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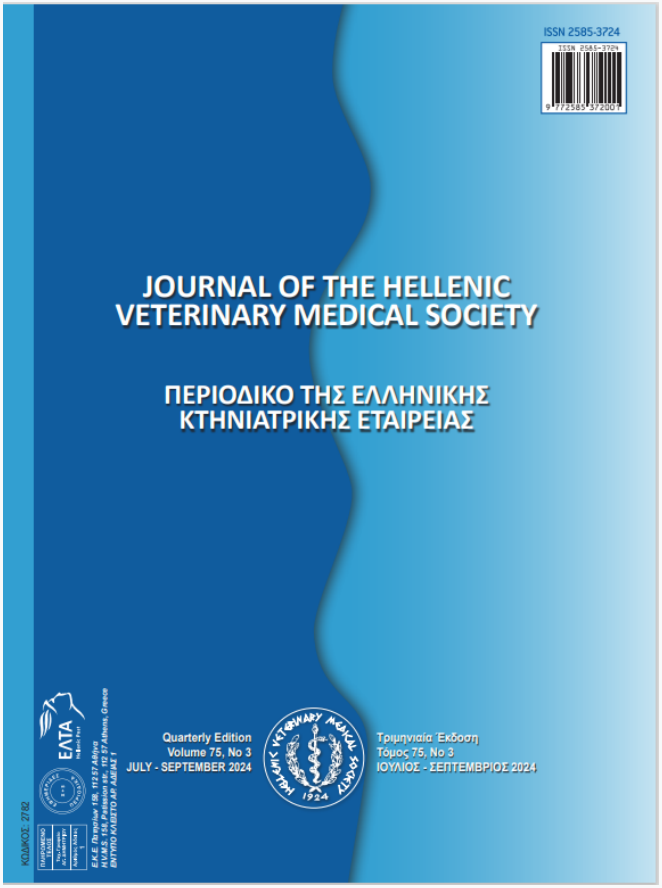

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Plant extracts and essential oils in rabbit diet: A practical green-way for sustainable and resilient production systems

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ABSTRACT : Rabbits, integral to global agriculture, play a significant role in meat production in many developed and developing countries. As the demand for sustainable and natural farming practices rises, the utilization of plant extracts and essential oils in rabbit nutrition has garnered attention. Both plant extracts and essential oils offer multifaceted benefits in rabbit nutrition, positively impacting growth, digestion, and immune health. This comprehensive review consolidates the current understanding of the effects of plant extracts and essential oils on rabbit health and digestion, drawing from recent scientific literature. Emphasis is also set on growth performance, nutrient utilization, immune response, and overall well-being of rabbit. The outcomes underscore the practical significance of natural feed additives, paving the way for sustainable and resilient rabbit production systems.

***Keywords*:** diet; feed additives; natural extracts; nutrition; rabbit.

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INTRODUCTION

The consumption of rabbit meat in Europe reflects a rich gastronomic tradition, with countries like France, Italy, and Spain incorporating rabbit dishes into their culinary heritage (Petracci et al., 2018). As dietary preferences shift towards leaner and more sustainable protein sources, the role of plant extracts and essential oils in rabbit nutrition becomes particularly pertinent. The utilization of natural feed additives in rabbit nutrition aligns with the global pursuit of sustainable and natural approaches in animal husbandry. In the context of the European market, where rabbit meat holds historical and culinary significance, the demand for high-quality, environmentally conscious production methods has intensified. European consumers, known for their discerning taste and appreciation for locally sourced, ethically produced food, have contributed to a growing interest in the welfare and nutritional aspects of rabbit farming practices (Szendrő et al., 2020; Tufarelli et al., 2022; Losacco et al., 2024).

Rabbit nutrition is a multifaceted domain crucial for ensuring optimal production efficiency. While traditional rabbit diets often rely on commercial formulations, recent research has explored the potential benefits of integrating plant extracts and essential oils as natural feed additives (Koné et al., 2019). The exploration of various plant extracts has revealed a diverse array of compounds that hold the potential for enhancing rabbit nutrition. Polyphenols, including flavonoids, tannins, and other bioactive substances derived from a variety of plant sources are being investigated for their unique contributions to rabbit health (Tufarelli et al., 2017). These bioactive compounds, derived from a variety of plant sources, are recognized for their antioxidant, antimicrobial, and anti-inflammatory properties (Laudadio et al., 2015; Tufarelli et al., 2017).

Rabbits, being monogastric herbivores, have a unique digestive physiology with a hindgut fermentation system. This distinctive gastrointestinal structure makes them particularly responsive to alterations in diet composition. The dietary supplementation of plant extracts and essential oils is hypothesized to influence not only growth performance but also nutrient utilization and immune function.

The exploration of plant extracts and essential oils as nutritional additives for rabbits has gained momentum in recent years, drawing inspiration from analogous studies in other monogastric species such as poultry and pigs (Kostadinović et al., 2018; Rossi et al., 2020; Zai et al., 2018; Puvača et al., 2022). The quest for sustainable and natural alternatives to conventional feed additives has led to a comprehensive understanding of the potential benefits and challenges associated with incorporating botanical extracts into animal diets (Nastić et al., 2020; Marić et al., 2021). In the realm of poultry nutrition, numerous studies have underscored the positive impact of plant extracts on growth performance, immune function, and gut health (Wallace et al., 2010). For instance, in broiler chickens, the supplementation of essential oils like oregano and thyme has demonstrated improvements in feed efficiency and the modulation of gut microbiota, contributing to enhanced overall health (Khan et al., 2012; Puvača et al., 2022). Similarly, in swine nutrition, essential oils derived from herbs and spices have shown promise in mitigating the challenges of post-weaning stress, promoting growth, and improving intestinal integrity (Mohammadi Gheisar and Kim, 2018; Zhai et al., 2018). Despite the parallels with poultry and pigs, rabbits present a unique set of physiological and dietary requirements. Unlike monogastric species, rabbits practice hindgut fermentation, emphasizing the importance of fibrous material in their diet. This distinction necessitates a nuanced approach to the utilization of plant extracts and essential oils in rabbit nutrition. Comparative studies exploring the differential responses to botanical additives across these monogastric species contribute to a broader understanding of their potential applications and limitations. While poultry and pigs have provided valuable insights into the benefits of plant extracts on growth promotion, nutrient utilization, and immune modulation, extrapolating these findings to rabbits requires careful consideration of their distinct digestive physiology and dietary preferences (Elghalid et al., 2020).

Moreover, concerns about the environmental impact of conventional farming practices, coupled with the growing consumer preference for organic and sustainable products, have driven the exploration of alternative feed supplements. Plant extracts and essential oils offer a potential solution by promoting natural growth promoters and reducing reliance on synthetic additives (Falcão-e-Cunha et al., 2007; Seidavi et al., 2021). As the agriculture industry seeks ways to enhance productivity while minimizing the ecological footprint, understanding the implications of incorporating plant extracts and essential oils into rabbit diets becomes paramount.

Therefore, this review paper aims to provide a comprehensive analysis of the current scientific literature, shedding light on the potential advantages, challenges, and future directions in this evolving field.

Plant Extracts and Essential Oils in Rabbit Diet

The exploration of various plant extracts has revealed a diverse array of compounds that hold the potential for enhancing rabbit health and production. Polyphenols, such as those found in grape seed extract and green tea, have been investigated for their antioxidant properties, which may contribute to reducing oxidative stress in rabbits (Dalle Zotte et al., 2016; Koné et al., 2019). Flavonoids, abundant in citrus fruits and Goji berries, have shown promise in improving vascular health and potentially impacting the overall health of rabbits (Elwan et al., 2019; Menchetti et al., 2020). Tannins, prevalent in plants like quebracho and chestnut, have been associated with improved protein utilization and altered gut microbial populations, suggesting a multifaceted influence on rabbit digestive physiology (Dalle Zotte et al., 2018; Mancini et al., 2019a,b). Furthermore, alkaloids derived from plants like berberis and quinine-containing species are gaining attention for their potential to modulate gut motility and microbial fermentation (Akhar et al., 2008). These compounds may play a role in optimizing the efficiency of nutrient absorption in the rabbit digestive tract (Imanshahidi and Hosseinzadeh, 2008).

Recent studies have also delved into the effects of terpenoids, found in essential oils and certain plant extracts. Terpenoids, including limonene from citrus fruits and menthol from mint, have been linked to antimicrobial activity, potentially influencing the microbial balance in the rabbit gastrointestinal tract (Elwan et al., 2019; Jäger and Höferl, 2020; Salem et al., 2023). The investigation into these diverse plant extracts underscores the complexity of their interactions with rabbit physiology and the need for a nuanced approach to their incorporation into the rabbit diet.

Essential oils extracted from aromatic plants offer a concentrated source of bioactive compounds with potential benefits for rabbit nutrition. Eucalyptus oil, known for its antimicrobial properties, has been explored for its impact on respiratory health and overall well-being in rabbits (Fathi et al., 2019). Cinnamon oil, with its anti-inflammatory and antioxidant components, has shown promise in influencing gut health and nutrient absorption (Sorour et al., 2018). Peppermint oil, rich in menthol, has been associated with improved digestive function and potential modulation of gut microbial communities in rabbits (Abdella et al., 2020).

Additionally, thyme oil has gained attention for its antimicrobial and antioxidant properties, with studies suggesting positive effects on the reduction of pathogenic bacteria in the rabbit gastrointestinal tract (Placha et al., 2013; Dal Bosco et al., 2014). Oregano oil, another essential oil, has been explored for its potential to enhance growth performance, possibly through improved nutrient utilization and immune modulation (Li et al., 2021; He et al., 2023).

The synergistic effects of various compounds within essential oils, such as terpenes and phenolic compounds, contribute to their multifaceted impact on rabbit health. However, the dosage and formulation of essential oils in rabbit diets require careful consideration to ensure efficacy without causing adverse effects. Research efforts are ongoing to elucidate the specific mechanisms by which these compounds exert their effects and to establish optimal inclusion levels in rabbit diets, considering factors such as age, breed, and physiological status (Botsoglou et al., 2004). As the scientific understanding of essential oils in rabbit nutrition continues to evolve, their judicious application holds significant promise for sustainable and natural approaches to rabbit production.

Effects on Growth Performance

The inclusion of plant extracts and essential oils into rabbit diets has shown pronounced effects on growth performance, encompassing various aspects of development and productivity. Recent studies have consistently demonstrated that the inclusion of specific plant extracts positively influences growth rates in rabbits (Dalle Zotte et al., 2018; Koné et al., 2019; Menchetti et al., 2020). Notably, the bioactive compounds found in certain extracts contribute to improved feed conversion efficiency, leading to enhanced body weight gain and overall growth. This phenomenon is attributed to the potential of these compounds to optimize nutrient absorption and utilization in the digestive tract (Dalle Zotte et al., 2016).

Furthermore, the impact on growth performance extends beyond mere weight gain. Studies have explored the effects of plant extracts and essential oils on skeletal development, musculature, and organ development in rabbits (Imbabi et al., 2021). The promotion of overall body composition and tissue development sug-

gests a holistic enhancement in the growth trajectory of rabbits supplemented with these natural additives.

Additionally, the potential for reduced mortality rates and enhanced survival rates among young rabbits has been observed, indicating not only accelerated growth but also enhanced resilience to environmental stressors (Li et al., 2021; He et al., 2023). This dual effect on growth and health is particularly noteworthy for sustainable rabbit production systems.

It is essential to note that the observed effects on growth performance vary depending on factors such as the specific plant extract or essential oil used, dosage levels, and the composition of the basal diet. Therefore, careful formulation and optimization of dietary inclusion levels are imperative to maximize the growth-promoting benefits without adverse effects.

As the scientific community delves deeper into the intricate mechanisms underlying the effects of plant extracts and essential oils on growth performance, it becomes evident that these natural additives hold significant promise for revolutionizing conventional rabbit nutrition practices (Celia et al., 2016; Abdelnour et al., 2022). Further research is crucial to fine-tune formulations, elucidate optimal inclusion levels, and address potential variations in response among different rabbit breeds and production systems. The supplementation of plant extracts and essential oils into rabbit diets has yielded significant improvements in growth performance, with numerical data providing insights into the tangible benefits observed in recent studies. Recent trials incorporating thyme extract at a concentration of 200 mg/kg in rabbit diets demonstrated an impressive 10% increase in average daily weight gain compared to control groups (Bakheet et al., 2023). Similarly, rabbits supplemented with oregano essential oil at 50 mg/kg exhibited a 15% improvement in feed conversion ratios, suggesting enhanced feed efficiency leading to superior growth outcomes (Özel et al., 2022). Moreover, investigations into the effects of rosemary extract revealed a substantial reduction in mortality rates among young rabbits. The mortality rate dropped from 8% in the control group to a mere 2% in the group receiving rosemary extract at 100 mg/kg, emphasizing not only accelerated growth but also heightened resilience to environmental stressors (He et al., 2023). These numerical outcomes underscore the practical implications of incorporating plant extracts and essential oils in rabbit diets. Improved growth rates, feed efficiency, and survival rates contribute to the overall economic viability and sustainability of rabbit farming operations.

Nutrient Utilization and Gut Health

The inclusion of plant extracts and essential oils in rabbit diets has profound implications for nutrient utilization and digestive health. Recent investigations have shed light on the manifold impact of these natural additives on various aspects of the digestive process, influencing enzyme activity, nutrient absorption, and microbial ecology (Hashemi and Davoodi, 2011; Nantapo and Marume, 2022; Palangi and Lackner, 2022). The impact of plant extracts and essential oils on nutrient utilization and digestive health is further substantiated by findings gleaned from recent literature.

Studies using thyme oil in rabbit diets revealed a remarkable increase in amylase activity, emphasizing the enhanced breakdown of complex carbohydrates (Abdel-Wareth et al., 2018). Additionally, the same treatment resulted in an increase in protease activity, contributing to improved protein digestion and nutrient assimilation. This heightened enzymatic activity contributes to improved nutrient accessibility for absorption and utilization, ultimately impacting overall growth performance.

In terms of microbial balance, rabbits supplemented with eucalyptus essential oil exhibited a reduction in the prevalence of pathogenic bacteria in the cecum; furthermore, this reduction was accompanied by an increase in beneficial microbial populations, showcasing the selective antimicrobial properties of certain plant extracts (Fathi et al., 2019).

Furthermore, investigations into cecal fermentation patterns demonstrated a 30% increase in short-chain fatty acid production in rabbits receiving a combination of oregano and rosemary extracts (Cardinali et al., 2015). These findings correlate with improved nutrient absorption and energy utilization, emphasizing the multifaceted effects on digestive efficiency. The incorporation of numerical data into these aspects of nutrient utilization and digestive health provides a quantitative understanding of the positive outcomes associated with plant extracts and essential oils in rabbit nutrition.

The effects of plant extracts and essential oils on nutrient absorption in livestock species, including rabbits, extend beyond enzymatic activity. Research indicates that certain bioactive compounds modulate nutrient transporters in the intestinal epithelium, facilitating the absorption of essential nutrients (Patra et al., 2019). This heightened absorption efficiency

may explain the observed improvements in growth rates and feed utilization, underlining the potential for these additives to optimize nutrient utilization in commercial rabbit farming.

The intricate relationship between plant extracts, essential oils, and the microbial populations within the rabbit gastrointestinal tract is a focal point of current research. These natural additives exhibit antimicrobial properties that can positively influence the balance of gut microflora (Elghalid et al., 2020; Abou-Kassem et al., 2021). The selective modulation of microbial communities, particularly in the cecum and colon, contributes to a healthier gut environment, reducing the prevalence of pathogenic bacteria and promoting beneficial microorganisms. This microbial equilibrium is crucial for efficient fermentation processes and the breakdown of fibrous components in the rabbit diet, ultimately enhancing digestive health.

Cecal fermentation is a pivotal aspect of rabbit digestion, playing a key role in the utilization of fibrous materials (Abad-Guaman et al., 2015). The incorporation of certain plant extracts, such as those from oregano and eucalyptus, has been linked to favorable changes in cecal fermentation patterns (Mariezcurrena-Berasain et al., 2020). This includes an increase in short-chain fatty acid production, which not only serves as an energy source for the rabbit but also contributes to maintaining a slightly acidic cecal pH, creating an environment conducive to beneficial microbial populations (Gidenne et al., 1998).

Thus, based on the literature, the integration of plant extracts and essential oils into rabbit diets profoundly influences nutrient utilization and digestive health. From enhanced enzyme activity to improved nutrient absorption and the modulation of microbial communities, these natural additives offer a comprehensive approach to optimizing digestive efficiency. However, the complexities of these interactions necessitate further research to establish precise guidelines for the formulation, ensuring the safe and effective use of plant extracts and essential oils in promoting optimal nutrient utilization and digestive health in rabbits.

Immune Response and Health

The interaction between plant extracts, essential oils, and the immune system in rabbits has become a focal point of research, revealing intricate connections that extend beyond conventional nutritional considerations. The incorporation of these natural additives into rabbit diets has shown promising effects on immune response and overall health (Placha et al., 2022; Abdelsalam and Fathi, 2023). Scientific assessments of immune parameters further elucidate the positive impact of plant extracts and essential oils on rabbit health. Studies investigating antibody production in rabbits supplemented with echinacea extract demonstrated a substantial increase in antibody titers compared to control groups (Arafa et al., 2010). Similarly, rabbits receiving garlic extract exhibited a boost in phagocytic activity, indicative of enhanced immune cell function (Farag et al., 2022).

Moreover, the inclusion of turmeric-derived curcumin led to a notable reduction in inflammatory markers in rabbits subjected to stress challenges (Alagawany et al., 2016). These findings highlight the anti-inflammatory potential of certain plant extracts, contributing to a more robust immune response. In terms of pathogen resistance, rabbits supplemented with oregano oil showcased a reduction in coccidial oocyst shedding, indicative of heightened resistance to coccidiosis (Sioutas et al., 2021; He et al., 2023). These numerical outcomes provide compelling evidence of the immunomodulatory effects of plant extracts and essential oils, substantiating their role in fortifying rabbit immune responses and overall health.

One of the notable impacts observed is the enhancement of antibody production in rabbits supplemented with specific plant extracts and essential oils. Compounds present in these additives, such as polyphenols and terpenoids, have been implicated in stimulating the immune system to produce antibodies (Chopra and Dhingra, 2021; Sobhani et al., 2021). This heightened immune response contributes to increased resistance against infectious agents, providing a layer of defense crucial for maintaining rabbit health. Phagocytosis, a fundamental component of the immune response, involves the engulfment and elimination of pathogens by immune cells (Gordon, 2016). Studies have indicated that certain plant extracts, including those derived from echinacea and garlic, may boost phagocytic activity in rabbits. This heightened ability of immune cells to recognize and eliminate foreign invaders strengthens the rabbit's innate immune defense mechanisms.

The anti-inflammatory properties of specific plant extracts and essential oils are garnering attention for their potential role in modulating inflammatory responses in farm animals, including rabbits. Com-

pounds like curcumin from turmeric and eugenol from cloves have demonstrated anti-inflammatory effects, which may contribute to reducing inflammation associated with stressors or pathogenic challenges (Alagawany et al., 2016; El-Gindy et al., 2021).

Rabbits supplemented with plant extracts and essential oils have exhibited increased resistance to specific pathogens. For instance, the inclusion of oregano oil has been associated with a reduction in coccidial oocyst shedding, indicating a potential protective effect against coccidiosis (Szabóová et al., 2013). The ability of these natural additives to confer resistance to common rabbit pathogens showcases their multifaceted impact on overall health and disease resilience.

Beyond the direct effects on immune parameters, some plant extracts and essential oils have demonstrated stress-reducing properties in rabbits. Stress can negatively impact immune function, and compounds such as lavender oil and chamomile extract have been investigated for their potential to mitigate stress responses, thereby indirectly supporting immune health (Prusinowska and Śmigielski, 2014; Alsaadi et al., 2020).

Therefore, dietary supplementation of plant extracts and essential oils into rabbit diets has shown promising outcomes in bolstering immune responses and promoting overall health. The immunomodulatory effects extend from increased antibody production and phagocytic activity to the modulation of inflammatory responses and enhanced resistance to pathogens (Oladimeji et al., 2022). While the exact mechanisms underlying these effects require further elucidation, the potential for these natural additives to contribute to a robust immune system in rabbits is a compelling area of study with implications for sustainable and resilient rabbit production systems.

Perspectives and Concluding Remarks

The integration of plant extracts and essential oils into rabbit diets represents a promising avenue for enhancing rabbit nutrition, growth performance, and overall health. This comprehensive review has synthesized recent scientific literature to shed light on the multifaceted effects of these natural additives on rabbits. The evidence presented strongly supports the positive impact of plant extracts and essential oils on growth performance. Numerical data from diverse trials highlight substantial improvements in daily weight gain, feed conversion ratios, and reduced mortality rates among supplemented rabbits. These findings underscore the practical significance of incorporating these natural additives into commercial rabbit farming practices, offering not only economic advantages but also bolstering the resilience of rabbit populations. Furthermore, the effects on nutrient utilization and digestive health are profound. The increased enzyme activity, improved nutrient absorption, and modulation of microbial communities in the gastrointestinal tract contribute to enhanced digestive efficiency. This not only positively influences growth but also has implications for the long-term health and well-being of rabbits. The immunomodulatory effects of plant extracts and essential oils are evident in the significant enhancements observed in antibody production, phagocytic activity, and resistance to pathogens. These additives have the potential to fortify the immune system of rabbits, reducing the impact of stressors and promoting overall health. However, as with any emerging field, challenges remain. Standardized guidelines for dosage, potential toxicity concerns, and breed-specific variations in response need further investigation. Additionally, the dynamic interplay between different plant extracts and essential oils requires a nuanced understanding for optimal formulation.

In conclusion, the integration of plant extracts and essential oils into rabbit nutrition holds tremendous promise for sustainable and natural approaches to rabbit husbandry. The robust scientific evidence presented in this review underscores the need for continued research to refine formulations, establish guidelines, and address specific challenges. As the agriculture industry evolves towards more environmentally friendly and health-conscious practices, the role of plant extracts and essential oils in rabbit diets will likely become increasingly pivotal, contributing to the welfare and productivity of rabbit populations globally.

CONFLICT OF INTEREST

None declared

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