Evaluation of essential oil or/and emulsifier in low energy density diets on growth performance, nutrient digestibility, blood cholesterol and meat quality in finishing pigs

Tian Shui Li, Wen Chao Liu, Pin Yao Zhao & In Ho Kim

To cite this article: Tian Shui Li, Wen Chao Liu, Pin Yao Zhao & In Ho Kim (2017): Evaluation of essential oil or/and emulsifier in low energy density diets on growth performance, nutrient digestibility, blood cholesterol and meat quality in finishing pigs, Italian Journal of Animal Science, DOI: 10.1080/1828051X.2017.1325718

To link to this article: http://dx.doi.org/10.1080/1828051X.2017.1325718
Evaluation of essential oil or/and emulsifier in low energy density diets on growth performance, nutrient digestibility, blood cholesterol and meat quality in finishing pigs

Tian Shui Li*, Wen Chao Liu*, Pin Yao Zhao and In Ho Kim

Department of Animal Resource & Science, Dankook University, Cheonan, Choongnam, South Korea

ABSTRACT
A 10-week feeding trial was carried to determine the effect of dietary supplementation with emulsifier or/and essential oil for finishing pigs. One hundred and twenty pigs were used with six pens per treatment and four pigs per pen. Dietary treatments include: (1) basal diet (BD), (2) low energy diet (LC), (3) LC +0.05% emulsifier (LE), (4) LC +0.05% essential oil (LO) and (5) LC +0.05% emulsifier +0.05% essential oil (LEO). Pigs fed BD and LEO had greater \((p < .05)\) gain:feed ratio (G:F) than those fed LC. The serum total cholesterol and high density lipoprotein cholesterol (HDL-c) concentrations in LE and LO were lower \((p < .05)\) than BD at wk 10. The low density lipoprotein cholesterol concentration (LDL) in LEO was higher \((p < .05)\) than BD, LE, and LO at wk 5. LC had higher \((p < .05)\) colour score and marbling than BD. Firmness score in LO, lightness \(\left(L^*\right)\) and yellowness \(\left(b^*\right)\) values in LEO were lower \((p < .05)\) than BD. The long muscle area (LMA) was higher \((p < .05)\) in LEO than LC. In low energy treatments, pigs fed the combination of essential oil and emulsifier diet had higher \((p < .05)\) G:F during wk 0 to 10. Serum low density lipoprotein cholesterol (LDL-C) and HDL-C concentrations were increased \((p < .05)\) by the combination of essential oil and emulsifier supplementation at wk 5 and 10, respectively. Positive interaction \((p < .05)\) effect was detected on \(a^*\) and \(b^*\) values. The water holding capacity was decreased \((p < .05)\) and LMA was increased \((p < .05)\) by essential oil.

Introduction
A considerable amount of researches have been devoted into finding potential alternatives to antibiotics growth promoters (AGP) in swine industry, because of the banned use of dietary AGP (Cho et al. 2006). Although the antimicrobial properties of essential oils have been well documented previously (Hong et al. 2004; Cho et al. 2006), it is still lack of evidence of fundamental mechanisms. Emulsifier may enhance fat utilisation in pigs fed high-fat diet in order to break down fat into fine particles and protecting against lipid oxidation, hence reducing deterioration of fats (Dierick & Decuyper 2004). Previous studies found that dietary emulsifier had beneficial effect on growth performance in chickens (Huang et al. 2007) and weaned pigs (Xing et al. 2004). In addition, Yan et al. (2009) reported that feed intake was highly affected by the energy density of diet, which suggested that the intake of animal fat and essential oils could also be influenced by the energy density of diet. As energy concentration being an important determinant of voluntary feed intake of pigs (Lewis 2001), the energy concentration was taken into consideration in our study. Moreover, plasma LDL-C and high density lipoprotein cholesterol (HDL-C) concentration (Bellows & Moore 2012), and carcass characteristics (De La Llata et al. 2001) could be differentially affected by the high energy levels diet, such as fat (saturated lipid and unsaturated lipid source) supplementation. The principal objective of this study was to assess the main effects of essential oils or/and emulsifier supplementation in relatively low energy density diets on growth performance, nutrient digestibility, blood cholesterol, and meat quality in finishing pigs.
Materials and methods

Source of essential oils and emulsifier

Emulsifier was obtained from AkzoNobel (Bredo®, Shanghai, China). This product, glyceryl polyethylene-glycol ricinoleate, is an emulsifying agent according to EU-legislation. Besides the property of breaking down fat into fine particles, Bredo® may act as protective barrier to the diffusion of lipid oxidation initiators into the fat droplets, hence reducing deterioration of fats.

Essential oil obtained from DSM (CRINA®, DSM Nutritional Products, Ltd., Korea), was formulated by abstracts of *Cinnamomum verum*, *Origanum vulgare* spp., *Syzygium aromaticum*, *Thymus vulgaris* and *Rosmarinus*, and the main antimicrobial components were cinnamaldehyde, carvacrol, eugenol, thymol and eugenol, with a degree of purity at least 99.5%.

Experimental design, animals and housing

A total of 120 finishing pigs [(Yorkshire × Landrace) × Duoroc] with an initial body weight (BW) of 60.86 ± 2.75 kg were used in a 10-wk experiment. Pigs were allotted to five experimental diets according to their initial BW and sex (two gilts and two barrows/pen; six pens/treatment). Dietary treatments include: (1) BD, basal diet; (2) LC, low energy diet (–ES –EM); (3) LE, LC +0.05% emulsifier (–ES +EM); (4) LO, LC +0.05% emulsifier +0.05% essential oil (+ES +EM); (5) LEO, LC +0.05% emulsifier +0.05% essential oil (+ES +EM). All experimental diets were formulated to meet or exceed NRC (2012) nutrient requirements (Table 1). All pigs were housed in an environmental controlled room. Each pen was equipped with a one-sided, stainless-steel self-feeder and a nipple drinker that allowed pig ad libitum access to feed and water. The Animal Welfare Committee of Dankook University approved the animal care protocol used for this experiment.

Experimental procedures and sampling

Individual pig BW and pen feed intake were measured at the end of wk 5 and 10 to determine the average daily gain (ADG), average daily feed intake (ADFI), and gain:feed ratio (G:F). Chromic oxide (0.20%) was added as an inert indicator at each phase for 7 d before faecal collection to determine apparent total tract digestibility (ATTD) of dry matter (DM), nitrogen (N) and gross energy (GE) (Fenton & Fenton 1979). At the last 2 d of each phase, fresh faecal grab samples collected from two pigs (one gilt and one barrow) per pen were mixed and pooled, and representative samples were stored in a freezer at −20°C until analysis.

| Item              | BD       | LC       |
|-------------------|----------|----------|
| Ingredients, %    |          |          |
| Corn              | 64.23    | 62.30    |
| Wheat bran        | 1.50     | 3.18     |
| Soybean meal      | 18.44    | 16.99    |
| Rape seed meal    | 1.30     | 2.22     |
| Distiller dried grains with solubles | 3.70 | 4.50 |
| Tallow            | 6.30     | 5.48     |
| Molasses          | 1.70     | 2.50     |
| Lysine            | 0.13     | 0.13     |
| Tricalcium phosphate | 1.00  | 1.00     |
| Limestone         | 0.85     | 0.85     |
| Salt              | 0.40     | 0.40     |
| Vitamin premixb   | 0.20     | 0.20     |
| Mineral premixc   | 0.25     | 0.25     |
| Calculated composition     |          |          |
| Metabolisable energy, MJ/kg | 14.64 | 14.23 |
| Crude protein, %   | 16.83    | 16.83    |
| Lysine, %          | 0.84     | 0.84     |
| Calcium, %         | 0.85     | 0.85     |
| Total phosphorus, %| 0.52     | 0.53     |
| Analyzed composition       |          |          |
| Crude protein, %   | 16.84    | 16.84    |
| Lysine, %          | 0.84     | 0.83     |
| Total phosphorus, %| 0.53     | 0.53     |

For determining the serum profiles, two pigs (one gilt and one barrow) from each pen were selected at the beginning, 5th and 10th wk, respectively, and 5-mL blood samples were collected into vacuum tubes for serum and plasma assay via anterior vena cava puncture. At the end of the experiment, all pigs were slaughtered at a local commercial slaughter house. After chilling at 2°C for at least 24 h, a piece of the right loin sample was removed between the 10th and 11th ribs.

Laboratory analysis

Before chemical analysis, faecal samples were thawed at 57°C for 72 h, after which they were ground to pass through a 1-mm screen. All feed and faecal samples were analysed for DM (Method 930.15; AOAC 2007), CP (Method 990.03; AOAC 2007). The concentration of chromium was analysed by UV absorption spectrophotometer (Shimadzu, UV-1201, Shimadzu, Japan) following the method described by Williams et al. (1962). The GE in the feed and faeces was determined using a Parr 6100 oxygen bomb calorimeter (Parr instrument Co., Moline, IL). The ATTD was then calculated using the following formula:

\[
\text{Digestibility} = \left\{1 - \left[\frac{(Nf \times Cd)}{(Nd \times Cf)}\right]\right\}.
\]
where \( N_f \) = nutrient concentration in faeces (% DM), 
\( N_d \) = nutrient concentration in diet (% DM), 
\( C_d \) = chromium concentration in diet (% DM) and 
\( C_f \) = chromium concentration in faeces (% DM).

The total cholesterol (TC), HDL-C and LDL-C in the serum samples were analysed with an autoanalyser (Automatic Biochemical Analyzer, RA-1000; Bayer Corp., Tarrytown, NY) using colorimetric methods. For meat quality, sensory evaluations (colour, marbling and firmness scores) were conducted according to the National Pork Producers Council Standards (NPPC 1991) at ambient temperature. Immediately after the subjective tests were conducted, the lightness (L*), redness (a*) and yellowness (b*) values were measured at three locations on the surface of each sample using a Model CR-410 Chromameter (Konica Minolta Sensing, Inc., Osaka, Japan). At the same time, duplicate pH values of each sample were directly measured using a pH metre (Fisher Scientific, Pittsburgh, PA). The water holding capacity (WHC) was measured in accordance with the methods described by Zhao et al. (2013). Briefly, a 0.3 g sample was pressed at 3000 psi for 3 min on a 125-mm-diameter piece of filter paper. The areas of the pressed sample and the expressed moisture were delineated and then determined using a digitising area-line sensor (MT-10S; M.T. Precision Co. Ltd., Tokyo, Japan). The ratio of water:meat area was calculated, giving a measure of WHC (a smaller ratio indicates increased WHC). The longissimus muscle area (LMA) was measured by tracing the longissimus muscle surface at the 10th rib, which was conducted using the aforementioned digitising area line sensor. Drip loss was measured using approximately 4.5 g of meat sample according to the plastic bag method described by Honikel (1998). Cook loss was determined as described previously by Sullivan et al. (2007).

### Statistical analysis

All data were subjected to the GLM procedures of SAS (2001) as a randomised complete block design, with pen as the experimental unit. Differences among dietary treatments were firstly separated by Tukey’s multiple range test, then data in low energy treatments were analysed as a \( 2 \times 2 \) factorial design. The model included the main effects of emulsifier and essential oil, as well as the interaction between emulsifier and essential oil. The variability in the data was expressed as standard error (SE). Probability value less than .05 was considered significant.

### Results

#### Growth performance and apparent total tract digestibility

During wk 0–10, pigs fed BD and LEO diets had greater (\( p < .05 \)) G:F than those fed LC diet (Table 2). No difference was observed on ADG, ADFI and G:F during wk 0–5 and wk 6–10. There was no difference on the ATTD of DM, N and GE among treatments at the end of wk 5 and 10 (Table 3). In low energy treatments, essential oil or emulsifier supplementation does not exert any effects on growth performance and nutrient digestibility during the experimental period, but pigs fed the combination of essential oil and emulsifier diet had higher (\( p < .05 \)) G:F during wk 0–10.

#### Blood cholesterol

The serum TC and HDL-C concentrations were decreased (\( p < .05 \)) in LE and LO treatments compared with BD treatment at the end of wk 10 (Table 4).

### Table 2. Effect of emulsifier and essential oil supplementation on growth performance in finishing pigsa.

| Items   | BD  | -EM | +EM | -EM | +EM | SEb | SEc | ES | EM     | ES × EM |
|---------|-----|-----|-----|-----|-----|-----|-----|----|--------|---------|
| wk 0–5  |     |     |     |     |     |     |     |    |        |         |
| ADG, kg | 765 | 734 | 753 | 753 | 758 | 22.2| 31.8| .71| .72    | .83     |
| ADFI, kg| 2019| 2042| 2007| 2004| 2013| 27.6| 26.2| .55| .62    | .42     |
| G:F    | 0.379| 0.359| 0.375| 0.375| 0.377| 0.010| 0.014| .53| .53    | .64     |
| wk 6–10 |     |     |     |     |     |     |     |    |        |         |
| ADG, kg | 845 | 804 | 833 | 844 | 844 | 15.1| 16.8| .15| .39    | .39     |
| ADFI, kg| 2433| 2480| 2464| 2510| 2422| 49.1| 37.3| .88| .18    | .34     |
| G:F    | 0.347| 0.324| 0.338| 0.337| 0.349| 0.009| 0.009| .20| .17    | .93     |
| wk 0–10 |     |     |     |     |     |     |     |    |        |         |
| ADG, kg | 805 | 769 | 793 | 798 | 801 | 12.1| 16.2| .26| .43    | .51     |
| ADFI, kg| 2211| 2261| 2235| 2257| 2218| 29.5| 21.7| .62| .15    | .75     |
| G:F    | 0.364a| .340a| .355a| .354a | .362a| 0.006| 0.008| .19| .15    | .04     |

aMean in the same row without a common superscript differ (\( p < .05 \)).

bPooled standard error of Tukey’s multiple range test.

cPooled standard error of \( 2 \times 2 \) factorial design.

d\( p \) Value of \( 2 \times 2 \) factorial design.

### Statistical analysis

All data were subjected to the GLM procedures of SAS (2001) as a randomised complete block design, with pen as the experimental unit. Differences among dietary treatments were firstly separated by Tukey’s multiple range test, then data in low energy treatments were analysed as a \( 2 \times 2 \) factorial design. The model included the main effects of emulsifier and essential oil, as well as the interaction between emulsifier and essential oil. The variability in the data was expressed as standard error (SE). Probability value less than .05 was considered significant.
The concentration of LDL-C in LEO treatment was higher \((p < .05)\) than those in BD, LE and LO treatments at wk 5. Additionally, LDL-C and HDL-C concentrations were increased \((p < .05)\) by the combination of essential oil and emulsifier supplementation at wk 5 and 10, respectively. No difference was observed on blood cholesterol at the beginning of experiment.

**Meat quality**

In sensory evaluation, the colour value in BD and LO treatments was lower \((p < .05)\) than that in LC and LEO treatments. The marbling value in LC treatment was higher \((p < .05)\) than that in BD treatment. The firmness value in LO treatment was decreased \((p < .05)\) compared with those in BD and LC treatments. In meat colour, the \(L^*\) value in LEO treatment was greatly decreased \((p < .05)\) compared with BD treatment; the \(b^*\) value in LEO treatment was lower \((p < .05)\) than BD, LE and LO treatments, and the \(b^*\) value in LE treatment was higher \((p < .05)\) than that in LC treatment. A positive interaction \((p < .05)\) effect was detected on colour, \(a^*\), and \(b^*\) values between essential oil and emulsifier (Table 5). The WHC was decreased \((p < .05)\) and long muscle area (LMA) was increased \((p < .05)\) in response to the addition of essential oil in LCs. Moreover, the LMA in LEO group was increased \((p < .05)\) compared with LC group. There was no difference in \(pH\), cook loss and drip loss among dietary treatments.

**Discussion**

**Growth performance**

Previous studies have proved that essential oil could stimulate immune function and had antimicrobial, antiviral and enzymatic properties (Platel & Srinivasan 1996; Wenk 2003). Researchers suggested that emulsifier enhanced the fat stability by providing an effective membrane coating small fat droplets, which might result in prevention of lipid oxidation of fat portions in the diet (Fomusa et al. 2002). In our study, no significant differences on ADG and feed intake among dietary groups were observed in our study. Similarly, several previous studies demonstrated that dietary oré-gano essential oil supplementation had no effects on growth performance and carcase characteristics in finishing pigs (Janz et al. 2007) and broiler chickens (Symeon et al. 2009). According to Jones et al. (1992), there was a significant improvement in ADG from d 0 to d 7 post-weaning when tallow and lecithin were used but the positive effect seemed to diminish as pigs approached 35 days post-weaning. This trend means the beneficial effect on growth performance is weakened as the increase of pig age, which could be

| Table 3. Effect of emulsifier and essential oil supplementation on coefficient of nutrient digestibility in finishing pigs\(^a\). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Items           | BD              | -ES             | + ES            | p Value\(^b\)   |                  |                  |
| DM              | 0.748           | 0.757           | 0.733           | 0.753           | 0.721           | 0.012           | 0.011           | 0.63            |
| N               | 0.762           | 0.764           | 0.764           | 0.757           | 0.010           | 0.009           | 0.55            | 0.16            | 0.57            |
| GE              | 0.723           | 0.756           | 0.745           | 0.745           | 0.151           | 0.145           | 0.65            | 0.65            | 0.70            |
| DM              | 0.739           | 0.733           | 0.749           | 0.755           | 0.009           | 0.008           | 0.60            | 0.86            | 0.06            |
| N               | 0.746           | 0.753           | 0.725           | 0.747           | 0.012           | 0.011           | 0.51            | 0.22            | 0.21            |
| GE              | 0.750           | 0.752           | 0.751           | 0.758           | 0.011           | 0.011           | 0.45            | 0.87            | 0.83            |

\(^a\)BD: basal diet; ES: 0.05% essential oil in low energy diet; EM: 0.05% emulsifier in low energy diet; DM: dry matter; N: nitrogen; GE: gross energy.  
\(^b\)Pooled standard error of Tukey’s multiple range test.  
\(^c\)Pooled standard error of 2 \(\times\) 2 factorial design.  
\(^d\)\(p\) Value of 2 \(\times\) 2 factorial design.

| Table 4. Effect of emulsifier and essential oil supplementation on blood cholesterol concentration in finishing pigs\(^a\). |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Items           | BD              | -EM             | + EM            | ES              | p Value\(^d\)   |
| TC              |                 |                 |                 |                 |                 |
| wk 0            | 76.0            | 73.3            | 77.5            | 75.3            | 77.0            | 3.03            | 3.96            | .85             | .46             | .76             |
| wk 5            | 85.3            | 93.8            | 81.8            | 83.3            | 93.5            | 8.57            | 8.84            | .94             | .92             | .23             |
| wk 10           | 100.3\(^1\)     | 88.0\(^a\)      | 76.5\(^a\)      | 80.8\(^a\)      | 86.0\(^a\)      | 5.46            | 5.34            | .84             | .57             | .14             |
| LDL-C           |                 |                 |                 |                 |                 |
| wk 0            | 41.3            | 42.5            | 43.0            | 41.3            | 42.8            | 1.30            | 1.54            | .64             | .53             | .75             |
| wk 5            | 40.3\(^1\)      | 51.3\(^1\)      | 44.5\(^1\)      | 44.8\(^b\)      | 61.0\(^b\)      | 4.22            | 4.79            | .32             | .34             | .03             |
| wk 10           | 50.3            | 43.3            | 37.8            | 39.8            | 40.0            | 3.81            | 4.10            | .88             | .53             | .50             |
| HDL-C           |                 |                 |                 |                 |                 |
| wk 0            | 39.5            | 39.8            | 40.3            | 39.5            | 39.8            | 1.05            | 1.44            | .80             | .80             | .93             |
| wk 5            | 43.3            | 41.8            | 38.5            | 36.3            | 31.8            | 6.93            | 7.15            | .41             | .60             | .93             |
| wk 10           | 47.0\(^1\)      | 41.0\(^1\)      | 33.5\(^1\)      | 34.3\(^b\)      | 41.8\(^b\)      | 3.36            | 3.15            | .82             | 1.00            | .03             |

\(^1\)Means in the same row without a common superscript differ \((p < .05)\).  
\(^2\)BD: basal diet; ES: 0.05% essential oil in low energy diet; EM: 0.05% emulsifier in low energy diet; TC: total cholesterol; LDL-C: low density lipoprotein cholesterol; HDL-C: high density lipoprotein cholesterol.  
\(^3\)Pooled standard error of Tukey’s multiple range test.  
\(^4\)Pooled standard error of 2 \(\times\) 2 factorial design.  
\(^5\)\(p\) Value of 2 \(\times\) 2 factorial design.
used to explain our result that there was no effect on ADG by supplementation of essential oil in finishing pigs. Lewis (2001) and Yan et al. (2009) have reported that the energy density of diet would highly impact the feed intake. However, in our study, feed intake was not affected by experimental treatments during any phases and the overall period. No difference was observed between BD and essential oil or/and emulsifier addition treatments in feed intake, the reason may be that the additive increased the energy utilisation by stimulating enzyme activity (Jang et al. 2004) or improving digestion of fat in finishing pigs.

In the present study, dietary supplementation of essential oil and emulsifier alone had no effect on growth performance, which may be related to the low dosage. It is in accordance with Hong et al. (2004), who reported G:F was not affected when weaned pigs were fed 0.1% or 0.2% plant extract. In addition, Overland et al. (1993) suggested that the positive effect of emulsifier on growth performance may be related to the animal fats used in the diet. However, these studies are not built in different energy density diets. The combined addition of essential oil and emulsifier resulted in a beneficial effect on G:F, which was similar with the pigs fed high energy diets. This could be explained by Dierick and Decuyper (2004), who proved that the combined utilisation of essential oil and emulsifier may break down fat into fine particles and protect lipid oxidation, so that the deterioration of fats was reduced and the fat utilisation was enhanced in pigs fed high-fat diet, thus obtaining a high absorption rate of essential oil.

### Nutrient digestibility and blood profiles

Essential oil has the ability of stimulating digestive enzyme activity, which was demonstrated by Platel and Srinivasan (1996). Therefore, essential oil is promising as feed additives to improve feed efficiency in livestock (Benchaar et al. 2008). Similarly, positive effect of emulsifiers on digestibility of nutrients is documented in pigs (Jones et al. 1992; Dierick & Decuyper 2004). However, essential oils or/and emulsifier did not increase the digestibility of DM, N and GE in this study. The lack of digestibility-improving effect in our study may be due to the more developed digestive system, improved immunity, and increased resistance to intestinal disorders in finishing pigs. Proper feed composition and optimum rearing conditions may also lead to the results. It is generally accepted that the positive effect of feed growth promoters is more pronounced when animals are not offered good quality feed or/and are reared in non-optimum conditions (Bozkurt et al. 2008).

Lysolecithin fed as an emulsifier raised low density lipoprotein cholesterol (LDL-C), but lecithin decreased the LDL-C in weanling pigs (Jones et al. 1992) and TC in rats (Clark et al. 1981). Additionally, supplementation of emulsifier (polyethylene glycol ricinoleate) decreased the LDL-C concentration in broilers (Roy et al. 2010). However, in our study, emulsifier together with essential oil increased the LDL-C concentration at the end of wk 5. Total cholesterol and HDL-C concentration was lower in LE and LO treatments compared with BD treatment at the end of experiment.

### Table 5. Effect of emulsifier and essential oil supplementation on meat quality in finishing pigs.

| Items                  | BD  | -EM | +EM | -EM | +EM | SE^b | SE^c | ES^d | EM | ES^d  | p Value^a |
|------------------------|-----|-----|-----|-----|-----|------|------|------|-----|------|----------|
| Sensory evaluation     |     |     |     |     |     |      |      |      |     |      |          |
| Colour                 | 2.07 | 2.34 | 2.17 | 2.06 | 2.38 | 0.08 | 0.05 | .52  | .17  | <.01  |          |
| Marbling               | 1.52 | 2.03 | 1.74 | 1.71 | 1.94 | 0.15 | 0.19 | .75  | .90  | .19   |          |
| Firmness               | 2.26 | 2.18 | 1.96 | 1.58 | 1.85 | 0.16 | 0.19 | .09  | .89  | .22   |          |
| Meat colour            |     |     |     |     |     |      |      |      |     |      |          |
| Lightness, L^b         | 59.78 | 54.71 | 56.78 | 55.95 | 52.08 | 1.72 | 1.53 | .28  | .57  | .08   |          |
| Redness, a^e           | 18.72 | 18.89 | 19.98 | 20.05 | 17.77 | 0.68 | 0.73 | .48  | .43  | .04   |          |
| Yellowness, b^e         | 10.08 | 7.77 | 10.36 | 10.13 | 6.47  | 0.74 | 0.75 | .33  | .49  | <.01  |          |
| WHC, %                 | 67.16 | 69.77 | 70.00 | 67.19 | 64.87 | 2.12 | 2.06 | <.01 | .47  | .41   |          |
| pH                     | 5.96 | 5.90 | 5.96 | 5.88 | 5.91  | 0.04 | 0.04 | .36  | .30  | .66   |          |
| LMA, cm^2              | 49.12 | 47.11 | 49.10 | 49.66 | 50.92 | 1.04 | 0.93 | .04  | .11  | .70   |          |
| Cook loss, %           | 29.44 | 31.91 | 30.88 | 30.93 | 30.11 | 1.02 | 1.14 | .46  | .43  | .93   |          |
| Drip loss, %           |     |     |     |     |     |      |      |      |     |      |          |
| d 1                    | 4.50  | 4.53  | 4.38  | 4.37  | 4.37  | 0.10 | 0.11 | .45  | .49  | .53   |          |
| d 3                    | 8.55  | 8.52  | 8.42  | 8.30  | 8.24  | 0.14 | 0.12 | .11  | .51  | .88   |          |
| d 5                    | 11.75 | 11.57 | 11.65 | 11.43 | 11.30 | 0.18 | 0.14 | .10  | .85  | .48   |          |

^a,b,c,d^Means in the same row without a common superscript differ (p < .05).

^ab^Pooled standard error of Tukey’s multiple range test.

^bc^Pooled standard error of 2 x 2 factorial design.

^d^p Value of 2 x 2 factorial design.
Harris et al. (2004) reported that concentration of blood cholesterol has been affected by fat intake, and saturated fatty acids would result in higher cholesterol concentration than polyunsaturated or monounsaturated fatty acids. As more tallow was included in BD treatment than other treatments, the higher TC might be detected. Due to the unclear effect of emulsifier or essential oil inclusion on the serum cholesterol concentration in livestock, more experiments need to be conducted.

**Meat quality**

Some authors have reported that natural antioxidants have no effect on sensory characteristics of meat in pigs (Janz et al. 2007). Active packaging is the only evidence of the effect of natural antioxidants on inhibiting off-odour formation and discolouration of meat (Camo et al. 2008).

Meat colour has been reported as the most important factor when consumers assess meat quality since the relationship between colour and freshness. Some reports demonstrated that natural antioxidants can retard meat colour loss by extending the red colour ($a^*$) and delaying malignant monoclonal gammopathy formation (Carpenter et al. 2007; Chouliara et al. 2007). Data from the current study suggested that positive effect was observed in yellowness ($b^*$) in treatment LEO than the other treatment and lightness ($L^*$) in LEO treatment was lower than that in BD treatment, which may be due to the anti-oxidative of essential oils. These findings are partially in agreement with Deans et al. (1993), who reported that plant oils may readily alter the fatty acid composition of all body lipid fractions by generally improving the oxidative stability of meat due to their natural antioxidants of tocopherols. However, it should be noted that inclusion of emulsifier alone increased the $b^*$ value, while inclusion of emulsifier and essential oil in combination decreased the $b^*$ value. The $b^*$ values reflect the myoglobin concentration and its redox state in meat, and it is positively related to sensory appreciation of meat colour degradation (Chouliara et al. 2007). Therefore, the findings of the present study may be due to the additive and synergistic effects of essential oil and emulsifier on oxidation processes. However, the underlying mechanism is not quite clear yet and requires further study.

In the present study, the LMA was significantly increased by the essential oil and emulsifier supplementation compared with LC group, which may be owing to the improved G:F or energy level caused by the inclusion of essential oil and emulsifier. Hsia and Lu (2004) observed reduced backfat thickness when pig fed higher energy, which suggested that higher energy could decrease the fat retention in the body and consequently increase the LMA. However, the effect of supplemental essential oil or emulsifier on LMA is scarce in literature and is necessary to be further investigated in order to control pork quality development.

**Conclusions**

Dietary essential oil or emulsifier supplementation in LC could increase serum TC concentration and decreased HDL-C concentration compared with BD. Meanwhile, dietary essential oil and emulsifier combination in LC could increase G:F, LDL-C concentration, sensory colour, LMA and decrease $L^*$, $b^*$ compared with BD in finishing pigs.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**References**

AOAC. 2007. Official methods of analysis of the Association of Official Analytical Chemists International. 18th ed. Gaithersburg, MD: AOAC.

Bellows L, Moore R. 2012. Dietary fat and cholesterol. Food and nutrition series. Colorado: Colorado State University.

Benchaar C, Calsamiglia S, Chaves AV, Fraser GR, Colombatto D, McAllister TA, Beauchemin KA. 2008. A review of plant-derived essential oils in ruminant nutrition and production. Anim Feed Sci Technol. 145:209–228.

Bozkurt M, Kucukyilmaz K, Cati AU, Cinar M. 2008. Growth performance and slaughter characteristics of broiler chickens fed with antibiotic, mannan oligosaccharide and dextran oligosaccharide supplemented diets. Int J Poult Sci. 7:969–977.

Camo J, Beltrán JA, Roncalés P. 2008. Extension of the display life of lamb with an antioxidant active packaging. Meat Sci. 80:1086–1091.

Carpenter R, O’Grady MN, O’Callaghan YC, O’Brien NM, Kerry JP. 2007. Evaluation of the antioxidant potential of grape seed and bearberry extracts in raw and cooked pork. Meat Sci. 76:604–610.

Cho JH, Chen YJ, Min BJ, Kim HJ, Kwon OS, Shon KS, Kim IH, Kim SJ, Asamer A. 2006. Effects of essential oils supplementation on growth performance, IgG concentration and fecal noxious gas concentration of weaned pigs. Asian Aust J Anim Sci. 19:80–85.

Chouliara E, Karatapanis A, Savvaidis IN, Kontominas MG. 2007. Combined effect of oregano essential oil and modified atmosphere packaging on shelf-life extension of fresh chicken breast meat, stored at 4 degrees C. Food Microbiol. 24:607–617.
Clark SB, Clark VE, Small DM. 1981. Effects of lecithin ingestion on plasma and lymph lipoproteins of normo- and hyperlipemic rats. Am J Physiol. 241:422–430.

De La Llata M, Dritz SS, Tokach MD, Goodband RD, Nelssen JL, Loughin TM. 2001. Effects of dietary fat on growth performance and carcass characteristics of growing-finishing pigs reared in a commercial environment. J Anim Sci. 79:2643–2650.

Deans SG, Noble RC, Penzes L, Imre SG. 1993. Promotional effects of plant volatile oils on the polyunsaturated fatty acid status during aging. Age. 16:71–74.

Dierick NA, Decuyper EA. 2004. Influence of lipase and/or emulsifier addition on the ileal and faecal nutrient digestibility in growing pigs fed diets containing 4% animal fat. J Sci Food Agric. 84:1443–1450.

Fenton TW, Fenton M. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Can J Anim Sci. 59:631–634.

Fomusa LB, Correding M, Akoh CC. 2002. Effect of emulsifier on oxidation properties of fish oil-based structured lipid emulsions. J Agric Food Chem. 50:2957–2961.

Harris KB, Pond WG, Mersmann HJ, Smith EO, Cross HR, Savell JW. 2004. Evaluation of fat sources on cholesterol and lipoproteins using pigs selected for high or low serum cholesterol. Meat Sci. 66:55–61.

Hong JW, Kim IH, Kwon OS, Min BJ, Lee WB, Shon KS. 2004. Influences of plant extract supplementation on performance and blood characteristics in weaned pigs. Asian-Aust J Anim Sci. 17:374–378.

Honikel KO. 1998. Reference methods for the assessment of physical characteristic of meat. Meat Sci. 49:447–457.

Hsia LC, Lu GH. 2004. The effect of high environmental temperature and nutrient density on pig performance, conformation and carcass characteristics under restricted feeding system. Asian-Aust J Anim Sci. 17:250–258.

Huang J, Yang DD, Wang T. 2007. Effects of replacing soy-oil with soy-lecithin on growth performance, nutrient utilization and serum parameters of broilers fed corn-based diets. Asian-Aust J Anim Sci. 20:1880–1886.

Jang IS, Ko YH, Yang HY, Ha JS, Kim JY, Kang SY, Yoo DH, Nam DS, Kim DH, Lee CY. 2004. Influence of essential oil components on growth performance and the functional activity of the pancreas and small intestine in broiler chickens. Asian-Aust J Anim Sci. 17:394–400.

Janz JAM, Morel PCH, Wilkinson BHP, Purchas RW. 2007. Preliminary investigation of the effects of low-level dietary inclusion of fragrant essential oils and oleoresins on pig performance and pork quality. Meat Sci. 75:350–355.

Jones DB, Hancock JD, Harmon DL, Walker CE. 1992. Effects of exogenous emulsifiers and fat sources on nutrient digestibility, serum lipids, and growth performance in weaning pigs. J Anim Sci. 70:3473–3482.

Lewis AJ. 2001. Amino acids in swine nutrition. In: Lewis AJ and Southern LL, editors. Swine nutrition. Boca Raton: CRC Press; p. 31–150.

NPPC. 1991. Procedures to evaluate market hogs. Des Moines, IA: National Pork Production Council.

NRC. 2012. Nutrient requirements of swine. 11th rev. ed. Washington, DC: National Academy Press.

Overland M, Tokach MD, Cornelius SG, Pettigrew JE, Rust JW. 1993. Lecithin in swine diets: I. Weanling pigs. J Anim Sci. 71:1187–1193.

Platel K, Srinivasan K. 1996. Influence of dietary spices or their active principles on digestive enzymes of small intestinal mucosa in rats. Int J Food Sci Nutr. 47:55–59.

Roy A, Haldar S, Mondal S, Ghosh TP. 2010. Effects of supplemental exogenous emulsifier on performance, nutrient metabolism, and serum lipid profile in broiler chickens. Vet Med Int. 2010:1–9.

SAS/STAT® Software. 2001. Changes and enhancements through release 8.2. Cary, NC: SAS Institute Inc.

Sullivan ZM, Honeyman MS, Gibson LR, Prusa KJ. 2007. Effects of triticale-based diets on finishing pig performance and pork quality in deep-bedded hoop barns. Meat Sci. 76:428–437.

Symeon GK, Zintilas C, Ayoutanti A, Bizelis JA, Deligeorgis SG. 2009. Effect of dietary oregano essential oil supplementation for an extensive fattening period on growth performance and breast meat quality of female medium-growing broilers. Can J Anim Sci. 89:331–334.

Wenk C. 2003. Herbs and botanicals as feed additives in monogastric animals. Asian-Aust J Anim Sci. 16:282–289.

Williams CH, David DJ, Iismaa O. 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J Agric Sci. 59:381–385.

Xing JJ, van Heugten E, Li DF, Touchette KJ, Coalson JA, Odgaard RL, Odle J. 2004. Effects of emulsification, fat encapsulation, and pelleting on weanling pig performance and nutrient digestibility. J Anim Sci. 82:2601–2609.

Yan L, Wang JP, Kim HJ, Meng QW, Ao X, Hong SM, Kim IH. 2009. Influence of essential oil supplementation and diets with different nutrient densities on growth performance, nutrient digestibility, blood characteristics, meat quality and fecal noxious gas content in grower–finisher pigs. Livest Sci. 128:115–122.

Zhao PY, Wang JP, Kim IH. 2013. Evaluation of dietary fructan supplementation on growth performance, nutrient digestibility, meat quality, fecal microbial flora, and fecal noxious gas emission in finishing pigs. J Anim Sci. 91:5280–5286.