Macedonian Journal of Animal Science, Vol. **12**, No. 1–2, pp. 29–38 (2022)
Article 287 In print ISSN 1857 – 6907
Received: August 30, 2022 On line ISSN 1857 – 7709433
Accepted: September 27, 2022 UDC: 636.52/.58.087.7:665.528.292.94
https://www.doi.org/10.54865/mjas22121-2029n

Review

REVIEW ON *LAMIACEAE* FAMILY SELECTED PLANTS DERIVED ESSENTIAL OILS AND THEIR EFFECTS IN BROILER CHICKEN PRODUCTION

Nedeljka Nikolova[1], Nikola Puvača[2]

[1]*Institute of Animal Science, Ss. Cyril and Methodius University in Skopje, Blvd. Ilinden 92a, Skopje, Republic of North Macedonia*
[2]*Department of Engineering Management in Biotechnology, Faculty of Economics and Engineering Management in Novi Sad, University Business Academy in Novi Sad, Serbia*
nikola.puvaca@fimek.edu.rs

A b s t r a c t: The use of essential oils in animal nutrition has attracted attention as a potential substitute for antibiotic growth promoters during the past twenty-five years. This paper will review the current scientific evidence on the usage of essential oils from *Lamiaceae* family members such as thyme, oregano, and rosemary in broiler nutrition in terms of production results, and meat quality properties. Essential oils are effective in broiler nutrition when incorporated into the diet on a variety of levels, such as dietary composition, level of feed inclusion, and bird genetics. Besides, the efficacy of essential oils is influenced by many factors, such as the composition of the oil. Due to the big difference in composition and source of essential oils, comparing different studies using them can be challenging. Therefore, biological effects may differ significantly. Despite this, a great deal of research supports essential oils' potential use as natural, antibiotic-free growth promoters for broilers. Growth promotion mechanisms are still not clearly understood. There is no question that essential oils consumption can reduce pathogen growth in the gut, but their effects on the intricate gut ecosystem as yet remain unclear. This review concludes with further recommendations regarding the application of dietary essential oils in broiler nutrition.

Key words: essential oils; poultry; chickens; animal nutrition; meat quality; medicinal plants; bioactive compounds

ПРЕГЛЕД НА ЕТЕРИЧНИТЕ МАСЛА ДОБИЕНИ ОД ИЗБРАНИ РАСТЕНИЈА НА FAM. *LAMIACEAE* И НИВНИТЕ ВЛИЈАНИЈА ВРЗ ПРОИЗВОДСТВОТО НА БРОЈЛЕРСКИ ПИЛИЊА

А п с т р а к т: Употребата на етерични масла во исхраната на животните го привлече вниманието како потенцијална замена за антибиотиците кои се користат како промотори на растеж во текот на изминатите дваесет и пет години. Во овој труд се разгледуваат тековните научни докази за употребата на етерични масла од fam. *Lamiaceae* како што се мајчина душичка, оригано и рузмарин во исхраната на бројлери во однос на производните резултати и параметрите за квалитетот на месото. Кога етеричните масла се вклучени во исхраната на бројлери, тие се ефикасни на различни нивоа: во составот на храната, процентот на вклученост во добиточната храна и генетиката на птиците. Освен тоа, врз ефикасноста на есенцијалните масла влијаат многу фактори, како што е, на пр., составот на маслото. Поради големата разлика во составот и изворот на етеричните масла, споредувањето во различни студии за нивното користење може да претставува предизвик. Значи, биолошките ефекти можат значително да влијаат. И покрај ова, голем дел од истражувањата ја поддржуваат потенцијалната употреба на есенцијалните масла за бројлери како природни промотори на растежот без антибиотици. Механизмите за поттикнување на растежот сѐ уште не се јасно разбрани. Несомнено е дека потрошувачката на есенцијални масла може да го намали растежот на патогенот во цревата, но нивните ефекти врз сложениот екосистем на цревата сѐ уште остануваат нејасни. Овој преглед завршува со дополнителни препораки во врска со примената на етерични масла во исхраната на бројлери.

Клучни зборови: етерични масла; живина; пилиња; храна за животни; квалитет на месо; медицински растенија; биоактивни компоненти

INTRODUCTION

Today, the production of broiler chickens is the most intensive branch of animal husbandry, since broiler chickens are characterized by very fast reproduction, short breeding periods, and relatively low investment compared to other branches of livestock production [1–4], which allows faster turnover and thus efficient and economical production. On the other hand, chicken meat is characterized by favorable nutritional composition [5], easy digestibility [6], and high energy value [7], and from an economic aspect, it is food available to all segments of society, accepted by all cultures and religions [8–11]. Therefore, the modern production of broiler chickens, as an important part of the chain of food production for the population that is increasing every day, aims to meet high legal regulations for quality and safe products for human consumption.

The quality and safety of feed for broiler chickens are key factors to meeting production priorities, but also increasing production and improving the quality of food of animal origin, such as meat [12, 13]. To maximize the genetic potential of chickens, it is necessary to satisfy their physiological needs, so we strive for nutritional mixtures to be nutritionally balanced [14]. However, in addition to the basic nutrients, today an increasing number of dietary supplements are used, which aim to improve the benefits and inhibit the harmful effects on the body of chickens [15]. For this reason, in recent years, in modern broiler production, more and more attention is paid to medicinal plants as an alternative to banned antibiotics [17].

Phytobiotics represent a new generation of natural supplements, which include medicinal plants and spices, but also plant extracts and essential oils, which are characterized by numerous biological properties [18, 19]. Medicinal and useful properties of essential oils in the diet of broiler chickens are reflected in improved production characteristics [20], as well as the ability to increase the body's immune response [21], which has a positive effect on maximizing the genetic potential of chickens and reducing mortality and thus increasing profitability. Also, phytobiotics and essential oils exhibit hypocholesterolemic effects by inhibiting the most important enzymes involved in the synthesis of cholesterol and lipids, which significantly reduces cholesterol in the blood and edible tissues, and significantly reduces the proportion of abdominal fat in broiler chickens [22]. This fact certainly supports phytobiotics and makes them a significant addition to the diet and production of foods necessary for the nutrition of special categories of consumers. In addition, essential oils increase the digestibility and utilization of nutrients, as well as improve the quality of carcasses and meat of broiler chickens.

The quality of carcasses and meat is a key element of competitiveness in the market, as it influences the decision to purchase products [23]. At the same time, quality influence the creation of a positive image of consumers about the product, whose expectations are significantly met since consumers are the last link in the production chain. The carcass quality of broiler chickens is a very complex concept and can be assessed from several aspects [24]. Thus, from the point of view of industry and cosumers, slaughtered broiler chickens must have good yields, desirable conformation, as much meat on the carcass, optimal fat distribution, appropriate skin color, and as little carcass damage as possible during production [25]. The presence of certain tissues in the more important parts of the carcass is, without a doubt, the element that determines the quality of the carcass of broiler chickens. In scientific and professional circles, it is accepted that the quality of meat is defined as the sum of all objectively measured nutritional, technological, sensory, and hygienic-toxicological properties, i.e., quality factors [26]. The quality of chicken meat, therefore, implies a large number of properties that determine the suitability of meat for consumption, processing, or storage, and depend on several interrelated factors that include the conditions of meat production.

Modern aspects in the production of chicken meat represent a perspective for all countries [27], bearing in mind that the products of animal origin obtained in this way represent a ticket to the world market. In addition, the advantages of such broiler chickens can be seen through the economic aspect, since the use of natural feed supplements such as essential oils insignificantly increases the price of feed, because they are added in very small quantities, and as a result of their use allows sustainable production of safe food of animal origin, without antibiotic residues, without affecting the broiler chickens breeding technology.

Given the importance and relevance of essential oils, it is scientifically justified and interesting for practice to examine the possibilities and effects of using selected natural growth stimulants in intensive breeding of broiler chickens on production characteristics, quality of chicken meat, digestibility of nutrients, the fatty acid composition of meat and on the economy of production itself.

SIGNIFICANCE OF POULTRY MEAT IN HUMAN DIET

In the past, meat was considered an essential nutrient for human growth and development. It has been found that excessive consumption of red meat may increase one's risk of developing several forms of cancer, cardiovascular and metabolic diseases, but meat consumption was an important factor in the evolution of the human species, especially the development of the brain. In European legislation, the term meat refers to the edible parts removed from the carcass of domestic ungulates including bovine, porcine, ovine and caprine animals as well as domestic solipeds; poultry; lagomorphs; wild game; farmed game; small and large wild game.

Since ancient times, meat has been one of the most important foods in human nutrition [28]. Even today, it is no different, and the demand for meat, especially poultry, is constantly growing [29]. Poultry, which includes chicken meat, is one of the foods of animal origin that are most accessible to the widest layers of consumers. Due to its high protein content and low fat content [30], nutritionists recommend besides poultry meat the rabbit meat [31], as well as the healthiest source of protein of animal origin.

Chicken meat is a biologically very valuable food with a high protein content, favorable amino acid composition, while it is characterized by low fat content with significant/high proportion of polyunsaturated fatty acids (PUFAs), which have become increasingly important in recent years [32, 33]. Also, the favorable ratio of saturated (SFAs) and unsaturated (UFAs) fatty acids, as well as the low content of total cholesterol (TC) makes chicken meat indispensable in the diet of children, convalescents, as well as chronic patients, and those suffering from cardiovascular diseases [34].

Petracci et al. [35] state that neutral taste, good texture, and light color are characteristic of this type of meat, which makes it more suitable for processing compared to other types of meat. The listed properties enable producers to optimize the taste and texture of meat according to the needs of the market and target groups of consumers.

An important advantage of chicken meat compared to other types of meat is certainly the fact that it is accepted by all cultures and religions [8], while the relatively low price of chicken meat [36] compared to beef, lamb, and pork, provides the opportunity to use this highly valuable food in everyday diet [37, 38].

ESSENTIAL OILS AND THEIR BIOACTIVE CONSTITUTES

Due to the very important biological properties they possess, but also due to their very wide distribution and diversity, essential oils in recent years represent an important gift of nature that intrigues many scientific teams around the world.

It is estimated that there are about 3,000 types of essential oils on the market today [39], for the production of which at least 2,000 plant species are used, of which 300 essential oils are of commercial importance [40]. Dima and Dima [41] reported that between 40,000 and 60,000 tons of essential oil worth about US $ 700 million are produced annually, indicating a significant increase in demand for essential oils worldwide. Essential oils are also recognized as safe for use in the food industry by the Flavor and Extracts Manufacturers Association (FEMA) and the Food and Drug Administration (FDA) and are on the Generally Recognized as Safe Lists (GRAS), as reported by Hallagan and Hall [42].

Essential oils are aromatic and easily volatile liquids, mostly colorless or yellowish in color. The consistency of most essential oils is similar to water or alcohol, but some can be sticky and viscous. No essential oil contains fats or oils, although in its name they carry the term oil, which is often a misconception about the composition of these heterogeneous mixtures [43]. It is characteristic of essential oils that they do not dissolve in water or dissolve very little, while they dissolve well in all organic solvents (ether, chloroform, gasoline, etc.). Also, essential oils thicken, darken and react acidically when left in the air for a long time. It can be said that it is difficult to determine the boiling point of these complex mixtures, given the large number of compounds of which they are composed, but they usually range between 150 and 280 °C, so that individual components can be separated by fractional distillation [44].

Data on methods of isolating essential oils from plant materials and the goals of these first procedures are poorly known and uncertain [44].

Essential oils from plant material are obtained by applying various methods: hydrodistillation [45], extraction with organic solvents [46], cold pressing [47], extraction with fluids in the supercritical state [48], extraction with non-volatile solvents [49], extraction with solvents supported by microwave action [50]. The method that will be used depends on the nature and type of raw material, as well as on the economy of the method and the application of the obtained oil.

The yield of essential oils from individual plants or parts of plants usually ranges between 0.2 and 2.0%, with exceptions, so the yield of rose oil does not exceed 0.03%, while the yield of clove essential oil reaches up to 20% [51].

Today, essential oils are most often used in the cosmetics [52] and pesticides industry [53], in the food [54] and pharmaceutical industries [55], but also in animal nutrition [20, 56–59], given the many positive properties they exhibit in an animal body.

Essential oils are highly concentrated mixtures of a large number of diverse, fragrant, and easily volatile compounds, localized in different parts of plants, and which play a key role in the treatment of various diseases in both humans and animals [58]. These are most often flavonoids, polyphenols, tannins, alkaloids, terpenoids, polypeptides, and many other compounds that make individual oils specific [60]. These plant compounds are known as secondary metabolites, as they are products of secondary plant metabolism. It is estimated that about 500,000 secondary molecules (SM - small organic molecules produced by an organism that are not essential for their growth, development and reproduction) have been identified to date, which are biologically active compounds. Although they do not participate in the basic life functions of plants and although their lack cannot negatively affect the growth and development of plants, biologically active compounds still play important roles in the life cycle of each plant. They are known to be inactivated forms and depots of harmful products, are components of certain enzyme systems (coenzymes), are characterized by hormonal activity, protect the plant by preventing infections with bacteria, fungi, and viruses, protect against an overdose of ultraviolet radiation, excessive transpiration, and other environmental factors. They also play an important role in regulating the plant's communication with the surrounding environment. On the other hand, in recent years, these compounds of plant origin have played an important role in pharmacy, medicine, but also animal nutrition, given the antioxidant, antibacterial, antifungal, antiviral, anti-inflammatory, and many other properties that distinguish them [61].

It is interesting to note that between 20 and 60 different biologically active compounds present in very different concentrations may be present in the essential oil of certain plant species [62], with only a few compounds being dominant (20–70%), while others are present in traces. However, the special combination of all these components gives a specific impression and it is assumed that even the biologically active components present in the traces can be of great importance in the biological activity of certain essential oils. The content of biologically active compounds can vary widely depending on the parts of the plant used (seed, leaf, root, flower, bud, and stem), the season of collection, and the geographical area in which they are grown [63]. Also, the procedure used to obtain essential oils can affect the content of biologically active compounds in the final product, and thus their effectiveness.

CHEMICAL COMPOSITION OF ESSENTIAL OILS DERIVED FROM LAMIACEAE FAMILY

Table 1 shows the qualitative and quantitative chemical composition of essential oils of selected plant species *Thymus vulgaris, Origanum vulgare* [64], and *Rosmarinus officinalis* [65].

In the analyzed *Thymus vulgaris* oil, the dominant group of compounds was represented by monoterpenes (95.02%), with significantly more oxidized compounds (66.35%) than hydrocarbons (28.67%). Sesquiterpenes (2.54%) were also present in a small percentage of the oil. The analysis of *Origanum vulgare* essential oil identified a total of 43 compounds, representing 98.08% of the essential oil. Comparing the basic groups of identified compounds in the essential oil of *Origanum vulgare*, it was found that the share of monoterpenes (94.67%) is far higher than the share of sesquiterpene compounds (2.52%), while in the group of monoterpenes oxidized monoterpenes (66.18%) are high quantitative values of phenolic compounds, primarily carvacrol (58.84%).

In the analyzed *Rosmarinus officinalis* oil, 19 compounds were identified, which made up 95.60% of the essential oil. The dominant group of chemical compounds was represented by bicyclic monoterpenes (87.20%), while monocyclic and acyclic monoterpenes were present in concentrations of 3.04 and 3.05%. The share of sesquiterpene compounds was significantly lower (2.32%) [65].

As can be seen from the chemical composition of selected plant species of thyme, oregano, and rosemary, terpenoids, or so-called isoprenoids, are one of the most common groups of secondary molecules, i.e. biologically active compounds in these plants [64, 65]. Degenhardt et al. [66] reported that this group of biomolecules numbers about 30,000 compounds.

Table 1

Chemical composition of Thymus vulgaris, Origanum vulgare and Rosmarinus officinalis essential oils

No.	Components (%)	Essential oil		
		Thymus vulgaris [64]	*Origanum vulgare* [64]	*Rosmarinus officinalis* [65]
1.	tricyclene	0.13	0.06	0.15
2.	α-thujen	0.19	0.25	–
3.	α-pinene	0.76	1.35	12.50
4.	camphene	0.27	0.39	2.85
5.	β-pinene	0.03	0.55	0.36
6.	1-octen-3-ol	0.16	0.14	–
7.	myrcene	0.79	0.87	0.90
8.	α-phellandrene	0.92	0.13	–
9,	Δ-3-carene	0.13	0.10	0.96
10.	α-terpinene	1.25	1.05	–
11.	p-cymene	18.71	19.90	1.80
12.	β-phellandrene	0.48	0.51	–
13.	1,8-cineole	0.61	0.16	16.10
14.	(Z)-β-ocimene	–	0.04	–
15.	(E)-β-ocimene	–	0.02	–
16.	trans-decahydro-naphthalene	0.04	–	–
17.	γ-terpinene	4.34	3.11	–
18.	cis-sabinene hydrate	0.14	–	–
19.	terpinolene cineole	0.06	–	–
20.	p-mentha-2,4-diene	–	0.02	–
21.	cis-decahyd-ronaphtalene	0.21	0.03	–
22.	undecane	0.05	0.18	–
23.	linalool	2.52	0.26	4.05
24.	camphor	0.08	0.10	17.70
25.	menthone	0.17	–	
26.	borneol	0.74	0.58	9.23
27.	terpinen-4-ol	1.27	0.78	2.05
28.	α-terpineol	0.24	–	2.67
29.	trans-dihyd-rocarvone	0.17	0.12	–
30.	dodecane	0.12	0.39	–
31.	dihydro citronellol	0.11	–	–
32.	methyl ester thymol	0.20	–	–
33.	methyl ester carvacrol	0.49	0.54	–
34.	carvone	0.05	–	–
35.	citrollene	0.03	0.04	–
36.	carvenone	0.18	–	–
37.	bornyl acetate	0.10	–	–
38.	isobornyl acetate	–	0.14	–
39.	tridecane	0.07	0.10	–
40.	thymol	43.20	4.76	–
41.	carvacrol	16.57	58.84	–
42.	thymol acetate	0.03	–	–
43.	carvacrol acetate	0.06	–	–
44.	α-ylangene	0.04	–	–
45.	α-copaene	0.05	–	–
46.	α-cubebene	–	0.08	–
47.	β-bourbonene	0.04	0.05	–
48.	tetradecane	0.05	0.05	–
49.	*trans*-β-caryo-phyllene oxide	1.01	1.04	0.21
50.	aromadendrene	–	0.05	–
51.	α-humulene	0.08	0.14	–
52.	γ-muurolene	0.06	–	–
53.	germacrene-D	–	0.04	–
54.	γ-amorphene	0.06	–	–
55.	viridiflorene	–	0.05	–
56.	α-muurolene	0.05	–	–
57.	β-bisabolene	0.21	0.63	–
58.	γ-cadinene	0.12	0.04	–
59.	δ-cadinene	0.16	0.10	–
60.	cariofilene oxide	0.53	0.30	–
61.	1,10-di epi cubenol	0.02	–	–
62.	10-epi-γ-eudesmol	0.02	–	–
63.	τ-cadinol	0.05	–	–
64.	cadalene	0.04	–	–
65.	verbenene	–	–	0.99
66.	limonene	–	–	2.96
67.	α-terpinolene	–	–	0.47
68.	phenol	–	–	0.99
69.	verbenone	–	–	13.80

Monoterpenes are the most common subgroup of terpenoids present in essential oils isolated from plant material, where they make up to 90.00% of most essential oils and are characterized by a very pleasant mild odor. In their structure, monoterpenes contain two isoprene units, i.e. 10 carbon atoms. This group of compounds includes thymol, carvacrol, α-pinene, γ-terpinene, and 1,8-cineole [67].

Thymol (2-isopropyl-5-methylphenol) is a phenolic derivative of cymene and an isomer of carvacrol. Thymol is characterized by a colorless crystalline structure with a very pleasant odor, which does not dissolve in water, but dissolves well in alcohol and other organic solvents. Carvacrol (5-isopropyl-2-methylphenol) is a colorless to pale yellow viscous liquid that does not dissolve in water, dissolving very well in ethanol, ethyl ether, propylene glycol, and bases. Thymol and carvacrol are compounds that inhibit lipid peroxidation, have a digestive-stimulating effect, and are characterized by antioxidant, antispasmodic, diuretic, antiviral, antibacterial, antifungal, and immunomodulatory properties. The presence and high percentage of monoterpene hydrocarbons, p-cymene and γ-terpinene, cannot be observed independently of the presence of thymol and carvacrol, since these compounds are their precursors, so they mostly occur simultaneously in essential oils [67].

Based on a review of previous research, it has been established that thymol and carvacrol are the most abundant biologically active compounds in thyme essential oil [68]. In these studies, the content of thymol ranged from 43.20 to 59.95%, and carvacrol from 2.40 to 16.57%. β-linalool and 1,8-cineole are also present in high concentrations in thyme essential oil, while other components are present in traces [68–70].

Numerous studies indicate that the chemical composition of oregano essential oil does not differ much compared to the chemical composition of thyme essential oil in terms of the most common compounds, with oregano essential oil having a significantly higher carvacrol content and lower thymol content compared to thyme essential oil [71–75].

Based on previous research, it has been established that monoterpene compounds such as camphor, 1,8-cineole, and α-pinene are the most dominant components present in rosemary essential oil. In the research of Šarić et al. [65] the mentioned three compounds accounted for about 46.00% of the rosemary essential oil compound, while this value is in the research conducted by Takayama et al. [76] amounted to as much as 77.50%. These biologically active compounds are responsible for antioxidant, antibacterial, antifungal, anti-inflammatory, anticancer and many other properties attributed to rosemary [76].

Compound 1,8-cineole is a monocyclic ether and monoterpene, which is characterized by a fresh, cooling odor [77]. It does not dissolve in water but is miscible with ether, ethanol, and chloroform. α-pinene is an organic compound from the group of bicyclic monoterpenes, and it is also an alkene. It dissolves very poorly in water but is miscible with acetic acid, ethanol, and acetone [77].

The differences in the composition of essential oils are supported by the already mentioned fact that the chemical composition of essential oils in medicinal plants is influenced by many factors. Thus, the geographical origin, climate, time of collection of plant material, as well as the process of obtaining essential oil from plant material affect the type and presence of certain biologically active compounds [44]. Mechergui et al. [78] investigated the influence of oregano harvest year on the composition of essential oil obtained from this plant material, concluding that the composition of essential oils has changed from year to year, not only in terms of the number of individual components but also in the number of identified components in the essential oil itself.

IMPACT OF ESSENTIAL OILS ON PRODUCTIVE PERFORMANCE OF BROILER CHICKENS

Global pressure to replace the use of antibiotics as growth promoters with safe feed additives in the broiler industry has led researchers to conduct a massive exploration in utilizing natural substance-based additives. Essential oils are formed by dozens of complex mixture components that can be classified into a group of terpenoids (menthol, linalool, geraniol, borneol, α-terpineol) and a group of low molecular weight aliphatic hydrocarbons (thymol, carvacrol, eugenol, cinnamaldehyde). The advantageous effects of essential oils are associated with their role on many metabolic pathways, including on lipid metabolism, stimulate digestive enzyme secretion and activity, act as antimicrobial, and enhance gut integrity of chickens leading to improve broiler performance in general. Essential oils have proven to be important factors in protecting animals from various stressors, ensuring optimal health and production characteristics of individuals [79].

Many authors state that the addition of essential oils to the diet of broiler chickens had a positive effect on production characteristics [80–85]. Denli et al. [86] point out that the use of 60 mg/kg of thyme essential oil in the diet of quail chickens leads to a statistically significant ($p<0.05$) increase in growth from 194.7 g, as in the control treatment, to 206.3 g, as well as up to a statistically significant ($p<0.05$) reduction in feed conversion ratio from 3.40 kg/kg, as in the control treatment, to 3.20 kg/kg [86]. In a study with the addition of thyme extract to the diet of broiler chickens, Al-Kassie [87] found a statistically significant ($p<0.05$) increase in the growth of broiler chickens during the fattening period lasting 42 days, from 2546 g, as in the control treatment, at 2617 g and 2882 g, as in the treatments with the addition of 0.01 and 0.02 g/kg of thyme extract in the diet of broiler chickens. The same author [87] states that at the end of fattening the consumption of feed in the treatment with the addition of 0.01 and 0.02 g/kg of thyme extract was 4423 and 4612 g, while the value of this indicator in the control treatment was 4380 g, while feed conversion was reduced by 1.72 kg/kg (control treatment) at 1.69 and 1.60 kg/kg, as in treatments with the addition of 0.01 and 0.02 g/kg of thyme extract in the diet of chickens. In a study conducted by Toghyani et al. [88] by adding 5 and 10 g/kg of thyme powder to the diet of broiler chickens, the final body weights of 2079 g and 1949 g were achieved, while the values of this indicator established in control chickens were 1956 g. In the treatment with the addition of antibiotics, the final body weight of broiler chickens of 2091 g was achieved. Regarding the average daily feed consumption for the entire fattening period, which lasted 42 days, no significant differences were observed between the experimental treatments, and the average values of this indicator ranged from 90.8 to 94.8 g. The same authors [88] state that the feed conversion was reduced from 1.95 kg/kg, as in the control treatment, to 1.86 and 1.90 kg/kg, as found in the treatment with the addition of antibiotics, or 5 g/kg of thyme in the form of powder in the diet of chickens, while in the treatment with the addition of 10 g/kg of the same thyme, the value of this indicator was 2.03 kg/kg. Statistically significant differences at the end of experiments are: control = thyme 10 g/kg < antibiotic = thyme 5 g/kg, therefore dietary thyme supplementation was effective in improving chicken final weights at the lowest level of supplementation, but not at the highest level, so the effect was concentration dependant. Bozkurt et al. [89] point out that the addition of commercial preparation based on oregano led to an increase in the final body weight of broiler chickens by 4.44%, feed consumption by 2.95%, as well as a decrease in feed conversion by 1.53% compared to these found in broiler chickens of control treatment [89]. All these positive effects in enhancing poultry productions performances can be the result of increase digestive enzyme secretion after ingestions of essential oils. Previously mentioned trials have shown positive effects of essential oils on nutrient utilization and poultry performance. However, it appears that the degree of response may be influenced by the level and type of essential oil used, and the health status of the birds.

One of the most common mechanisms that explain the stimulating effect of essential oils on the production characteristics of broiler chickens is the impact on stabilizing feed hygiene, which affects the ecosystem of gastrointestinal microorganisms, which means reducing the number of unwanted bacteria [90–92]. Similarly stated Kroismayr et al. [93] emphasized that essential oils and oleoresins affect the cecal microflora, which favorably affects the activity of desirable microorganisms in the gastrointestinal tract. By stabilizing intestinal health, animals are less exposed to toxins and undesirable products of microbiological activity, such as ammonia and biogenic amines. The formation of biogenic amines in the intestinal tract was defined by the researchers as undesirable, not only due to their toxicity but also since they are mainly formed by decarboxylation of essential amino acids. For this reason, reducing microbiotic fermentation in the small intetine of individuals can improve the availability of essential nutrients [93]. Windisch et al. [94] explain that essential oils have a beneficial effect on the organism in stressful situations and increase the availability and absorption of essential nutrients, which enables more intensive growth of chickens and achievement of maximum genetic potential. Reduction of microbiological activity also leads to reduced production of volatile fatty acids, which affects the stabilization of intestinal pH, thus ensuring optimal activity of digestive enzymes. Jamroz et al. [95] state that the addition of plant extracts to the diet of broiler chickens affects the increased secretion of mucus covering the walls of the stomach and jejunum by creating a thin layer that has a protective role, reducing the possibility of adhesion of undesirable microorganisms to epithelial cell mucosa.

High variability, when it comes to the impact of essential oils on the production characteristics of broiler chickens, can be due to the action of various internal (stress exposure, sex, age, etc.) and external factors such as the physiological status of animals, breeding methods, environment, infections, diseases, the composition of feed, the content of active substances [56, 96–98].

However, despite extensive research conducted over the last decade, it is still unclear which of these mechanisms is responsible for improving the production characteristics of broiler chickens, or a combination of several of these mechanisms.

CONCLUSIONS

Results presented in this review have showed that the active components present in the essential oils of thyme, oregano, and rosemary stimulated the activity of beneficial bacteria, thus contributing to a balanced microflora, i.e., an effective prerequisite for protection against pathogenic microorganisms. Increasing the number of beneficial bacteria not only reduces the number of available substrates for pathogenic microorganisms but also stabilizes intestinal pH, thus ensuring optimal activity of pancreatic enzymes, which further leads to improved digestibility of nutrients and thus improved production characteristics.

Therefore, a balanced diet for broiler chickens, with the optimal composition and content of a mixture of essential oils of thyme, oregano, and rosemary, can achieve positive, i.e., economical fattening and produce broiler chickens that have good yields, more meat on the carcass, and significantly improved meat quality.

The chicken meat obtained in this way will enable producers to place in the demanding markets of the EU and beyond, which reflects the scientific and practical significance of this paper.

REFERENCES

[1] Puvača, N., Stanaćev, V., Glamočić, D., Lević, J., Perić, L., Stanaćev, V., Milić, D. (2013): Beneficial Effects of Phytoadditives in Broiler Nutrition. *Worlds Poult Sci J*, **69**, 27–34. DOI:10.1017/S0043933913000032.

[2] Lika, E., Kostić, M., Vještica, S., Milojević, I., Puvača, N. (2021): Honeybee and Plant Products as Natural Antimicrobials in Enhancement of Poultry Health and Production. *Sustainability*, **13**, 8467. DOI:10.3390/su13158467.

[3] Puvača, N. (2018): Honeybee and Medicinal Plants Products in Poultry Postantibiotic Era Production. *J Agron Technol Eng Manag*, **1**, 8–17.

[4] Puvača, N., Tufarelli, V., Giannenas, I. (2022): Essential Oils in Broiler Chicken Production, Immunity and Meat Quality: Review of *Thymus vulgaris, Origanum vulgare,* and *Rosmarinus officinalis. Agriculture*, **12**, 874. DOI:10.3390/agriculture12060874.

[5] Lorenzo, J. M., Sarriés, M. V., Tateo, A., Polidori, P., Franco, D., Lanza, M. (2014): Carcass Characteristics, Meat Quality and Nutritional Value of Horsemeat: A review. *Meat Science*, **9**6, 1478–1488. DOI:10.1016/j.meatsci.2013.12.006.

[6] Marangoni, F., Corsello, G., Cricelli, C., Ferrara, N.,, Ghiselli, A., Lucchin, L., Poli, A. (2015): Role of Poultry Meat in a Balanced Diet Aimed at Maintaining Health and Wellbeing: An Italian Consensus Document. *Food & Nutrition Research*, **59**, 27606. DOI:10.3402/fnr.v59.27606.

[7] Beauclercq, S., Nadal-Desbarats, L., Hennequet-Antier, C., Collin, A., Tesseraud, S., Bourin, M., Le Bihan-Duval, E. Berri, C. (2016): Serum and Muscle Metabolomics for the Prediction of Ultimate PH, a Key Factor for Chicken-Meat Quality *J. Proteome Res*., **15**, 1168–1178. DOI:10.1021/acs.jproteome.5b01050.

[8] Magdelaine, P., Spiess, M. P., Valceschini, E. (2008): Poultry Meat Consumption Trends in Europe. *World's Poultry Science Journal*, **64**, 53–64. DOI:10.1017/S0043933907001717.

[9] Devi, S. M., Balachandar, V., Lee, S. I., Kim, I. H. (2014): An Outline of Meat Consumption in the Indian Population – A pilot review. *Korean J Food Sci Anim Resour,* **34**, 507–515. DOI:10.5851/kosfa.2014.34.4.507.

[10] Seleshe, S., Jo, C., Lee, M. (2014): Meat Consumption Culture in Ethiopia. *Korean J Food Sci Anim Resou*r, **34**, 7–13. DOI:10.5851/kosfa.2014.34.1.7.

[11] Khan, R. U., Naz, S., Javdani, M., Nikousefat, Z., Selvaggi, M., Tufarelli, V., Laudadio, V. (2012): The Use of Turmer4021859610001188.

[14] Khan, R. U., Fatima, A., Naz, S., Ragni, M., Tarricone, S., Tufarelli, V. (2022): Perspective, Opportunities and Challenges in Using Fennel (*Foeniculum vulgare*) in Poultry Health and Production as an Eco-Friendly Alternative to Antibiotics: A Review. *Antibiotics*, **11**, 278. DOI:10.3390/antibiotics11020278.

[15] Ismail, I. E., Alagawany, M., Taha, A.E., Puvača, N., Laudadio, V., Tufarelli, V. (2021): Effect of Dietary Supplementation of Garlic Powder and Phenyl Acetic Acid on Productive Performance, Blood Haematology, Immunity and Antioxidant Status of Broiler Chickens. *Anim Biosci*, **34**, 363–370. DOI:10.5713/ajas.20.0140.

[16] Kostadinović, L. M., Popović, S. J., Puvača, N. M., Čabarkapa, I. S., Kormanjoš, Š. M., Lević, J. D. (2016): Influence of *Artemisia absinthiu*m Essential Oil on Antioxidative System of Broilers Experimentally Infected with *Eimeria oocysts*. *Veterinarski arhiv*, **86**, 253–264.

[17] Marić, M., Stajčić, I., Prodanović, R., Nikolova, N., Lika, E., Puvača, N. (2021): Chili Pepper and Its Influence on Productive Results and Health Parameters of Broiler Chickens. *J, Agron, Technol. Eng. Manag*., **4**, 540–546.

[18] Giannenas, I., Bonos, E., Skoufos, I., Tzora, A., Stylianaki, I., Lazari, D., Tsinas, A., Christaki, E., Florou-Paneri, P. (2018): Effect of Herbal Feed Additives on Performance Parameters, Intestinal Microbiota, Intestinal Morphology and Meat Lipid Oxidation of Broiler Chickens. *Br Poult Sci*, **59**, 545–553. DOI:10.1080/00071668.2018.1483577.

[19] Puvača, N., Ljubojević, D., Kostadinović, Lj., Lević, J., Nikolova, N., Miščević, B., Könyves, T., Lukač, D., Po-

vić, S. (2015): Spices and Herbs in Broilers Nutrition: Hot Red Pepper (*Capsicum annuum* L.) and Its Mode of Action. *Worlds Poult Sci J*, **71**, 683–688. DOI:10.1017/S004393391500241X.

[20] Brenes, A., Roura, E. (2010): Essential Oils in Poultry Nutrition: Main Effects and Modes of Action. *Anim Feed Sci Tech*, **158**, 1–14. DOI:10.1016/j.anifeedsci.2010.03.007.

[21] Ezzat Abd El-Hack, M., Alagawany, M., Ragab Farag, M., Tiwari, R., Karthik, K., Dhama, K., Zorriehzahra, J., Adel, M. (2016): Beneficial Impacts of Thymol Essential Oil on Health and Production of Animals, Fish and Poultry: A review. *Journal of Essential Oil Research*, **28**, 365–382. https://doi.org/10.1080/10412905.2016.1153002.

[22] Puvača, N., Ljubojević, D., Kostadinović, Lj., Lukač, D., Lević, J., Popović, S., Đuragić, O. (2015): Spices and Herbs in Broilers Nutrition: Effects of Garlic (*Allium sativum* L.) on Broiler Chicken Production. *Worlds Poult Sci J*, **71**, 533–538. DOI:10.1017/S0043933915002214.

[23] Troost, C., Kirsten, J. F. (2022): Producer Prices, Carcass Classification and Consumers' Willingness to Pay for Different Sheep Meat Grades: An experimental auction approach. *Agrekon*, 1–17. DOI:10.1080/03031853.2022.2047079.

[24] Harris, D. L. (1970): Breeding for Efficiency in Livestock Production: Defining the Economic Objectives. *Journal of Animal Science*, **30**, 860–865. DOI:10.2527/jas1970.306860x.

[25] Khaksefidi, A., Rahimi, Sh. (2005): Effect of Probiotic Inclusion in the Diet of Broiler Chickens on Performance, Feed Efficiency and Carcass Quality. *Asian Australas. J. Anim. Sci*, **18**, 1153–1156. DOI:10.5713/ajas.2005.1153.

[26] Mir, N. A., Rafiq, A., Kumar, F., Singh, V., Shukla, V. (2017): Determinants of Broiler Chicken Meat Quality and Factors Affecting Them: A review. *J Food Sci Technol*, **54**, 2997–3009. DOI:10.1007/s13197-017-2789-z.

[27] Trichopoulou, A., Soukara, S., Vasilopoulou, E. (2007): Traditional Foods: A Science and Society Perspective. *Trends in Food Science & Technology*, **18**, 420–427. DOI:10.1016/j.tifs.2007.03.007.

[28] Mann, N. J. (2018): A Brief History of Meat in the Human Diet and Current Health Implications. *Meat Science*, **144**, 169–179. DOI:10.1016/j.meatsci.2018.06.008.

[29] Lupenko, Y. O., Kopytets, N. H., Voloshyn, V. M., Varchenko, O. M., Tkachenko, K. O. (2022): Quality of Poultry Meat as a Basis of Export Potential of the Meat Products. *IOP Conf. Ser.: Earth Environ. Sci.*, **949,** 012020. DOI:10.1088/1755-1315/949/1/012020.

[30] Fletcher, D. L. (2002): Poultry Meat Quality. *World's Poultry Science Journal*, **58**, 131–145. DOI:10.1079/WPS20020013.

[31] Cavani, C., Petracci, M., Trocino, A., Xiccato, G. (2009): Advances in Research on Poultry and Rabbit Meat Quality. *Italian Journal of Animal Science*, **8**, 741–750. DOI:10.4081/ijas.2009.s2.741.

[32] Hargis, P. S., Van Elswyk, M. E. (1993): Manipulating the Fatty Acid Composition of Poultry Meat and Eggs for the Health Conscious Consumer. *World's Poultry Science Journal*, **49**, 251–264. DOI:10.1079/WPS19930023.

[33] López-Ferrer, S., Baucells, M. D., Barroeta, A. C., Grashorn, M. A. (2001): N-3 Enrichment of Chicken Meat. 1. Use of Very Long-Chain Fatty Acids in Chicken Diets and Their Influence on Meat Quality: Fish Oil. *Poultry Science*, **80**, 741–752. DOI:10.1093/ps/80.6.741.

[34] Milićević, D., Vranić, D., Mašić, Z., Parunović, N., Trbović, D., Nedeljković-Trailović, J., Petrović, Z. (2014): The Role of Total Fats, Saturated/Unsaturated Fatty Acids and Cholesterol Content in Chicken Meat as Cardiovascular Risk Factors. *Lipids Health Dis.*, **13**, 42. DOI:10.1186/1476-511X-13-42.

[35] Petracci, M., Bianchi, M., Mudalal, S., Cavani, C. (2013): Functional Ingredients for Poultry Meat Products. *Trends in Food Science & Technology*, **33**, 27–39. DOI:10.1016/j.tifs.2013.06.004.

[36] Escobedo del Bosque, C. I., Spiller, A., Risius, A. (2021): Who Wants Chicken? Uncovering Consumer Preferences for Produce of Alternative Chicken Product Methods. *Sustainability*, **13**, 2440. DOI:10.3390/su13052440.

[37] Triki, M., Herrero, A. M., Jiménez-Colmenero, F., Ruiz-Capillas, C. (2018): Quality Assessment of Fresh Meat from Several Species Based on Free Amino Acid and Biogenic Amine Contents during Chilled Storage. *Foods*, **7**, 132. DOI:10.3390/foods7090132.

[38] Elmasry, G., Barbin, D. F., Sun, D.-W., Allen, P. (2012): Meat Quality Evaluation by Hyperspectral Imaging Technique: An Overview. *Critical Reviews in Food Science and Nutrition*, **52**, 689–711. DOI:10.1080/10408398.2010.507908.

[39] Pyakurel, D., Subedee, B. R., Subedi, C. K., Gurung, J., Chaudhary, R. P. (2022): Trade Potentiality of Oils Extracted from *Prunus davidiana* (Wild Apricot), *Sapindus mukorossi* (Soapnut) and *Zanthoxylum armatum* (Nepalese Pepper) in Kailash Sacred Landscape, Nepal. *Environmental Challenges*, **7**, 100490. DOI:10.1016/j.envc.2022.100490.

[40] Yeshi, K., Wangchuk, P. (2022): Essential Oils and Their Bioactive Molecules in Healthcare. In: *Herbal Biomolecules in Healthcare Applications*, Mandal, S.C., Nayak, A.K., Dhara, A.K. (Eds.). Academic Press, pp. 215–237. ISBN 978-0-323-85852-6.

[41] Dima, C., Dima, S. (2015): Essential Oils in Foods: Extraction, Stabilization, and Toxicity. *Current Opinion in Food Science*, **5**, 29–35. DOI:10.1016/j.cofs.2015.07.003.

[42] Hallagan, J. B., Hall, R. L. (1995): FEMA GRAS – A GRAS Assessment Program for Flavor Ingredients. *Regulatory Toxicology and Pharmacology*, **21**, 422–430. DOI:10.1006/rtph.1995.1057.

[43] Ríos, J.-L. (2016): Essential Oils: What They Are and How the Terms Are Used and Defined. In: *Essential Oils in Food Preservation, Flavor and Safety*, Preedy, V.R., (Ed.), Academic Press, San Diego, pp. 3–10. ISBN 978-0-12-416641-7.

[44] Turek, C., Stintzing, F. C. (2013): Stability of Essential Oils: A review: *Comprehensive reviews in food science and Food Safety*, **12** (1), 40–53. DOI:10.1111/1541-4337.12006.

[45] Lucchesi, M. E., Chemat, F., Smadja, J. (2004): Solvent-Free Microwave Extraction of Essential Oil from Aromatic Herbs: Comparison with Conventional Hydro-Distillation. *Journal of Chromatography A*, **1043**, 323–327. DOI:10.1016/j.chroma.2004.05.083.

[46] Luque de Castro, M. D., Jiménez-Carmona, M. M., Fernández-Pérez, V. (1999): Towards More Rational Techniques for the Isolation of Valuable Essential Oils from Plants. *TrAC Trends in Analytical Chemistry*, **18**, 708–716. DOI:10.1016/S0165-9936(99)00177-6.

[47] Bento, R., Pagán, E., Berdejo, D., De Carvalho, R.J., García-Embid, S., Maggi, F., Magnani, M., De Souza, E. L., García-Gonzalo, D., Pagán, R. (2020): Chitosan Nanoemulsions of Cold-Pressed Orange Essential Oil to Preserve Fruit Juices. *International Journal of Food Microbiology*, **331**, 108786. DOI:10.1016/j.ijfoodmicro.2020.108786.

[48] Gomes, P. B., Mata, V. G., Rodrigues, A. E. (2007): Production of Rose Geranium Oil Using Supercritical Fluid Extraction. *The Journal of Supercritical Fluids*, **41**, 50–60. DOI:10.1016/j.supflu.2006.08.018.

[49] Ferreira, D. F., Lucas, B. N., Voss, M., Santos, D., Mello, P. A., Wagner, R., Cravotto, G., Barin, J. S. (2020): Solvent-Free Simultaneous Extraction of Volatile and Non-Volatile Antioxidants from Rosemary (*Rosmarinus officinalis* L.) by Microwave Hydrodiffusion and Gravity. *Industrial Crops and Products*, **145**, 112094. DOI:10.1016/j.indcrop.2020.112094.

[50] Filly, A., Fernandez, X., Minuti, M., Visinoni, F., Cravotto, G., Chemat, F. (2014): Solvent-free microwave extraction of essential oil from aromatic herbs: From laboratory to pilot and industrial scale. *Food Chemistry*, **150**, 193–198. DOI:10.1016/j.foodchem.2013.10.139.

[51] Lukas, B., Schmiderer, C., Novak, J. (2015): Essential Oil Diversity of European *Origanum vulgare* L. (Lamiaceae). *Phytochemistry*, **119**, 32–40, DOI:10.1016/j.phytochem.2015.09.008.

[52] Sarkic, A., Stappen, I. (2018): Essential Oils and Their Single Compounds in Cosmetics – A critical review. *Cosmetics*, **5**, 11. DOI:10.3390/cosmetics5010011.

[53] Isman, M. B., Miresmailli, S., Machial, C. (2011): Commercial Opportunities for Pesticides Based on Plant Essential Oils in Agriculture, Industry and Consumer Products. *Phytochem Rev*, **10**, 197–204. DOI:10.1007/s11101-010-9170-4.

[54] Sedaghat Doost, A., Nikbakht Nasrabadi, M., Kassozi, V., Nakisozi, H., Van der Meeren, P. (2020): Recent Advances in Food Colloidal Delivery Systems for Essential Oils and Their Main Components. *Trends in Food Science & Technology*, **9**9, 474–486. DOI:10.1016/j.tifs.2020.03.037.

[55] Elshafie, H. S., Camele, I. (2017): An Overview of the Biological Effects of Some Mediterranean Essential Oils on Human Health. *BioMed Res. Int.*, **2017** (2),1–14. PMID: 29230418; PMCID: PMC5694587. DOI:10.1155/2017/9268468.

[56] Giannenas, I., Bonos, E., Christaki, E., Florou-Paneri, P. (2013): Essential Oils and Their Applications in Animal Nutrition. *Medicinal & Aromatic Plants*, 2. DOI:10.4172/2167-0412.1000140.

[57] Franz, C., Baser, K., Windisch, W. (2010): Essential Oils and Aromatic Plants in Animal Feeding – A European Perspective. A review. *Flavour Fragr J*, **25**. 327–340. DOI:10.1002/ffj.1967.

[58] Kostadinović, L., Lević, J. (2018): Effects of Phytoadditives in Poultry and Pigs Diseases. *J Agron Technol Eng Manag*, **1**, 1–7.

[59] Omonijo, F.A., Ni, L., Gong, J., Wang, Q., Lahaye, L., Yang, C. (2018): Essential Oils as Alternatives to Antibiotics in Swine Production. *Animal Nutrition*, **4**, 126–136. DOI:10.1016/j.aninu.2017.09.001.

[60] Wink, M. (2015): Modes of Action of Herbal Medicines and Plant Secondary Metabolites. *Medicines*, **2**, 251–286. DOI:10.3390/medicines2030251.

[61] Bourgaud, F., Gravot, A., Milesi, S., Gontier, E. (2001): Production of Plant Secondary Metabolites: A Historical Perspective. *Plant Science*, **161**, 839–851. DOI:10.1016/S0168-9452(01)00490-3.

[62] Lahlou, M. (2004): Methods to Study the Phytochemistry and Bioactivity of Essential Oils. *Phytother. Res.*, **18**, 435–448. DOI:10.1002/ptr.1465.

[63] Lietzow, J. (2021): Biologically Active Compounds in Mustard Seeds: A Toxicological Perspective. *Foods*, **10**, 2089. DOI:10.3390/foods10092089.

[64] Čabarkapa, I. (2015): *Ability to form biofilm of different Salmonella enteritidis strains and inhibitory effect of essential oils on initial adhesion and formed biofilm*. PhD, University of Novi Sad, Novi Sad. Serbia.

[65] Šarić, L., Čabarkapa, I., Šarić, B., Plavšić, D., Pavkov, S., Kokić, B. (2014): Composition and Antimicrobial: Activity of Some Essential Oils from Serbia. *Agro Food Industry Hi-Tech*, **25**, 40–43.

[66] Degenhardt, J., Köllner, T. G., Gershenzon, J. (2009): Monoterpene and Sesquiterpene Synthases and the Origin of Terpene Skeletal Diversity in Plants. *Phytochemistry*, **70**, 1621–1637. DOI:10.1016/j.phytochem.2009.07.030.

[67] *Flavours and Fragrances: Chemistry, Bioprocessing and Sustainability*, Berger, R.G. (Ed.). Springer, Berlin – New York, 2007. ISBN 978-3-540-49338-9.

[68] Abu-Lafi, S., Odeh, I., Dewik, H., Qabajah, M., Hanuš, L.O., Dembitsky, V. M. (2008): Thymol and Carvacrol Production from Leaves of Wild Palestinian Majorana Syriaca. *Bioresource Technology*, **99**, 3914–3918. DOI:10.1016/j.biortech.2007.07.042.

[69] Kowalczyk, A., Przychodna, M., Sopata, S., Bodalska, A., Fecka, I. (2020): Thymol and Thyme Essential Oil-New Insights into Selected Therapeutic Applications. *Molecules*, **25**, 4125. DOI:10.3390/molecules25184125.

[70] Siroli, L., Patrignani, F., Gardini, F., Lanciotti, R. (2015): Effects of Sub-Lethal Concentrations of Thyme and Oregano Essential Oils, Carvacrol, Thymol, Citral and Trans-2-Hexenal on Membrane Fatty Acid Composition and Volatile Molecule Profile of *Listeria monocytogenes*, *Escherichia coli* and *Salmonella enteritidis*. *Food Chemistry*, **182**, 185–192. DOI:10.1016/j.foodchem.2015.02.136.

[71] Radünz, M., Mota Camargo, T., Dos Santos Hackbart, H. C., Inchauspe Correa Alves, P., Radünz, A. L., Avila Gandra, E., Da Rosa Zavareze, E. (2021): Chemical composition and in vitro antioxidant and antihyperglycemic activities of clove, thyme, oregano, and sweet orange essential oils. *Lebensmittel-Wissenschaft + Technologie*, Vol. **138,** 110632. DOI:10.1016/j.lwt.2020.110632.

[72] Božik, M., Nový, P., Klouček, P. (2017): Chemical Composition and Antimicrobial Activity of Cinnamon, Thyme, Oregano and Clove Essential Oils against Plant Pathogenic Bacteria. *Acta Univ. Agric. Silvic. Mendelianae Brun.*, **65**, 1129–1134. DOI:10.11118/actaun201765041129.

[73] Tomaino, A., Cimino, F., Zimbalatti, V., Venuti, V., Sulfaro, V., De Pasquale, A., Saija, A. (2005): Influence of Heating on Antioxidant Activity and the Chemical Composition of Some Spice Essential Oils. *Food Chemistry*, **89**, 549–554. DOI:10.1016/j.foodchem.2004.03.011.

[74] Sakkas, H., Papadopoulou, C. (2017): Antimicrobial Activity of Basil, Oregano, and Thyme Essential Oils. *Journal of Microbiology and Biotechnology*, **27**, 429–438. DOI:10.4014/jmb.1608.08024.

[75] De Martino, L., De Feo, V., Nazzaro, F. (2009): Chemical Composition and *in vitro* Antimicrobial and Mutagenic Activities of Seven Lamiaceae Essential Oils. *Molecules*, **14**, 4213–4230. DOI:10.3390/molecules14104213.

[76] Takayama, C., De-Faria, F. M., De Almeida, A. C. A., Dunder, R. J., Manzo, L. P., Socca, E. A. R., Batista, L. M., Salvador, M. J., Souza-Brito, A. R. M., Luiz-Ferreira, A. (2016): Chemical Composition of R*osmarinus officinalis* Essential Oil and Antioxidant Action against Gastric Damage Induced by Absolute Ethanol in the Rat. *Asian Pacific Journal of Tropical Biomedicine*, **6**, 677–681. DOI:10.1016/j.apjtb.2015.09.027.

[77] Van der Werf, M. J., De Bont, J. A. M., Leak, D. J. (1997): Opportunities in Microbial Biotransformation of Monoterpenes. In: *Biotechnology of Aroma Compounds*, Berger, R. G., Babel, W., Blanch, H. W., Cooney, Ch. L., Enfors, S.-O., Eriksson, K. -E. L., Fiechter, A., Klibanov, A. M., Mattiasson, B., Primrose, S. B., Rehm, H. J., Rogers, P. L., Sahm, H., Schügerl, K., Tsao, G. T., Venkat, K., Villadsen, J., Von Stockar, U., Wandrey, C. (Eds.), Advances in Biochemical Engineering/Biotechnology, Springer, Berlin, Heidelberg, Vol. **55**, pp. 147–177. https://doi.org/10.1007/BFb0102065.

[78] Mechergui, K., Jaouadi, W., Coelho, J. P., Khouja, M. L. (2016): Effect of Harvest Year on Production, Chemical Composition and Antioxidant Activities of Essential Oil of Oregano (*Origanum vulgare* subsp. *glandulosum* (Desf.) Ietswaart) Growing in North Africa. *Industrial Crops and Products*, **90**, 32–37. DOI:10.1016/j.indcrop.2016.06.011.

[79] Popović, S., Puvača, N., Kostadinović, L., Džinić, N., Bošnjak, J., Vasiljević, M., Djuragić, O. (2016): Effects of Dietary Essential Oils on Productive Performance, Blood Lipid Profile, Enzyme Activity and Immunological Response of Broiler Chickens. *Europ. Poult. Sci*, **80**. DOI: 10.1399/eps.2016.146.

[80] Kirkpinar, F., Ünlü, H. B., Serdaroğlu, M., Turp, G. Y. (2014): Effects of Dietary Oregano and Garlic Essential Oils on Carcass Characteristics, Meat Composition, Colour, pH and Sensory Quality of Broiler Meat. *British Poultry Science*, **55**, 157–166. DOI:10.1080/00071668.2013.879980.

[81] Adaszyńska-Skwirzyńska, M., Szczerbińska, D. (2019): The Effect of Lavender (*Lavandula angustifolia*) Essential Oil as a Drinking Water Supplement on the Production Performance, Blood Biochemical Parameters, and Ileal Microflora in Broiler Chickens. *Poultry Science*, **98**, 358–365. DOI:10.3382/ps/pey385.

[82] Kırkpınar, F., Ünlü, H. B., Özdemir, G. (2011): Effects of oregano and garlic essential oils on performance, carcas, organ and blood characteristics and intestinal microflora of broilers. *Livestock Science*, **137** (1–3), 219–225. DOI:10.1016/j.livsci.2010.11.010.

[83] Yarmohammadi Barbarestani, S., Jazi, V., Mohebodini, H., Ashayerizadeh, A., Shabani, A., Toghyani, M. (2020): Effects of dietary lavender essential oil on growth performance, intestinal function, and antioxidant status of broiler chickens. *Livestock Science*, **233**, 103958. DOI:10.1016/j.livsci.2020.103958.

[84] El-Ashram, S., Abdelhafez, G. A. (2020): Effects of Phytogenic Supplementation on Productive Performance of Broiler Chickens. *Journal of Applied Poultry Research*, **29**, 852–862. DOI:10.1016/j.japr.2020.07.005.

[85] Seidavi, A. R., Laudadio, V., Khazaei, R., Puvača, N., Selvaggi, M., Tufarelli, V. (2020): Feeding of Black Cumin (*Nigella sativa* L.) and Its Effects on Poultry Production and Health. *World's Poultry Science Journal*, **76**, 346–357. DOI:10.1080/00439339.2020.1750328.

[86] Denli, M., Okan, F., Uluocak, A. (2004): Effect of Dietary Supplementation of Herb Essential Oil on the Growth Performance, Carcass and Intestinal Characteristics of Quail (*Coturnix coturnix* Japonica). *South African Journal of Animal Sciences*, **34**, 174–179.

[87] Al-Kassie, G. A. M. (2009): Influence of Two Plant Extracts Derived from Thyme and Cinnamon on Broiler Peformance. *Pakistan Veterinary Journal*, **29**, 169–173.

[88] Toghyani, M., Tohidi, M., Gheisari, A. A., Tabeidian, S. A. (2010): Performance, Immunity, Serum Biochemical and Hematological Parameters in Broiler Chicks Fed Dietary Thyme as Alternative for an Antibiotic Growth Promoter. *African Journal of Biotechnology*, **9**, 6819–6825. DOI:10.4314/ajb.v9i40.

[89] Bozkurt, M., Küçükyılmaz, K., Çatlı, A., Çınar, M. (2009): Effect of Dietary Mannan Oligosaccharide with or without Oregano Essential Oil and Hop Extract Supplementation on the Performance and Slaughter Characteristics of Male Broilers. *SA J. An. Sci.*, **39**, No. 3. DOI:10.4314/sajas.v39i3.49157.

[90] Giannenas, I., Florou-Paneri, P., Papazahariadou, M., Christaki, E., Botsoglou, N. A., Spais, A. B. (2003): Effect of Dietary Supplementation with Oregano Essential Oil on Performance of Broilers after Experimental Infection with *Eimeria tenella*. *Archives of Animal Nutrition*, **57**, 99–106. DOI:10.1080/0003942031000107299.

[91] Botsoglou, N. A., Florou-Paneri, P., Christaki, E., Giannenas, I., Spais, A. B. (2004): Performance of Rabbits and Oxidative Stability of Muscle Tissues as Affected by Dietary Supplementation with Oregano Essential Oil. *Archives of Animal Nutrition*, **58**, 209–218. DOI:10.1080/00039420410001701404.

[92] Zhang, T., Zhou, Y.F., Zou, Y., Hu, X.M., Zheng, L.F., Wei, H.K., Giannenas, I., Jin, L.Z., Peng, J., Jiang, S.W. (2015): Effects of Dietary Oregano Essential Oil Supplementation on the Stress Response, Antioxidative Capacity, and HSPs MRNA Expression of Transported Pigs. *Livestock Science*, **180**, 143–149. DOI:10.1016/j.livsci.2015.05.037.

[93] Kroismayr, A., Sehm, J., Pfaffl, M.W., Schedle, K., Plitzner, C., Windisch, W. (2008): Effects of Avilamycin and Essential Oils on mRNA Expression of Apoptotic and Inflammatory Markers and Gut Morphology of Piglets. *Czech J. Anim. Sci.*, **53**, 377–387. DOI:10.17221/338-CJAS.

[94] Windisch, W., Schedle, K., Plitzner, C., Kroismayr, A. (2008): Use of Phytogenic Products as Feed Additives for Swine and Poultry. *Journal of Animal Science*, 86, E140–E148. DOI:10.2527/jas.2007-0459.

[95] Jamroz, D., Wertelecki, T., Houszka, M., Kamel, C. (2006): Influence of Diet Type on the Inclusion of Plant Origin Active Substances on Morphological and Histochemical Characteristics of the Stomach and Jejunum Walls in Chicken. *J Anim Physiol Anim Nutr*, **90,** 255–268. DOI:10.1111/j.1439-0396.2005.00603.x.

[96] Zhai, H., Liu, H., Wang, S., Wu, J., Kluenter, A.-M. (2018): Potential of Essential Oils for Poultry and Pigs. *Anim Nutr*, **4**, 179–186, DOI:10.1016/j.aninu.2018.01.005.

[97] Hippenstiel, F., Abdel-Wareth, A., Kehraus, S., Südekum, K.-H. (2011): Effects of Selected Herbs and Essential Oils, and Their Active Components on Feed Intake and Performance of Broilers – A review. *Archiv für Geflugelkunde*, **75**, 226–234.

[98] Krishan, G., Narang, A. (2014): Use of Essential Oils in Poultry Nutrition: A New Approach. *J Adv Vet Anim Res*, **1**, 156. DOI:10.5455/javar.2014.a36.