PHYTOGENIC AND PHYTOCHEMICAL AS ALTERNATIVE FEED ADDITIVES FOR ANIMAL PRODUCTION

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FOREWORD

In recent years, the field of animal nutrition has witnessed a transformative shift towards more sustainable and eco-friendly practices. The growing concern over antibiotic resistance, the demand for natural and safe food products, and the overarching need for environmental sustainability have driven researchers and practitioners to explore alternative feed additives. It is within this context that "Phytogenic and Phytochemical as Alternative Feed Additives for Animal Production", written by a fantastic group of authors, and many other highly respected colleagues, emerges as an essential contribution to the scientific literature and practical applications in animal nutrition.

Phytogenic substances derived from plants are a promising alternative to conventional feed additives. Their natural origins and diverse bioactive properties make them invaluable for promoting animal health, enhancing growth performance, and ensuring feed and food safety. This book provides a comprehensive exploration of various phytogenics and phytochemicals and details their roles, benefits, and practical applications in animal nutrition.

The first chapter, "Phytogenic Substances as Novel Feed Supplements and their Application in Livestock Nutrition," sets the stage by introducing the fundamental concepts and potential of phytogenics in revolutionizing animal feed. This chapter underscores the importance of integrating natural substances into animal diets to foster sustainable and healthy animal production systems.

Following this, the chapter on "Phytobiotics in Animal Nutrition" delves deeper into the specific categories and mechanisms by which these plant-derived compounds exert their beneficial effects. This discussion extends beyond mere supplementation, encompassing broader implications for animal health and productivity.

Subsequent chapters provide an in-depth examination of specific phytogenic substances, such as thyme, rosemary, milk thistle, turmeric, oregano essential oils, ginger, bee pollen, and propolis. Each chapter offers detailed insights into the unique properties, modes of action, and practical applications of these remarkable plant-based and natural additives. For instance, the therapeutic and antimicrobial properties of thyme and rosemary essential oils, the hepatoprotective effects of milk thistle, the anti-inflammatory and antioxidant benefits of turmeric, and the multifaceted health-promoting attributes of ginger, bee pollen, and propolis have been thoroughly explored.

As an academic and practitioner dedicated to advancing sustainable and health-oriented approaches in animal production, this book is a timely and invaluable resource. This brings together the latest research findings, practical insights, and real-world applications, providing a holistic understanding of how phytogenics and phytochemicals can be harnessed to achieve more sustainable and resilient animal production systems.

I was delighted when I received a request to write a brief foreword to the reprint of this book because, for several years, I have admired authors for incredible work. I commend the authors for their rigorous research and thoughtful presentation on this critical subject. This book will undoubtedly serve as a cornerstone reference for researchers, practitioners, students, and policymakers keen to foster a more sustainable future in animal nutrition.

With great enthusiasm, I invite you to delve into this comprehensive guide and explore the vast potential of phytogenics and phytochemicals to enhance animal health and production.

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PREFACE

Phytogenic feed additives (PFAs) have emerged as significant substitutes for antibiotics in animal nutrition, thereby addressing the urgent need for alternative growth promoters and health enhancers in livestock production. Plant-derived substances, including phytogenic substances and their bioactive components such as essential oils, flavonoids, and saponins, have been used to enrich growth rates, feed utilization, gut health, and overall animal immunity, productivity, and health. However, the ban on antibiotics as growth promoters owing to their contribution to antimicrobial resistance, carry-over effects, and health concerns has necessitated the search for alternatives; PFAs have gained attention for their multifunctional benefits. They not only promote growth, but also enhance gut health, modulate microbiota, and improve oxidative status without adverse effects associated with antibiotic use. The efficacy of specific PFAs such as thyme, curcumin, milk thistle, rosemary, bee pollen, and propolis has been highlighted, demonstrating potent antioxidant and antimicrobial activities. The roles and importance of PFAs in animal nutrition, product safety, and quality are multifaceted. They are viable alternatives to antibiotics and contribute to sustainable livestock production and consumer health. Continued research and development of PFAs are crucial for optimizing their use and realizing their full potential in various animal species. This book provides up-to-date reviews on valuable natural phytogenic growth promoters to completely or partially replace antibiotics as classical growth promoters, thus decreasing the adverse effects of antibiotics on animals, humans, and the environment. The book also supplies the scientific basis of phytogenic additives and services to scientists, students, the livestock industry, and the feed and food sectors for their efforts to improve animal and human health, product quality, and food safety.

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CHAPTER 1

Introduction and Background

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Abstract: For centuries, plant-based ingredients extracted from herbs, spices, and medicinal flora have been used to enhance feed quality, flavor, and preservation, as well as in traditional healing medicine. As our understanding of their functional mechanisms grows, new opportunities arise for their application in the treatment of metabolic disorders and as feed supplements to promote positive physiological responses in various animal species. These naturally derived products are environmentally friendly and safe for living organisms, offering a wide range of beneficial properties, including antimicrobial, antioxidant, antiallergic, anticancer, antimutagenic, liver-protective, and immunomodulatory effects. Following the European Union's prohibition on antibiotic use as growth promoters in food-producing animals in 2006, researchers have turned their attention to natural alternatives, such as phytogenic substances, also referred to as phytobiotics or botanicals. These compounds have been demonstrated to boost animal productivity, encourage feed consumption, enhance nutrient absorption, and support optimal intestinal health. Promising feed additives include medicinal plants, such as milk thistle seeds, turmeric, rosemary leaves, and thyme. Additionally, bee pollen and propolis, which have both plant and animal origins, have been explored as substitutes for antibiotics and coccidiostats in animal nutrition, and have shown potential as growth enhancers and immune boosters. This book provides a comprehensive overview of the most commonly used natural substances as alternatives to growth-promoting antibiotics and details their mechanisms of action and effects in animals. The aim is to update the current knowledge and promote further research to identify additional beneficial natural molecules that can help reduce the negative impacts of antibiotics on animals, humans, and the environment.

Keywords: Animal nutrition, Antibiotic alternatives, Natural growth promoters (NGPs), Phytogenic feed additives.

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BACKGROUND

Since their discovery, antibiotics have been tested and used for growth promotion when incorporated into the diet at sub-therapeutic levels. In addition, it is strictly related to the antimicrobial effect, which is normally used for disease control and/or prevention. The use of antibiotics as growth-promoting agents in food-producing animals was banned in the European Union in the beginning of 2006 because of cross-resistance and possible residues in animal products. This has prompted researchers to search for natural alternatives to antibiotics.

INTRODUCTION

Herbs, spices, and medicinal plants contain phytogenic ingredients that have been essential to human and animal health since ancient times. They have been used mainly to improve feed quality, taste, and preservation and in flak medicine for centuries. Growing awareness and understanding of the mechanisms of action of phytogenic constituents may provide opportunities to develop therapeutic interventions for metabolic diseases and their use as feed additives to stimulate positive physiological activities in mammals, birds, and fish. Phytogenic plants are a good source of diverse types of antioxidants and bioactive molecules. Additionally, natural products are safe for both living organisms and the environment. However, their compositions vary widely owing to their botanical origin, agronomical and environmental factors, and processing methods. Medicinal herbs and their derivatives possess numerous antimicrobial, antioxidative, antiallergic, anticancer, antimutagenic, hepatoprotective, and immunomodulatory properties.

Phytogenic substances, called phytobiotics or botanicals, are a group of natural growth promoters (NGPs) used as feed additives and are derived from herbs or other plants, but also products of animal origin or, better, with a double vegetable and animal origin. In the past, these products have been used to enhance animal productivity, stimulate feed intake, and improve nutrient digestibility, thus improving the feed conversion ratio in farms. These effects are believed to be due to increased endogenous digestive enzyme secretion, nutrient absorption, antioxidant immune stimulation, and antimicrobial and anthelmintic properties. However, when the various products were studied in greater depth, and therefore their mechanisms of action were known more precisely and in detail, it became clear that they can also have a positive effect on the animal's health, in particular exerting a positive effect on the intestinal microbiota. Today, it is well known that the intestinal environment represents an important barrier to the entry of pathogens into an organism; therefore, maintaining a good health status of the intestine contributes to maintaining good health and well-being.

Medicinal plants are used as growth enhancers in animal production to boost economic performance, improve the gut ecosystem, increase milk yield, enhance food quality, and improve fertility. Milk thistle seeds (*Silybum marianum L. Gaert., Asteraceae*), turmeric (curcumin), rosemary leaves (*Rosmarinus officinalis L.*) and thyme (*Thymus vulgaris*) are possible feed additives that may have promising effects.

Bee pollen (BP) and propolis (Pro) are products of double origin, and the raw materials (pollen or propolis) are of vegetable origin. However, both raw materials are partially modified by honeybees, which, once collected, mix them with their salivary secretions. Therefore, the positive effects of BP and Pro are due to both the raw materials and secretions of the honey bee. BP and Pro have been investigated as alternatives to antibiotics and coccidiostats in animal nutrition. Some studies have shown that these substances can be used as growth promoters and/or immune enhancers instead of antibiotics, as both have very interesting antioxidant activity.

This book provides an overview of the most common natural substances currently used as alternatives to growth-promoting antibiotics. The description of the different substances, their mechanisms of action, and their effects on animals aims to provide a precise and updated picture of the state of the art, with the aim of stimulating further research in the identification of other natural molecules with benefits that could be present in the plant world and beyond, to decrease the adverse effects of antibiotics on animals, humans, and the environment.

CHAPTER 2

Phytogenic Substances as Novel Feed Supplements and their Application in Livestock Nutrition

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Abstract: Phytogenic substances derived from plant organs are bioactive compounds widely used to enhance health, food safety and shelf-life. These substances exhibit diverse biological activities, supporting animal and human health by promoting antioxidant defenses and enhancing immune function. They can mitigate the production of oxygen-containing reactive species (ROS) generated by environmental stressors, inhibit enzymes implicated in cellular damage, enhance mitochondrial function, and improve energy biosynthesis and availability. Incorporating phytogenic additives into livestock diets is a safe, effective, and economically viable strategy for mitigating the adverse effects of conventional feed additives on animal and human health. Reducing antibiotic use in livestock production is critical and can be achieved by integrating phytogenic substances, herbs, spices, medicinal plants, probiotics, prebiotics, synbio-

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tics, and postbiotics along with implementing robust biosecurity measures. This chapter emphasizes the role of phytogenic products as growth promoters in livestock production, and their potential applications in enhancing food safety and security. The subtherapeutic use of antibacterial drugs has significantly enhanced meat, egg, and milk production over the centuries. However, the use of antimicrobial agents promotes the selection of resistant microbes that can proliferate rapidly and become dominant within microbial populations, potentially compromising the effectiveness of treatment for microbial infections in humans.

Keywords: Antioxidants, Bioactive substances, Immunity, Production enhancers, Phytogenic.

INTRODUCTION

Phytogenic plants are rich sources of antioxidants and bioactive compounds, making them suitable alternatives to antimicrobial agents because of their beneficial effects on animal nutrition [1]. Phytogenic substances are environmentally safe and compatible with sustainable livestock production. However, their efficacy can vary significantly depending on factors such as processing methods, botanical origin, and agronomic and environmental conditions [1, 2]. Medicinal plants, herbs, spices, and their derivatives contain a wide array of bioactive compounds with diverse properties including antioxidant, antimicrobial [3], anti-allergic [4], anticancer [5], anti-mutagenic [6], hepatoprotective [7], and immunomodulatory [8] effects. Fig. (**1**) presents a historical overview of the inhibition of antibiotics as growth promoters, which has driven global research efforts to identify natural alternatives. Among these, phytogenic products have emerged as prominent candidates for replacing antibiotics in livestock production.

Phytogenic substances, also referred to as phytobiotics or botanicals, are natural growth promoters (NGPs) that are used as feed supplements derived from herbs or other plants to enhance animal productivity and improve digestibility [9]. Their effects are believed to stem from increased endogenous digestive enzyme secretion, improved nutrient absorption, enhanced antioxidant activity, immune stimulation, and potential antimicrobial and anthelminthic properties [10, 11]. Medicinal plants have been utilized to boost livestock performance by improving gut microbiota, milk yield, food quality, and fertility [12 - 18]. Various plant-derived feed additives, such as thyme [19, 20], milk thistle seeds [21 - 24], rosemary leaves [25, 26], and turmeric, have demonstrated promising effects on livestock immunity and overall health, based on cost-benefit analyses [16]. Additionally, probiotics and prebiotics, such as fructooligosaccharides and mannan oligosaccharides (MOS), have emerged as effective non-antibiotic growth promoters [27 - 33]. Organic acids and their salts, as well as essential oils, are recognized as safe by the EU, and have been widely adopted as natural feed additives in animal production [34 - 41]. Bee pollen and propolis have also been explored as antibiotic and coccidiostat alternatives in animal nutrition, with studies indicating that both can serve as growth promoters and immune enhancers [42 - 49]. This chapter focuses on the current alternatives to antibiotic growth promoters (AGPs) and their potential applications in animal nutrition. The aim was to encourage further research on natural growth promoters to replace AGPs, thereby reducing the detrimental effects of antibiotics on animals, humans, and the environment.

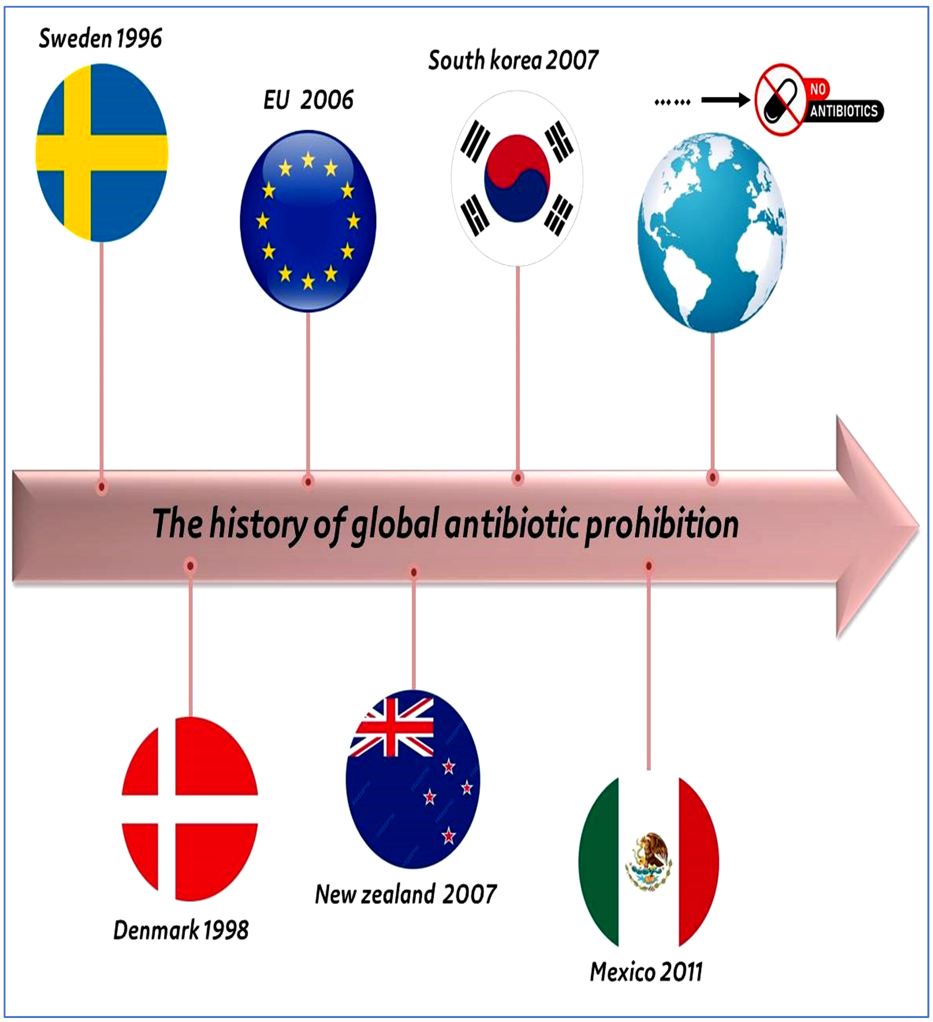

Fig. (1). The history of antibiotic prohibition.

CHAPTER 3

Phytobiotics in Animal Nutrition

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Abstract: The modern animal industry faces a persistent challenge: meeting growing consumer demand for high-quality, low-cost food while maintaining stringent standards of sanitation, health, and welfare. In recent decades, antibiotic-supplemented diets have been widely adopted to maximize the growth potential of livestock. However, alternative approaches have emerged, including the use of phytochemicals as substitutes for antibiotics, to enhance avian productivity. Phytobiotics, which consist of herbs and their derivatives, have numerous therapeutic effects and are available in various forms. Recently, this type of feed manipulation has gained popularity in the animal industry as an alternative to antibiotics, primarily because of the lack of adverse

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side effects and their ability to bolster the immune system and improve stress tolerance. In addition to enhancing intestinal integrity and reducing gut damage, phytobiotics promote increased feed intake by compensating for the nutritional demands of local and systemic immune responses. Furthermore, they reduce the concentration of pathogenic microflora in the gastrointestinal tract and mitigate the local inflammatory responses. In poultry, these benefits are demonstrated by improved feed consumption, increased digestive enzyme secretion, and enhanced immune function. Phytobiotics exhibit a wide range of biological activities, including immunity-boosting, antibacterial, antiviral, coccidiostatic, antiparasitic, anti-inflammatory, and antioxidant properties. Herbs and their derivatives have been used since ancient times for their health benefits and minimal side effects. However, recent studies have highlighted that certain herbs and their metabolites may pose risks, raising concerns among consumers regarding the safety of using these compounds as feed supplements or treatments. This chapter explores the beneficial effects and latest developments related to phytobiotics and highlights their practical applications and health advantages. Understanding these features is essential for veterinarians, scientists, pharmacists, physiologists, pharmaceutical industries, nutritionists, and animal breeders as they consider the use of phytobiotics in modern animal husbandry.

Keywords: Essential oils, Herbs, Nutritionists, Phytobiotics, Reproductive performance.

INTRODUCTION

Herbs have emerged as a relatively new class of growth promoters, attracting significant interest in the animal feed industry in recent years. This category includes a wide range of herbs, spices, and their derivatives, with essential oils being the most common [1, 2]. For thousands of years, humans have utilized plant-based products for nutrition and treatment of various ailments [3]. In ancient societies, natural remedies derived from herbs and spices have been used as feed supplements for domestic animals, paralleling the use of pharmaceutical products. Windisch *et al.* [4] defined phytobiotics as plant-derived constituents incorporated into the diets of livestock to enhance performance. This term distinguishes them from plant products used for pharmacological purposes such as the prevention and treatment of specific health conditions. As efforts to eliminate antibiotic growth promoters have intensified in many regions, phytobiotics have emerged as a promising natural alternative containing biologically active compounds. Unlike synthetic antibiotics or inorganic chemicals, phytobiotics are natural, residue-free, and non-toxic [5], making them suitable as feed supplements in livestock production.

This chapter explores the various beneficial applications and newly discovered aspects of phytobiotics. These features are particularly relevant to scientists, physiologists, nutritionists, pharmacists, veterinarians, the pharmaceutical industry, and animal breeders.

PHYTOBIOTICS AND THEIR CHARACTERISTICS

Phytobiotics are derived from various plant parts, including the leaves, roots, flowers, and even entire plants. The products may consist of dried whole plants or plant portions as well as extracts containing specific bioactive components. Phytobiotics are generally classified based on their primary and secondary plant compounds [6]. Primary compounds include basic nutrients such as proteins and fats, while secondary compounds comprise essential (ethereal) and volatile oils, bitters, pungent substances, colorants, and phenolic compounds, among others [7].

In general, phytobiotics have minimal effects on the intake of primary nutrients by animals. Thus, secondary plant compounds are of primary interest because of their biologically active properties [8 - 10].

Phytobiotics can be categorized into four main classes, each of which encompasses a wide array of substances.

- Spices: Plants with strong aromas or flavors commonly used as food additives (*e.g.*, garlic, ginger, and cinnamon).
- Herbs: Non-woody, non-perennial flowering plants, used either whole or in part (*e.g.*, flowers, roots, leaves).
- Essential oils: Volatile lipophilic components extracted from plants.
- Oleoresins: Concentrated extracts from spices containing both volatile and non-volatile compounds [11] (Fig. **1**).

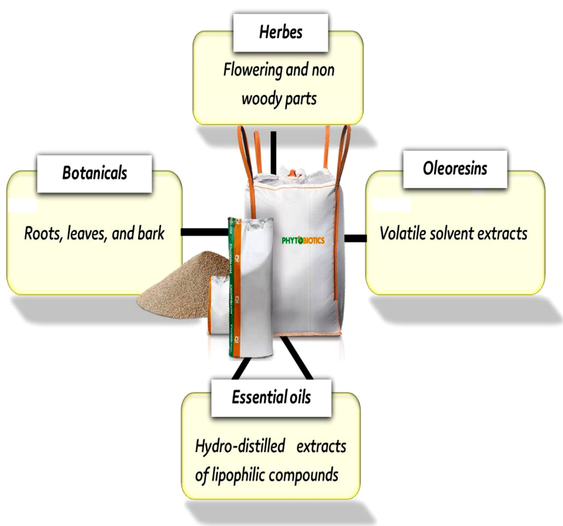

Fig. (1). Classes of phytobiotics.

CHAPTER 4

Thyme

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Abstract: *Thymus vulgaris* L., a member of the *Lamiaceae* family, is a herb widely used in conventional medicine because of its various therapeutic properties. Thyme, mostly cultivated in the Mediterranean region, is used as a spice and medicine worldwide, owing to its antioxidant and antibacterial properties. This chapter focuses on data supporting the use of thyme as a productive enhancer in animal feed and as a partial or full substitute for antibiotics. The essential oils found in the aerial portions of thyme are a source of fragrance and therapeutic qualities. The main active constituents

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of thyme extract are thymol, carvacrol, and other mono- and sesquiterpenes. These compounds contribute to the flavor, fragrance, and antibacterial properties of thyme. The effect of thyme on animal performance is attributed to its bioactive compounds, which vary depending on several factors. Thyme supplementation has been documented to be advantageous in poultry production, with thymol reported to prevent oral bacterial infections and to influence the permeability of pathogenic bacterial cell walls, leading to cell death. Essential oils from thyme can also support digestive functions by stimulating endogenous enzyme activity, nitrogen absorption, and regulating the ammonia content and odor of excreta. The antibacterial properties of thyme are influenced by the chemical structure and lipophilic characteristics of its essential oils, allowing them to pass through bacterial membranes and affect the interior of the cell.

Keywords: Antibiotic, Feed additives, Growth promoters, Poultry, Thyme.

INTRODUCTION

Thyme (*Thymus vulgaris* L.) (Fig. **1**), a member of the *Lamiaceae* family and regionally known as “zaatar” or “zaitra” in Arabic, is used extensively in folk medicine for its expectorant, antitussive, antispasmodic, antibroncholitic, anthelmintic, carminative, and diuretic properties. Thyme is a widely used medicinal herb that is mostly cultivated in the Mediterranean region and used worldwide for culinary and medicinal purposes. Owing to its antibacterial and antioxidant properties, it is a herbal plant that has received increasing attention [1 - 3]. Many fragrant herbs of significant scientific and commercial value, including thyme, marjoram, mint, rosemary, and oregano belong to the *Lamiaceae* family. The essential oils found in the peltate glandular trichomes in the aerial portions of the herbs are the source of the scent associated with this vegetation. Highly specialized secretory cells are found in glandular trichomes, where essential oils are produced and stored in a subcuticular storage chamber [4]. *Thyme* is a widespread plant worldwide because of its fragrant and therapeutic qualities. Some *Thymus* species are utilized as medicinal herbs, herbal teas, and flavorings (condiments and spices) [5]. The genus *Thymus* includes 18 wild species and one cultivated species, *Thymus vulgaris* L., a fragrant plant [6]. *Thymus vulgaris* exhibits polymorphic diversity in the synthesis of monoterpenes, and the genus *Thymus* is known for its intraspecific chemotype variation. The names of the six chemotypes were derived from their predominant monoterpenes: α-terpineol (A), geraniol (G), thuyanol-4 (U), carvacrol (C), linalool (L), and thymol (T) [5, 7, 8]. (Fig. **1**) shows the primary active ingredients found in the thyme extract.

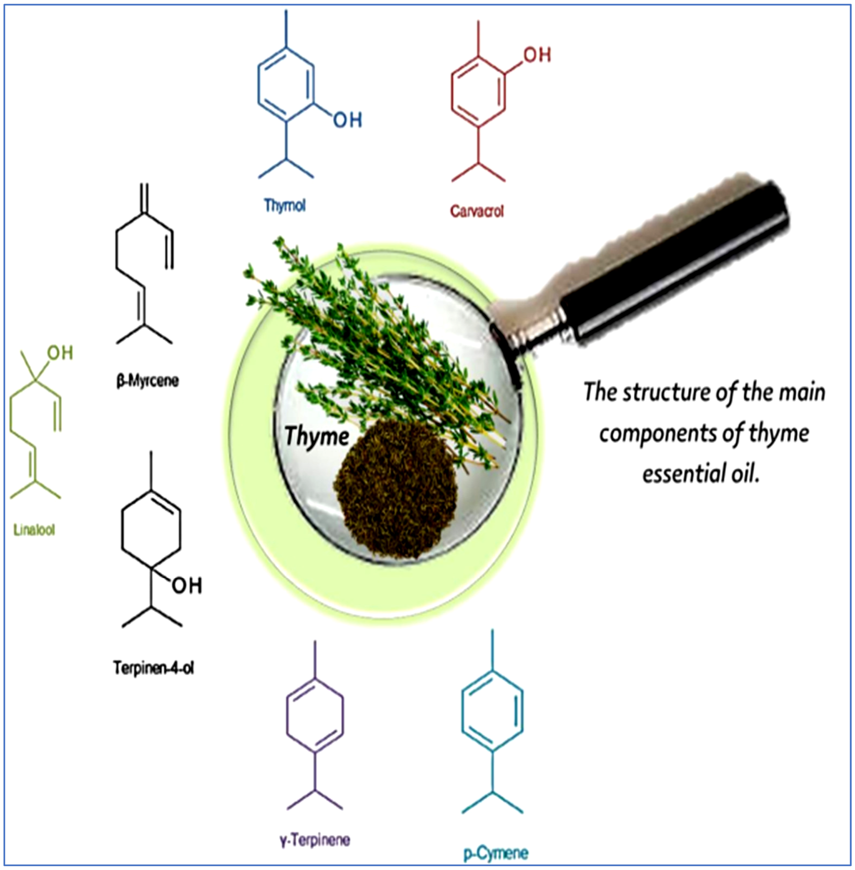

Fig. (1). The main active constituents present in thyme extract.

Thymus vulgaris contains several active compounds, including phenols, such as thymol (40%) and carvacrol (15%), according to Mikaili *et al.* [1]. Furthermore, Stahl-Biskup [5] discovered that mono- and sesquiterpenes predominate in the makeup of marjoram and thyme essential oils. These substances give these plants their flavor and fragrance, and the essential oils extracted can be utilized as antibacterial or antiseptic agents in pharmaceutical and medical applications, as well as in the production of cosmetics and fragrances [5, 9, 10]. Mono- and sesquiterpenes are believed to protect vegetation from herbivores and infections [11]. Carvacrol and thymol, two monoterpenes of the *Lamiaceae* family frequently found in thyme, have attracted considerable attention. The main benefits of these two phenolic monoterpenes are their antiherbivorous, antibacterial, and antioxidant properties [12 - 15]. A total of 41 components (97.85% of the total detectable compounds) were identified by GC and GC–MS analysis of the essential oil from thyme [5]. β-pinene (4.32%); borneol (5.03%), 1, 8-cineole (5.57%), α-pinene (9.55%), camphene (17.57%), and camphor (39.39%)

CHAPTER 5

Rosmarinus officinalis (Rosemary)

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Abstract: Rosemary is a phytogenic aromatic plant, abundant in phenolic acids, such as caffeic (0.69-1.0 mg/g) and rosmarinic acids (16.77-29.91 mg/g), flavonoids, and diterpenes. Additional components of rosemary include camphor, 1,8-cineole, and α-pinene. Rosmarinic acid (RA) exhibits antioxidant, antiviral, antibacterial, anti-inflammatory, and antimutagenic properties. Furthermore, rosemary significantly reduced the peroxidation of unsaturated lipids and enhanced the levels of reduced glutathione and antioxidant enzyme activities in the kidney and testis compared to aspartame controls. Additionally, rosemary essential oil augments the resistance of rat

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hepatocytes against DNA-damaging oxidative agents and serves as an effective free radical scavenger. Caffeic and rosmarinic acids have demonstrated potential in the treatment of inflammatory diseases and hepatotoxicity. Rosemary is also rich in phyto-chemical derivatives such as triterpenes, flavonoids, and polyphenols. This review will focus on the beneficial effects of rosemary and its application in improving the productive performance and health of livestock.

Keywords: Bioactive substances, Immunity, Livestock, Productive performance, Reproductive, Rosemary.

INTRODUCTION

Rosmarinus officinalis L., commonly known as rosemary, from the family *Lamiaceae* [1] is a perennial shrub with fragrant leaves (Fig. **1**). It is popular for culinary use because its leaves have a pungent and slightly bitter taste [2].

Fig. (1). Rosemary plant.
Source: Contribution of Hans by Pixabay [3].

Rosemary is a phytogenic aromatic plant, rich in phenolic acids, such as caffeic (0.69-1.0 mg/g) and rosmarinic acids (16.77-29.91 mg/g), flavonoids, and diterpenes [4, 5]. Other components of rosemary include camphor, 1,8-cineole, and α-pinene [6].

Rosmarinic acid is an ester of 3,4-hi hydroxyphenyl lactic acid and caffeic acid [7], which has antioxidant [4, 8, 9], antiviral [10 - 12], antibacterial [13, 14], anti-inflammatory [4, 15, 16], and antimutagenic [17] properties.

Moreover, rosemary significantly decreased the elevation in peroxidation of unsaturated lipids and boosted the levels of reduced glutathione and antioxidant enzyme actions in the kidney and testis compared to aspartame controls [4, 18, 19]. Furthermore, Isles *et al.* [20] and Harvàthová *et al.* [21] stated that rosemary essential oil enhances the resistance of rat hepatocytes to DNA-damaging Caffeic and rosmarinic acids, which have the potential to treat inflammatory diseases and hepatotoxicity [22, 23]. Rosemary is also rich in phytochemical derivatives such as triterpenes, flavonoids, and polyphenols [4, 24, 25] and can protect against oxidative stress as an effective agent for scavenging free radicals [26, 27]. Fareed *et al.* [28] showed that rosemary essential oil restored normal kidney function in diabetic rats, reducing the blood glucose, urea, creatinine, uric acid, malondialdehyde, and catalase concentrations to normal levels.

Rosemary contains many bioactive compounds such as phenolic acids; polyphenols, phenolic diterpenoid bitter substances, tripenoid acids, flavonoids; 1.2 to 2.5% volatile oil, and tannins [29, 30]. Epirosmanol phenolic diterpenes of rosemary prevent peroxidation of unsaturated lipids [31]. Rosemary also contains essential components such as carnosic acid, carnosal, and caffeic acid, and its derivatives such as rosmarinic acid. These constituents displayed potent antioxidant activities. Moreover, rosemary and its components have therapeutic potential for peptic ulcers, bronchial asthma, liver toxicity, prostate disorders, stroke, inflammatory diseases, leukemia, atherosclerosis, ischemic heart disease, and cataracts. It is widely utilized in food processing as a flavoring agent and spice [22]. The main bioactive compounds of rosemary are illustrated in Fig. (**2**).

Effects on Livestock Productive Performance

The beneficial effects of rosemary supplementation on the productive performance of animals could be ascribed to its bioactive substances, such as borneol, carnosol, carnosic acid, and caffeic acid. These substances stimulate the digestion of nutrients by increasing digestive enzymes and boosting nutrient utilization through heightened liver function [32, 33].

In addition, 1% rosemary can be used as an antimicrobial agent for broiler chickens [34], decreasing the presence of *E. coli*, *Salmonella typhimurium, Bacillus cereus*, and *Staphylococcus aureus* [35] and enhancing animal health and performance [36]. The antibacterial effect is due to the interaction with the cell membrane, which changes the genetic material and the transport of electrons, allowing the leakage of cellular components and the loss of membrane functionality and structure [37].

CHAPTER 6

Silybum marianum (Milk Thistle)

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Abstract: Silymarin, a polyphenolic flavonoid complex extracted from milk thistle seeds (*Silybum marianum*), has a wide range of therapeutic properties, including anti-inflammatory, immunomodulatory, and antioxidant effects. This review explores the applications of milk thistle and silymarin in animal nutrition, focusing on their effects on productive performance, animal health, metabolic profiles, and detoxification processes. Milk thistle seeds contain various nutritional components that have been shown to improve nutrient utilization, stimulate appetite, and enhance the intestinal environment. Studies have reported that milk thistle supplementation significantly improves productive performance, carcass yield, and digestibility in growing rabbits, broilers, and quail. The hepatoprotective effects of milk thistle are attributed to its inhibition of lipid peroxidation, stabilization of membrane permeability, reduction of apoptosis in hepatocytes, and limited leakage of hepatic enzymes. The potent antioxidant properties of silymarin protect cells from oxidative stress by scavenging reactive oxygen species and inhibiting lipid peroxidation. Milk thistle extract also acts

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as a free radical scavenger, protecting against glutathione depletion, and enhancing glutathione peroxidase activity in the brain and kidneys. Furthermore, milk thistle supplementation has been shown to improve hematological parameters, such as leukocyte count, hemoglobin levels, and packed cell volume, in birds exposed to ochratoxin A. The beneficial effects of milk thistle on animal immunity, oxidative stress, performance, and reproduction make it a valuable candidate for use as a feed additive in animal nutrition.

Keywords: Antioxidants, Livestock, Liver function, Milk thistle, Productive performance, Silymarin.

INTRODUCTION

Silybum marianum, commonly known as milk thistle, is a spiny herb belonging to the *Asteraceae* family and has a long history of medicinal use. Theophrastus, in the 4th century BC, was likely the first to describe it under the name "Pternix." Later, it was referenced by Dioskurides in Materia Medica and by Pliny the Elder in the 1st century AD [1]. Milk thistle seeds (MTS) contain various nutritional components, with moisture levels ranging from 5.01% to 6.27%, ash from 1.25% to 2.37%, fat from 19.74% to 23.19%, fiber from 4.39% to 7.40%, protein from 20.74% to 30.09%, and nitrogen-free extract from 34.13% to 45.42% [2].

Silymarin, a polyphenolic flavonoid complex extracted from MTS [3], comprises silybin A and B, isosilybin A and B, silydianin, silychristin, and isosilychristin [4 - 7]. These compounds have demonstrated estrogenic effects in ovariectomized rats [8], with silibinin binding to cytosolic estrogen receptors [9, 10]. The antioxidant properties of milk thistle have been extensively studied and confirmed by Camini and Costa [5], Aghemo *et al.* [11], and Yardimci *et al.* [12], with silybin being the primary bioactive component, constituting about 4-6% of the milk thistle seed extract [13].

In addition to silybin, MTS contains other health-promoting components, including lipids such as triglycerides, proteins, sugars, tocopherol, sterols [14], silybonol, apigenin, betaine, fixed oils, and free fatty acids [15]. Milk thistle has been used for centuries in Europe to treat various dysfunctions, particularly in the liver, gall bladder, heart, and kidneys [16 - 20]. The health effects of silymarin are attributed to its numerous beneficial properties, including anti-inflammatory [21, 22], immunomodulatory [23, 24], and antioxidant activities [5, 11]. Additionally, silymarin enhances protein synthesis [6, 25] and mitigates the effects of toxins [26, 27]. The active ingredients present in MTS and their beneficial properties are shown in Fig. (**1**).

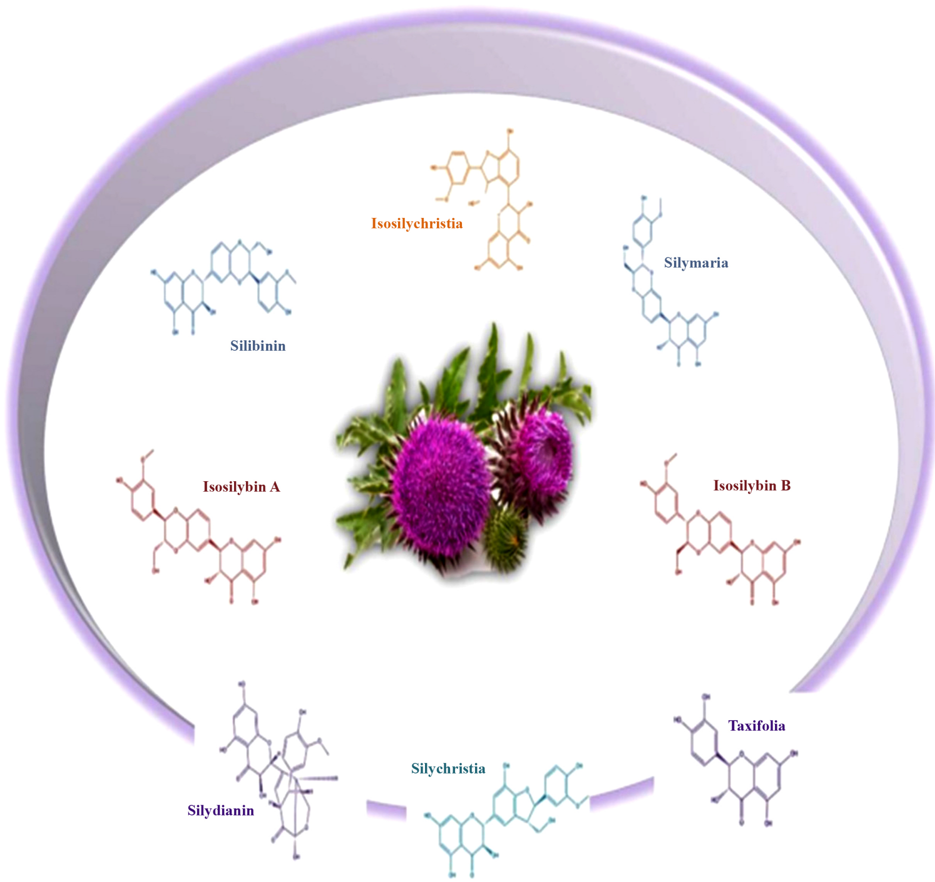

Fig. (1). Active ingredients present in MTS.

Effect of Milk Thistle on Productive Performance

Milk thistle seeds (MTS) have demonstrated the potential to improve nutrient utilization [28, 29], stimulate appetite [30, 31], and enhance the intestinal environment by increasing lactic acid bacteria concentrations and reducing harmful bacteria [32, 33]. These effects positively influence the productive performance of the animals.

Several studies have reported the effect of milk thistle on the productive performance of poultry and other animals [10, 25, 34]. For instance, Attia *et al.* [33] observed that MTS supplementation at 10 g/kg significantly improved productive performance, carcass yield, and digestibility of crude protein, organic matter, and dry matter in growing rabbits compared with the control group, with the best results at 10 g/kg inclusion. Similarly, Bagno *et al.* [35] demonstrated that

CHAPTER 7

Turmeric (*Curcuma longa*)

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Abstract: Two molecules of feruloyl-CoA and one molecule of malonyl-CoA are combined to generate turmeric (*Curcuma longa*), also known as curcumin, through two enzymatic processes mediated by curcumin synthase (CURS) and DIKETIDE-CoA SYNTHASE (DCS). DCS and CURS are members of polyketide synthase family type III. Turmeric, a homegrown spice, has several health benefits in the medical field. One specific bioactive ingredient produced by turmeric is curcumin, a polyphenolic phytochemical with antibacterial, anti-inflammatory, anticancer, and antioxidant properties. Research indicates that turmeric can substitute for antibiotics in chicken feed and is effective. When powdered turmeric rhizomes are fed to broiler chicks, morbidity and mortality are reduced. Furthermore, it has been shown that including turmeric in chicken feed does not negatively impact the overall health of animals. The use of turmeric in animal nutrition as a helpful feed additive, as well as its bioactive components and effects on blood biochemistry, animal health, and productive performance as an antibiotic substitute, will be covered in this chapter.

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Keywords: Animal health, Bioactive substances, Growth promoter, Livestock, Productive performance, Turmeric.

INTRODUCTION

Over the past 10 years, commercially available antibiotics have been added to chicken feed to aid in defense against exogenous infections [1 - 3]. Antibiotics may be harmful to public health even if they help reduce morbidity and mortality issues related to the production of poultry [4, 5]. Since January 2006, antibiotics have been prohibited in poultry feed across Europe [4]. As a result, to produce chicken feed without antibiotics, enterprises must find necessary alternatives [6]. Antibiotic-free meals are supplemented with a variety of bioactive substances to enhance animal production and quality of life [7 - 9].

Medical biology makes extensive use of the household spice turmeric (*Curcuma longa*); (Fig. **1**) [10]. One specific bioactive ingredient of turmeric is curcumin, a polyphenolic phytochemical with antibacterial, anti-inflammatory, anticancer, and antioxidant activities [10 - 12]. Present research indicates that turmeric may replace antibiotics in chicken feed and is successful in doing so [1]. The addition of turmeric rhizome powder to poultry feed lowers the morbidity and mortality of meat-type chickens [10]. Furthermore, it has been shown that turmeric in chicken feed does not negatively affect the health of animals [1].

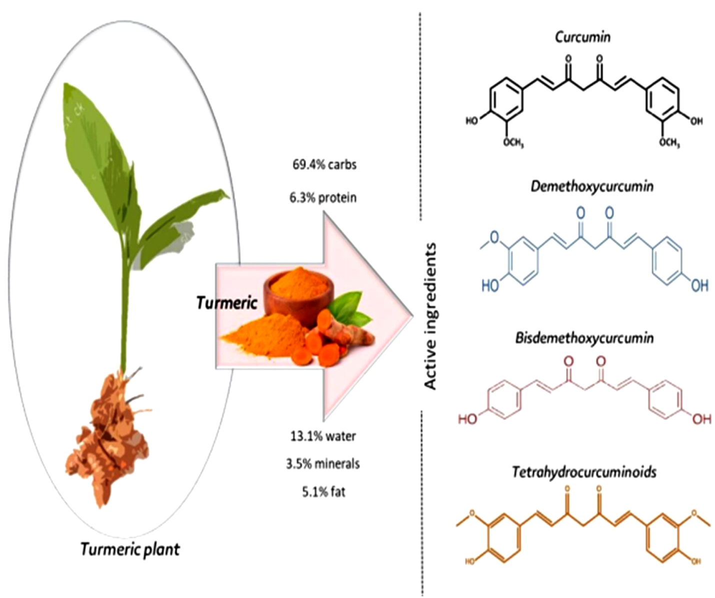

Fig. (1). The main bioactive ingredients present in turmeric extract.

Two molecules of feruloyl-CoA and one molecule of malonyl-CoA combine to generate curcumin through two enzymatic processes mediated by DIKETIDE-CoA SYNTHASE (DCS) and CURCUMIN SYNTHASE (CURS). The type III polyketide synthase family includes DCS and CURS [13 - 15].

Importance of Turmeric Feed in Poultry Nutrition

Humans employ an abundant supply of bioactive compounds found in turmeric rhizomes for both medicinal and non-medicinal purposes [16, 17]. Turmeric is a natural, safe, and appropriate dietary supplement that is often included in the daily diet, as opposed to antibiotics that are easily obtained on the market [17, 18]. Turmeric is composed of 69.4% carbohydrates, 6.3% protein, 5.1% fat, 3.5% minerals, and 13.1% water [19, 20]. It also contains large amounts of the phenolic constituents curcumin, dimethoxy curcumin, bisdemethoxy curcumin, and metabolites of tetrahydrocurcumin [21, 22]. Turmeric polyphenolic molecules have a wide range of biological activities, including antiviral, anti-inflammatory, antibacterial, antihypertensive, anti-carcinogenic, and anti-fungal activities [23, 24].

The body weight and growth rate of broiler chicks were greatly boosted by adding turmeric powder to their food, according to the literature that is now accessible [26]. Turmeric supplements stimulate the digestive system by increasing intestinal maltase, lipase, and sucrose activity as well as pancreatic lipase, amylase, trypsin, and chymotrypsin synthesis [27, 28]. Evidence suggests the beneficial effects of turmeric on chicken egg production [29]. Supplementation of the diet with turmeric increased egg production, yolk weight, and yolk index [29]. However, the effectiveness of turmeric as a natural growth booster has been debated. This section reviews the literature that has been reported in this field.

Bio-active Compounds

Turmeric contains a variety of bioactive compounds, including curcumin, demethoxycurcumin, bisdemethoxycurcumin, and tetrahydrocurcuminoids [11, 14, 30 - 32]. These compounds have antioxidant, anti-inflammatory, and nematocidal properties [13, 15, 30, 33 - 37], as well as protective properties against aflatoxin-induced hepatocarcinogenesis, mutagenicity [38, 39], and coccidiosis [40 - 43]. (Fig. **1**) summarizes the bioactive components of the turmeric plants.

Growth Performance

The benefits of supplementing chickens with turmeric at 0–10 g/kg have been inconsistently reported. For instance, broilers fed diets containing 5 g/kg turmeric

CHAPTER 8

Oregano Essential Oils

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Abstract: Essential oils (EOs) are aromatic products made from a combination of components extracted from plant materials used in food, cosmetics, and medicine, among several other applications. EOs are extracted using various extraction methods from the bark, seeds, leaves, peel, buds, flowers, and other components of medicinal plants. Techniques used to extract EO include steam distillation, solvent-assisted extraction, hydrodistillation, ultrasonic extraction, supercritical fluid extraction, and solvent-free microwave extraction. EO affects the intestinal health and growth efficiency of different animal species. EO has been reported to improve pancreatic amylase, trypsin, and maltase levels and increase digestibility. EO has antioxidant action, lowers lipid oxidation in meat, and enhances shelf-life. The present chapter summarizes some of the beneficial effects of oregano EO on poultry production and health.

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Keywords: Essential oil, Gut health, Growth promoter, Livestock, Oxidative stress.

INTRODUCTION

For several decades, antibiotics have been used as growth and health promoters in animal production [1]. Feed additives can also improve animal performance. However, some additives may be added as substitutes for antibiotics to prevent disease. The effectiveness of feed additives varies significantly [2]. One such additive is essential oils (EO), which have broad effects on different parameters of poultry under various management and environmental conditions [3, 4].

Essential oils are aromatic products made from a combination of components extracted from plants. These plants' products are utilized in food, cosmetics, and medicine, among several other applications [5], and the EO are extracted using a variety of extraction methods from the bark, seeds, leaves, peels, buds, flowers, and other components of medicinal plants [6]. The methods used to extract EO include steam distillation, solvent-assisted extraction, hydro distillation, ultrasonic extraction, supercritical fluid extraction, and solvent-free microwave extraction [7].

The primary ingredients of each oil vary [3]. Sesquiterpenes, monoterpenes, aldehydes, alcohols, esters, and ketones constitute some of the various volatile compounds that constitute essential oils. They have been linked to the development of plant defenses against pathogens, herbivores, fungi, and bacteria [8]. Essential oils are used as feed additives in animal production because of their antiviral, antimicrobial, anti-parasitic, and antifungal properties. Additionally, EO plays a role in appetite stimulation, enhancing the secretion of food digestion enzymes and activating the immune response [9].

EO affects the intestinal health and growth efficiency of pigs [10, 11], fishes [12 - 14], rabbits [15, 16], poultries [17 - 19], and ruminants [20 - 22]. Jang *et al.* [23] showed that broilers fed a combination of EO exhibited higher pancreatic trypsin, amylase, and maltase (digestive enzyme activity) in the gut compared to birds not fed EO.

Therefore, greater nutritional absorption may result from a combination of the antibacterial action of EO and an increase in digestive secretions. Changes in the microscopic anatomy of the small intestine and shifts in the gut microbiota are the two primary mechanisms by which EO affect gut health. When these two effects are combined, animals can better fight diseases from pathogenic organisms [24, 25].

Little information is available, particularly on the effect of EO on intestinal histology in poultry. Because of their antioxidant action, EO, including oregano, sage, carvacrol, thymol, and rosemary, are also known to reduce lipid oxidation in meat [25 - 27]. The present chapter summarizes some of the beneficial effects of oregano EO on poultry production and health.

OREGANO ESSENTIAL OILS

Origanum vulgare, also known as wild marjoram (family *Lamiaceae*), is native to North America, originally from the Mediterranean, and has a long history of use as a food and medicinal plant. Its name is derived from the Greek, origanon, a perennial herb that can be as tall as 80 cm, with dark oval, fragrant leaves, and spikes of pink, white, or purple flowers [28]. Oregano essential oil (OEO) contains high concentrations of carvacrol, p-cymene, c-terpinene, limonene, terpinene, ocimene, caryophyllene, β-bisabolene, linalool, and 4-terpineol [29].

Chemical and Bioactive Constituents

Alkhafaji and Jayashankar [30] discovered 66 distinct compounds in oregano oil, which accounted for 100% of the makeup. Oregano oil has been shown to have a 187.94 mg KOH/g saponification value, a 6.22 mg/g peroxide value, and a 3.645 mg/g P-anisidine value.

Carvacrol and thymol represent most of the phenolic chemicals found in oregano oil, accounting for more than 50% of it [31]. Terpenes, typically mono- and sesquiterpenes, are the main elements of EO and carvacrol, while thymol, -terpinene, and p-cymene are the primary terpenes found in oregano [32, 33], as shown in Fig. (**1**).

The chemotype of a species is determined by the ratio of these and other essential oil (EO) components. Typically, the main EO components are used to designate the chemotype, such as carvacrol, thymol, -citronellol, and 1, 8-cineole. For instance, Lukas *et al.* [34] identified three chemotypes of *O. vulgare* based on the amounts of cymyl-, sabinyl-, and linalool/linalyl acetate in extracts of 502 distinct plants from 17 different nations.

Mechanism of Biological Activity

Herbal plants can affect animal health and production in several ways. Many plants have antioxidant, antimicrobial, anti-inflammatory, and antiproliferative properties [32, 35, 36] that enhance digestibility, immunity, and intestinal health [19, 37].

CHAPTER 9

Zingiber officinale (GINGER)

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Abstract: *Zingiber officinale*, commonly known as ginger, is a spicy plant with active ingredients such as gingerol and shogaol (Fig. **1**). Ginger has been widely used in traditional medicine to improve digestion, as it has been shown to increase the digestive enzyme protease (zingibain). Ginger is well known for its antibacterial and antiphlogistic properties, in addition to its ability to lower cholesterol levels in the bloodstream. In this chapter, we focus on the use of ginger as a feed supplement for enhancing poultry nutrition and the impact of this phenomenon on productive efficiency, carcass characteristics, hematology, gut microbiota, and toxicity.

Keywords: Blood biochemistry, Carcass traits, Gut microbiota, Ginger, Productive performance, Toxicity.

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INTRODUCTION

Ginger, scientifically known as *Zingiber officinale*, exhibits properties that are both antioxidant and hypoglycemic in nature [1 - 5] along with providing immunological advantages and enhanced digestive functions. According to emerging evidence, ginger can also be utilized as an alternative phytogenic growth enhancer for antibiotics [6, 7]. Furthermore, some studies have found that ginger can have favorable effects on weight gain, feed efficiency, and survival rate in animals [8 - 11]. It has been seen that the recommended dose of ginger in the poultry diet should be around 1% [12 - 14]. However, an increase in the ginger dose by more than 1% would result in an increase in expenditure associated with nourishment [15, 16]. Moreover, the results from adding intermittent supplementation were similar to those obtained from continuous supplementation with ginger, and this reduced the cost with the same outcome, showing a better economic benefit [17 - 19]. Ginger was found to have a positive influence on improving the antimicrobial and antioxidant status of animals and this results in improving overall performance [2, 20, 21] and in enhancing the quality of poultry products [22, 23]. Antioxidants can mitigate the undesired effects of exposure to stressful conditions by modulating inflammatory responses and physiological functions. In addition, antioxidants can enhance the viability of animals by boosting immunity and product quality [24 - 26]. In addition, chickens receiving higher vitamin E supplementation than the commonly recommended levels could be a useful subject to enhance both performance and immunity [27]. The chemical composition and bioactive constituents of ginger are shown in Fig. (**1**).

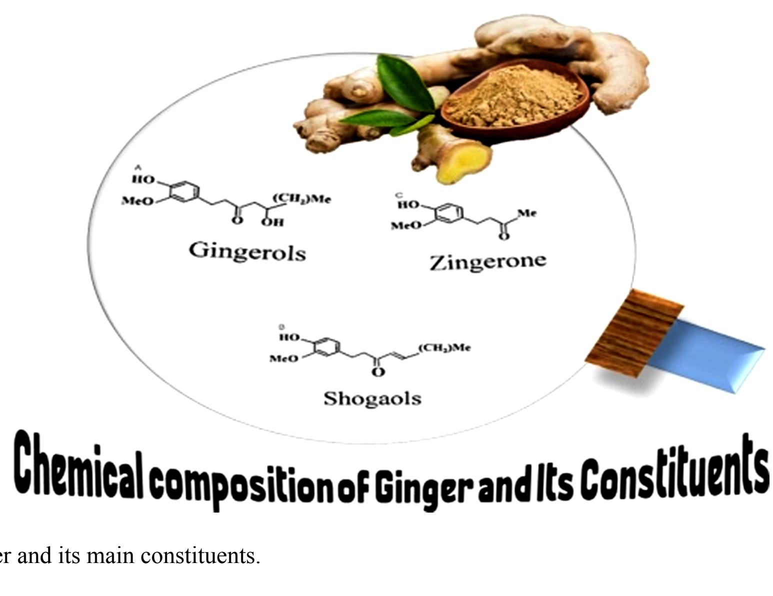

Fig. (1). Ginger and its main constituents.

APPLICATION METHODS OF FEED ADDITIVES

In recent years, more attention has been paid to the application methods that feed additives, and this is a result of the low cost of their supplementation [9]. This may be most effective during stressful conditions (heat stress, vaccination, handling, transportation, diseases, and debeaking) and/or early ages of animals Nasir and Grashorn [18]. The importance of ginger application in broiler diets is illustrated in Fig. (**2**).

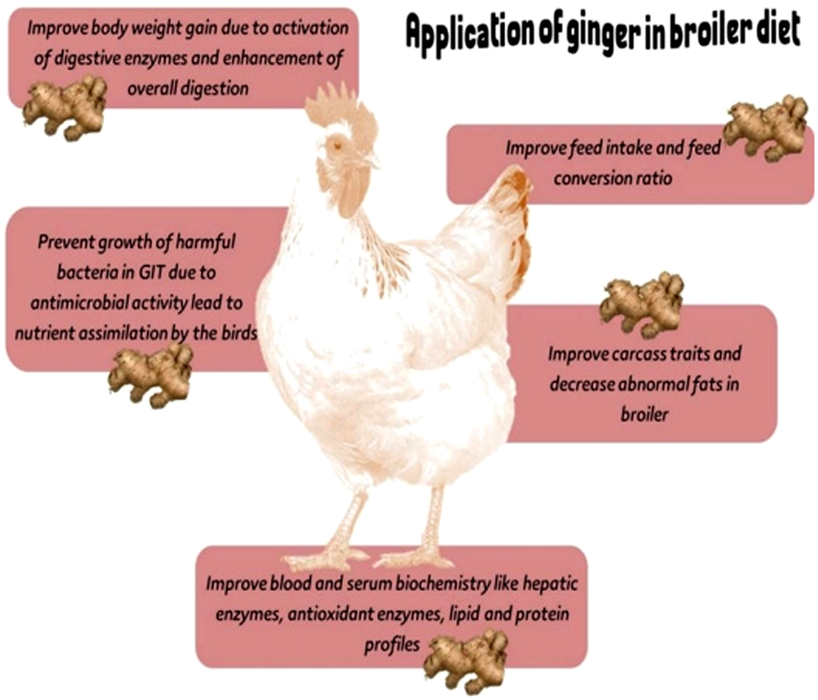

Fig. (2). Importance of ginger application in broiler diet.

Growth and Body Weight Gain

In a study by Karangiya *et al.* [16], poultry diets supplemented with 1% ginger had a significantly higher feed intake ($p< 0.05$) than the untested group. In addition, the birds that were provided ginger-supplemented food experienced a higher rate of growth compared to the untested group. The supplemented broilers had a greater growth rate than the untested group, and their feed utilization was sustainably better ($p<0.05$). There was a marked increase in the intestinal villi width, length, and cryptal depth ($p<0.05$) in the ginger-fed group than in the other groups, indicating an enhanced absorptive surface area. There was no significant difference ($p<0.05$) in the cost of the feed and the European production index when compared to the untested group.

CHAPTER 10

Bee Pollen

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Abstract: Bee Pollen (BP) is a mixture of nectar, salivary secretions from bees, and pollen grains collected from the flowers. It contains a wide range of nutrients, including proteins (10-40%), carbohydrates (13-55%), lipids (1-20%), vitamins (0.02-0.1%), minerals (0.5-3%), flavonoids (0.04-3%), and other bioactive substances such as phenolic compounds. BP has been reported to possess various therapeutic properties including antioxidant, anti-inflammatory, immunomodulatory, and antimicrobial activities. The chemical composition and bioactive substances in BP may differ significantly owing to factors such as plant species, nutritional status, environmental conditions, age, and vegetation during the flowering period. BP has been shown to have beneficial effects on human health, including the prevention of prostate problems, arteriosclerosis, and tumors. In animal science, BP supplementation has been evaluated primarily in poultry with encouraging results. BP can improve the cell immune response, antibody production speed and reinforce the immunological system. The positive effects of BP on animal productive performance may be due to its nutritive value, appetite-stimulant properties, and the presence of digestive enzymes. In domestic animals such as sheep, broilers, rabbits, and quails, supplementation with BP

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has been reported to improve the immune response, increase feed digestibility, reduce oxidative stress, and improve animal performance. This chapter emphasizes the use of Bee Pollen in livestock nutrition as a feed supplement to improve productive performance as an eco-friendly alternative to antibiotics.

Keywords: Antioxidants, Animal performance, Bioactive components, Bee Pollen, Growth promoters, Livestock.

INTRODUCTION

Ordinary and organic Bee Pollen (BP) are shown in Figs. (**1** and **2**). BP (Fig. **1**) is one of the purest and potential natural foods ever discovered and has shown incredible nutritional and medicinal value [1 - 3]. Pollen collected by bees is superior to that collected directly from flowering plants, and bees are highly discriminated about selecting the best pollen from the millions of grains present, and those only rich in all the nutrients, particularly nitrogenous substances [4 - 7]. Bees mix the pollen particles with sticky material secreted from their stomachs, allowing the BP to adhere to their rear legs in "pollen baskets" to transport it to their hives safely [8, 9]. The color and shape of BP, as indicated in Fig. (**1**) reveal the plant species from which it was obtained and the particular geographical area. Although pollen color is normally neglected, it ranges from golden yellow to black, according to the source [3, 10 - 12].

Fig. (1). Bee Pollen. Source: Contribution of conger design by Pixabay [13].

Fig. (2). Organic Bee Pollen. Source: Contribution of conger design by Pixabay [13].

BEE POLLEN

Pollen contains different coloring agents and pigments, only a small amount of which has been isolated [3, 14]. Certain pigments are fat soluble, whereas others are water-soluble [7]. The chemical compositions and bioactive components of BP are listed in Table **1**.

Table 1. Nutritive composition of Bee Pollen.

Component	Amount	Component	Rate
Energy (kcal/kg)	2.46	Ni (ppm)	4.50
Protein (%)	23.7	B_1 (ppm)	9.40
Carbohydrate (%).	27	Niacin (ppm)	157
Lipid (%).	4.8	B_2 (ppm)	18.6
P (%)	0.53	B_6 (ppm)	9
K (%)	0.58	Pantothenate (ppm)	28
Na (%)	0.044	Folic acid (ppm)	5.20
Ca (%)	0.225	Biotin (ppm)	0.32
Mg (%)	0.148	Vit. C (ppm)	350
Zn (ppm)	87	Carotenes (ppm)	95

CHAPTER 11

Propolis

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Abstract: Propolis, a resinous substance collected by bees from plant exudates and buds, has gained renewed interest as a natural feed additive for animal nutrition. Its composition varies depending on the plant source, time, and place of collection; however, it is primarily composed of phenolic acids, flavonoids, and their derivatives. Egyptian propolis contains phenolic acid esters (72.7%), dihydrochalcones (6.5%), flavones (4.6%), aliphatic acids (2.4%), flavanones (1.9%), chalcones (1.7%), phenolic acids (1.1%), and tetrahydrofuran (THF) derivatives (0.7%). Turkish propolis contains flavonoids (37.83%), organic acids (18.54%), aromatic acids and their esters (35.8%), hydrocarbons (4.89%), and other undefined components (2.94%). Propolis also contains vitamins, minerals, enzymes, fatty acids, amino acids, terpenes, and polysaccharides. Its bioactive components, including CAPE, artepillin C, caffeic acid, chrysin, galangin, quercetin, apigenin, kaempferol, pinobanksin, and pinocembrin contribute to its antibacterial, antifungal, anti-inflammatory, and antioxidant properties. These characteristics make propolis a promising natural growth promoter for livestock production and a potential replacement for antibiotics. In addition, propolis has applications in food technology as a preservative, with the added benefit of its residues being beneficial to human health. Ethanol is the preferred solvent for preparing propolis, although other solvents can also be used for the extraction and identification of its constituents. Polyphenols and flavonoids in propolis have been reported to positively affect the immune systems of various species, making it a valuable addition to livestock production practices.

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Keywords: Animal performance, Antioxidants, Bioactive components, Growth promoters, Livestock, Propolis.

INTRODUCTION

The use of propolis as a feed supplement for animal nutrition has sparked interest in recent years. This material can be regarded as a natural source in the chemical and traditional medicine sectors [1]. Bees collect propolis, a raw resinous substance, from plant parts, exudates, and buds [2]. Bees use it to seal their hives [3] and, more importantly, to prevent the decomposition of animals that they have killed after invading the hive [4]. Propolis composition is influenced by several factors, including the source of the plant, time, and location of collection [5, 6].

Phenolic acids, phenolic acid esters, flavonoids, and terpenoids such as CAPE, artepillin C, caffeic acid, chrysin, galangin, quercetin, apigenin, kaempferol, pinobanksin 5-methyl ether, pinobanksin, pinocembrin, and pinobanksin 3-acetate are known to contribute to the biological activity of propolis [7, 8]. As of 2012, more than 500 composites have been found in propolis from various countries. They are classified as prenylated derivatives of coumarins, lignans, stilbenes, phenylpropanoids, terpenoids, and flavonoids [7, 9]. However, other typical chemical components, such as alkaloids and iridoids, have not been found in propolis, which is frequently attributed to plant sources [10 - 12].

Tetrahydrofuran derivatives (0.7%), phenolic acids (1.1%), chalcones (1.7%), flavanones (1.9%), aliphatic acids (2.4%), flavones (4.6%), dihydrochalcones (6.5%), and phenolic acid esters (72.7%) are the components of Egyptian propolis [13, 14]. Turkish propolis was found to contain 37.83% flavonoids, including pinocembrin, chrysin, and galangin; 18.54% organic acids; fatty acids, including n-hexadecanoic acid, coumaric acid, octadecanoic acid, cinnamic acid, and derivatives; 35.8% aromatic acids and their esters; 4.89% various hydrocarbons; and 2.94% other undefined components. These findings were also reported by Ozkok *et al.* [15]. Table **1** lists the elements of both the propolises.

Numerous vitamins (B1, B2, B6, C, and E), mineral elements (Ca, Cu, I, K, Mg, Na, Zn, Mn, and Fe), and enzymes (adenosine triphosphatase, succinic dehydrogenase, glucose-6-phosphatase, acid phosphatase, maltase, esterase, transhydrogenase α-amylase, β-amylase, α-lactamase, and β-lactamase) are all abundant in propolis [16 - 19]. Additionally, it contains several fatty acids, amino acids, terpenes, flavonoids, and derivatives of cinnamic acid [3, 20].

Vitamin A (6.1 IU/g of fresh matter and 8.1 IU/g of DM), vitamin B1 (4.5 μg/g on fresh matter basis and 6.5 μg/g of DM), vitamin B2 (20 μg/g of new matter and 28 μg/g of DM), and vitamin B6 (5 μg/g of fresh weight) were found to be present in propolis [21]. Cu (26.5 mg/kg) and Mn (40 mg/kg) were also found in propolis, according to this study, and the ash residue comprised Fe, Ca, Al, vanadium, strontium, and silicon.

Table 1. The bioactive components of the Egyptian and Turkish propolis (Ozkok *et al.* [15]).

Class of Components	%	References
Phenolic acid ester	72.7	Egyptian propolis Abd El-Hady and HegazI [13]
Phenolic acid	1.1	
Aliphatic acids	2.4	
Dihydrochalcones	6.5	
Chalcones	1.7	
Flavanones	1.9	
Flavones	4.6	
Tetrahydrofuran derivatives	0.7	
Flavonoids	37.83	Turkish propolis Ozkok *et al.* [3]
Organic acids and fatty acids	18.54	
Aromatic acids and their esters	35.8	
Various Hydrocarbon	4.89	
Other undefined components	2.94	

Atomic emission/absorption spectrometry was used to identify trace elements (Al, B, Ba, Cr, Fe, Mn, Ni, Sr, and Zn) and hazardous elements (As, Cd, Hg, and Pb) in propolis samples collected from several areas of Croatia [22]. Neutron activation analysis was used to identify many minerals, including Br, Co, Cr, Fe, Rb, Sb, Sm, and Zn, in several Argentinean propolis samples [23]. Based on their location, these investigations demonstrate that trace element profiles can be useful for propolis identification. Propolis frequently contains polysaccharides such as starch and the di- and monosaccharides fructose, ribose, rhamnose, talose, glucose, and saccharose [16, 24]. The most representative propolis compounds reported by Attia *et al.* [17] are listed in Table **2**.

Table 2. The major compounds in propolis (Attia *et al.* [17]).

Proximate Analysis of Propolis	%	Major Fatty Acids of Propolis	%
Crude protein	1	Palmitic	13.3
Ash	4.1	Stearic	6.4
Fat	1.2	Oleic	12.3
Carbohydrates	1.8	Linoleic	1.5

CHAPTER 12

General Conclusion and Recommendations

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Abstract: The use of phytogenic additives in livestock nutrition as an alternative to classical feed additives has shown promising results in improving animal performance and product quality while avoiding the negative effects of antibiotics on animal health, product quality, and human health. This book reviews the recent advances in photogenic nutrition and its application in animal nutrition as a means of antibiotic replacement and eco-friendly feed additives. This chapter summarizes the outcomes of the 11 chapters reviewed, and their possible applications in animal nutrition. Numerous possible alternatives to antibiotic growth promoters can be used in mono-gastric animal nutrition, including thyme, rosemary, milk thistle seeds, turmeric, phytogenic, essential oils, bee pollen, and propolis. These alternatives and eco-friendly feed additives serve as sources of bioactive ingredients such as flavonoids, phenols, and polyphenols [1–4]. To date, the results have been inconclusive because of the different factors involved in animal responses, such as strain and age of the animal, health conditions, housing conditions, environmental status, part of the plant, type of plant product (leaves, seeds, and roots), drying methods, extraction methods, water *vs.* organic solvents, dose of administration, and methods of delivery (feed and water). Thus, further studies are needed to identify the dose, bioactive substances, and application root to develop commercial products on an individual basis and/or mixed agents that need to be tested. These promising additives may partially or completely replace antibiotic growth promoters and overcome the possible problems caused by the withdrawal of antibiotics from the feed additives market [2, 5, 6]. The use of phytogenic feed supplements in farm animal nutrition as a substitute for classical feed additives has shown promising

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results in enhancing animal performance and product quality, while avoiding the negative effects of antibiotics on human and animal health, product quality, and food security and safety.

Keywords: Bioactive substances, General recommendations, Livestock, Photogenic.

CONCLUSION AND REMARKS

In conclusion, the use of phytogenic additives in livestock nutrition is a promising alternative to traditional feed additives, offering potential benefits for animal performance and product quality without the drawbacks associated with antibiotics. This review highlights various natural sources of bioactive ingredients such as thyme, rosemary, and milk thistle seeds, which can serve as eco-friendly feed additives. However, the inconsistent results observed across studies underscore the need for further research to address the complex interplay between factors influencing animal responses. Future investigations should focus on optimizing dosages, identifying specific bioactive substances, and developing standardized application methods. Additionally, exploring the long-term effects of phytogenic additives on animal health, product quality, and environmental impacts is crucial. As the livestock industry moves towards more sustainable practices, the development of cost-effective production methods for phytogenic additives is essential. By addressing these research gaps, the potential of phytogenic additives to replace antibiotic growth promoters can be fully realized, contributing to improved food security, safety, and overall animal well-being.

IMPLICATIONS

- Phytogenic additives show promise as alternatives to antibiotic growth promoters, addressing concerns regarding antibiotic resistance and residues in animal products.
- These natural additives may enhance animal growth and the quality of animal products, without the negative effects associated with antibiotics.
- By reducing reliance on antibiotics, phytogenic additives could contribute to improved food security and safety for consumers.
- These inconsistent results across studies highlight the importance of developing standardized protocols for using phytogenic additives, including optimal dosages and application methods.
- The use of eco-friendly feed additives aligns with the growing demand for sustainable livestock production.

- Future studies should focus on the long-term effects, cost-effective production methods, and the potential impact on environmental factors, such as greenhouse gas emissions.
- The variety of phytogenic sources and their bioactive ingredients suggest the potential for developing tailored feed additives for different livestock species and production systems.
- The development of effective phytogenic additives could reshape the feed additive market and affect the economics of livestock production.
- Further research is required to explore the efficacy of these additives across different livestock types and geographical regions.
- Advancing this field requires collaboration among animal nutritionists, plant scientists, and environmental researchers to fully understand and optimize the use of phytogenic additives in livestock production.
- The data in Table **1** summarize natural phytogenic sources, their bioactive ingredients, and their importance for human and animal well-being. The dose of use cannot be suggested herein because of huge differences in the literature according to different experimental conditions, birds, age, and feed strategies.

Table 1. Natural phytogenic sources, their bioactive ingredients, and their importance for human and animal well-being (Adapted from [3, 6 - 9]).

Herbs	Bioactive ingredients in herbs	Benefits concerning health
Turmeric powder	Flavonoids compounds	Antimicrobial, antioxidant
Garlic, onion and their leaves	Allicin, Allyl sulfide	Reduce LDL cholesterol, anticarcinogenic properties
Sugar beet, grape pulp	Betaine	Decrease plasma homocysteine which ruptures arterial walls
Alfaalfa, marigold petals, red pepper, spirulina	Carotenoid pigments	Antioxidant, anticarcinogenic
Basil leaves	Eugenic acid, Eugenol	Immunomodulatory properties
Marigold petals, bay	Lutein	Antioxidants, improve vision
Tomato pomace, grape pulp	Lycopene	Decrease LDL cholesterol, antioxidant, anticarcinogenic
Citrus pulp	Nirangenin	Reduce LDL cholesterol
Flaxseed, canola, fish, oils, insects, worms	n-3 PUFA	Decrease LDL, hypertension, angina, atherosclerosis
Seeds, legumes, weeds, yeast, fermented products	Phytosterols	Increase HDL, decrease blood sugar
Fenugreek, spices	Quercitin, Lutein, Citogenin	Induce insulin secretion, antimicrobial, and tonic activity.

SUBJECT INDEX

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Youssef A. Attia

Prof. Youssef A. Attia has had an extensive academic journey through institutions in the United States (University of Georgia), Germany (TUM), Saudi Arabia (King Abdulaziz University), and Egypt (Damanhour University). His research spans animal and poultry science, nutrition, and agriculture. Prof. Attia has authored numerous publications, books, and book chapters and has mentored over 1,000 students and early-career researchers. He has received prestigious awards, including the Khalifa Education Award and the Rashed Bin Humaid Cultural & Sciences Award, and has been recognized by Stanford University as one of the Top 2% Scientists worldwide (2020–2024). Additionally, he holds the #1 ranking in Saudi Arabia in Veterinary and Animal Sciences fields. His work in teaching, mentoring, and research significantly contributes to advancing animal production and industry standards globally.

Mohamed E. Abd El-Hack

Dr. Mohamed E. Abd El-Hack is a distinguished academic at Zagazig University, Egypt, specializing in poultry nutrition with a focus on enhancing poultry productivity, welfare, and food security. He has authored and edited influential books, including Organic Feed Additives for Livestock (2024) and Antibiotic Alternatives in Poultry and Fish Feed (2022). Dr. Abd El-Hack has been recognized among Stanford University's Top 2% Scientists (2020–2024) and received the Distinguished Order of First Class in Sciences from the President of Egypt in 2020. He has also been honored with the State Encouragement Award in Agricultural and Veterinary Sciences (2019) and the Alltech Young Scientist Award (2015), among other accolades, solidifying his reputation in sustainable poultry nutrition.

Mahmoud M. Alagawany

Prof. Dr. Mahmoud Alagawany is a Professor of Poultry Nutrition at Zagazig University, Egypt. He was awarded the State Encouragement Prize in Agricultural Sciences in 2018. According to Web of Science, he was listed among the Highly Cited Researchers (2023) in Animal and Plant Sciences. He has also been recognized by Stanford University as one of the Top 2% Scientists worldwide (2019–2024). Prof. Alagawany has an extensive record of scientific contributions, including research and review articles, four international books, and 25 book chapters. He serves as a scientific editor for the Journal of Animal Physiology and Animal Nutrition and as an associate editor for Frontiers in Physiology and Revista Brasileira de Zootecnia.

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Prof. Asmaa Elnaggar is a Professor of Poultry Physiology at the Faculty of Agriculture, Damanhour University, Egypt. Her research interests include endocrinology, immunology, and stress physiology and their effects on poultry performance, health, and productivity. She has numerous highly cited publications in peer-reviewed journals. Prof. El-Naggar is an active member of several scientific journals and the Poultry Science Association.