The increasing pressure of abolishing and/or decreasing the use of antibiotics as antimicrobial growth promoters for livestock calls for alternative solutions to sustain the efficiency of current livestock production. Among the alternatives, essential oils have a great potential and are generally considered natural, less toxic, and free from residues. Essential oils have been proven in numerous in vitro studies to exert antimicrobial effects on various pathogens. The current review touched on the basics of essential oils, and the in vivo effects of essential oils on growth, intestinal microflora, anti-oxidation, immune functionality, meat qualities as well as the possible modes of action in poultry and pigs, and the future research areas were proposed.

1. Introduction

The recognition of microorganisms being responsible for a variety of diseases in the late half of the 19th century ushered in the discoveries of antibiotics, which saw its golden era between 1950s and 1970s. But since then, no new classes of antibiotics had been discovered (Aminov, 2010). Meanwhile, the improper use of antibiotics resulted in the selection of bacteria resistant to antibiotics. One of the solutions is to implement bans of using antibiotics as antimicrobial growth promoters (AGP) for farm animals, which makes it imperative to find effective alternatives to antibiotics to sustain the efficiency of current livestock production. Among the alternatives, essential oils have a great potential. The essential oils are generally considered natural, less toxic, and free from residues when compared with antibiotics (Gong et al., 2014).

Essential oils are complex mixtures of volatile compounds produced by living organisms and isolated by physical means only (pressing and distillation) from a whole plant or plant part of known taxonomic origin (Franz and Novak, 2009). The term “essential oils” emerged because “oils” were wishfully believed to be “essential” to life, and have a long history of being used by human for cosmetic and medicinal purposes. The development of essential oils, however, was delayed by the advent of antibiotics in the middle of the 19th century, and was renewed recently. It was estimated that, out of 3,000 known essential oils, 300 were recognized as commercially important and mainly used in the flavors and fragrances market (van de Braak and Leijten, 1994). The global essential oil market is expected to reach 11.67 billion USD by 2022.

The aim of the current review was to identify the well-recognized efficacy of essential oils for poultry and pigs as well as the conflicting research findings, whereupon more research efforts could be directed to the inconclusive area to facilitate a better understanding of essential oils.

2. Basics of essential oils

Essential oils are a sum of constituent volatiles, and thus the effects of essential oils should be a totality of effects of all components and their interactions. However, 2 or 3 components could account for up to 85% of the total mixture compared with the minors (Miguel, 2010), and thereby contribute to the primary property of the mixture. For example, the phenols (thymol and carvacrol) constitute about 80% of the essential oils of oregano, the...
most widespread species of Lamiaceae family, and are mainly responsible for its antibacterial and antioxidant activities. Besides thymol and carvacrol, p-cymene was found as another dominant component of oregano (Bouhaddoua et al., 2016). Although the p-cymene is not an effective antimicrobial agent by itself, it could facilitate the transport of carvacrol across the cytoplasmic membrane (Oke et al., 2009).

The composition of essential oils is primarily determined by the homogeneity of the starting materials, whose characteristics could be influenced by a plethora of factors. For example, the total content of monoterpene hydrocarbons (mostly γ-terpinene and p-cymene) and phenol terpenes (mostly thymol and carvacrol) ranges from 57.3% to 62.5% of the essential oils from a Thyme (Thymus pulegioides L.), relatively constant over different harvesting times, but the phenol content starts to increase at the beginning of the flowering and reaches its greatest value during the full flowering period of the plant (Senatore, 1996). The biological activities in in vivo trials largely depend on the chemical profile of essential oils.

Essential oils account for only a small proportion (usually less than 1%) of the wet weight of plant materials, which makes it imperative to improve the yield of essential oils by continuous developments in relevant fields such as genetic engineering and extraction methods. These developments presented challenges to the concept of essential oils as well as the knowledge of biological activities of essential oils. For example, the steam-distilled essential oils from Origanum vulgare showed a great antibacterial activity against reference strains with a moderate antioxidant activity, while the methanolic extract exhibits no antibacterial activity but a high antioxidant activity (Bouhaddoua et al., 2016), which suggests that the bioactivity of essential oils is indeed based on the method of extraction (Vigan, 2010). In addition, there is a growing part of chemically-synthesized essential oils used in feed industry.

Most constituents of essential oils are terpenoids and phenylpropanoids. Phenylpropanoids occur less frequently and less abundantly than terpenoids (Hammer and Carson, 2011). The well-known plant families for producing essential oils with medicinal and industrial values include Alliaceae, Apioaceae, Asteraceae, Lamiaceae, Myrtaceae, Poaceae, and Rutaceae (Raut and Karuppayil, 2014). Some representative essential oils include, but not limited to, anise (Apiaceae), oregano (Lamiaceae), cinnamon (Laureaceae), garlic (Liliaceae), thyme (Myrtaceae), black pepper (Piperaceae), and Turmeric (Zingiberaceae).

3. Essential oils for poultry

3.1. Growth performance

Essential oils are perceived as growth promoters in poultry diets (Zhang et al., 2014). Animal trial results, however, are considerably variable. Table 1 gives a summary of the factors which could influence the efficacy of essential oils for both poultry and pigs. These factors relate to the experimental essential oils, animals, diets, and environment.

3.1.1. Feed intake

Recently-published reviews (Brenes and Roura, 2010; Bozkurt et al., 2014; Franz et al., 2010; Hashemi and Davoodi, 2010; Hippenstiel et al., 2011) reported that feed intake in chicks was unchanged or slightly reduced by dietary inclusion of essential oils. For the decreased feed consumption, one possible explanation is that essential oils possess an irritating smell, which renders the palatability of diet disagreeable to birds. Amad et al. (2011) and Halle et al. (2004) reported that daily feed intake of broilers was numerically decreased by increasing the dietary level of a blend of thyme, star anise, and oreganun leaves, and its associated essential oils compared with control. Similarly, Cabuk et al. (2006) noted a significantly reduced feed intake of broilers from young breeders by graded inclusion of a cocktail of essential oils (oregano oil, laurel leaf oil, sage leaf oil, myrtle leaf oil, fennel seed oil, and citrus peel oil). In contrast to pigs, information of poultry concerning feed preference was scarce. Moran (1982) reported that poultry might not be sensitive to flavor as pigs, and Roura et al. (2008) reported that birds are more tolerant to exposure of moderate levels of essential oils than pigs.

3.1.2. Feed utilization

Unlike feed intake, improvements in weight gain and feed conversion ratio dominate the observations. Two well-accepted mechanisms are the stimulation of digestive enzyme secretion and the stabilization of ecosystem of gut microflora, leading to improved feed utilization and less exposure to growth-depressing disorders associated with digestion and metabolism (Bento et al., 2013; Franz et al., 2010; Kurecki et al., 2014; Lee et al., 2003; O’Bryan et al., 2015; Williams and Losa, 2001). The positive effects of essential oils on digestive enzyme secretion from pancreas and intestinal mucosal have been reported in many broiler studies (Basmacioglu Malayoglu et al., 2010; Jamroz et al., 2006; Jing et al., 2007). These effects were confirmed by the increased digestibility of nutrients, but did not translate into improvement in growth performance (Amad et al., 2011; Botsoglou et al., 2004; Garcia et al., 2007; Hernández et al., 2004; Lee et al., 2003). It is noteworthy that there is an inadequate description of the environmental conditions under which these trials were conducted, and poor hygienic conditions might be instrumental for essential oils to favorably affect the growth performance of broilers.

3.2. Antimicrobial and anticoccidial activity

The antimicrobial activity of essential oils has been explored in many in vitro assays which showed that thymol, eugenol and carvacrol have high antimicrobial activity against pathogenic bacteria such as Escherichia coli and Salmonella typhimurium, both of which are potential risk factors of enteric infections (Bassolé and Juliani, 2012; Franz et al., 2010; Hippenstiel et al., 2011). Thymol, eugenol and carvacrol are structurally similar, and have been proved to exert synergistic or additive antimicrobial effects when combined at lower concentrations (Bassolé and Juliani, 2012). Therefore, it is necessary to unravel the synergistic mechanism to optimize their formulation. Different in vitro methods as well as different pathogens exist for ranking the antimicrobial capacity of essential oil components, which could vary dramatically as shown in Table 2. In in vivo studies, essential oils used either individually or in combination have shown clear growth inhibition of Clostridium perfringens and E. coli in the hindgut and ameliorated intestinal lesions and weight loss than the challenged control birds (Jamroz et al., 2006; Jerzsele et al., 2012; Mitsch et al., 2004). One well-known mechanism of antibacterial activity is linked to their hydrophobicity, which disrupts the permeability of cell membranes and cell homeostasis with the consequence of loss of cellular components, influx of other substances, or even cell death (Brenes and Roura, 2010; Solórzano-Santos and Miranda-Novales, 2012; Windisch et al., 2008; O’Bryan et al., 2015). It is of note that Gram-negative bacteria are more tolerant to the actions of essential oil than Gram-positive bacteria due to their hydrophilic constituents in the outer membrane (Brenes and Roura, 2010; Giannenas et al., 2013; Seow et al., 2014).

Coccidiosis, a common parasitosis disease caused by protozoa of the genus Eimeria, leads to malnutrition and performance depression in poultry. There is an increasing interest in using essential oils against coccidiosis infection. The supplementation of essential oils
led to a significant reduction of coccidial oocyst excretion and an alleviation of intestinal lesions in chicks (Alp et al., 2012; Bozkurt et al., 2014; Barbour et al., 2015). However, the underlying mechanisms still need to be elucidated.

3.3. Anti-oxidative activity and carcass hygiene

Chicken body antioxidative stability could be improved by essential oils. Karadas et al. (2014) fed a blend of carvacrol, cinnamaldehyde, and capsicum oleoresin to Ross 308 broilers, and found a significant increase in the hepatic concentration of carotenoids and coenzyme Q10 at d 21 of age. Habibi et al. (2014) and Placha et al. (2014) observed that malondialdehyde concentration in liver, duodenal mucosa, and kidney was significantly decreased by supplementing ginger power and thyme oil to broiler diet.

Poultry products are particularly prone to oxidative deterioration due to their high concentrations of polyunsaturated fatty acids. The reviews by Lee et al. (2003) and Khan et al. (2012) showed that

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### Table 1
Factors influencing the efficacy of essential oils.

| Factors                      | Essential oils                                      | Results or speculations                                      | Species     | Reference          |
|------------------------------|-----------------------------------------------------|--------------------------------------------------------------|-------------|--------------------|
| Dietary form                 | Menthol, cinnamaldehyde                             | A pelleting temperature of 58 °C led a recovery of 17% to 56% of the indicator substances | Pigs        | Maenner et al., 2011 |
| Dietary nutrient density     | Buckwheat, thyme, curcuma, black pepper, ginger     | Benefits of essential oils are more dramatic with high nutrient density diets | Pigs        | Yan et al., 2010   |
| Dietary composition          | Thymol, cinnamaldehyde, CRINA Poultry               | Highly digestible diet may diminish the efficacy of essential oils | Broilers    | Lee et al., 2003   |
| Essential oils composition   | Menthol, cinnamaldehyde                             | The essential oil mixture with menthol, not cinnamaldehyde, as the primary component improved gain to feed intake | Pigs        | Maenner et al., 2011 |
| Essential oils composition   | Caraway, fennel                                      | Caraway oil, not fennel oil, at 100 mg/kg feed, tended to decrease feed intake | Pigs        | Schöne et al., 2006 |
| Essential oils composition   | Thyme, oregano, marjoram, rosmary, yarrow           | Various herbs and oils have different effects, which may be primarily related to differences in their terpene composition | Broilers    | Cross et al., 2007  |
| Dosage                       | Cinnamon, thyme, oregano                            | Feed intake and weight gain responded to the supplementation of oregano quadratically | Pigs        | Namkung et al., 2004 |
| Dosage                       | Oregano                                             | The absence of benefit could be due to improper doses          | Pigs        | Maenner et al., 2011 |
| Environment                  | Menthol, cinnamaldehyde                             | Feeding trials under simulated research station or commercial farm conditions gave similar results | Pigs        | Kornmer et al., 2006 |
| Environment                  | Anis, citrus, oregano, flavors                      | The supplementation of phytophobtics was not beneficial in research facility without sufficient disease challenges | Pigs        | Schöne et al., 2006  |
| Environment                  | Caraway, fennel                                      | A positive effect of fennel and caraway oil seems to occur only during gastrointestinal disorders | Pigs        | Lee et al., 2003    |
| Environment                  | Thymol, cinnamaldehyde, CRINA Poultry               | A clean environment led to diminished efficacy | Broilers    | Lee et al., 2003    |
| Age of animals               | Thymol, cinnamaldehyde, CRINA Poultry               | The effect on endogenous enzyme activities decreased with increasing age | Broilers    | Lee et al., 2003    |
| Growth performance level     | Oregano                                             | Little or no response to oregano oil can be expected at high performance levels, but at low poor performance levels the response may increase | Broilers    | Botsoglou et al., 2002 |

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### Table 2
Rankings of in vitro antimicrobial capacity of some essential oil components.

| Reference                          | Test methods                      | Pathogens                  | Rankings                        |
|------------------------------------|-----------------------------------|-----------------------------|---------------------------------|
| Kim et al., 1995                   | Disk diffusion method             | E. coli                    | Citronellal > perillaldehyde > citral > geraniol > linalool > eugenol > terpineol > carvacrol |
| Kim et al., 1995                   | Disk diffusion method             | S. typhimurium             | Citronellal > citral > geraniol > perillaldehyde > linalool > eugenol > terpineol > carvacrol |
| Ait-Ouazzou et al., 2011           | Disk diffusion method             | S. enteritidis             | Carvacrol > terpineol > linalool |
| Ait-Ouazzou et al., 2011           | Microdilution + agar culture      | E. coli O157:H7            | Carvacrol > terpineol > linalool |
| Friedman et al., 2002              | Microdilution + agar culture      | E. coli                    | Carvacrol, cinnamaldehyde > thymol > eugenol > geraniol |
| Friedman et al., 2002              | Microdilution + agar culture      | S. enterica                | Cinnamaldehyde > thymol > carvacrol > eugenol > geraniol |
| Si et al., 2006                    | Microdilution + optical density   | E. coli K88                | Thymol, carvacrol > cabbage oil < eugenol |
| Si et al., 2006                    | Microdilution + optical density   | E. coli O157:H7            | Carvacrol > cabbage oil < eugenol |
| Si et al., 2006                    | Microdilution + optical density   | S. typhimurium DT 104      | Carvacrol > cabbage oil < eugenol |
| Van Zyl., 2005                     | Microdilution + p-iodonitrotetrazolium violet | S. aureus ATCC 25923 | Eugenol > carvacrol > geraniol > linalool > citronellal |
| Van Zyl., 2005                     | Microdilution + p-iodonitrotetrazolium violet | B. cereus ATCC 11778 | Eugenol > carvacrol > geraniol > linalool > citronellal |
| Michiels et al., 2009              | Simulated stomach                | Total anaerobic bacteria    | Carvacrol > thymol > eugenol > trans-cinnamaldehyde |
| Michiels et al., 2009              | Simulated jejunum                | Clostridial bacteria        | Carvacrol > thymol > eugenol > trans-cinnamaldehyde |
| Michiels et al., 2009              | Simulated jejunum                | E. coli                    | Carvacrol > thymol > eugenol > trans-cinnamaldehyde |

1 The ranking was based on 5% concentration.
2 The ranking was based on minimum bactericidal concentrations.
3 The ranking was based on the concentration that resulted in complete growth inhibition of 10^6 cfu/mL.
4 The ranking was based on the concentration that gives a reduction of 0.5 log cfu/mL compared to control.
thyme oil is effective in retarding oxidant degradation in poultry-derived products, such as meat and eggs. The possible reason might be the antioxidant activity derived from the phenolic OH group which acts as a donor of hydrogen interacting with peroxyl radicals during the initial process in lipid oxidation and thereby inhibiting or retarding the hydroxyl peroxide formation (Lee et al., 2003). There was a linear relationship between the amount of total phenols and antioxidant capacity of medicinal plants (Fig. 1). Rosemary, oregano, and sage of the Lamiaceae family were also reported for their effective antioxidative activities in broiler meat (Brenes and Roura, 2010; Franz et al., 2010; Windisch et al., 2008). Regarding the metabolic fate of essential oils in poultry, the research is still lacking. Kohler et al. (2000) reported that the metabolic fates of essential oils are chemical structure depended; essential oil components are quickly eliminated; and accumulation is unlikely due to the high clearance and short half-lives in human, which lends support to no residue of essential oils in animal products.

Carcass hygiene could be improved by essential oils, which should be attributed to their reducing the load of pathogens. Alali et al. (2013) reported that a blend of carvacrol, thymol, eucalyptol, and lemon might reduce the Salmonella heidelberg-positive crops and subsequently reduce the cross-contamination in carcass processing. Venkitanarayanan et al. (2013) reported that a blend of caprylic acid and essential oils (trans-cinnamaldehyde, eugenol, carvacrol, and thymol) reduced Salmonella Enteritidis and Campylobacter jejuni in cecal contents of birds, which indicates a less likelihood of microbial contamination of poultry meat and eggs. An interesting study by Witkowska and Sowinska (2013) showed improvement in hygiene conditions in poultry house via air disinfectants using thyme and peppermint oils individually as primary components.

3.4. Future research for poultry

Environmental conditions play a key role in poultry husbandry. The interaction between environment and the effects of essentials oils should be more researched. Detailed description of the hygienic conditions is necessary for better interpretation of the experimental results and variations. The anticoccidial and immunomodulatory properties of essential oils in poulty have gained interest and require more in-depth research. The metabolic fates of essential oils in poultry should be studied, and the corresponding analytical methods should be established to track the active compounds and their metabolites. Research on the interactions among individual essential oils and with other categories of feed additives should be explored for identifying practical applications.

4. Essential oils for swine

4.1. Growth performance

4.1.1. Feed intake

Voluntary feed intake could be influenced by many factors in association with housing and social environments, and dietary characteristics (Nyachoti et al., 2004), one of which could become the predominant determinant over the other factors under certain conditions. Essential oils usually possess a pungent smell, which might make the feed appealing and thereby arouse the interest of pigs to explore in a larger degree and then consume more frequently and/or a larger amount at each meal before another factor such as the gut fill seizes the dominance and weakens the feeding drive of pigs, or, on the contrary, simply deter pigs from feeding due to the aversive smell.

The effects of essential oils on feed intake of pigs were ambiguous. Feed intake change relative to control due to dietary supplementation of essential oils ranged from −9% to 12% in the review of Franz et al. (2010), and a recent review by Zeng et al. (2015b) reported a range of −3% to 19%. These numerical changes derived mainly from growth performance trials might not qualify as evidence for the animal’s preference or aversion to essential oils-supplemented feed because of the latent assumption that more feed should be consumed if it is desirable. The observed improvement in feed intake might be only affiliated to the improved growth rate of animals as commonly seen with most growth-promoting additives (Windisch et al., 2008). In feeding-preference studies, fennel oil significantly decreased the feed intake of piglets (Schöne et al., 2006), and piglets showed no preference for feed supplemented with 125 and 500 mg/kg thymol, while the supplemental level of 2,000 mg/kg almost caused a complete refusal of feed (Michiels et al., 2009). The effects of essential oils on feed intake of pigs are not consistent in the feeding-preference and growth performance trials conducted by Michiels et al. (2009). Therefore, it is advisable to take cautious to judge the feeding preference from different types of animal trials, and more in-depth investigations are warranted to reconcile the incongruent results.

4.1.2. Feed utilization

The literature has registered several studies showing the improved digestibility of energy and nutrients with the supplementation of essential oils. Cinnamaldehyde and thymol (250 mg/kg) significantly improved apparent total tract digestibility (ATTD) of dry matter, crude protein, and energy in piglets (Li et al., 2012; Zeng et al., 2015a). A cocktail of essential oils (250 mg/kg) significantly improved ATTD of crude protein and energy in grower-finisher pigs (Yan et al., 2010). The apparent ileal digestibility of crude protein and most amino acids were improved by the cocktail of essential oils (300 mg/kg) with menthol as the primary component, but not by the cocktail with cinnamaldehyde (Maenner et al., 2011).

The improved apparent digestibility of fat and nutrients could be attributable to the enhanced secretion of bile and enzymes, which was suggested as the primary mode for the digestive stimulant action of spices by Platel and Srinivasan (2004), and in some degree, to the decreased endogenous losses of nutrients (Maenner et al., 2011).

Essential oils have also shown to regulate the relaxation and contraction of the gut, and thereby influence the transit of digesta and the resultant interaction between feed and the endogenous enzymes in the gut. The essential oils (cineol, methyl-
essential oils could leverage the development and function of the their antimicrobial activities to the hindgut to favorably modify the found to be absorbed nearly completely in the stomach and the 4.2. Antimicrobial

Balchin et al., 2001). The essential oils from Ferula heuffeli inhibited spontaneous contraction of isolated rat ileum dose-dependently possibly by blocking voltage Ca\(^{2+}\) channels or by opening K\(^{+}\) channels (Pavlovic et al., 2012). Blocking calcium channels seemed to be of higher significance for Agathosma betulina essential oils than Agathosma crenulata regarding their initial spasmodic action followed by a spasmyloptic action on the guinea-pig ileum (Lis-Balchin et al., 2001).

4.2. Health

4.2.1. Antimicrobial

In piglets, carvacrol, thymol, eugenol, and cinnamaldehyde were found to be absorbed nearly completely in the stomach and the proximal small intestine within 2 h after oral administration (Michels et al., 2008). Therefore, to deliver the essential oils and their antimicrobial activities to the hindgut to favorably modify the microflora ecosystem, essential oils need to be protected to circumvent the absorption in the foregut (de Lange et al., 2010). Some essential oils could influence the gut microflora selectively. A cocktail of carvacrol, cinnamaldehyde, and capsicum oleoresin increased the population of Lactobacilli and the ratio of Lactobacilli to Enterobacteria in the jejunum (Manzanilla et al., 2006) and cecum (Castillo et al., 2006) of early-weaned piglets using qPCR method. This is in agreement with the in vitro study results that cinnamaldehyde was highly inhibitory for coliform bacteria and \(E. coli\) while it hardly inhibited the growth of Lactobacilli (Michels et al., 2008). The antimicrobial activity of essential oils could also be exploited as a green preservative to prevent food from contamination of pathogens. Tuscan sausages treated with bay leaf essential oils showed reduced population of total coliforms (da Silveira et al., 2014). To realize the same using in vitro antimicrobial effects, however, it is necessary to use 10 to 100-fold higher concentrations of an essential oil in foods (Burt, 2004).

4.2.2. Immunity

Essential oils could change the lymphocyte distribution in the gut. Since a cross talk between gut microbiota and the mucosal immune system is beneficial for a mutual growth and survival (Purchiaromi et al., 2013), it is understandable to surmise that essential oils could leverage the development and function of the gut immune system via modifying the gut microflora, and/or the essential oils might be recognized as foreign stimulants and directly attacked by the immune system. A mixture of carvacrol, cinnamaldehyde, and capsicum oleoresin decreased the population of intraepithelial lymphocyte (IEL) in jejunum and ileum, but increased lymphocyte in the lamina propria of early-weaned pigs (Manzanilla et al., 2006). Capsaicin and cinnamaldehyde might be responsible for the reduced IEL population in jejunum because of their inhibition of the activation or proliferation of T cells (Nofrarias et al., 2006). It is difficult to conclude whether these changes could be construed as beneficial for the gut immune system, because a healthy gut immune system calls for a delicate balance between recognizing threats such as pathogens followed by initiation of immune defense attacks and tolerating the non-threatening foreign substances.

Essential oils might potentiate the immune responses. Supplementing essential oils improved serum lymphocyte proliferation rate, phagocytosis rate, immunoglobulin (Ig) G, IgA, IgM, C3 and C4 levels in piglets (Li et al., 2012). An essential oil cocktail (250 mg/kg) consisting of oregano, clove, and cinnamon induced more lymphocytes against the non-specific mitogens, but not to the specific mitogen (Halas et al., 2011). Halas et al. (2011) concluded that both the non-specific cellular and humoral immune responses were enhanced with the supplementation of essential oils to the weaned piglets. On the contrary, the essential oil failed to increase the serum IgG level in piglets (Cho et al., 2006), and there was no significant effect of the essential oils on serum IgG level in grower-finisher pigs (Yan et al., 2010). Ariza-Nieto et al. (2011) proved that adding 250 mg/kg oregano to the diet of sows during gestation and lactation did not improve the immune responses in suckling piglets. But Tan et al. (2015) proved that adding 15 mg/kg oregano to the diet of sows improved the performance of their piglets by counterbalancing the oxidative stress experienced by sows during the late gestation and early lactation.

4.3. Meat quality

Using essential oils to improve the meat quality is promising due to its easier acceptance by customers than synthetic preservatives. Meat quality could be influenced via the dietary supplementation of essential oils by being integrated in meat to modify the fatty acid profile of meat or to change the oxidative stability of meat and meat products (Wenk, 2003), or by being directly applied to meat products. Meanwhile, essential oils as antioxidants could be cytotoxic at certain concentrations because, after penetrating cells, the antioxidants are oxidized and react as pro-oxidant damaging DNA and protein (Bakkali et al., 2008).

Dietary supplementation of essential oils or oleoresins of rosemary, garlic, oregano, or ginger (500 mg/kg) failed to change the pork quality attributes and fatty acid profile, but the oregano-fed pork showed a tendency for less lipid oxidation (Janz et al., 2007). A feed additive of oregano essential oil and sweet chestnut wood extract increased anti-oxidant species in the blood, induced higher levels of glutathione peroxidase and glutathione reductase, and prevented lipid oxidation of pork, but did not affect the cooking loss, drip loss, Warner-Batzler shear force values, and chemical composition of the pork (Ranucci et al., 2015).

It is generally accepted that lipid oxidation is mainly responsible for meat quality deterioration during storage. Oxygen availability is the most critical factor in the development of lipid oxidation (Jo et al., 1999). Meanwhile, protein oxidation increases meat product toughness, which is characterized by the oxidation of protein thiol and the resultant formation of myosin heavy chain disulfide cross-links (Nieto et al., 2013). The rosemary essential oil (150 mg/kg) significantly reduced the generation of thiobarbituric acid reactive substances (TBARS) and hexanal, indicators of lipid oxidation, and carbonyl, an indicator of protein oxidation in White pigs, while higher levels of 300 and 600 mg/kg had no effect on lipid oxidation, but significantly enhanced the oxidation of proteins; for Iberian pigs, the inhibitory effects of rosemary essential oil were stronger at higher supplementary concentrations (Estévez and Cava, 2006). Nieto et al. (2013) also showed essential oils of oregano and rosemary can protect the thiols in pork patties and reduce the crosslinks of the myosin heavy chains, while essential oils of garlic exhibited the opposite effects.

Meat could contract the desirable or distasteful flavor of essential oils, which depends on a myriad of factors such as the application method and the dosage of the selected essential oils,
the flavor preference of the customers of different geographical locations, and others. The sensory panelists did not differentiate the pork of pigs fed diets supplemented with essential oils (Janz et al., 2007). But the overall liking was higher in all the tests for the meat of pigs supplemented with a combination of oregano essential oil and sweet chestnut extract than the control (Ranucci et al., 2015). In addition, using bay leaf essential oils to pork sausages significantly impacted all the sensory evaluation attributes including appearance, odor, firmness, flavor, and overall acceptability (da Silveira et al., 2014).

4.4. Future research for pigs

Research on the olfactory effects of essential oils is still scarce. The direct physiological effects of essential oils on the relaxation, contraction, resistance, and peristalsis of gut could be a significant factor behind the improved digestibility of energy and nutrients. The absorbable attribute of essential oils makes it essential to explore different techniques to deliver their release at the targeted sites in the gastro-intestinal tract. Different challenge models should be employed to ascertain the specific modulatory effects of essential oils on the immune system.

5. Summary

The success of essential oils depends on whether our knowledge of their actions is based on a solid scientific ground. This review shows that the positive effects of essential oils on the growth performance of poultry and pigs exist both abundantly and comprehensively, which makes the specificity underlying mechanisms further questionable. Firstly, more attention should be paid to dietary characteristics and experimental environments, and the description of the tested essential oils should be stricter. The description of the starting materials and extraction methods cannot guarantee the stable chemical composition of essential oils in animal trials, which should be further disclosed by analytical methods. These analytical results are essential for congregating the animal trial results and reconciling the conclusions. Secondly, the metabolic effect of essential oils should be better understood, which could cast light on the chemical forms and the locales in the animal body for the essential oils or their derivative metabolites to present themselves, and consequently to connect to their declared benefits. Lastly, the evidence for the link between essential oils and animal health is not robust yet. Anecdotal evidence and in vitro studies could not warrant the in vivo effects of essential oils. The direct effects on gut microbiota and the indirect effects via the gut-associated immune system should be further explored.

Conflict of interest

The authors declare there is no conflict of interests.

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