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# EFFICACY OF PHYTOGENIC FEED ADDITIVE ON PERFORMANCE, PRODUCTION AND HEALTH STATUS OF MONOGASTRIC ANIMALS – A REVIEW

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**Abstract**

**The growing concerns of consumers on the use of antibiotic as a growth promoter in livestock feed have fueled the interest in alternative products. In the recent years a group of natural products known as phytogenics has been a focus of several studies. Phytogenics are a heterogeneous group of feed additives originating from plants and consist of herbs, spices, fruit, and other plant parts. These feed additives are reported to have a wide range of activities including antimicrobial, anthelminthic, antioxidant, growth enhancer, and immune modulator. Besides these properties they are also reported to stimulate feed intake and endogenous secretion and enhance production. They include many different bio-active ingredients such as alkaloids, bitters, flavonoids, glycosides, mucilage, saponins, tannins phenolics, polyphenols, terpenoids, polypeptide, thymol, cineole, linalool, anethole, allicin, capsaicin, allylisothiocyanate, and piperine. These feed additives have been tested in the form of extracts, cold pressed oils, essential oils in a number of animals but the results are variable. Therefore, their application as feed additive has been limited, largely owing to their inconsistent efficacy and lack of full understanding of the modes of action. The future of these feed additives depend on the characteristics of herbs, the knowledge on their major and minor constituents, the in-depth knowledge on their mode of action and their value based on the safety to animal and their products. The aim of this review is to summarize on the current knowledge on the use of phytogenic as a feed additive in monogastric animals.**

**Key words: feed additive, monogastric animal, phytogenic**

The use of antibiotic growth promoters (AGP) in livestock feed has been practiced for many decades. There were serious concerns on the resistance issue of antibiotics based on different research studies. The resistance to antimicrobial agents as a serious threat to human health was only emphasized in the 1990s (Neu, 1992; Kunin, 1993) due to the fact that there were great public concerns on the usage of antibiotics as AGP in food animals. This led to the ban on most of the antibiotic feed additives in the European Union in 1999. Eventually, its use as a growth promoter in livestock feed has been fully banned in the European Union since January 2006 (Regulation 1831/2003/EC). The concerns about development of antibiotic resistance and the ban of antibiotics as AGP have initiated the surge of exploring alternatives to antibiotics with similar antimicrobial and growth-promoting effects. Such feed additive is expected not to induce resistance to bacteria and to have no potential side effects to animals. In the recent years, some feed additives such as probiotics (Musa et al., 2009), prebiotics (Gibson et al., 2004), organic acids (De Lange et al., 2010; Upadhaya et al., 2014, 2016 a), enzymes (Bedford and Cowieson, 2012) and phytogenics (Randrianarivelo et al., 2010; Gong et al., 2014; Dhama et al., 2015) are used as a replacement for AGP. Phytogenic feed additive has been reported to enhance performance, feed conversion ratio, carcass meat safety and quality in animals (Stanacev et al., 2011; Dhama et al., 2014, 2015). Besides enhancing performance, phytogenic also has anti-oxidant property, the effects of which are associated with essential oils (EOs) and their components (Lee and Shibamoto, 2001; Alagawamy et al., 2016). Phytogenic also has beneficial effects on nutrient utilization possibly by stimulating digestive enzymes such as lipase, amylase, or protease (Platel and Srinivasan, 2004) and improves gastrointestinal morphology (Jamroz et al., 2006; Upadhaya et al., 2016 b). Janz et al. (2007) indicated that oregano fed pigs had a tendency of lower oxidation in meat. Phytogenic supplementation may have a positive impact on nutrient digestibility (Hernandez et al., 2004). The supplementation of blends of EOs also demonstrated the stable egg yield and reproductive performance compared with that of an AGP (Bozkurt et al., 2009).

However, the lipophilic nature of phytogenic compounds limits the efficient delivery of these compounds to the gut. This problem could be resolved by microencapsulation and combination with other compounds (Yang et al., 2015). A study by Hafeez et al. (2016) demonstrated that matrix encapsulation of essential oils with active ingredients such as carvacrol, thymol and limonene at the dosage of 100 mg/kg feed, improved performance and apparent ideal digestibility of nutrients compared with control in broiler chickens.

Considering this collective information, this study sought to provide an overview of current knowledge on the efficacy of phytogenic feed additive on performance, production and health status of monogastric animals based on literature review from different studies.

## Characteristics of phytogenic feed additive

The phytogenic feed additives (PFA) derived from herbs, spices or aromatic plants (Windisch et al., 2008) are relatively young classes of feed additive that have gained considerable attention in the recent years in feed industry (Hashemipour et al., 2013; Dhama et al., 2015; Abd El-Hack et al., 2016; Alagawany et al., 2016). These plant derived products are residue-free unlike synthetic antibiotics and are also generally considered safe to be used as the ingredients in the food industry as well as in animal diet as an ideal growth promoter (Varel, 2002; Hashemi et al., 2008; Li et al. 2016). The herbs and plant extracts used as feed additives include many different bio-active ingredients such as alkaloids, bitters, flavonoids, glycosides, mucilage, saponins, tannins phenolics, polyphenols, terpenoids, polypeptide, thymol, cineole, linalool, anethole, allicin, capsaicin, allylisothiocyanate, and piperine (Wenk, 2006; Windisch et al., 2008; Grashorn, 2010; Kiczorowska et al., 2015; Al-Yasiry and Kiczorowska, 2016). Therefore, the effects expected of herbs and plant extracts are also various. Furthermore, the phytogenic feed additives have considerable variation in their chemical composition depending on their ingredients, influences of location, climatic conditions, harvest or storage conditions (Huyghebaert et al., 2011). Some other factors that influence the efficacy of the phytogenic mainly include the plant parts and their physical properties, the genetic variation of the plant, age of the plant, different dosage used, extraction method, harvest time, and compatibility with other ingredients (Yang et al., 2009). In addition, the beneficial effect of dietary phytogenic can be influenced by the nutritional status of animals, the infection, the diet composition and the environment condition (Giannenas et al., 2003).

The mode of action of most phytogenics is still not fully elucidated. Nevertheless, the antimicrobial, immunomodulatory, antioxidative, and growth-promoting effects in animals have been reported by various researchers (Windisch et al., 2008; Jacela et al., 2010; Abd El- Hack and Alagawany, 2015).

## Phytogenic feed additive and animal health

### *Antimicrobial activity*

The primary mode of action of PFA is the modulation of beneficial intestinal microbiota by controlling potential pathogens. The essential oils (EOs) present in PFA contain most of the bioactive substances of the plant which include carvacrol, eugenol, thymol, capsaicin, cineole and so on are well known for their antibacterial, antifungal, antiviral and anti-coccidial properties (Windisch et al., 2008; Giannenas and Kyriajakis, 2009; Dragan et al., 2014; Gopi et al., 2014; Oyuntsetseg et al., 2014; Farag et al., 2016; Patil and Patil, 2016). For instance, clove, which is rich in eugenol, is used as antibacterial in human and veterinary medicine (Rhayour et al., 2003). Likewise, the blend of EO of oregano and thyme (0.05%) with carvacrol and thymol as active compounds were reported to be effective against Salmonella located in the digestive tract of chicken (Koscova et al., 2006). In an *in vitro* study, cinnamaldehyde supplementation at the dose rate of 10 and 100 μg/ml reduced the viability of *Eimeria tenella* parasites as compared with control (Lee et al., 2011). The reduction in fecal *E. coli* count was also observed in our previous study when 1 g/kg of eugenol was supplemented in growing pigs' diet (Yan and Kim, 2012) and reduction in the proliferation of *Clostridium perfringens* and *E. coli* were also detected in the small and large intestine of *Clostridium perfrigens* challenged broilers when PFA containing 250 mg/kg EOs of thyme and star anise was added to the diet (Cho et al., 2014). In another challenge experiment, Wati et al. (2015) demonstrated that when *Salmonella enteritidis* and *E.coli* challenged broilers were fed diet containing 150 mg/kg PFA (fennel, lemon balm, peppermint. anise, oak, clove and thyme), lower counts of *Salmonella, E. coli* and *Clostridium* and higher counts of *Lactobacillus* were observed. The antimicrobial mode of action is supposed to be due to the hydrophobicity of these phenolic compounds and due to the fact that these compounds can enter the bacterial cell membrane leading to disintegration of cell membrane, leakage of ions and eventually cell death (Burt, 2004). However, limonene, a non-phenolic compound is also reported to exhibit anti-bacterial effect (Burt, 2004). The antibacterial activity of EO from spices such as cinnamon, clove, garlic, mustard, onion and oregano was found to be slightly more against gram-positive than gram-negative bacteria (Ceylan and Fung, 2004). The effect of blends of EO consisting of clove, coriander and curcuma (50–500 ppm) on cell integrity, as measured using propidium iodide for gram-positive bacteria, was found to be dose dependent and the growth inhibition of gram-negative bacteria, in contrast, occurred mostly without cell integrity loss (Thapa et al., 2012). The additive effects of EOs such as thymol and carvacrol with organic acids such as lactic acid, citric and acetic acid or oregano essential oil with citric acid have been reported to reduce pathogenic bacteria thereby producing adequate antimicrobial effects (Zhou et al., 2007; Hulankova and Borilova, 2011). Our previous study also showed that when 0.2% Korean pine extract along with 2% citric acid was supplemented to the weaning pigs' diet, it significantly increased fecal lactobacillus counts (Zhang et al., 2012). Some other studies reported that blends of Eos (10 g/kg herb such as thyme, oregano, marjoram, rosemary or yarrow or 1 g/kg of essential oil) and (0.05%, 0.1% and 0.15% EOs of thymol and carvacrol) had no effect on the microbial population and composition in the digestive tract or fecal excretions of broilers (Cross et al., 2007) and pigs (Muhl and Liebert, 2007 a). In their review, Brenes and Roura (2010) suggested that minor components in EO may have a critical role as the bacteriostatic activity and may have synergistic effects. The EOs from peppermint and eucalyptus (250 ml/L drinking water) has been reported to inhibit respiratory pathogens such as *Mycoplasma gallisepticum* and protect against H9N2 virus infection (Barbour et al., 2011). Likewise, administration of eucalyptus and peppermint oil blends via oral (0.25 ml/L drinking water for 12 hours/day) and spray route (0.1 ml/20 ml water/10 birds) reduced Newcastle disease infection in broilers (Awaad et al., 2016). The findings of different studies warrant more detailed investigation to develop a blend of EOs having better antimicrobial properties.

*Impact on animal immunity*

For the alleviation of diseases, modulation of immune response has been of great interest to researchers (Ozek et al., 2011; Mahima et al., 2012). Nuclear factor "kappa light-chain-enhancer" of activated B cells (NFκB) represents a key transcription factor regulating the synthesis of genes involved in immune reactions and inflammatory response (Ghosh et al., 1998). Several herbs and EOs have been reported as having immunomodulatory effects such as lymphocyte expression, phagocytosis, modulation of cytokine and immunoglobulin secretion, histamine release and so on (Mahima et al., 2012). A blend of oregano, anise, and citrus peel (40 mg/kg diet) supplementation to piglets' diet has been demonstrated to evolve anti-inflammatory effect by reducing the gene expression of NFkB and TNF alpha (Kroismayr et al., 2008). The supplementation of poultry feed with anise was reported to improve lymphocyte counts (Soltan et al., 2008). The increase in IgG in broilers was noted with the inclusion of 0.1% of herb mixture consisting of *Phlomis umbrosa Turez, Cynancum wilfordii Hem, Zingiber officinale Rosc* and *Platycodi Radix* in broiler (Begum et al., 2014). Yan and Kim (2012) also indicated that eugenol and cinnamaldehyde (1 g/kg) exhibited lymphocyte enhancing activity in growing pigs. A study by Li et al. (2012 a) demonstrated that when 0.01% of EO product containing 18% thymol and cinnmaldehyde was supplemented to weaning pigs' diet, it reduced inflammatory mediator, interleukin-6 concentration in the plasma indicating the positive effect of PFA on animal health. Administration of encapsulated EOs containing thymol and cinnamaldehyde (50, 100 or 150 g/ton of feed) has been reported to confer positive immune effects such as increase in lymphocyte proliferation rate, phagocytic rate as well as increase in immunoglobulins such as IgA and IgM in the blood of weaning pigs (Li et al., 2012 b). Some studies reported that when 10 or 20 g plant extract per liter water from herb such as *Withania somnifera* having bioactive compound withanolides (a steroidal lactone) was administered to broiler chick diets, it improved hemoglobin, packed cell volume, white blood cells count and antibody titre against viral disease such as infectious bursal disease and infectious bronchitis suggesting the improvement in hematological profile and immunological status of birds (Mushtaq et al., 2012; Pant et al., 2012). Studies conducted on the immunomodulatory potential of the herbs such as *W. somnifera, T. cordifolia* and *A. indica* against chicken infectious anemia, an immunosuppressive viral disease of young chicks, revealed that these herbs have excellent capacity in stimulating both the cellular and humoral immune responses in chicks against the causative virus and also ameliorating effects on viral pathogenesis were observed (Latheef et al., 2013). In another study, Alhajj et al. (2015) reported that inclusion of 6 g anise seed per kg diet showed higher antibody titer against Newcastle disease virus and infectious bronchitis in broiler chickens. The precise mechanism of phytogenic on immunomodulation is still not fully clear and therefore further studies are needed to clarify the role of PFA on immune modulation.

*Impact on gastrointestinal morphology and nutrient digestibility*

Phytogenic feed additives originating from different herbs are known to have laxative, spasmolytic and anti-flatulence effects in gastro-intestinal tract. Essential oils such as 0.01% thymol and cinnamaldehyde (Li et al., 2012 a) and PFA such as menthol or cinnamaldehyde (Maenner et al., 2011) have been reported to positively affect nutrient digestibility in swine. Likewise, feeding broilers a diet supplemented with 200 mg/kg EO from peppermint led to the increase of crude protein digestibility (Emami et al., 2012). A study by Ahmed (2013) reported that the supplementation of blends of oregano, anise, orange peel and chicory essential oils (0.0125%) in the diet of weaned pig improved protein digestibility. Beneficial effects on nutrient digestibility using different PFA in some of our previous studies as summarized in Table 1 have also been observed in pigs and poultry (Yan et al., 2010; 2011 a, 2012 a, 2012 b; Zhang et al., 2012; Gheisar et al., 2015; Upadhaya et al., 2016 b). The reason for improvement in nutrient absorption may be partly explained due to stimulation in secretions of saliva, bile and enhanced enzyme activity (Platel and Srinivasan, 2004; Jang et al., 2007). The improved nutrient digestibility consequently enhances the health status of animals. In contrast, Muhl and Liebert (2007 b) failed to observe improved nutrient digestibility and enzymatic activity in weaned piglets fed diets containing a 0.05%, 0.10% or 0.15% phytogenic product having carvacrol, thymol and tannins as key constituents. The inconsistent results in apparent digestibility may be caused

Table 1. Response of phytogenic additive by non-ruminant animals as per the research studies conducted at Dankook University

| Feed additive | Dose | Major compounds | Species | Overall growth performance response | | | Other responses | Reference |
|---|---|---|---|---|---|---|---|---|
| | | | | ADG | FI | G:F | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Essential oil blend | 0.1 mg/kg | Thyme, rosemary, oregano | Growing-finishing pigs | Yes | N/A | N/A | Positive effect on nitrogen and energy digestibility, Improved longissimus area | Yan et al., 2010 |
| Herb extract | 1 g/kg | *Saurus chinensis* | Finishing pigs | N/A | N/A | N/A | | Ao et al., 2011 |
| | 2 g/kg | | | N/A | N/A | N/A | Serum triglyceride and LDL/C were reduced, Ammonia levels reduced in slurry | |
| Herb extract | 1 g/kg | *Houttuynia cordata* | Finishing pigs | Yes | Yes | N/A | Improved meat quality | Yan et al., 2011 a |
| | 1 g/kg | *Taraxacum officinale* | | N/A | Yes | N/A | Improved nitrogen digestibility, Improved longissimus muscle area | |
| Herb extract mixture | 250 mg/kg | Buckwheat, thyme, curcuma, black pepper and ginger | Growing pigs | Yes | Yes | N/A | Both doses increased WBC and reduced fecal $NH_3$ and $H_2S$ gas emission | |
| | 500 mg/kg | | | Yes | Yes | N/A | | Yan et al., 2011 b |
| Herb | 1 g/kg | Date pits | Weaning pigs | N/A | N/A | N/A | | Cho et al., 2012 |
| | 0.5 g/kg | Japenese honeysuckle | | Yes | N/A | N/A | | |
| | 1 g/kg | *Houttuynia cordata* | | Yes | N/A | N/A | | |
| | 1 g/kg | Laquer tree extract | | Yes | N/A | N/A | | |
| | 1 g/kg | Yellow ginger | Growing pigs | Yes | N/A | N/A | Improved meat quality | |
| | 1 g/kg | Hoantchy root | | Yes | N/A | N/A | | |
| Essential oil blend | 1 g/kg | Eugenol | Growing pigs | N/A | N/A | N/A | Reduced fecal *E. coli* and reduced fecal $NH_3$ and $H_2S$ gas emission, higher lymphocyte concentration | Yang and Kim, 2012 |
| | 1 g/kg | Cinnalmaldehyde | | N/A | N/A | N/A | | |
| Herb extract mixture | 250 mg/kg | Buckwheat, thyme, curcuma, black pepper and ginger | Weaning pigs | N/A | N/A | N/A | Improved nutrient digestibility and reduced fecal *E. coli* population | Yan et al., 2012 a |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Herb extract | 1 g/kg | *Houttuynia cordata* | Weaning pigs | N/A | N/A | N/A | Reduced fecal *E. coli* | Yan et al., 2012 b |
| | 1 g/kg | *Taraxacum officinale* | | Yes | N/A | Yes | Improved energy digestibility and reduced fecal *E. coli* counts | |
| Herb extract | 2 g/kg | Korean pine (flavonoids and phenolic compounds) | Weaning pigs | N/A | N/A | N/A | Improved DM digestibility | Zhang et al., 2012 |
| Herb extract | 0.5 mg/kg | *Coptis chinensis* (berberine) | Finishing pigs | N/A | N/A | N/A | | Zhou et al., 2013 |
| | 1 mg/kg | | | N/A | N/A | N/A | Improved meat quality | |
| Herb extract | 0.5 mg/kg | Evening primrose | Weaning pigs | | | | | Lei et al., 2014 |
| | 1 mg/kg | | | | | | | |
| | 2 mg/kg | | | Yes | N/A | Yes | Increased lactobacillus counts and reduced LDL/cholesterol, Increased DM digestibility | |
| Gel based additive | 50 g/pig | Caraway (limonene and carvone) | Weaning pigs | Yes | N/A | Yes | Improved digestibility of nutrients and increased ileum and jejunum villi length | Upadhaya et al., 2016 |
| | 100 g/pig | | | Yes | N/A | Yes | | |
| Essential oil, herb and spices mix | 250 mg/kg | Thyme and star anise | Broilers | N/A | N/A | Yes | Reduced serum total cholesterol, Inhibited *Clostridium* spp. and *E. coli* in GIT | Cho et al., 2014 |
| Phytogenic blend | 151 ppm | Quillaja, anise and thyme | Ducks | Yes | N/A | Yes | Improved nutrient digestibility and reduced drip loss and cooking loss | Gheisar et al., 2015 |
| Fermented plants | 0.5 mg/kg | *Gynura procumbens, Rehmannia glutinosa, Scutellaria baicalensis* fermented by *L. plantarum, S. cerevisiae and B. licheniformis* respectively | Broilers | Yes | N/A | Yes | Linear reduction in ammonia gas emission from excreta, Improved dry matter and nitrogen retention | Jeong and Kim, 2015 |
| | 1 mg/kg | | | Yes | N/A | Yes | | |
| | 2 mg/kg | | | Yes | N/A | Yes | | |

Table 1 contd.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| Herb extract | 0.5 mg/kg | Korean pine (Flavonoids and phenolic compounds) | Broilers | Yes | Yes | Yes | Reduced excreta gases emission | Li et al., 2015 |
| | 1 mg/kg | | | | | | | |
| Herb extract | 0.5 mg/kg | *Phlomis umbrosa Turez, Cynancum wilfordii Hem, Zingiber officinale Rosc* and *Platycodi Radix* | Broilers | N/A | N/A | N/A | | Begum et al., 2014 |
| | 1 mg/kg | | | Yes | N/A | N/A | Improved IgG levels and reduced abdominal fat | |
| | 1.5 mg/kg | | | N/A | N/A | N/A | | |

by endogenous loss from mucus secretion induced by plant extracts (Jamroz et al., 2006). Besides imparting positive health benefit, the improved nutrient absorption may reduce feed cost by allowing appropriate modifications to nutrient density diets. Zeng et al. (2015) investigated the acceptance of commercial EO product at the dosage of 0.025% consisting of 4.5% cinnamaldehyde and 13.5% thymol in low energy density in weaned pig diets with wheat and extruded full-fat soybean as the major ingredients. The supplementation of EOs improved the apparent digestibility of dry matter; crude protein and energy compared with pigs fed the low energy density diet without EO indicating PFA may contribute to the reduction of feed cost. The ability of epithelial cells to regenerate villus can be improved though decreased numbers of pathogenic bacteria in the gut thereby enhancing intestinal absorptive capacity (Mourao et al., 2006). Inclusion of blend of plant extracts from sage, lemon, balm, nettle and coneflower (20, 30, 30, and 20%, respectively) at 500 mg/kg feed has been reported to improve the villus height in weaning pigs (Hanczakowska and Swiatkiewicz, 2012). The inclusion of 100 and 200 mg/kg thymol and carvacrol in broiler chickens' diet improved villus surface, villus height, villus height to crypt depth and muscular layer of jejunum and ileum (Hashemipour et al., 2013). The addition of *Euphorbia hirta* (7.5 g/kg) increased the villus height compared to the control birds (Hashemi et al., 2014). Our recent study about gel based feed additive (50 or 100 g/pig/day) supplementation to weaned pig with essential oils from caraway seed as main ingredient improved the villus length of ileum and jejunum (Upadhaya et al., 2016 b). The dietary supplementation with 2.0 and 2.5% of *Boswellia serrata* resin to broiler led to a significant increase in the length of the duodenum and total intestine (Kiczorowska et al., 2016). Such an effect of PFA is expected due to their well-documented inhibitory effects against pathogens. However, the use of PFA in relation to gut morphology is not consistent. For instance, Manzanilla et al. (2004) reported that weaning pigs under stress fed plant extract mixture (150 or 300 mg/kg) consisting of 5% carvacrol, 3% cinnamaldehyde and 2% capsicum oleoresin reduced villus length. Likewise, Oetting et al. (2006) indicated birds fed 700 ppm, 1,400 ppm and 2,100 ppm of herbal extract consisting of a mixture of essential oils of thyme, clove, oregano, eugenol and carvacrol did not have any significant change in gastrointestinal morphology. The negative or no influence of phytogenic in gut morphology was hypothesized due to irritation of intestinal tissues (Windisch et al., 2009).

**Impact of phytogenic feed additive on animal performance**

Several studies documented the use of PFA as a growth promoter (Srinivasan, 2006; Windisch, et al., 2008; Jacela et al., 2010; Kim et al., 2012; Elagib et al., 2013; Bartos et al., 2016; Li et al., 2016). Pastorelli et al. (2012) noted that 10 mg/kg of *Lippia citriodora* led to faster growth in finishing pigs. However, Bruno et al. (2013) noted that there was no effect of 2000 ppm of herb extract consisting of *Rosmarinus officinalis*, *Mentha piperita, Lippia sidoides* and *Porophyllum ruderale* on growth performance in weaning pigs. Garlic, thyme and cornflower as feed additives in broilers have been reported to improve growth performance (Aji et al., 2011; Khan et al., 2011; Rahimi et al., 2011). The body weight was significantly improved when 50 or 100 mg of garlic and onion was administered to the diet of broiler chickens (Aji et al., 2011). The supplementation of fenugreek seeds (1, 2 and 3%) significantly improved feed conversion ratio of broiler chickens (Mamoun et al., 2014). The dietary supplementation of 0.5 g/kg anise seed containing anothole as active ingredient significantly improved body weight gain and performance index but had no significant effect on feed intake and feed conversion ratio in broilers; moreover, a higher level of anise seed (1.5 g/kg) reduced growth performance compared with control (Soltan et al., 2008). Another study reported that supplementation of 1 or 2 g of anise seed in broilers diet improved body weight, daily weight gain and feed conversion ratio but had no effect on feed intake (Alhajj et al., 2015). The studies on PFA at Dankook University from 2010 to 2016 by our research groups have shown that the effects of different kinds of phytogenic additive on growth performances by swine and poultry were variable as presented in Table 1. The physiological difference in the digestive tract, the origin of the EOs or herb species, the dose of phytogenic supplemented to the feed and the environmental conditions used in the trial might have caused the difference in the results. Dietary supplementation of phytogenic compounds has the potential to increase feed intake by improving the palatability of diet possibly due to enhanced flavor and odor, especially with the use of EOs (Kroismay et al., 2006). The stability of EOs during feed processing has to be taken into consideration because processing may lead to loss of activity by the active ingredients present in the phytogenic compound. A considerable loss of activity of EOs has been reported when pelleting temperature of 58°C was applied (Maenner et al., 2011). Addition of a blend of EO from basil, caraway, laurel, lemon, oregano, sage, tea and thyme (100 g/t) in broiler diet has been demonstrated to improve the body weight gain with positive effects on feed to gain ratio (Khattak et al., 2014). The reason for increase in voluntary feed intake resulting in improved weight gain was reported to be due to the improvement in the flavor and palatability of feed by the aromatic EOs. However, feed intake was significantly reduced when feed was supplemented with fennel (100 mg/kg) or caraway oil (100 mg/kg) indicating that the palatability was reduced due to flavor in a choice feed experiment conducted in growing pigs by Schone et al. (2006). Our recent study by Upadhaya et al. (2016 b) on phytogenic feed additive (50 or 100 g/pig/day) containing caraway oil showed no significant effect on feed intake in weaning pigs. A study by Czech et al. (2009) indicated that inclusion of herbal extract (0.8 g/kg feed) from garlic bulbs, common liquorice roots and tillers, common thyme herb and caraway fruits stimulates growth performance and exerts beneficial actions in the gastro-intestinal tract by increasing the activity of digestive enzymes. Therefore, the properties of improved flavor and palatability are variable depending on the type and dose of PFA used. Akthar et al. (2003) reported that the inclusion of black cumin seeds into laying hen diets at a level of 1.5% led to a 12% increase of laying rate from 40 to 52 weeks of age. Consistently, diets supplemented with 3% black cumin seeds increased egg production and egg weight of 27-week-old laying hens during a 5-week experimental period in contrast to the supplementation of 1% (Aydin et al., 2008). On the other hand, Bolukbaşi et al. (2009) observed no improvement of laying hen performance with respect to black cumin seed oil (1, 2 or 3 ml/kg diet) supplementation. No effect was observed on laying rate and weight of settable eggs in response to an EO mixture (consisting of EO from oregano, laurel, sage, myrtle, fennel and citrus) supplementation at 24, 36 or 48 mg/kg (Bozkurt et al., 2009). Likewise, Bolukbasi et al. (2008) observed no effect on laying rate but an increase in egg weight when diets were supplemented with 200 mg/kg EO of thyme, sage or rosemary over a period of 12 weeks. The supplementation of herb blends consisting of 0.05% garlic powder, 0.3% cinnamon powder and 0.03% of each of the following dried herbs: yarrow, rosemary, thyme, basil and oregano improved egg laying capacity of hen by 1.79% as compared with control (Gerzilov et al., 2015). The beneficial influence of the PFA on improved performance and feed conversion ratio could be also explained due to the antioxidant activity of bioactive compounds such as carvacrol, thymol, cineol and pinene (Faleiro et al., 2005; Hazzit et al., 2006) as well as from improved enzyme activity in the alimentary tract, stimulation of useful and inhibition of pathogenic microflora which eventually resulted in improved absorption and utilization of nutrients (Windisch et al., 2008; Frankic et al., 2009).

**Other health benefits of phytogenic feed additive**

Besides, immune enhancing, antimicrobial, and performance enhancing effects, phytogenics also have anti-oxidant property. The excellent plant derived antioxidants are obtained from rosemary, olive leaves, thyme, marjoram, sage, oregano, etc (Botsoglou et al., 2005, 2013; Rahal et al., 2014). Some other common herbs, spices and fruits that have antioxidant property are ginger, turmeric, garlic, plum, pine bark extract, berries, pomegranate, caraway, cinnamon, clove etc (Khan et al., 2012; Zhao et al., 2011; Botsoglou et al., 2013), the effects of which are associated with EOs and their components (Lee and Shibamoto, 2001; Miura et al., 2002). The demand for natural antioxidants in food is increasing due to their health benefits against oxidative stress and several diseases (Labaque et al., 2013; Perez-Barron et al., 2015; Juadjur et al., 2015; Kim et al., 2015). For instance, leaf powder from herbs such as *Ocimum sanctum* and *Withania somnifera* at the dose rate of 0.1% has been demonstrated to reverse the cadmium-induced oxidative stress in chicken due to the active ingredients (withanolides, methyl eugenol and flavonoids) of these herbs possessing antioxidants effect (Bharavi et al., 2010) and by neutralization of superoxide, hydrogen peroxide and nitric oxide by scavenging radicals or due to increased production of catalase, superoxide dismutase and glutathione peroxidase (Ali et al., 2006; Yarru et al., 2009). The supplementation of thymol (80 mg/animal/day) helped to reduce fear responses in quail when exposed to stressful situations (Labaque et al., 2013). A study by Pastorelli et al. (2012) demonstrated that the supplementation of *Lippia citriodora* containing verbascoside as active constituent at the dose rate of 10 mg/kg for 56 days led to higher levels of serum IgA and lower levels of reactive oxygen metabolites in fattening pigs.

**Impact of phytogenic FA on meat and egg quality**

*Meat quality*

Plant oils used as feedstuffs in monogastric nutrition may readily alter fatty acid composition of all body lipid fractions by generally increasing the amount of polyunsaturated fatty acid and, therefore, their susceptibility to oxidation leading to the development of oxidative rancidity and associated increase in unpleasant odours. Concomitantly, plant oils usually contain natural antioxidants, which may contribute to an improved oxidative stability of meat and meat products, compensating for the increased degree of unsaturation. Herbs such as oregano and sage have been extensively studied for their antioxidant activity (Brenes and Roura, 2010). The supplementation of plant extract mix containing the combination of oregano essential oil and sweet chestnut wood extract (0.2%) to pigs' diet was reported to reduce the lipid oxidation of meat (Ranucci et al., 2014). The oxidative stability of meat obtained from broilers, hens or turkeys in a series of studies have been reported to increase with the use of dietary supplementation of EOs (Florou-Paneri et al., 2006; Giannenas et al., 2005). For instance, dietary supplementation of 100 mg/kg EO blends with 5% carvacrol, 3% cinnamaldehyde and 2% capsicum oleoresin as active constituents improved the concentration of anti-oxidants in the liver of broiler chicken (Karadas et al., 2014). Likewise, a study by Ghazaghi et al. (2014) noted that supplementation of *Mentha spicata* (1–4%) in the diet improved meat quality of Japanese quail. Al-Kassie et al. (2014) reported that the inclusion of mixture of hot red pepper and black pepper at a level of 0.75 and 1% in the diets significantly improved the dressing percentage of broilers. Our studies with some of the PFA have shown no adverse effect in meat quality in finishing pigs (Li et al., 2016) and ducks (Gheiser et al., 2015) or positive effect in meat quality aspects of pigs which could be attributed to anti-oxidative properties of PFA (Yan et al., 2010, 2011 a; Zhou et al., 2013). On the contrary, Simitzis et al. (2010) reported that dietary oregano EO (0.25, 0.5 and 1 ml/kg of fed diet) failed to improve the lipid oxidation status of pork. The inconsistency in findings may be contributed by the different fatty acid composition in the meat of poultry and swine. Although poultry meat contains low lipid content, its relative concentration of polyunsaturated fatty acids is higher than pork (Janz et al., 2007). Thus, poultry meat is highly susceptible to oxidative deterioration, which might contribute to an enhanced response on dietary EOs supplementation on the lipid oxidation status of poultry meat.

*Egg quality*

The study on the effects of PFA on egg quality is limited and variable. In a previous study, Bolukbaşi et al. (2008) reported that supplementing 200 mg/kg of thyme, sage or rosemary EO increased the proportion of egg shell. However, in another study, no benefit was determined in relative shell weight with respect to dietary supplementation with three different levels (1, 2 or 3 ml/kg) of black cumin EO (Bolukbaşi et al., 2009). Similarly, EO of oregano (50 or 100 mg/kg) did not influence egg quality characteristics such as yolk color score, Haugh unit or shell thickness when supplemented to the diet at the age of 32 weeks (Florou-Paneri et al., 2005). In another study, Abdel-Wareth and Lohakare (2014) noted that the inclusion of peppermint (*Mentha piperita*) leaves (0, 5, 10, 15, or 20 g/kg for 12 weeks) in HyLine brown laying hens (64-week-old) led to significantly increased egg weight, egg production and egg mass. More studies are needed to verify the effects of PFA on egg quality characteristics.

## Conclusion

The search for alternatives to antibiotics is gaining grounds in recent years. Phytogenic compounds represent one of the most promising alternatives to antibiotics because they consist of a large variety of active ingredients. However, their application in food animal production has been limited, largely owing to their inconsistent efficacy and lack of full understanding of the modes of action. Differences between or within PFA depend significantly on several variables, which makes it necessary to define the exact composition of the supplements which have been added to diets. In addition, minor components present are critical to the activity of PFA and may have a synergistic influence. Sometimes the minor components may counteract the exerted effects. Therefore, in the future, the detailed study on the constituents of PFA including EOs is needed so as to evaluate their different biological effects, their safety with regards to animal health and the quality of animal products. To make the best use of phytogenic substances for economically effective and sustainable animal production, a better understanding of the effects of phytogenic compounds and their mode of action is a must.

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