Essential oils in broiler chicken diets as antimicrobial agents: Systematic review

Beatriz Delcarme Lima | Robson Mateus Freitas Silveira | Daniela Bernadete Rozza

Abstract The search for alternative ingredient options in the animal diet that have antimicrobial activity is due to many factors, such as pathogens increasing resistance and the presence of antibiotic residues in animal products consumed by humans. Therefore, there is a rising demand for natural additives that do not interfere with animal development or human health. Here, we compare studies on the use of essential oils as antimicrobial agents in broiler chicken diets. First, 90 papers were found using the key words “broilers”, “antimicrobial”, and “essential oils”. The second step was to select the papers according to the scales of Jadad and Medeiros and Stein, where six remaining researchers were selected to describe the antimicrobial activity of essential oils in response to enteric pathogens. Essential oils (EOs) have antimicrobial activity against different pathogens, such as E. coli, S. Enteritidis, S. Heidelberg and C. perfringens, and are considered alternatives to antibiotics used in animal production. The EOs that showed the greatest effectiveness were oregano essential oil (EO), cinnamaldehyde and thymol concentrates; when used together with additives such as sodium butyrate and xylanase, there was better antimicrobial action and improved animal performance. Ginger and carvacrol EOs also demonstrated antimicrobial activities, as did thymol, cinnamaldehyde and eucalyptus EO concentrates, but studies on the specific action of plant species that produce EOs for certain pathogens are still lacking; thus, the topic lacks an ongoing study addressing the addition of EOs in the feed of poultry production.

Keywords: anti-infectious, domestic birds, poultry, volatile oils

1. Introduction

The antimicrobial activity of essential oils and their compounds, such as bacteriostatic or bactericidal, or against other pathogens, such as fungi and protozoa, is well documented (Chao et al 2000; Burt 2004). The more effective in this sense are the phenolic compounds carvacrol, thymol and eugenol but also other substances, such as phenylpropane, limonene, geraniol, or citronellal (Franz et al 2010). Are differences in the activities among species and parts of plants observed, and this is due to the variable chemical composition of the plant (chemotype, morphology, and ontogenetic variation).

As plants are biological systems, they are variable in nature, with the occurrence of chemotypes being frequent, i.e., chemically distinct groups within the same plant species, which are characterized by being phenotypically similar but differing in their chemical constituents. Different chemotypes from the same plant may be different in terms of properties and actions, interfering with the formation of the essential oil.

An example present in this review is Origanum vulgare. Origanum can be divided into three intraspecific chemotypes according to the predominance of their aromatic monoterpenes: carvacrol-type, thymol-type, and terpinen-4-ol-type (Skoula and Harbone 2002). This classification was confirmed by the results of the study by Betancourt et al (2014), who identified three chemotypes: OH with a high proportion of carvacrol, OL with a high proportion of thymol, and OM with a high content of compounds derived from sabinene.

Another example is Lippia graveolens (Mexican oregano or lipia), whose essential oil (EO) exhibits significant levels of carvacrol and thymol (Sánchez et al 2010; Bautista-Hernández et al 2021). The high levels of these components provide this EO with an antimicrobial capacity, since the antimicrobial activity of essential oils is probably associated with the phenolic compounds carvacrol and thymol, when present in major fractions (Simões and Spitzer 2004). However, comparisons between recent studies show that the EOs of oregano and thyme, in addition to the compounds carvacrol and thymol, are the most used in research and have proven efficiency (Franz et al 2010). For this reason, these compounds and EOs were chosen as the subject of this review.

One mechanism of action of essential oil compounds as antimicrobials is the rapid depletion of the intracellular pool of ATP by reducing ATP synthesis and simultaneously increasing hydrolysis in bacteria (Lambert et al 2001; Veldhuizen et al 2006). Furthermore, changes in the fatty acid compositions of bacterial cell membranes were observed at sublethal doses of various essential oils (Pasqua and Hoskins 2006).
Other effects are demonstrated by substances such as carvacrol, which prevents the synthesis of flagellin, causing bacterial cells to be afflicted and therefore nonmotile. These cells are significantly less able to adhere to epithelial cells, which makes the strains potentially pathogenic in noninfectious bacteria (Burt et al 2007), a mechanism similar to dietary galacturonic acids (Guggenbichler et al 2004). In vitro antimicrobial activities were evaluated with several essential oils and unique compounds, mainly against the enteropathogenic bacteria Escherichia coli, Salmonella spp. or Clostridium perfringens. Using the broth microdilution method or the agar diffusion test, essential oils with the highest percentage of phenolic compounds had the strongest inhibitory capacity in terms of minimum inhibitory concentration (MIC) (Penalver et al 2005; Ben Arfa et al 2006; Jugl-Chizzola et al 2006).

Reducing the intestinal microbiota, as with broad-spectrum antibiotics, is undesirable, but microbiota balance can be achieved by essential oil treatments (Franz et al 2010). In view of this important scenario described, this systematic review aims to evaluate the effectiveness of the antimicrobial action, mainly of the essential oils of oregano and thyme and of the compounds carvacrol and thymol, in the creation of broilers on the pathogenic agents E. coli, Salmonella spp. and Clostridium perfringens. Furthermore, the reliability of each method will also be analyzed, according to the consulted literature.

2. Materials and Methods

All papers selected for this systematic review are randomized controlled experimental studies. Following the selection of articles, the scale of Jadad et al (1996) was applied with the objective of assuring the quality of the selected papers. These were also classified in relation to the level of scientific evidence and degree of recommendation as Medeiros and Stein says (2002), according to the authors, presented in Table 1.

Table 1 Classification of scientific articles according to the Jadad et al Quality Scale (1996) and to Degree of Recommendation and Level of Scientific Evidence according to Medeiros and Stein (2002).

<table>
<thead>
<tr>
<th>Authors and year of publication</th>
<th>Quality scale</th>
<th>Degree of Recommendation</th>
<th>Level of evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betancour et al (2014)</td>
<td>3</td>
<td>A</td>
<td>1b</td>
</tr>
<tr>
<td>Cerisuelo et al (2014)</td>
<td>2</td>
<td>A</td>
<td>1b</td>
</tr>
<tr>
<td>Jerzsele et al (2012)</td>
<td>3</td>
<td>A</td>
<td>1b</td>
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<tr>
<td>Amerah et al (2012)</td>
<td>1</td>
<td>A</td>
<td>1b</td>
</tr>
<tr>
<td>Santurio et al (2011)</td>
<td>3</td>
<td>A</td>
<td>1b</td>
</tr>
<tr>
<td>Timbermont et al (2010)</td>
<td>2</td>
<td>A</td>
<td>1b</td>
</tr>
</tbody>
</table>

All the publications were randomized controlled experimental studies.

2.1. Scientific classifications of papers

Essential oils are considered alternative options to antibiotics used in poultry production. In recent years, several studies have been carried out to evaluate their effectiveness as growth promoters, anticoccidials and antimicrobials, and this last factor is evaluated in the present review. The most expressive papers were chosen, which are shown in Table 1, which classifies scientific articles according to the type of study and according to the Quality Scale by Jadad et al (1996). Still in Table 1, the articles were classified according to the Degree of Recommendation and Level of Scientific Evidence according to Medeiros and Stein (2002).

The quality scale by Jadad is used to evaluate randomized clinical trials and was constructed by a multidisciplinary panel of six experts, which summarized three items directly related to the reduction of bias. All items have two answer options: yes or no. The questions asked are as follows: “Was the study described as randomized (use of words such as “random”, “randomization”, “randomization”)?”, “Was the study described as double-blind??”, and “Was there a description of losses and exclusions?”. For each “yes” answer to these questions, one point should be assigned to the work. For each “no” answer, the work receives zero points. In addition to these questions, one should answer if: “Has the randomization method been described and is it adequate?” and “Has double-blind masking been described and is it adequate?” For each “yes” answer to these two questions, one more point was added, and for each “no” answer, one point was removed from the study. A maximum of five points can be obtained: three points for each yes, an additional point for a suitable method of randomization, and an additional point for a suitable method of masking. A study is considered of low quality if it receives two points or less after its evaluation (Jadad et al 1996).

In the papers analyzed, the lowest number of points awarded was one, and the highest was three. For example, in the work by Santurio et al (2011), which received the lowest score, it was found that the study was described as random and correct, adding up to a total of two points. However, there was no description of whether the study was double-blind, nor did it describe losses and exclusions. As there was also no adequate description of double-blind masking, one point was removed, and with that, his final score was one point. In the studies by Cerisuelo et al (2014) and Timbermont et al (2010), their final scores were two points, as there was an adequate description of randomization and the study was described as double-blind, adding three points; however, there was no adequate description of masking, thus removing one point. There was also no description of losses and exclusions.
Regarding the studies by Betancourt et al. (2014), Jerzsele et al. (2012) and Amerah et al. (2012), the total sum was three points. The studies had an adequate description of randomization and description of losses and exclusions, adding up to three points. They were also considered double-blind, adding one more point; however, as the description was not adequate, one point was removed, and the final sum of the studies was three points.

To classify articles according to the level of scientific evidence and degree of recommendation, Medeiros and Stein's (2002) classification was used. In the case of this systematic review, all the studies used received the same classification since they all had the same characteristics and were randomized controlled experimental studies.

The level of evidence of the analyzed studies is considered 1b, which comprises individual randomized and controlled studies with a narrow confidence interval. The Grade of Recommendation A, which includes all works in this review, consists of level 1 studies. These are studies with strong recommendations in choice; the levels of evidence to routinely recommend conduct are excellent. The benefits outweigh the harm, and there is good evidence to support the recommendation (Medeiros and Stein 2002).

3. Results and Discussion

Table 2 contains the main information about the treatments used and the results of each experiment according to each bacterium analyzed, which are the tools used to conduct the discussion.

<table>
<thead>
<tr>
<th>Authors and year of publication</th>
<th>Essential oils used</th>
<th>Bacteria analyzed</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Betancourt et al. (2014)</td>
<td>Oregano Essential Oil: Origanum vulgare L. (OL); O. vulgare L. ssp. hirtum (OH); O. majorana (OM); O. vulgare L. ssp. hirtum (OG).</td>
<td><em>Escherichia coli</em></td>
<td>EO treatments reduced differences in microbiota and ascites mortality.</td>
</tr>
<tr>
<td>Cerisuelo et al. (2014)</td>
<td>Specific blend of essential oils with an 18% concentration of cinnamaldehyde and thymol.</td>
<td><em>Salmonella Enteritidis</em></td>
<td>Birds fed with EO and SB showed less contamination by Salmonella Enteritidis in the cecum.</td>
</tr>
<tr>
<td>Jerzsele et al. (2012)</td>
<td>Protected blend of ginger and carvacrol essential oils (1%).</td>
<td><em>Clostridium perfringens</em></td>
<td>In birds that received EOS and SB + EOS there was greater weight gain and reduction of lesions by Clostridium perfringens.</td>
</tr>
<tr>
<td>Timbermont et al. (2010)</td>
<td>Essential oils (thymol, cinnamaldehyde, eucalyptus essential oil) microencapsulated in a polysugar matrix.</td>
<td><em>Clostridium perfringens</em></td>
<td>Butyric acid and medium chain fatty acids and EO reduced lesions by Clostridium perfringens.</td>
</tr>
</tbody>
</table>

3.1. Treatments used and antimicrobial actions of essential oils

3.1.1. Antimicrobial action of EOs against *Escherichia coli*

Although some studies prove the effectiveness of essential oils as antimicrobial agents, there are differences in relation to the ingredients and compounds of these oils and in which bacteria it is possible to observe this effect.

The study by Betancourt et al. (2014) represents the first study that evaluated the antimicrobial effects of the three main chemotypes of the genus *Origanum* on intestinal bacterial communities in broilers. Each chemotype contains different amounts of secondary metabolites, such as carvacrol, thymol and sabine. Oregano essential oils (EOEs) from the varieties *Origanum vulgare L.* (OL), *O. vulgare L. ssp. hirtum* (OH), *O. majorana* (OM) and *O. vulgare L. ssp. hirtum* (OG), which were obtained by steam distillation. These authors used 750 birds kept at 2,600 m above sea level, divided into 30 cages of 25 birds, consisting of five replicates of each treatment. The treatments performed were 1) 200 mg/kg of the OH chemotype; 2) 200 mg/kg of the OL chemotype; 3) 200 mg/kg of the OM chemotype; 4) 50 mg/kg of the OG chemotype; 5) 500 mg/kg of chlortetracycline; and 6) control treatment without additives. The experiment was carried out for 42 days.

On days 21 and 42 of the experiment, five birds from each group were randomly selected and euthanized. The digestive system was aseptically removed, and part of the duodenal, jejunal, ileal and cecal contents of the birds was collected. The contents were analyzed by denaturing gradient gel electrophoresis using 16S rDNA standards for *Escherichia*...
coli identification. In the group of supplemented broilers, there was a reduction in the difference in the microbiota profiles of the small intestine (duodenum, jejunum, and ileum) and large intestine (cecum and colon). The OEO groups showed a higher coefficient of similarity (62.7%) of the microbiota between these two compartments in relation to the control groups (coefficient of similarity of 53.7%).

In the birds supplemented with OEO and antibiotics, the mortality of broilers caused by ascites was reduced in 59% of the birds when compared to the control group without additive. There is a higher incidence of A5 in animals located at altitudes above 1,500 meters, as in the case of this study, due to the rarefaction of oxygen in the air in these places, where the reduced partial pressure of oxygen in the atmosphere causes tissue hypoxia and increased cardiac output (Jenisch, et al 2001). This study by Betancourt et al (2014) demonstrated that treatments performed with OEO improved the microbiological profile of the gastrointestinal tract and reduced mortality from ascites, thus suggesting an antimicrobial action of these oregano chemotypes.

Santurio et al (2011) analyzed the antimicrobial activity of EOs from *Origanum vulgare* (oregano), *Thymus vulgaris* (thyme), *Cinnamomum zeylanicum* (cinnamon), *Lippia graveolens* (Mexican oregano), *Salvia officinalis* (sage), *Rosmarinus officinalis* (rosemary) and *Ocimum basilicum* (basil) against *Escherichia coli* isolated from poultry (n=43) and cattle (n=36) feces. The antimicrobial action of all analyzed EOs was tested in all samples. Mexican oregano and thyme EOs were equally active against the bird isolates, and cinnamon EO was the least active (P<0.0001) against both isolates. In the present study by Santurio et al (2011), cinnamon EO was less active than oregano, lipia and thyme for both poultry and bovine isolates. Regarding the EOs of rosemary, sage, basil and ginger, the results presented did not show any antimicrobial activity of these EOs in relation to the evaluated microorganisms. The EOs of oregano, Mexican oregano, thyme, and cinnamon showed antimicrobial activity against the *E. coli* isolate from the feces of birds and cattle. The most effective EO in relation to the antimicrobial activity of both isolates was the oregano EO, and the least effective was the cinnamon EO. The studies by Betancourt et al (2014) and Santurio et al (2011) confirmed the antibacterial potential of some EOs against *E. coli*, especially oregano.

### 3.1.2. Antimicrobial action of EOs against *Salmonella* spp.

The study by Cerisuelo et al (2014) evaluated the effect of EO and the combination of EO with sodium butyrate on enteric colonization of *Salmonella* spp. In 480 broilers for 42 days. Dietary treatments consisted of the addition of different doses of EO (control - 0 mg/kg; EO50 - 50 mg/kg and EO100 - 100 mg/kg) or a combination of EO with 1 g/kg of SB (B - sodium butyrate; OEB50 - sodium butyrate + 50 mg/kg of EO and OEB100 - sodium butyrate + 100 mg/kg of EO) to a basal diet. On the seventh day after the beginning of the study, the birds were orally infected with 108 CFU of *Salmonella Enteritidis*. The prevalence and enumeration of *Salmonella Enteritidis* in feces were evaluated at 72 hours postinfection and on days 23 and 37 of the study. On day 42, all birds were euthanized, and both the cecum and liver were aseptically removed from 80 birds (two birds/repeat/treatment) and sampled for *Salmonella* spp. detection and pH measurement. In the treatments performed, no differences were observed in the enteric colonization of *Salmonella* spp., and all fecal samples analyzed were positive for *Salmonella* spp. from the 10th day to the 42nd day.

Treatment with EO50 had the lowest level of enteric colonization (6.3%) compared to the other treatments (P < 0.05). The control group had the highest percentage of *Salmonella* spp.-positive birds (68.8%). The pH of the cecal content was not different between treatments. At high doses, EO or its combination with sodium butyrate did not affect enteric colonization by *Salmonella* spp., but it is suggested that low doses of EO combined with SB (EOB50) are effective in controlling *Salmonella* spp.

The study by Amerah et al (2012) consisted of analyzing the effect of xylanase and a mixture of essential oils on the enteric colonization of *Salmonella Heidelberg* in broilers. For this, 2000 birds were raised for 42 days, separated by five different treatments, and only the animals of group 1 were not challenged with *Salmonella* spp. The five groups were as follows:

1) Control – animals received ration without food additives and were not challenged with *Salmonella* spp.;
2) Challenge control, which did not contain food additives and was challenged with *Salmonella* spp.;
3) Basal diet with EO addition, where the active ingredients were cinnamaldehyde and thymol (100 g/ton of diet);
4) Basal diet with the addition of xylanase (2000 U/kg of feed);
5) Basal diet containing a combination of EO (100 g/ton of feed) and xylanase (2000 U/kg of feed). On the first day, half of the birds from each treatment were marked and dosed with *Salmonella* Heidelberg (5×10⁵ CFU/mL). On day 42, ten birds from each treatment were killed, and their caeca were removed and tested for *Salmonella* spp.

Combined xylanase and EO treatment improved body weight gain and feed efficiency compared to treatment with xylanase alone. Supplementation with xylanase and EO reduced (P < 0.05) the incidence of horizontal transmission of *Salmonella* spp. infection among birds by up to 77% compared to the control. On day 42, xylanase supplementation had no effect on positive smear samples compared to the challenged control. However, EO and the combined EO and xylanase treatment reduced (P < 0.05) positive smear samples compared to the challenged control.
It can be suggested that in the studies by Cerisuelo et al. (2014) and Amerah et al. (2012), the addition of EOs, whose active compounds were cinnamaldehyde and thymol, improved bird performance and reduced contamination and the incidence of Salmonella spp. transmission among animals, contributing to food safety. In both studies, the best results were presented when EOs was used concomitantly with other additives, such as sodium butyrate and xylanase, which intensified the beneficial action of these EOs.

3.1.3. Antimicrobial action of EOs against Clostridium perfringens

The study by Jerzsele et al. (2012) analyzed the action of EOs on an artificial model of infection by Clostridium perfringens, which causes necrotic enteritis (NE). Five treatments were performed: 1) control group, in which the animals were fed the basic diet, without any food additive; 2) BP70 (highly concentrated and protected sodium butyrate); 3) a spore suspension of Bacillus amyloliquefaciens (BAL) at a concentration of 109 CFU/g; 4) protected essential oils without additives at 1% [EO; ginger oil and carvacrol]; and 5) a protected combination of SB and the same 1% OES (BP70 + EO). A total of 160 birds were used for a period of 25 days. These were challenged with 2 mL of suspension of Clostridium perfringens of avian origin (6-8×10^8 CFU) orally on days 18, 19, 20 and 21 of the experiment three times a day. The body weights of the animals were measured and compared during the experiment on days 3, 7, 10, 14, 16, 20 and 25. On the 25th day, the beneficial effects of BP70 + EO and EO led to a significantly higher weight gain in the animals compared to the other groups. At the end of treatment, the animals were euthanized, followed by necropsy and histopathological analysis of the collected organs (liver, spleen, duodenum, jejunum, ileum and pancreas).

A high percentage of the animals showed the clinical signs of necrotic enteritis (NE), such as diarrhea with dark, hemorrhagic stools, apathy, anemia, dehydration, inappetence and death. In the control group (A), all animals developed mild, moderate or severe signs of NE. The macroscopic findings in the small intestine were extensive catarhral necrohemorrhagic enteritis. Macroscopic and microscopic findings were discrete in animals treated with 1.5 g/kg EO (P<0.05) compared to the control, while a highly significant deviation (P<0.005) was observed in the case of the supplementation group of animals BP70 + EO.

Only the use of sodium butyrate (SB) did not provide a beneficial effect in relation to the control of the growth of Clostridium perfringens. It is suggested that essential oils potentiate the effect of SB, although this phenomenon must be confirmed in vitro. The explanation for this synergistic action is probably that SB improves the regeneration of the intestinal epithelium, thus decreasing the amount of α-toxigenic Clostridium perfringens that can bind to the villi surface and produce the toxin that causes NE. No significant differences were found between EO and EO+BP70 in histopathological scores or weight gain after 25 days (P>0.05). According to the results, it is suggested that supplementation with EO and BP70 + EO has important beneficial effects in the evaluation of the pathological findings of subclinical MS.

In conclusion, birds infected with Clostridium perfringens and treated with EO and BP70 + EO showed significantly better weight gain, increased villus length, and decreased macroscopic and histopathological scores compared to the control. SB alone and the B. amyloliquefaciens spore suspension had no beneficial effects on the course of the disease. Essential oils were primarily responsible for the better performance and greater resistance to NE. According to the results, the protected combination of SB and EOs, as well as the protected OEs, may be potential candidates for the prevention and treatment of NE in broilers.

Timbermont et al (2010) performed two experiments evaluating the antimicrobial action of EO on Clostridium perfringens isolates. In the first experiment, four groups of animals were separated, with 25 chickens in each group. The separation took place as follows: Butc Group, the animals were fed a diet supplemented with butyric acid; Butc/Fat group, diet supplemented with butyric acid in combination with fatty acids mainly lauric acid; Butc/Fat/Eo Group diet supplemented with butyric acid in combination with medium chain fatty acids and EOs (thymol, cinnamaldehyde and eucalyptus essential oil) and Eo Group diet supplemented only with EOs. In the second experiment, the same products were tested, but at higher concentrations, and an extra group (Group Fat) was included; in this group, the animals received a diet supplemented only with medium-chain fatty acids.

The concentrations varied according to the experiments. In the first one, 0.86 mg/mL butyric acid, 0.0078 mg/mL lauric acid, 0.029 mg/mL thymol, 0.008 mg/mL cinnamaldehyde and 0.67 mg/mL eucalyptus essential oil were used. Eucalyptus. In the second experiment, higher concentrations of 220 mg/mL butyric acid, 0.5 mg/mL lauric acid, 3.76 mg/mL thymol, 1 mg/mL cinnamaldehyde and 10.67 mg/mL eucalyptus essential oil were used.

Animals were reared for 25 days, and all groups were challenged orally using a plastic tube (three times a day) with approximately 4,108 CFU of Clostridium perfringens bacteria on days 19, 20, 21, and 22. On days 23, 24 and 25, eight birds from each group were euthanized for macro and microscopic evaluations of the intestinal tract. In both experiments, there was a decrease in the number of birds with macroscopic lesions compared to the untreated infected control group (positive control).

In experiment one, in all groups, with the exception of the one that received only butyric acid, a statistically significant decrease was found in the number of birds with necrotic lesions compared to the infected and untreated control group (positive control). The combination of butyric acid with medium-chain fatty acids and EOs provided the best protection.
against the induction of NE lesions. In trial two, the addition of butyrate, medium-chain fatty acids or EOs alone provided a statistically significant reduction in the number of birds that developed necrotic lesions in the intestine. The combination of butyrate and medium-chain fatty acids provided the best protection. Feed supplementation with butyric acid, medium-chain fatty acids and EOs did not result in a significant decrease in the number of birds with macroscopic lesions of NE. When the results of the two assays were combined and evaluated for significant differences, considering the concentration difference, all groups differed significantly from the positive control group. In conclusion, it is shown that butyric acid, medium-chain fatty acids (mainly lauric acid) and EOs (thymol, cinnamaldehyde and eucalyptus essential oil), or combinations of these additives, can be used to control necrotic enteritis in broilers.

When evaluating the works of Jerzsele et al (2012) and Timbermont et al (2010), it is suggested that the EOs of ginger and carvacrol, thymol, cinnamaldehyde and eucalyptus EO may exert antimicrobial activity against Clostridium perfringens, especially when there is synergism with other additives, such as sodium butyrate, butyric acid, or fatty acid medium chain.

4. Conclusions

OES has antimicrobial activity against different pathogens, such as Escherichia coli, Salmonella Enteritidis, Salmonella Heidelberg and Clostridium perfringens, and is considered an alternative to antibiotics used in animal production.

The EOs that showed the greatest effectiveness were oregano EO, cinnamaldehyde and thymol concentrates; when used together with additives such as sodium butyrate and xylanase, there was better antimicrobial action and improved animal performance. Ginger and carvacrol EOs also demonstrated antimicrobial activities, as did thymol, cinnamaldehyde and eucalyptus EO concentrates, but studies on the specific action of plant species that produce EOs for certain pathogens are still lacking; thus, the topic lacks an ongoing study addressing the addition of EOs in the feed of production animals.

Ethical Considerations

Not applicable.

Conflict of Interest

The authors report no conflicts of interest. The authors themselves are responsible for the content and writing of the paper.

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