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Review paper

NATURAL ALTERNATIVES TO GROWTH-PROMOTING ANTIBIOTICS (GPA) IN ANIMAL PRODUCTION

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ABSTRACT

There is a worldwide tendency to produce the best meat regardless of their origin (i.e., poultry, goats, cows, and pigs) free of drug residues, bacteria causing food toxicity, and contaminants (chemicals), ensuring consumers high-quality products. These pollutants are used in animal feed to improve the characteristics of raw materials, fodders, and/or animal products, to prevent diseases, and to increase production. The most commonly used additives are antibiotics or antimicrobial agents used as growth promoters (GPA) whose global trend is to avoid their use due to the risk of developing bacterial resistance, and vertical and horizontal transmission that can impact on human health, on animal wellness, and on productivity. Therefore, the search for new plant origin alternatives to replace the GPA's such as herbs, spices, plant extracts and/or essential oils to be used as antimicrobials and to also make them available to contribute to animal nutrition.

Keywords: antibiotic (antimicrobial) growth promoters, additives, plant extracts, essential oils.

INTRODUCTION

The use of additives in animal feed began in the forties to improve the organoleptic characteristics of raw materials, fodders, and/or animal products, to prevent diseases and to improve the production efficiency by decreasing the mortality, and stimulating the weight gain in the forties (Dibner, and Richards, 2005; Castanon, 2007; Upadhayay and Vishwa, 2014).

Additives used in animal feed are diverse and heterogeneous. Different categories are found depending on their properties and functions (Marroquin-Cardona *et al*., 2010; Upadhayay and Vishwa,2014). The European Union (EU) classifies them as follows (Barton, 2000): antibiotics; antioxidants; aromatics and flavorings; coccidiostats and other medicinal substances; emulsifiers, stabilizers, thickeners, and gelling; colorants including pigments; preservatives; vitamins, provitamins, and other chemically well-defined substances with similar effect; trace elements (oligo elements); binders, anti-caking agents, and coagulants; acidity regulators; enzymes; microorganisms; radionuclide binders.

There are antimicrobial nature additives in this classification; that is to say, antibiotic additives or antimicrobial agents used as growth promoters (GPA) in animals (Casewell *et al.*, 2003; Allen *et al*., 2013) also known as "digestive modifiers" (Singh, 2015).

Antimicrobial or antibiotic growth promoters (GPA) played an essential role in the economic development of modern poultry production that benefitted producers and consumers of animal products (Upadhayay and Vishwa, 2014). Nevertheless, due to the risk posed by GPAs to create cross-resistance to antibiotics used in human medicine and the presence of these compounds in animal products, their use has dropped dramatically, and it has been banned in some cases on the formulation of fodders for animal husbandry (Gaucher *et al.*, 2015). In 1969, The Swann Committee recommended restrictions on the use of antimicrobials in animal fodders and allowed only those not used as therapeutics in human and veterinary medicine. In 1993, the first studies showing a relationship between the use of avoparcin and an increment and transmission of vancomycin-resistant enterococci, the same antibiotic group (glycopeptides), arises. Later in 1998, the EU prohibits ardamicina as GPA because of the risk of generating cross-resistance, and since 1999, another four antibiotics (virginiamycin, bacitracin zinc, tylosin phosphate, spiramycin) as a precaution. In the same year, The US Permanent Scientific Committee recommends abandoning the GPA that can be used in human and veterinary medicine or those who promote cross-resistance. It is prohibited the use of inhibitors (carbadox and olaquindox) for reasons of occupational health. In 2006, the use of GPAs (avilamycin, flavophospholipol, salinomycin, monensin) was prohibited. The last two GPAs could be used in chickens as coccidiostats until January 2012 (Livermore, 2005; Wise, 2005; Aminov, 2010; Gaucher *et al*.,2015).

Nonetheless, some researchers have suggested that the removal of these substances is causing an increase in the incidence of bacterial infections (i.e., diarrhea, coccidiosis and intestinal necrosis) (Castanon, 2007: Allen *et al.*, 2013). These prohibitions impact the livestock sector economically because it leads to increased production costs. American industry shows that the use of GPS in poultry production is associated with losses for producers (Dibner and Richards, 2005; Graham *et al*., 2007).

So, there is the need to find alternatives to the use of antibiotics (Gaucher *et al*.,2015). Among these alternatives, the most used are probiotics, prebiotics, enzymes, essential oils, herbs, spices and vegetable extracts (Table 1) (Huyghebaert *et al*., 2011; Upadhayay and Vishwa, 2014).

In this last category, the use of GPA substitutes or replacements focuses on the control of the intestinal and/or bacterial flora, particularly the pathogen type (Casewell*et al*., 2003; Dibner and Richards, 2005). Herbs, plant extracts, and essential oils used as food additives include different bioactive ingredients such as alkaloids, flavonoids, tannins, and saponins that are expected to act on the appetite of the animal and gut microflora, on the stimulation of production of digestive enzymes. Also, they can act on the intensification of endogenous enzymatic activity and immune system along with a wide antimicrobial and antioxidant properties that can benefit health and weight gain of farm animals (Umar Lule and Xia, 2005; Hervert-Hernández and Goni, 2011; Cicerale *et al.*, 2012). The primary action mode of growth promoting additives can be started in stabilizing fodders hygiene and beneficially affecting the ecosystem of the gastrointestinal microflora by controlling potential pathogens. This applies primarily to the critical stages in the development of animals when having a high susceptibility to digestive disorders (Platel*et al.*, 2004).

In 1945, Sanders *et al*. reported more than 120 species of plants exhibiting inhibitory properties against the growth of Bacillus subtilis and Escherichia coli. Recently, many scientific studies have focused on the antimicrobial effects of herbs and plant extracts (Dorman and Deans, 2000).

Effect of the compound type and structure in bacterial activity: The effect and the structural requirements are not fully defined for antimicrobial activity. Studies have proved there must be, at the least, hydroxyl (OH) and methoxy ($-OCH_3$) groups, and some degree of lipophilicity (Mandalari *et al*., 2007; Sánchez-Maldonado *et al*., 2011). These groups yield an oxidative phosphorylation, causing a rising of pH, and hence, toxicity. Sanchez-Maldonado *et al*., (2011) found that in phenolic acids such as benzoic acid, cinnamic acid, hydroxybenzoic acids (p-hydroxybenzoic, protocatechuic, gallic acid, and syringic), and hydroxycinnamic acids (p-coumaric, caffeic and ferulic), the antimicrobial activity of the hydroxycinnamic acids was comparable or higher than that of hydroxybenzoic acids with the same number of hydroxyl groups.

Polyphenolic compounds are more efficient uncoupling as long as they have a higher number of hydroxyl groups per molecule transferring more protons, which increases their degree of lipophilicity (Mandalari*et al*., 2007; Sánchez-Maldonado *et al*., 2011).

As in polyphenolic compounds, in essential oils, there is no absolute definition of antimicrobial activity, which in this case, is attributed to different mechanisms ranging from damage to the cytoplasmic membrane, proteins, and cell wall. Consequently, there is cell content filtration driving force reduction (Lambert *et al*., 2001; Cava-Roda *et al.*, 2012.). This effect is due to the high degree of hydrophobicity or lipophilicity that allows the separation of the lipid structure of the cell membrane and mitochondria, disordering the structure. Therefore, it affects their permeability, allowing the migration of ions and other compounds, and resulting in a homeostatic imbalance (Bajpai *et al.*,2013) that leads to a cytotoxic effect on the cells (Bakkali *et al*., 2008).

Some plant materials that can be considered as substitutes for GPAs because of their antimicrobial activity by the presence of polyphenolic compounds and essential oils would be garlic (*Allium sativum*), oregano (*Origanum vulgare*), thyme (*Thymus vulgaris*), and moringa (*Moringa oleifera*), which are addressed in this review as proposals.

1. Garlic (Allium sativum) and Growth-Promoting Antibiotics (GPAs): Garlic is a crop that is considered one of the most studied natural alternatives to be used as GPA. Several potential antimicrobial compounds can be extracted from Garlic. Garlic extracts have been studied as effective against organisms as *Helicobacter pylori*, *Mycobacterium tuberculosis, Shigelladysenteriae 1, Shigellaflexneri Y, Shigellasonnei*, *Escherichia coli, Staphylococcus aureus, Streptococcus, Viridins, Streptococcumhemolyticus, Llebsiellapneumonae* and *Proteus vulgaris* (Table 2) (Cellini *et al.*, 1996; Chowdhury *et al.*, 1991; Santhosha *et al.*, 2013; Uchida *et al.*, 1975). Extracted garlic compounds have broad-spectrum antibacterial properties acting against Gram (+) and Gram (-). The garlic compound whose antimicrobial activity is attributed to is known as allicin, an organosulfur compound from which the metabolites diallyl sulfide and diallyl disulfide are formed. The action mechanism of allicin is given by its chemical reaction with thiol groups of various enzymes (alcohol dehydrogenase, thioredoxin reductase, and RNA polymerase); it also inhibits the formation of enzyme complexes as acetyl-CoA whose process is reversible and noncovalent (Ankri and Mirelman, 1999; Rabinkov *et al*., 1998).

1.1. Using garlic as a Growth-Promoting Antibiotic: It has been found that garlic supplementation of $1 g•kg^{-1}$ for 35 days did not have a significant effect on weight gain, feed rate, feed efficiency, plasma cholesterol, triglycerides, and glucose (Horton *et al*., 1991). Nevertheless, reported that using garlic in chicken diets reduced cholesterol biosynthesis by inhibiting lipogenic enzymes (Qureshi *et al*., 1983;Cross *et al.*, 2011). Also, Cross *et al*. (2011) supplemented diets of broiler chickens with garlic and reported a significant weight gain after seven days of being fed. However, they reported that supplementation with garlic affects the flavor intensity of the meat, either unusual taste or garlic flavor.

It has also been reported that the total plasma cholesterol concentration, dried fecal matter, and relative weights of organs such as heart, pancreas, liver, and spleen are not significantly affected by the garlic diet. However, compared with the group of chickens supplemented with commercial antibiotic that exhibited reduced weight in the small intestine than those animals fed with garlic (Sarica *et al*., 2005).

Additionally, the use of garlic in the diet of broiler chickens has proven to lower the lipid content and cholesterol in plasma and liver (Konjufca *et al*., 1997; Sarica *et al*., 2005). In another study, Carreño-Botía and Hortúa-Lopez (2013) evaluated the use of garlic extract as an alternative to growth promoters in broilers. They reported that the inclusion of garlic extracts in diets improved weight gain and feed conversion rate; on the other hand, no effect was observed on the parameters of mortality and presence of endoparasites. In contrast, Toghyani *et al.*, (2011) used powdered garlic supplement in diets for broilers. They reported Feed intake, feed efficiency, internal organ weights and carcass characteristics were not significantly influenced by consuming de garlic, similarly, serum protein, albumin, triglyceride and Serum glutamic pyruvic transaminase were not affected by dietary treatments. Garlic powder significantly increased red blood cell count, hemoglobin concentration, and hematocrit percentage compared to the control group. Sensory evaluation of thigh meat displayed no abnormal odor or flavor in the meat.

In conclusion, the main advantage of using garlic as GPA strives on its effect without harmful side effects for broiler chickens and consumers. However, the main disadvantage is reported in some cases modifying the flavor to the meat. These aspects should be studied further in experiments with better control and/or inter-laboratory experiments.

2. Oregano (*Origanum vulgare*): Oregano is the common name used to define a characteristic aroma and taste derived from a broad range of plant genera and species used as a spice. At least 61 species and 17 genera from six plant families are known as oregano being the most important *Verbenaceae* and *Lamiaceae* (Kintzios, 2012). Besides being used as condiments to flavor foods, oregano has been attributed to other properties such as antioxidant, anti-inflammatory, and antimicrobial. These properties are related to the presence of various types of phytochemicals such as phenolic compounds, flavonoids, and terpenoids among others (Baratta *et al*., 1998; Loizzo *et al.*, 2009; Kogiannou *et al.*, 2013.). Although a broad range of active compounds of oregano has been isolated, the most important group because of their commercial and industrial applications are essential oils consisting mainly of terpenoids (Kintzios, 2012).

Oregano has brought great interest as an alternative to the use of Growth-Promoting Antibiotic because its essential oil is rich in monoterpenoids, carvacrol, and thymol that exhibit antioxidant and antimicrobial properties in vitro and in vivo along with animal digestion stimulation (Hernández *et al*., 2004). Various studies have been conducted to determine the antimicrobial properties of essential oil of oregano and evaluate their complementary use in animals diets. Table 3 shows some studies that have evaluated the antimicrobial activity of oregano extracts. The incorporation of dried oregano leaves in the diet of sheep was tested. The carcasses of lambs fed with the supplement of dried oregano leaves had a similar productive performance to the control; i.e., no significant differences between the final carcass weight and the conversion of food (Bampidis *et al*., 2005). The same research group determined the effect of including dried oregano leaves to feed turkeys by detecting the body weight of the animal, feed conversion efficiency, the characteristics of the channel, and the concentration of cholesterol in blood serum. This study showed that adding oregano to diet for turkeys does not significantly affect the parameters mentioned in these animals at 42 days of age. However, the inclusion of oregano improved feed conversion efficiency in animals at 43 to 84 days of age. These researchers suggest oregano growth promoter in turkeys (Bampidis *et al*., 2005). Meanwhile, Soultos *et al*. (2009) analyzed two diets supplemented with oregano essential oil at concentrations of 100 and 200 $mg \cdot kg^{-1}$ for feeding rabbits. It was observed that the performance parameters, the end of the channel, and feed conversion ratio of weight were not affected significantly; while the population count of *Pseudomonas spp.* and *Enterobacteriaceae* in the channels was significantly decreased compared to the control (standard diet without an inclusion of essential oil) (Soultos *et al*., 2009). Mohiti-Asliand Ghanaatparast-Rashti (2015) evaluated the effectiveness of essential oil of oregano on growth and prevention of coccidiosis, an intestinal disease caused by *Eimeria coccidiosis* in broilers. The inclusion of essential oils at 500 ppm in the diet of broilers mitigates the negative effects of coccidiosis without affecting weight gain of chickens (Mohiti-Asli and M. Ghanaatparast-Rashti 2015).

These studies suggest that the addition of oregano essential oil in the diet for animal feeding does not affect performance parameters, but has an effect on microbial growth; so oregano is an excellent choice for use as an alternative to Growth-Promoting Antibiotic.

3. Thyme (*Thymus vulgaris* L.): Thyme is an aromatic annual herb belonging to the *Lamiaceae* family that can be used fresh or dried as a spice and has various biological activities as antiseptic, expectorant, and antioxidant. It has also been reported to possess antibacterial activity against a broad number of pathogen microorganisms (Vincent, 2000). Furthermore, it has been reported beneficial effects in controlling coccidosis in chickens (Allen *et al*., 1998). These activities are related to the presence of phenolic compounds and terpenoids as thymol and carvacrol, constituting between 40 to 50% of its essential oil (Siatis *et al*., 2005).

In Table 4 some studies with thyme, extracts or essential oils on the activity and survival of microorganisms related to birds' microbiota.

There have been several studies to evaluate the use of thyme and its essential oil in the diet of poultry and determine their antimicrobial activity. Rahim *et al*. (2001) studied the effect of aqueous extracts of thyme used as an alternative to antibiotics for chickens' growth, in the efficiency of feed conversion, and blood factors. The extract showed no significant effect of the above factors.

Denli *et al*. (2004) evaluated the effect of thyme essential oil (60 mg•kg^{-1} diet) assessing the parameters of growth, carcass characteristics, and organ weight in quail (*Coturnix japonica coturnix*) compared with commercial antibiotic (flavomycyn). No significant effect was observed on weight gain related to the control diet, a decrease in the percentage of abdominal fat and intestine weight, the weight, and length of the carcass, and gizzard weight were not affected either. This group concluded that the use of essential oil of Thymus improves feed conversion efficiency and tends to decrease the percentage of abdominal fat quail; therefore, thyme is suggested as a growth promoter in quail.

Bölükbaşi *et al*.,2008 studied the effect of adding thyme at levels of 0.1, 0.5 and 1% of the total weight of the basal diet for laying hens. They found an improvement in the efficiency of feed conversion and production eggs was significantly improved with supplementation of thyme to levels of 0.5% that significantly reduced the presence of *Escherichia coli* in feces compared to the basal diet. This study agrees with the results of the study by Sarıca *et al*. (2005) who found that broiler chickens fed with 0.1% of thyme in the basal diet had a significant effect in reducing the count of Escherichia coli in the small intestine compared to the control diet.

Several studies have shown that essential oils and herbal extracts improve animal performance and have antibacterial and anticoccidial effects, but other authors report that these additives are not effective in this regard. Still they have received considerable attention as replacements to Growth-Promoting Antibiotics.

4. Moringa (*Moringaoleifera*): *Moringaoleifera*is the best-known species of the genus *Moringa*, a small group of plants within the order *Brassicales*, a family that includes cabbage and radish along with the family of cress and capers (APG, 2009). The most closely related family to *Moringaceae* is *Caricaceae*, which includes papaya, sharing both, the characteristic of glands at the apex of the petiole (Olson, 2002). *Moringaceae* comprises only one genus, *Moringa*. *Moringa* embraces 13 species; *arborea, concanensis, drocanensis, drouhardii, hildebrandtii, pygmeae, pilgrim, rospolianaovalaifolia, stenopetala, rivae, oleifera*, and *borziana*, which cover a diverse range of habits or growing ways from sorts of herbs and shrubs to large trees (Olson and Razafimandimbison, 2000; Olson, 2001; Atawodi, *et al.*, 2010). While varying greatly in form, it is very easy to distinguish a member of *Moringa* from any other plant. It is a tree from the southern Himalayas, northeast India, Bangladesh, Afghanistan, and Pakistan. It is widely distributed over a large part of the planet and in Central America. It is known by several common names: Moringa, benzolivo, mlonge, mulangay, stick, kelor, moringa, Reseda, nébéday, saijhan, and sajna among others. Its main use is as a nutritional supplement using flour Moringa leaves for this purpose. Moreover, the leaves, either ground into flour or extract have anti-inflammatory and antimicrobial antioxidant properties (Olson and Fehey, 2011). Their antimicrobial property is possibly linked to different phenolic compounds such as Benzoic acid, zeatin, quercetin, beta-sitosterol, caffeoylquinic acid, kaempferol, and especially benzyl isocyanate (Prakash *et al.*, 2007; Atawodi *et al*., 2010; (Jideani and Diedericks, 2014).

In this regard, it has been reported that leaves extracts of *Moringa oleifera* (Moringa) have antimicrobial activity against Gram (+) and Gram (-) (Viera *et al*., 2010). On the other hand, Nkukwana *et al.*, (2014) evaluated flour fodders of Moringa leaves as food sources for broiler chickens as a partial replacement of protein in a commercial fodder. The replacement of commercial feed within levels t levels ranging between 1 and 25 g per kg of feed in the starter, grower and finisher diets; did not alter the nutrient composition of the diets. Moringa flour did not reveal differences in weight gain, nutrient utilization, feed intake, and digestibility as from 2.5% level of substitution. This evidence allows to consider the Moringa leaf meal as a substitute for GPA in the production system of animal protein from birds. Further study is needed, at inclusion levels higher than 2.5% are recommended to determine nutrient flow and retention directly from digestibility.

Although the vast majority of studies have focused on Moringa leaf, there is also evidence of the antimicrobial activity of extracts of other plant organs such as fruit, bark, seeds, and roots (Table 5) (Nikkon *et al.*, 2003; Chuang *et al.*, 2007; Singh *et al.*, 2013; Arora and Onsare, 2014; Ndhlala *et al.*, 2014; Rim Jeon *et al.*, 2014; Elumalai *et al.*, 2015). These studies have shown results from mild to very high inhibition effects of different microorganisms; thus, becoming a potential source of GPA. It is only pending studies on their cytotoxic and aggregate level in consumers to establish their degree of substitution and safety.

Other plant sources with potential as antimicrobials and/or GPA: Herbs, extracts, and essential oils obtained from plants have been used as alternatives to antibiotics, but with contradictory results. Therefore, it is ever more important to study them for their possible antimicrobial effects and the stimulatory effect on the animal digestive System.

Table 6 shows other sources of plant extracts, essential oils and/or components of their oils.

Cinnamon extracts with methylene chloride inhibit *Helicobacter pylori* to a concentration range similar to those of common antibiotics. These properties are primarily related to the content of cinnamaldehyde and eugenol followed by carvacrol (Tabak *et al.*,1999).

The addition of 200 mg•kg^{-1} and 500 mg•kg^{-1} of rosemary essential oil in a mixture of wheat-corn-soy diet does not improve the overall weight gain, nor the feed conversion efficiency compared to the control diet and diet with antibiotic avilamycina (Hernández *et al.*, 2004). Furthermore, Spernakova *et al.*, (2007) reported that the addition of 500 mg•kg^{-1} rosemary powder sample in broiler chickens' diets shows a high gain in weight compared with the control group.

300 g•t^{-1}of a commercial preparation of a natural blend of essential oils from basil, caraway, laurel, lemon, oregano, sage, tea, and thyme (Tecnaroma Herbal Mix PL) were added to the basal diet of broilers. It was found that the improvement in growth performance was not dose dependent (Khattak *et al.*, 2014).

On the other hand, Yurtseven *et al.*, (2008) found that there is no significant effect on the addition of 7.5 mL of sage extract per kilogram of food in weight gain, feed intake, feed conversion, and carcass weight compared to diets containing 0.1% of flavomycin antibiotic. Sage essential oil has shown an inhibitory effect to *Escherichia coli* (Rahimi *et al.*, 2011).

Previous authors evaluated the effects of *Echinacea purpurea* extracts added to drinking water in the growth, immune system, blood factors, and intestinal population in broilers. They concluded that the weight of these chickens was lower as compared with the antibiotic virginiamycin, feed conversion rate is higher when the extracts are used, and the inhibition of *Escherichia coli* does not have a difference between the control diet and when extracts are added. Roth-Maier et al., (2005) reported that the use of 10 mg•kg^{-1} of *Echinacea purpurea* added to the broilers diet produced a fall in food consumption and weight when comparing with the utilization of the antibiotic flavomycin. In this study, they also added the aerial parts of *Echinacea* in the diet of healthy broilers and laying hens, which did not give any beneficial effect on feed intake and animals' growth. These authors concluded that *Echinacea purpurea* should not be considered as an alternative to antibiotics as growth promoters in animal feed.

Most essential oils exert their antimicrobial activity affecting bacterial cell walls by breaking them given the lipophilic character of oils, which accumulate themselves in membranes, and coagulating proteins. On the other hand, the outer membrane of a gram (+) contains lipopolysaccharide that forms a hydrophilic surface by creating a barrier to permeation of hydrophobic substances such as essential oils (Dorman and Deans, 2000).

These studies have shown that several herbs, herbal extracts, and essential oils have different effects on the performance of broilers, which seems related to the composition of phenolic compounds and terpenoids. The inclusion of a simple herb extract or essential oil does not always have a similar effect on bird performance. The quality of diet and environmental conditions are important in testing the inclusion of bioactive diets. So, herbs, extracts, and essential oils can influence the performance and production of secretions in broilers.

The results of previous studies warrant further research in this area to determine optimal levels of inclusion in the diet of animals and their mode of action for optimal growth and digestion.

Conclusions and future trends in the field: Notwithstanding the existence of different plant constituents that can replace the use of GPAs, replacing these remains partial and its effectiveness has not been entirely convincing. It should, therefore, be complemented with other hygiene measures and animal management practices. In Sweden, ten years after the banning of GPAs, poultry production doubled reaching 68 million per year (more than 15% to export). At present, nutritional diseases are rare in Sweden (Wierup, 2001).

The banning of GPAs continues to gain ground worldwide and its trend is increasing, especially in the demand for "free" or free of contaminants, drug residues, and bacteria that cause food toxic infections ensuring consumers high-quality products at "acceptable" costs. Educating consumers to "eat more healthy foods does not necessarily cost more» (Torres and Zarazaga, 2002).

Besides, it leads to a change of approach on the sight of producers not focusing solely on lowering feed costs (IC) and compromising the quality of the final product, but also adding value to their products by guaranteeing their customers an almost zero risk to consumption.

Additionally, these actions should focus directly on animal welfare with better breeding, fattening, and products derived from them.

Table 1.Alternatives to GPAs.

Additive Type	Possible Action Mechanism
Organic acids	Inhibition of bacterial growth
Prebiotics	Stimulus of desirable bacteria in the intestinal tract
Probiotics	Introduction of desirable bacteria in the intestinal tract
Enzymes	Removing enzymes antinutritional effects of non-starch polysaccharides (NSP)
Herbs, species, extracts vegetables, Essential Oils	Multiple depends on the composition

Table 2.Antimicrobial Properties of Garlic.

Extract type	Microorganism	Reference
Aqueous	*Shigelladysenteriae 1*, *Shigellaflexneri* Y, *Shigellasonnei*, *Escherichia coli*	Chowdhury *et al.*, 1991
Aqueous (10 mM, pH 7.0, phosphate buffer)	*Helicobacter pylori*	Cellini *et al.*, 1996
Purified Aline	*Mycobacterium tuberculosis*	Uchida *et al.*, 1975

Table 3. Antimicrobial activity of essential oils extracted from oregano.

Extract type	Chemical Components	Microorganism/bacteria	Reference
Distilled with vapor	Essential Oils: Carvacrol, *p*-Cimeno	*Listeriamonocytogenes* and *Salmonellaenteritidis*	Pesavento *et al.*, 2015
Hidrodistilled	Carvacrol, thymol, and terpineol	*Staphylococcus aureus*	Marques *et al.*, 2015
	Essential Oils	*Listeria monocytogenes*, *Escherichiacoli* y *Salmonella enteritidis*	Siroli *et al.*, 2015
Orego-Stim®	Essential Oil	Sporulatedoocystsof Eimeiraacervulina, *Eimeira máxima* and *Eimeiratenella*	Mohiti-Asli and Ghanaatparast-Rashti, 2015
Orego-Stim®	Essential Oil	*Pseudomonas*spp., *Enterobacteriaceae*, *Brochothrixthermosphacta*, Yeast and fungi.	Soultos *et al.*, 2009

Table 4. Antimicrobial activity of essential oils extracted from thyme polyphenolic compounds.

Material or extract	Chemical Composition	Strain or microorganism	Reference
Thyme powder basal diet	Flavonoids Phenolic Acids	*Escherichia coli*	Sarıca *et al.*, 2005 Bölükbaşi *et al.*, 2008
Essential Oil	Thymol Carvacrol	*Clostridium perfringens* *Escherichia coli*	Acamovic and Cross, 2007. Mitsch *et al.*,2004).

Table 5. Antimicrobial activity of Photochemicals extracted from Moringa

Part of the plant	Chemical component (s) Component group (s)	Bacterial Strain/ Microorganism	Extract type	Reference
Leaves	Alkaloids, Flavonoids Phenolics compounds	*Staphylococcus aureus* *Bacillus subtilis* *Pseudomonas aeruginosa* *Escherichia coli* *Proteus mirabilis* *Candida albicans* *Candida tropicalis*	Aqueous	Elumalai *et al.*, 2015
	Flavonoids Phenolic compounds	*Klebsiellapneumoniae* *Staphylococcus aureus* *Candida albicans*	Ethanol 70%	Ndhlala *et al*.,2014
	Essential Oils	*Trichophytonrubrum* *Trichophytonmentagrophytes* *Epidermophytonxoccosum* *Microsporumcanis*	Ethanol	Chuang *et al.*, 2007
Pod/ Fruit	-	*Staphylococcus aureus* *Staphylococcus epidermidis* *Escherichia coli*	Acetone	Arora and Onsare, 2014
Seeds	Gallic acid Catechin Epicatechin p-Coumaric acid Ferulic acid Vanillin Caffeic acid Protocatechuic acid Cinnamic acid Quercetin	*Staphylococcus aureus* *Bacillus cereus* *Escherichia coli* *Yersinia enterocolitica*	Ethanol Methanol Acetone Hexane Chloroform (10:1 (v/w))	Singh *et al.*, 2013
	4-(α-L-rhamnosyloxy)-benzyl isothiocyanate	*Staphylococcusaureus* *Escherichiacoli* *Pseudomonasaeruginosa* *Candidaalbicans* *Aspergillusniger*	Ethanol 70% Methanol	Rim Jeon *et al*.,2014
root bark	Desoxy-niazimicinaglycone	*Shigellaboydii* *Shigelladysenteriae* *Staphylococcus aureus* *Bacillus megaterium* *Candida albicans* *Aspergillisflavus*	Chloroform	Nikkon *et al.*, 2003.

Table 6. Antimicrobial activity of vegetable extracts.

Plant/Extract	Chemical Composition	Microorganism	Reference
Cinnamon (*Cinnamomumverum*) Extract with methylene chloride	Cinnamaldehide Eugenol Carvacrol	*Helicobacter pylori*	Tabak*etal.*, 1999. Mitsch*etal*., 2004
Cinnamon (*Cinnamomumverum*)	Cinnamaldehide	*Escherichia coli*	Chang *et al.*,2001
Echinacea (*Echinacea purpurea*)		*Escherichia coli*	Rahimi*et al*.,2011
Sage(*Salvia officinalis*)	α-pinene 1,8-cineole	*Escherichia coli*	Tzakou*et al.*,2001

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