate regulatory oversight, scientific validation and technology transfer, plant-based and nano-herbal interventions can contribute significantly to sustainable agriculture, animal health and food security, fostering resilient agro-veterinary systems worldwide.

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