CHAPTER

13

Application of plant essential oils in pig diets

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OUTLINE

Introduction

Plant essential oils (EOs) are volatile aromatic concentrated hydrophobic oily liquids which are obtained from various plant parts such as flowers, buds, seeds, leaves, twigs, bark, woods, fruits, and roots (Nuzhat and Vidyasagar, 2014). The word "essential" is

Feed Additives
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postulated by Paracelsus in the theory of "quinta essentia," which means that the quintessence can be useful medically due to its effectiveness (Lemmens and Lemmens, 1989). EOs have potential to become a new generation of products for animal nutrition and health, replacing antibiotic growth promoters in animal diets due to their positive effects on digestion, gut microbial community, antioxidant effects, barrier function of the intestine, growth performance, and welfare (Bento et al., 2013; Franz et al., 2010; Wei et al., 2017). The purpose of this chapter is to provide an overview of the effects of EOs on swine. The effects of plant EOs on performance of growing-finishing pigs, sows, and boars are discussed along with the underlying mechanisms of activity.

Application of EOs in weaning piglets

Young piglets during the pre- and postweaning period have a high susceptibility to various stressors, including bacterial pathogens, oxidative stress, and inflammation, leading to reduced growth performance, high mortality and morbidity rates, and compromised animal welfare. Antibiotic growth promoters (AGP) have widely been used in pig diets, especially in nursery diets, to control incidences of postweaning diarrhea and to improve growth performance. Total consumption of antimicrobials in food animal production worldwide was estimated at 63,151 t in 2010 with an increasing trend and the annual consumption of antimicrobials per kilogram body weight is 148 mg/kg for pigs(Van Boeckel et al., 2015). The use of AGP in food animal production has been banned in European Union (2006), USA (2016) and Canada (2017). Therefore, it is critical to develop cost-effective antibiotic alternatives for ensuring the long-term sustainability of pig production(Valenzuela-Grijalva et al., 2017). EOs have been widely recognized as promising alternatives to antibiotics in feeds (Gong et al., 2014).

Performance response generated by EOs

Numerous studies have documented the benefits of EOs on the performance of swine. For piglets, the improvement in performance was on average 10% and 3% for weight gain and feed conversion, respectively (Table 13.1).

Antimicrobial activity

EOs are well known to exert antibacterial, antifungal, and antiviral activity in vitro and in vivo experiments. 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 (O'Bryan et al., 2015; Solórzano-Santos and Miranda-Novales, 2012). It is generally accepted that EOs are slightly more active against gram-positive than gram negative bacteria (Brenes and Roura, 2010; Burt, 2004). 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 13.2. Comparable in vivo studies also found inhibiting effects

TABLE 13.1 Effects of essential oils (EOs) on the performance of swine.

			Treatment effects (%, difference to control)			
Feed additive	Dose, mg/kg	Major components	ADG	ADF	FCR	References
Plant extract	150	5% Carvacrol (Origanum spp.), 3% cinnamaldehyde and 2% capsicum oleoresin	−5	−6	1	Manzanilla et al., 2004
	300		−2	–	−2	
Herbal extracts	7500	Cinnamon, thyme, oregano and a carrier	−10	−17	8	Namkung et al., 2004
EO blend	300	Fenugreek (40%), clove (12.5%), cinnamon (7.5%) and carrier (40%)	7	5	−2	Cho et al., 2006
Phytobiotics	1000	Anis oil, citrus oil, oregano oil, and natural flavors	4	1	−2	Kommera et al., 2006
Plant extract	300	5% (wt/wt) carvacrol, 3% cinnamaldehyde, and 2% capsicum oleoresin	33	26	−4	Manzanilla et al., 2006
Plant extract	300	5% (wt/wt) carvacrol (Origanum spp.), 3% cinnamaldehyde (Cinnamonum spp.), and 2% capsicum oleoresin (Capsicum annum)	33	26	−4	Nofrarias et al., 2006
Fennel	100	Fennel and caraway oil were obtained by steam distillation from fennel or caraway seeds	6	3	−3	Schone et al., 2006
Caraway	100		0	−1	−2	
EO blend	100	Buckwheat, thyme, curcuma, black pepper and ginger	0	−3	−4	Yan et al., 2011
EO blend	1000	Cinnamomum verum, Origanum vulgare spp., Syzygium aromaticum, Thymus vulgaris and Rosmarinus	2	–	−2	Huang et al., 2010
EO blend	300	4.44 g of anise oil, 1.30 g of clove oil, and 2.0 g of cinnamon oil/kg of additive	10	5	−4	Maenner et al., 2011
EO blend	300	27.8 g of anise (Pimpinella anisum) oil, 12.5 g of clove (Syzygium aromaticum) oil, and 46.0 g of peppermint (M. arvensis) oil/kg of additive	7	4	−3	

(*Continued*)

TABLE 13.1 Effects of essential oils (EOs) on the performance of swine.—cont'd

Feed additive	Dose, mg/kg	Major components	Treatment effects (%, difference to control)			References
			ADG	ADF	FCR	
EO blend	50	Thymol, cinnamaldehyde	11	7	−3	Li et al., 2012
	100		22	19	−2	
	150		22	15	−5	
EO blend	1000	Oregano, which contained 60% active substance (Cymene, Terpinene, carvacrol) and 40% carrier (dextrin)	2	2	−1	Zhang et al., 2012
Chinese medicinal herbs	1000	20% of each of Dioscoreaceae batatas, A. macrocephala, G. uralensis and Platycodon grandiflorum	16	–	−14	Huang et al., 2012
	3000		13	–	−11	
EO blend	100	18% thymol and cinnamaldehyde (EOD)	12	1	−10	Li et al., 2012
EO blend	100		10	−1	−10	Zeng et al., 2014

Modified from Zeng, Z., Zhang, S., Wang, H., Piao, X. 2015. Essential oil and aromatic plants as feed additives in non-ruminant nutrition: a review. J Anim. Sci Biotechnol, 6, 7.

against pathogens such as *C. perfringens*, *E. coli* or *Eimeria* species (Table 13.3). Attention should also be paid to the potential negative effects induced by EOs on healthy intestinal bacteria. EOs had no effect on the microbial population and composition in the digestive tract or fecal excretions (Muhl and Liebert, 2007). In addition, the beneficial commensal *Fecalibacterium prausnitzii* was sensitive to EOs at similar or even lower concentrations than the pathogens (Thapa et al., 2012).

Anti-oxidative effects

Oxidative stress is widely recognized as a state of imbalance between prooxidants and antioxidants. Excessive production of reactive oxygen species (ROS) and/or a deficiency of antioxidants result in endogenous oxidative stress. For piglets, decreased antioxidant activity and increased production of ROS is involved in weaning-induced intestinal dysfunction, resulting in intestinal oxidative stress. The antioxidative properties of extracts of oregano, thyme, clove, pepper, lavender, and basil have been evaluated by many studies in vitro (Gülçin et al., 2004; Oboh et al., 2007) and in vivo (Wei et al., 2017). A recent study reported that *Lactobacillus* was negatively correlated with oxidative stress, while, conversely, *E. coli* showed a strong positive correlation with oxidative stress in the intestines of early-weaned

TABLE 13.2 Rankings of in vitro antimicrobial capacity of some essential oil components.

Reference	Test methods	Pathogens	Rankings
Kim et al. (1995) [a]	Disk diffusion method	*E. coli*	Citronellal > perillaldehyde > citral > geraniol > linalool > eugenol > terpineol > carvacrol
Kim et al. (1995) [a]	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)	Disk diffusion method	*E. coli O157:H7*	Carvacrol > terpineol > linalool
Frideman et al. (2002)	Microdilution + agar culture	*E. coli*	Carvacrol, cinnamaldehyde > thymol > eugenol > geraniol
Frideman et al. (2002)	Microdilution + agar culture	*S. enterica*	Cinnamaldehyde > thymol > carvacrol > eugenol > geraniol
Frideman et al. (2002)	Microdilution + agar culture	*C. jejuni*	Cinnamaldehyde > carvacrol > eugenol > thymol > geraniol
Si et al. (2006) [b]	Microdilution + optical density	*E. coli K88*	Thymol, carvacrol > cinnamon oil > clove oil > eugenol
Si et al. (2006) [b]	Microdilution + optical density	*E. coli O157:H7*	Cinnamon oil > thymol > geraniol, clove oil, carvacrol > eugenol
Si et al. (2006) [b]	Microdilution + optical density	*S. typhimurium DT 104*	Cinnamon oil > carvacrol > thymol > clove oil
Van Zyl et al., (2006) [c]	Microdilution p-iodonitrotetrazolium violet	*S. aureus ATCC 25923*	Carvacrol > geraniol > linalool > citronellal > eugenol
Van Zyl et al., (2006) [c]	Microdilution t p-iodonitrotetrazolium violet	*B. cereus ATCC 11778*	Eugenol > carvacrol > geraniol > linalool > citronellal
Van Zyl et al., (2006) [c]	Microdilution t p-iodonitrotetrazolium violet	*E. coli ATCC 11775*	Eugenol > carvacrol > geraniol > linalool > citronellal
Michiels et al. (2009) [d]	Simulated stomach	*Total anaerobic bacteria*	Carvacrol > thymol > eugenol > trans-cinnamaldehyde
Michiels et al. (2009)	Simulated stomach	*Coliform bacteria*	Trans-cinnamaldehyde > carvacrol > thymol > eugenol
Michiels et al. (2009)	Simulated stomach	*E. coli*	Trans-cinnamaldehyde > carvacrol > thymol > eugenol

[a]*The ranking was based on 5% concentration.*
[b]*The ranking was based on minimum bactericidal concentrations.*
[c]*The ranking was based on the concentration that resulted in complete growth inhibition of 107 cfu/mL.*
[d]*The ranking was based on the concentration that gives a reduction of 0.5 log10 cfu/mL compared to control.*
Modified from Zhai H., Liu H., Wang S., Wu J., and Kluenter AM. Potential of essential oils for poultry and pigs. Anim. Nutri. 4, 2018, 179-186.

TABLE 13.3 Effects of essential oils and aromatic plants on the microflora in swine.

	Dose, g/kg	Species	Measured responses	References
Herbal extracts	7500	Weaned pigs	Reduced coliform bacteria counts in fecal; less diverse of microbiota in ileal digesta base on PCR-DGGE	Namkung et al.
EO blend	50−150	Weaned pigs	Increased Lactobacillus and decreased E. coli counts in feces	Li et al.
EO blend	1000	Weaned pigs	Increased Lactobacillus counts	Zhang et al.
Chinese medicinal herbs	1000/3000	Weaned pigs	Increased Lactobacilli counts in ileum and decreased Coliform counts in colon	Huang et al.
EO blend	100	Weaned pigs	Reduced E. coli and total aerobic bacteria in the rectum; increased Lactobacilli to E. coli ratio in colon	Li et al.
Phytogenic additive	50−150	Weaned pigs	Microbial counts in feces (aerobes, gram negatives, anaerobes and lactobacilli) didn't change	Muhl and Liebert

Modified from Zeng, Z., Zhang, S., Wang, H., Piao, X. 2015. Essential oil and aromatic plants as feed additives in non[HYPHEN]ruminant nutrition: a review. J Anim. Sci Biotechnol, 6, 7.

piglets (Xu et al., 2014). Dietary supplementation with 100 mg/kg carvacrol−thymol (1:1) increased populations of *Lactobacillus* and decreased populations of *E. coli* and decreased the intestinal oxidative stress (Wei et al., 2017). In addition, OEs protects against H_2O_2-induced IPEC-J2 cell damage by inducing Nrf2 and related antioxidant enzymes (Zou et al., 2016). OEs also exerted a protective effect against diquat-induced oxidative injury in intestine of rats (Wei et al., 2015). The antioxidant activity of plant extracts is highly correlated with their chemical compositions (Teissedre and Waterhouse, 2000). The presence of phenolic OH groups in thymol, carvacrol, and other plant extracts act as hydrogen donors to the peroxy radicals produced during the first step in lipid oxidation, thus retarding the hydroxyl peroxide formation (Djeridane et al., 2006).

Improved barrier function of the intestine

During weaning, piglets suffer social, environmental and dietary stress, all of which contribute to a decrease in their performance and welfare. Numerous studies have shown that dysfunction of the intestine, which has important immunological, metabolic and barrier functions, has been demonstrated to play a crucial role in weaning-induced growth check (Campbell et al., 2013; Wijtten et al., 2011). Recent studies have indicated that the intestinal oxidative stress, intestinal inflammation and intestinal flora disorder can induce the decreased abundance of tight junction proteins including zonula occludens (ZO-1) and occludin and thus undermine the integrity of the intestinal barrier (Suzuki et al., 2011; Xu et al., 2014; Zhu et al., 2012). Dietary supplementation with 100 mg/kg carvacrol−thymol

(1:1) had an increased population of *Lactobacillus genus* but reduced populations of *Enterococcus genus* and *E. coli* in the jejunum and decreased mRNA levels of TNF-α (Wei et al., 2017).

Application of EOs in sows

During 2011–2013, several studies showed that pregnant sows had elevated oxidative stress during late gestation and lactation which was responsible for impaired milk production, reproductive performance, and finally longevity of sows (Berchieri-Ronchi et al., 2011; Lapointe, 2014; Zhao, 2011; Zhao et al., 2013). Accumulated evidence suggests that excessive ROS affect the insulin signaling cascade, which leads to insulin resistance (Rains and Jain, 2011; Vinayagamoorthi et al., 2008). Insulin resistance during peripartal period was shown to have a negative effect on lactation feed intake of sows (Mosnier et al., 2010; Weldon et al., 1994). Thus, dietary antioxidant concentrations need to be reevaluated for their sufficiency in sow diets, especially to prevent excessive oxidative stress during gestation and lactation. There is an increased systemic oxidative stress during late gestation and early lactation of sows. This is not conducive to the reproductive potential of sows. OEs have a strong antioxidant effect which can improve GSH-Px activity, reduce plasma MDA levels, and improve plasma total antioxidant capacity during late gestation and early lactation of sows. Therefore, removal of excess ROS, reduce damage to proteins, DNA, and cell membrane lipids which provide a better environment for embryo development. The EOs supplementation to sows' diet improved performance of their piglets, which may be attributed to the reduced oxidative stress (Tan et al., 2015). TNF-α can inhibit insulin signaling downstream through multiple pathways and play an important role in insulin resistance. OEs can improve insulin resistance in sows by lowering plasma TNF-α and improve sows' lactation intake. In addition, EOs diet also increased the sows' counts of fecal *Lactobacillus* while reducing *Escherichia coli* and *Enterococcus*.

Application of EOs in boars

The ROS in sperm is produced by the oxidation of NADPH by nicotinamide adenine nucleotide oxidase (NOX). NOX in sperm is distributed on the head and mitochondria of sperm. Mitochondria are the main site of sperm ROS production. In addition to the production of normal sperm, the ROS in semen can also be produced by white blood cells, immature sperm, and bacteria. Physiological levels of ROS play an important role in sperm capacitation, maturation, zona pellucida and cell signal transduction. Sperm is in an oxidative stress state when the level of ROS inside and outside the sperm exceeds the ability of the sperm to clear itself. Excessive ROS will play a toxic effect on sperm. ROS is expressed as attacking sperm PUFA, sperm nuclear DNA and sperm proteins. Therefore, impaired sperm membrane and mitochondrial membrane affects its functionality. OEs can alleviate the damage of ethanol-induced oxidative stress on mouse sperm production, sperm motility, and serum testosterone. It can effectively protect the damage of male testis induced by deltamethrin and improve the semen quality of male rats. The effect of OEs on the quality of boar semen is relatively small. Diet supplemented with 500 mg/kg EOs can improving boar semen antioxidant capacity, inhibit sperm lipid peroxidation to promote sperm motility. Attention should also be paid to the potential negative effects induced by EOs on semen quality. Essential oil from *C. citratus* reduced sperm motility, membrane functionality and integrity and mitochondrial membrane potential even in concentrations as low as 0.001%. However, the effect of OEs EOs on the quality of boar semen needs further research. Studying EOs on boar semen quality requires a focus on the types of EOs, dosages of diet supplementation, interaction with fat content, its fatty acid composition and boar breeds.

Effect of oregano oil against transportation stress

Pig transport is an indispensable part in pork production process. When pigs are transported to the slaughterhouse, the pigs are subjected to a variety of stresses, including increased risk of reduced animal welfare, damage to the carcass quality of the pig, resulting in inferior meat quality and even mortality. During transportation, ROS levels can increase dramatically and any imbalance between production of these molecules and their safe disposal can lead to oxidative stress. Free radical oxidation is the main mechanism of food quality degradation, especially in meat products. It causes undesirable changes in taste, color, texture and nutritional value and can lead to the production of toxic compounds in meat, reducing consumer's acceptability. Therefore, the oxidative state of pigs during slaughter is critical to meat quality. The addition of antioxidants to preslaughter fattening pigs is considered to be an effective means to improve the quality of fattening pork due to transport stress. In our previous study, pigs fed OEO showed reduced live weight contraction and higher hot carcass weights and dressing percentages after transportation than pigs fed a control diet (Zhang et al., 2015; Zou et al., 2016a,b). In addition, OEO were superior to vitamin E in increasing antioxidant enzyme activity, thereby reducing transportation-induced oxidative stress and improving meat quality. In addition to oxidative stress, increased intestinal permeability in fattening pigs during transport is reported to be closely related to meat quality and carcass traits. Therefore, the protective effect on the intestinal barrier of transport-stressed finishing pigs may be the site of action to alleviate the negative effects of transport stress in finishing pigs. In our previous study, we found that the villi were scattered and seriously desquamated in the jejunum of transport stress pigs. Interestingly, OEO was superior to Vit E in decreasing the stress response, thereby reducing transportation-induced intestinal injury and improving meat quality (Zou et al., 2017). These results indicate OEO can act as an efficient dietary supplement to alleviate transport stress in finishing pigs.

Conclusions

EOs are naturally occurring phytochemicals which have various applications and have long been known and used throughout the world for treatment of many diseases. EOs have positive effects on digestion, gut microbial community, antioxidant effects, barrier function of the intestine, growth performance and welfare. These characteristics could be a useful alternative to AGPs in animal diets. EOs can increase the performance of swine and growing-finishing pigs, alleviate transport stress in finishing pigs, and increase reproductive performance of boars and sows.

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