Biological Activity of Plant Essential Oils and Their Application in Animal Production: Postprint

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Abstract

Plant essential oils are volatile liquids produced by plants, typically possessing aromatic properties. Research has revealed that plant essential oils contain multiple active components, and as novel feed additives, they exhibit antimicrobial, antioxidant, anti-inflammatory, and immunity-enhancing effects in animals. Therefore, this article provides a comprehensive review of the primary biological activities of plant essential oils and their applications in animal production.

Full Text

Biological Activity of Plant Essential Oils and Their Application in Animal Production

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Abstract: Plant essential oils are volatile liquids produced by plants, typically possessing aromatic properties. Research has revealed that essential oils contain various active components and, as novel feed additives, exhibit antibacterial, antioxidant, anti-inflammatory, and immune-enhancing effects in animals. Therefore, this article reviews the primary biological activities of plant essential oils and their applications in animal production.

Keywords: plant essential oil; novel feed additive; animal; biological activity; immunity

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In intensive farming operations, animals are vulnerable to various stressors such as weaning, tail docking, castration, group transfer, moldy feed, and irrational antibiotic use, which reduce feed intake, alter intestinal environments, and compromise immunity. These factors can lead to diarrhea, anorexia, emaciation, and ultimately slow growth, disease, or death. Therefore, enhancing stress resistance, improving gastrointestinal function, and boosting immunity are critical for profitable animal production. Plant essential oils, as plant extracts, are aromatic volatile liquids that have attracted increasing attention in recent years as natural antioxidants with appetite-stimulating, growth-promoting, antibacterial, anti-inflammatory, anti-stress, disease-preventing, and anti-mycotic properties [1]. Studies report that dietary essential oil supplementation can elevate immunoglobulin levels in pigs [2], promote duodenal villus development in broilers [3], scavenge free radicals and alleviate stress [4], modulate gut microbiota [5], reduce disease incidence [6], and improve growth performance [7]. This article reviews the biological activities of plant essential oils and their applications in animal production to provide a reference for their practical use.

1 Sources, Active Components, and Classification of Plant Essential Oils

Plant essential oils are aromatic molecules secreted by plant cells through biochemical reactions following photosynthesis. They are primarily distributed in flowers, leaves, stems, roots, twigs, seeds, fruits, or bark, and stored in glandular trichomes, oil chambers, secretory cells, or resin ducts. Most exist as oil droplets, sometimes combined with resins and mucilage, and are obtained through pressing, distillation, or extraction. As concentrated lipophilic and hydrophobic compounds, they volatilize to produce characteristic aromas, are prone to oxidative rancidity under natural conditions, are water-insoluble but soluble in organic solvents, and are flammable. Their chemical composition includes terpenes, alcohols, phenols, aldehydes, ketones, esters, and other complex hydrocarbons [9].

The main components fall into four categories: 1) Terpenes: the most abundant, such as linalool, geraniol, and borneol; 2) Aromatic derivatives: the second largest group, such as thymol, carvacrol, and cinnamaldehyde; 3) Aliphatic compounds: smaller molecules found in almost all essential oils, such as isovaleraldehyde, linalool, and zingerone; 4) Nitrogen and sulfur compounds: found in Alliaceae plants, such as allicin with its pungent aroma, trisulfides in onions, and isothiocyanates in black mustard. Phenols, terpenes, monoterpenes, and sesquiterpenes typically constitute over 70% of the chemical composition, sometimes exceeding 85%. The aromatic scents not only provide allelopathic effects protecting plants from other plants, herbivores, and microorganisms, but also attract bees and butterflies for pollination. Current research focuses primarily on aromatic plants from Lamiaceae, Rutaceae, Lauraceae, Asteraceae, and Zingiberaceae families. The physicochemical properties and yields of common plant essential oils are shown in Table 1 .

2.1 Antimicrobial Activity of Plant Essential Oils

Research demonstrates that essential oils can degrade bacterial cell walls, disrupt cell membrane protein structures, cause cytoplasmic coagulation, and diminish proton motive force, thereby inhibiting and killing bacteria. Hammer et al. [13] and Ambrosio et al. [14] attribute the antimicrobial activity primarily to phenolic compounds. Other studies indicate that carbonyl functional groups in terpenoid structures enhance antimicrobial activity [9]. Wang et al. [15] found that *Dodartia orientalis* L. essential oil exerts antibacterial effects by disrupting cell structures and resisting biofilms, significantly inhibiting *Escherichia coli*, *Salmonella*, and *Staphylococcus aureus*. Sun [16] reported that cinnamaldehyde inhibits *Aspergillus flavus* growth and toxin production through both short-term and long-term stress effects. Short-term exposure reduces reactive oxygen species (ROS) and oxidative stress, slowing metabolic rates, while long-term exposure increases ROS, causing cellular oxidative damage that obstructs physiological activities. Huang et al. [17] found that thymol, p-cymene, and terpenes damage *E. coli* cytoplasmic membranes, disrupt proton pump function, and cause cell death. Published data rank antimicrobial activity as: oregano > eugenol > cinnamon > thyme > mint > rosemary > mustard > coriander/sage. Kalemba et al. [18] reported that antifungal activity of active components follows: phenols > cinnamaldehyde > alcohols > aldehydes > ketones > ethers > hydrocarbons, with phenolic antifungal activity increasing with greater steric hindrance.

2.2 Antioxidant Activity of Plant Essential Oils

Essential oils contain various antioxidant components such as thymol, p-cymene, and flavonoid phenylpropanoids. Mechanisms include: 1) Phenolic components binding with peroxyl radicals to reduce or scavenge free radical activity; 2) Phenolic hydroxyl groups chelating transition metal ions (Fe2+, Cu2+) to form stable complexes, blocking biological oxidation and reducing metal-induced radical generation; 3) Terpenes upregulating endogenous antioxidant enzyme activity [19]. Si et al. [20] found that 6% gingerenone A and 10% gingerol showed higher antioxidant activity at 60°C than 6% gingerol and 8% gingerol. Multiple essential oils demonstrate antioxidant activity: thyme oil inhibits lipoxygenase and acetylcholinesterase [21]; olive oil stimulates superoxide dismutase (SOD) production in rats, protecting against oxidative stress [22]; peony petal oil aromatic components strongly scavenge DPPH and ABTS radicals [23]. Han et al. [24] found that oregano flowers and leaves contain nearly 50% carvacrol and thymol, showing maximum antioxidant activity at 1.25 mg/mL. Wang et al. [25] reported that plant-derived extracts containing polyphenols, polysaccharides, alkaloids, and saponins exhibit varying antioxidant activity through different pathways. Thus, antioxidant mechanisms vary depending on active components.

2.3 Immunomodulatory Activity of Plant Essential Oils

Animals maintain health through humoral and cellular immunity. Essential oil active components can enhance immunity by regulating antioxidant enzyme levels and reducing pro-inflammatory cytokines [26]. The mechanisms remain unclear, but Alliaceae essential oils exhibit anti-inflammatory and antioxidant properties due to sulfur compounds [27]. Trans-2-hexenal in willow leaf oil inhibits Ca2+ influx in vascular smooth muscle, showing anti-inflammatory and anti-bronchospastic effects [28]. Jia et al. [29] noted that anti-inflammatory activity relates to antioxidant effects, modulating signal transduction pathways of cytokines and transcription factors to suppress pro-inflammatory gene expression at the molecular level. Zhang et al. [30] found that *Potentilla discolor* essential oil inhibits tumor cell growth and induces apoptosis through mitochondria-mediated intrinsic pathways. However, Bellassoued et al. [31] reported that 502 mg/kg peppermint oil fed for 7 days to CCl4-stressed rats showed no significant effects on serum ALT, AST, ALP, LDH, -GT activities or urea and creatinine levels, while pretreatment with 15 and 4,002 mg/kg significantly reduced these stress parameters. Studies show anise, cinnamaldehyde, and linalool significantly reduce IL-1 , IL-18 [32], TNF- , and IFN- [33] in mice. Xu et al. [34] and He et al. [35] demonstrated that essential oils improve growth performance, serum immune indices, alleviate intestinal inflammation, and reduce diarrhea incidence. Thus, essential oils possess anti-inflammatory and immunomodulatory activities, though mechanisms require further investigation.

2.4 Effects on Feed Intake and Nutrient Digestibility

Feed intake is essential for nutrient acquisition. Essential oils stimulate the trigeminal nerve to induce feeding behavior, stimulate appetite, promote digestive tract motility, and increase secretion of digestive juices and enzymes (saliva, gastric juice, bile, intestinal fluids), thereby improving nutrient digestibility. Chen et al. [36] found that essential oils increase feed intake through antioxidant and antimicrobial functions that inhibit harmful gut bacteria and enhance digestive enzyme activity. Wang [37] suggested that sweeteners in some plant extracts improve feed palatability, increasing preference and average daily feed intake in weaned piglets. Gan et al. [38] noted that essential oils improve nutrient and energy efficiency and regulate growth-related hormone secretion. However, Plg et al. [39] found that 1.5 g/kg red pepper essential oil did not improve growth performance or organ weight in weaned piglets, while 4.0 g/kg reduced diarrhea rates and improved performance. Yu et al. [40] reported that 600 mg/kg essential oil in low-energy diets (13.37 MJ/kg) significantly reduced feed conversion ratio compared to control (14.27 MJ/kg), improving economic benefits. In summary, essential oils as natural feed additives can increase feed intake and positively affect growth performance.

3 Application of Plant Essential Oils in Animals

Essential oils positively affect lipid metabolism [41-42], digestion [43], antimicrobial activity [44], anti-stress effects [45], antioxidant and anti-inflammatory properties [46-47], as confirmed by numerous studies.

3.1 Application in Swine Production

Essential oils improve growth performance, promote beneficial gut bacteria proliferation, and enhance pork quality. Studies show that adding 0.01% essential oil to weaned piglet diets significantly increased average daily gain, feed intake, and *Lactobacillus* counts, while improving serum leukocyte phagocytosis rates and immunoglobulin and complement 4 (C4) levels [48-49]. Diao et al. [50] found that 100 mg/kg thymol and 2,000 mg/kg benzoic acid increased ileal villus height and cecal propionate and total volatile fatty acids. Walia et al. [51] reported that an essential oil and organic acid blend reduced *Salmonella* in finishing pig feces to 27.9% on day 14, though not on day 28. Zhang et al. [52] found that essential oil supplementation reduced fecal ammonia nitrogen content and urease activity in weaned piglets. Research shows that essential oils in finishing pig diets maintain free radical balance, improve meat tenderness [53], increase intramuscular fat (IMF) and n-3 polyunsaturated fatty acids (n-3PUFA) [54], and enhance sensory quality and antioxidant status, though aromatic odors may alter meat flavor when used as preservatives [9]. Wang et al. [55] found essential oils reduce oxidative damage in sows, improve lactation performance, and reduce reproductive tract disease prevalence. These results indicate essential oils improve swine performance at all stages by inhibiting harmful bacteria, altering digestive enzyme activity, and enhancing immunity.

3.2 Application in Poultry Production

Essential oils in chicken diets improve nutrient digestibility, reduce nitrogen excretion, significantly increase body weight gain [56] and serum SOD activity [57], improve laying rate and egg quality [58], and affect intestinal wall structure and microbiota [59]. Zhang et al. [60] added 80 and 160 mg/kg essential oil (main components: eugenol, thymol, carvacrol) to broiler diets, finding significantly higher average daily gain, with 80 mg/kg reducing feed conversion ratio and 160 mg/kg increasing feed intake and feed conversion ratio. Du [61] found that 120 g/kg thymol and carvacrol upregulated mRNA expression of IFN- , IL-1 , and IL-4 in broiler intestines and significantly increased Newcastle disease and infectious bursal disease antibody titers. Altop et al. [62] reported that 0.08 g/kg pine resin essential oil in 1-day-old male broilers reduced jejunal *E. coli*, *Staphylococcus*, *Enterococcus faecalis*, and *Listeria* while increasing carcass, abdominal fat, and live weight. Chowdhury et al. [57] found that 300 mg/kg cinnamon bark essential oil in 1-day-old broilers significantly increased duodenal, jejunal, and ileal villus heights and serum SOD activity.

3.3 Application in Ruminant Production

Essential oils in ruminant diets improve nitrogen and energy utilization in the rumen [63], reduce methane production [64], and enhance meat quality [42]. Kholif et al. [65] found that 2 mL red pepper essential oil and 4 g enzyme mixture in lactating ewe diets improved feed conversion by 22.1% and increased milk unsaturated fatty acids by 10.6%. Wallace [66] reported that 100 mg/d essential oil reduced ammonia-producing bacteria by 77% in low-protein sheep diets but not high-protein diets. Cobellis et al. [67] found that essential oils significantly reduced methane and ammonia emissions in rumen fermentation. Studies show cinnamaldehyde at different pH levels affects volatile fatty acid production, increasing acetate/propionate at pH=7 but decreasing it at pH=5.5 [68]. Kahvand et al. [69] found sage essential oil positively altered rumen fermentation to produce more beneficial microorganisms. Khorrami et al. [70] reported that 500 mg/kg thyme and cinnamon essential oils could replace monensin as rumen modifiers, reducing *Fibrobacter succinogenes* and *Ruminococcus albus* populations. Thus, essential oils improve rumen fermentation, enhance nutrient absorption, and reduce environmental methane emissions.

4 Conclusion

In summary, essential oils are diverse, contain multiple active components, and possess important physiological functions. Dietary supplementation improves animal growth performance and nutrient utilization. Recent domestic research has advanced significantly, with microencapsulation formulations enabling targeted delivery and maximal biological activity. However, studies on synergistic effects with other additives are limited and require extensive validation. Additionally, research on essential oils as antibiotic alternatives is insufficient, necessitating investigation into efficacy and optimal dosages. Finally, mechanisms of action require further elucidation at the molecular nutrition level. Future research in these areas will promote the development and utilization of essential oils in animal production.

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Note: Figure translations are in progress. See original paper for figures.