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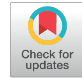
Original Research Article

Dietary lecithin improves feed efficiency without impacting meat quality in immunocastrated male pigs and gilts fed a summer ration containing added fat



Henny Akit [a, *, 1], Cherie Collins [b], Fahri Fahri [a], Alex Hung [a], Darryl D'Souza [c], Brian Leury [a], Frank Dunshea [a]

[a] Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, Victoria, 3010, Australia
[b] Rivalea Australia Pty Ltd., Corowa, 2646, Australia
[c] Australian Pork Ltd., Level 2, 2 Brisbane Avenue, Barton Capital Territory, 2600, Australia

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ABSTRACT

The aim of this study was to investigate the effects of sex and dietary lecithin on growth performance, meat quality, muscle collagen content and gene expression of key genes involved in collagen synthesis in finisher pigs. A total of 256 pigs (Large White × Landrace) were allotted to a 2 × 2 factorial arrangement involving sex (gilt or immunocastrated [IC] male) and dietary treatment (0 or 5 g/kg of dietary lecithin). All diets were formulated to contain 4.6% tallow with relatively high total fat of 6.3%. After 5 weeks of dietary treatment, pigs were slaughtered and *Longissimus dorsi* muscle was obtained for evaluation of meat quality and collagen content. *Rectus abdominis* muscle was analysed for gene expression of key genes involved in collagen synthesis namely, type I ($\alpha 1$) procollagen (*COL1A1*), type III ($\alpha 1$) procollagen (*COL3A1*), α-subunit of prolyl 4-hydroxylase (*P4H*), lysyl oxidase and metalloproteinase-1 (*MMP-1*). The results showed that lecithin improved feed efficiency of all pigs ($P < 0.05$) but it had no effect on feed intake, average daily gain and dressing percentage ($P > 0.05$). Lecithin also had no effect on meat compression, shear force, collagen content and gene expression ($P > 0.05$). Immunocastrated male had higher growth rate and increased *COL1A1* expression than gilts. However, sex had no effect on fat depth at the P2 site (65 mm from the midline over the last rib), collagen content and expression of other genes ($P > 0.05$). In conclusion, lecithin improved feed efficiency in finishing pigs without impacting pork quality. Thus, inclusion of lecithin in diets containing high amount of tallow during the summer period could be beneficial.

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1. Introduction

Soy lecithin, a by-product from the processing of soybean oil, contains a mixture of various phospholipids. Lecithin is an emulsifier and it is generally used in various food applications, cosmetics and pharmaceutical industries. Lecithin also has been used in young pig starter diets to enhance the utilisation of dietary fat (Jones et al., 1992; Overland et al., 1993a; Reis de Souza et al., 1995; Soares and Lopez-Bote, 2002). The addition of high levels of fat in the pig finisher diet is particularly common in the summer period where the growth rate is slower compared with pigs reared in autumn (Myer and Bucklin, 2002). Fats and oils are used as energy sources in animal diets because of their high energy value and low heat increment of digestion. However, animal fats such as

* Corresponding author.
E-mail address: henny@upm.edu.my (H. Akit).
[1] Present address: Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Selangor, 43400, Malaysia.

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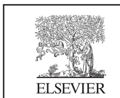

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tallow and lard are rich in saturated fatty acids which are less digestible than vegetable oils (Cera et al., 1988; Soares and Lopez-Bote, 2002). A welfare friendly alternative to castration of male pigs is immunization against gonadotrophin releasing factor (GnRF) which allows producers to capitalize on the superior feed efficiency and carcass characteristics of boars without the risk of boar taint (Dunshea et al., 2001). It has been reported that immunocastrated (IC) males have higher feed intake and faster growth rate than gilts (Gispert et al., 2010; Morales et al., 2011; Font-i-Furnols et al., 2012). Rapid growth rate in animals can affect meat tenderness through increased muscle collagen synthesis and degradation (Fishell et al., 1985; Harper et al., 1999). Faster growing groups of cattle were reported to have more tender meat than slower growing groups of cattle (Harper et al., 1999; Zgur, 2003; Perry and Thompson, 2005). High growth rate before slaughter in IC males was suggested to be associated with lower pork shear force values in IC males compared with barrows and boars (Pauly et al., 2009). However, studies comparing meat tenderness between IC male pigs and other sex are limited (Channon et al., 2016). The aim was to investigate the impacts of sex and dietary lecithin on growth performance, meat quality and muscle collagen content of finisher pigs. In order to understand some of the mechanisms, the effects of dietary lecithin and sex on gene expression of key genes involved in intramuscular collagen synthesis and degradation were also investigated.

Table 1
Ingredients and nutrient composition of experimental diets (as-fed basis).

Item	Experimental diets	
	Control	Lecithin
Ingredients, %		
Wheat	59.9	59.9
Barley	8.0	8.0
Millmix	13.6	13.6
Canola meal	7.0	7.0
Meat meal	3.8	3.8
Water	1.0	1.0
Tallow	4.6	4.6
Salt	0.2	0.2
Limestone	1.3	1.3
Lysine HCL	0.4	0.4
Threonine	0.1	0.1
Copper premix	0.1	0.1
Rivalea finisher premix	0.1	0.1
Rumensin	0.1	0.1
Lecithin	0.0	0.5
Estimated nutrient composition[1], %		
Digestible energy (DE), MJ/kg	14.2	14.2
Crude protein	15.2	15.2
Crude fat	6.3	6.3
Crude fibre	4.1	4.1
Total lysine	0.9	0.9
Available lysine to DE ratio, g/MJ DE	0.5	0.5

[1] Estimated from Rivalea Australia Pty Ltd. (NSW, Australia) composition data. This project was funded by Pork CRC. This was reported in Pork CRC report, 2011.

2. Materials and methods

2.1. Diets, animals and experimental design

A total of 256 pigs (Large White × Landrace) (PrimeGro Genetics, NSW, Australia) were identified at 17 weeks of age and transferred to a finisher accommodation with 32 pens. Each pen consisted of 8 pigs (same-sex). Pen weights (average start weight = 66.2 ± 0.70 kg) were recorded at entry to the finisher pens. Pens were randomly allocated to a 2 × 2 factorial experiment with the respective factors: 0 or 5 g/kg dietary lecithin (ADM Australia Pty Ltd., NSW, Australia) and sex (IC male or gilt). The priming dose of Improvac (CSL Pty Ltd., VIC, Australia) vaccination was administered to male pigs at 13 weeks of age with the second vaccination at 17 weeks of age. All diets were formulated to contain 0.52 g available lysine/MJ DE, 14.2 MJ DE/kg and 4.6% tallow (Table 1). Experimental diets were fed to pigs for 5 weeks starting from 17 weeks of age until slaughter at 22 weeks of age. Pen weights were recorded at the beginning of the experimental period at d 0 (17 weeks of age) and again at d 14. At d 35 (pre-slaughter), individual live weights were recorded. Pen feed intake was recorded over the intervals between d 0 to 14 and d 15 to 35 as measured by feed disappearance. Feed efficiency was subsequently calculated. At d 35, the pigs were slaughtered according to the standard procedures practised in commercial abattoirs. All procedures for animal care were approved by the Rivalea Animal Care and Use Committee.

2.2. Carcass quality measurements and sampling

Rectus abdominis muscles from a subset of 64 carcasses (2 median-weight pigs per pen) were collected. The tissues were immediately immersed in liquid nitrogen and then stored at −80 °C. This muscle was selected because of convenience of sampling at the slaughter house. The individual hot standard carcass weight was recorded. Fat depth at the P2 site (65 mm from the midline over the last rib) were measured using a PorkScan ultrasound system (PorkScan Pty Ltd., Canberra, Australia). Individual live weight and carcass weight measures were used to calculate dressing percentage. Twenty-four hours post-slaughter, *Longissimus dorsi* muscle (loin) from a subset of 64 carcasses (2 pigs per pen) was removed from the right side of each pig carcass. The loin samples for collagen content analysis were vacuum packed and stored at −20 °C until ready for use. Meanwhile, loin samples for texture analysis were vacuum packed and left to age for 5 days at 4 °C. Then, the muscle samples were stored at −20 °C for future analyses.

2.3. Meat pH and colour measurements

The pH of loin between 12th and 13th rib was measured at 45 min and 24 h post-slaughter using a portable pH/temperature metre Model 6009 (Jenco Electronic Ltd., Taipei, Taiwan, China) fitted with a polypropylene spear-type gel electrode (Ionode IJ42S, QLD, Australia) and a temperature probe.

Following a bloom time of 30 min, meat colour (L^*, a^* and b^*) was measured with a Minolta Chromameter CR-400 (Minolta, Osaka, Japan) using D65 lighting, a 2° standard observer, and an 8-mm aperture in the measuring head. L^* values correspond to lightness, a^* values to redness and b^* values to yellowness in the three-dimensional HunterLab colour space.

2.4. Cooking method and cooking loss

The cooking procedure was adopted from the method of Bouton et al. (1971). The loin was cut to a 70 ± 5 g cube (40 mm × 40 mm × 40 mm). Weight of each cube was recorded as weight before cooking. Then the samples were cooked in water bath at 70 °C for 35 min. After cooking, the samples were immersed in ice cold water for 20 min and then patted dry to remove excess moisture. Samples weight after cooking was recorded before being refrigerated overnight. Cooking loss was calculated as a percentage of weight loss before and after cooking.

2.5. Warner–Bratzler shear force and compression analyses

Texture of cooked meat was determined using Warner–Bratzler shear force and compression analyses (Bouton and Harris, 1972). For shear force, each sample was cut into 6 rectangular strips of 1 cm^2 cross-section, parallel to the muscle fibres. The shear force blade was driven to cut the samples at a crosshead speed of 300 mm/min and a 1 kN load cell was used. The meat tenderness was estimated using the mean of the peak shear force.

For compression analysis, each sample was cut into 6 cross-section samples (1-cm thick) with the fibres lying perpendicular on the face of the largest area. The sample was placed under a flat-ended plunger that moved downwards at about 80% through the sample. Hardness is defined as the peak force required for the first compression. Then, the plunger moved upwards and then returned to the same damaged area to measure the second compression. The ratio of the force required for the second compression to the force required for the first compression is defined as cohesiveness. Consequently, chewiness value was calculated as the product of hardness and cohesiveness (Bouton and Harris, 1972).

2.6. Meat collagen content analysis

Hydroxyproline content was determined using a colourimetric method developed by Kolar (1990) with minor modifications. Hydroxyproline was oxidised to pyrrole with chloramine-T reagent. Then, the complex formed by the liberated pyrrole and 4-dimethylaminobenzaldehyde was determined by the colourimetric method. The absorbance values of the sample solutions were measured on a plate reader (Thermo Multiskanner, Vantaa, Finland) at 558 nm wave length. The concentration of hydroxyproline (μg/mL) was determined from a standard curve. The total collagen content was determined using a factor of 7.46 (Colgrave et al., 2008) and was reported as milligramme of collagen per gram of sample.

2.7. Quantification of mRNA by real-time RT-PCR

Total RNA was extracted from 200 to 300 mg samples using Trizol reagent and PureLink Micro-to-Midi RNA isolation system kit (Invitrogen, San Diego, CA, USA) following the manufacturer's instructions. The RNA quality was evaluated using Experion automated electrophoresis system and Experion RNA StdSens analysis kit (BIORAD, Gladesville, NSW, Australia). Samples displaying 28S:18S ribosomal RNA ratio close to 1.5 were considered acceptable. Then, cDNA was synthesised using 1 μg of total RNA from each sample using the SuperScript III First-Strand Synthesis System (Invitrogen) for RT-PCR and 50 ng/μL random hexamer primer (Invitrogen), following manufacturer's instructions. Primers matrix metalloproteinase-1 (*MMP-1*) and ribosomal 18s (*R18s*) were designed based on porcine sequences. Type I (*α1*) procollagen (*COL1A1*), type III (*α1*) procollagen (*COL3A1*), α-subunit of prolyl 4-hydroxylase *(P4H)* and lysyl oxidase primers were designed based on mouse (*Mus musculus*) sequences because complete genomes of the pig are not available (Table 2).

The reverse transcription PCR was performed on a MyiQ system (BIORAD) using SYBR green (BIORAD) in triplicate. The temperature profile consisted of initial hot start at 95 °C for 3 min as the initial denaturation step of one cycle, followed by 40 cycles at 95 °C for 10 s (denaturation), 51.0 to 61.2 °C for 45 s (annealing) and an extension step at 95.0 °C for 1 min. Melting curve analysis was performed to confirm the specificity of the primers. Non-template controls were included with each PCR run to validate that primers were not amplifying contaminating DNA. Relative gene expression was calculated using the $2^{-\Delta\Delta Ct}$ method, as described by Livak and Schmittgen (2001).

2.8. Statistical analysis

The main effects of dietary lecithin and sex on growth performance and carcass quality were analysed using an analysis of variance (ANOVA) for a randomised design. Replicate was used as a blocking factor. The experimental unit for all analyses was the pen of pigs. The meat colour, pH, collagen content, cooking loss, texture and gene expression data from a subset of pigs were analysed using restricted maximum likelihood (REML) to determine the main effects of dietary lecithin and sex. The pen number was included as a random model. All results were considered statistically significant when $P < 0.05$ and trends when $0.05 \le P \le 0.10$. All analyses were performed using the Genstat software 13th edition (VSN International Ltd, Hertfordshire, UK).

3. Results

3.1. Growth performance and carcass quality

Table 3 shows the results on the growth performance and carcass quality. During the initial d 0 to 14, lecithin tended to improve feed efficiency compared with pigs fed the control diet ($P = 0.068$). However, lecithin had no effect on feed intake and weight gain. Immunocastrated males had higher weight gain and better feed efficiency than gilts ($P < 0.001$). Feed intake was similar between sexes. Interactions between sex and diet

Table 2
Characteristics of the primers used for quantitative real-time PCR.

Gene	Accession number	Primers	Primer sequences (5′ to 3′)	Annealing temperature, °C	Amplicon size, bp
COL1A1	BC050014.1	Forward	GTCTGGTTTGGAGAGAGCAT	60.9	189
		Reverse	CTTCTTGAGGTTGCCAGTCT		
COL3A1	NM_009930.2	Forward	TGATGTCAAGTCTGGAGTGG	53.4	223
		Reverse	TCCTGACTCTCCATCCTTTC		
MMP-1	EU722905.1	Forward	GTTCCACAAATGAGTGCTGA	60.9	212
		Reverse	ATAATAACGACGGCTCATCC		
Lysyl oxidase	M65142.1	Forward	CTGCTTGATGCCAACACA	58.7	156
		Reverse	TGCCGCATAGGTGTCATA		
α-subunit *P4H*	BC009654.1	Forward	CCCAGTCAGGTCTGCTATTC	51.0	204
		Reverse	GGAACAGTCTCTGGACAACC		
R18s	AY265350.1	Forward	GAACGCCACTTGTCCCTCTA	61.2	219
		Reverse	GACTCAACACGGGAAACCTC		

COL1A1 = type I (α1) procollagen; *COL3A1* = type III (α1) procollagen; *MMP-1* = matrix metalloproteinase-1; α-subunit *P4H* = α-subunit of prolyl 4-hydroxylase; *R18s* = ribosomal 18s.

Table 3
Effects of sex and dietary lecithin on average daily gain (ADG), average daily feed intake (ADFI), feed conversion ratio (FCR) and carcass quality.[1]

Item	Gilt		Immunocastrated male		SED	P-value		
	Control	Lecithin	Control	Lecithin		Sex	Diet	Sex × Diet
Initial bodyweight, kg	65.1	65.1	67.3	67.3	0.70	<0.001	1.00	0.98
Final bodyweight[2], kg	96.8	98.5	105.3	104.7	1.31	<0.001	0.53	0.18
From 0 to 14 d on experiment								
ADG, kg/d	0.83	0.95	1.09	1.00	0.042	<0.001	0.65	0.002
ADFI, kg/d	2.48	2.53	2.61	2.45	0.066	0.60	0.26	0.028
FCR, kg/kg	3.04	2.68	2.40	2.46	0.114	<0.001	0.068	0.015
From 15 to 35 d on experiment								
ADG, kg/d	0.87	0.87	1.17	1.20	0.048	<0.001	0.64	0.66
ADFI, kg/d	2.76	2.64	3.54	3.39	0.120	<0.001	0.13	0.87
FCR, kg/kg	3.22	3.07	3.02	2.82	0.121	0.015	0.051	0.75
From 0 to 35 d on experiment								
ADG, kg/d	0.85	0.90	1.14	1.12	0.037	<0.001	0.56	0.21
ADFI, kg/d	2.65	2.60	3.17	3.02	0.091	<0.001	0.12	0.43
FCR, kg/kg	3.13	2.90	2.78	2.69	0.078	<0.001	0.006	0.21
Carcass quality								
Carcass weight[2], kg	75.5	76.8	80.3	80.1	1.04	<0.001	0.39	0.29
P2 backfat depth[3], mm	10.8	10.2	10.5	10.8	0.40	0.49	0.40	0.067
Dressing, %	78.4	78.5	75.9	76.1	0.47	<0.001	0.70	0.79

SED = standard error of the difference; P2 = the site of 65 mm from the midline over the last rib.
[1] From Pork CRC report, 2011.
[2] Initial bodyweight was included as a covariate in the analysis.
[3] Carcass weight was included as a covariate in the analysis.

Table 4
Effects of sex and dietary lecithin on meat quality of longissimus muscle.

Meat quality	Gilt		Immunocastrated male		SED	P-value		
	Control	Lecithin	Control	Lecithin		Sex	Diet	Sex × Diet
pH at 45 min	6.46	6.35	6.41	6.39	0.111	0.93	0.41	0.58
pH at 24 h	5.76	5.75	5.80	5.79	0.075	0.47	0.81	0.99
Lightness (L*)	49.41	48.59	48.50	49.16	0.593	0.68	0.85	0.085
Redness (a*)	5.66	6.04	5.81	5.97	0.307	0.86	0.22	0.63
Yellowness (b*)	2.09	1.94	2.10	2.22	0.234	0.37	0.91	0.41
Cooking loss, %	20.6	23.0	21.5	23.1	0.01	0.49	0.007	0.55
Warner–Bratzler shear force, kg	3.04	3.07	3.43	3.16	0.208	0.11	0.41	0.32
Chewiness	1.53	1.52	1.51	1.51	0.082	0.82	0.87	0.92
Cohesiveness	0.35	0.36	0.35	0.35	0.007	0.90	0.48	0.76
Hardness, kg	4.36	4.26	4.30	4.26	0.185	0.79	0.60	0.83
Collagen content, mg/g	0.65	0.64	0.67	0.69	0.055	0.46	0.94	0.79

SED = standard error of the difference.

showed that weight gain ($P = 0.002$) and feed intake ($P = 0.028$) were greater in gilts when offered the lecithin diets but not in IC males. As a result, gilts offered the lecithin diets had better feed efficiency ($P = 0.015$). During the subsequent period (d 15 to 35), there was a strong trend for improved feed efficiency in pigs fed lecithin diets ($P = 0.051$) but there was no effect on feed intake and weight gain. Immunocastrated males had higher weight gain and feed intake as well as better feed efficiency than gilts over this period ($P < 0.05$). There was no interaction between sex and diet on the growth performance during this period. Over the entire experimental period (d 0 to 35), lecithin improved pig feed efficiency ($P = 0.006$). However, lecithin had no effect on feed intake and weight gain. Immunocastrated males had higher weight gain and feed intake as well as better feed efficiency than gilts ($P < 0.001$). There was no interaction between sex and diet on the growth performance over the entire experiment.

Lecithin had no effect on final live weight, carcass weight, P2 backfat depth and dressing percentage whereas IC males had heavier final live weight and carcass weight than gilts ($P < 0.001$). Gilts had higher dressing percentage than IC males ($P < 0.001$). The P2 backfat depths were similar in both sexes. There was no interaction between sex and diet on the carcass quality.

3.2. Meat quality

Dietary lecithin or sex had no impact on meat pH, colour, collagen content, shear force, chewiness, cohesiveness and hardness (Table 4). Lecithin increased cooking loss ($P = 0.007$), but cooking loss was similar in both sexes. There was no interaction between sex and diet on the meat quality.

3.3. Skeletal muscle gene expression

Dietary lecithin or sex had no impact on the gene expression of the genes involved in muscle collagen synthesis and degradation (data on effect of lecithin was not shown). The exceptions were for *COL1A1* mRNA expression that was increased in IC males ($P = 0.051$) and *COL3A1* that tended to increase in IC males compared with gilts ($P = 0.093$) (Fig. 1). There was no interaction between sex and diet on the gene expression (data not shown).

4. Discussion

The major finding from the present study was that dietary lecithin improved feed efficiency in both gilts and IC male pigs fed a summer diet containing 4.6% tallow added. Similarly, Kim et al.

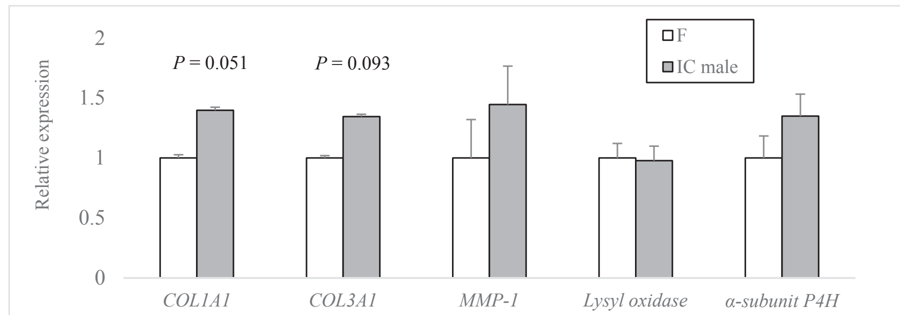

Fig. 1. Relative mRNA expression of type I (α1) procollagen (*COL1A1*), type III (α1) procollagen (*COL3A1*), matrix metalloproteinase-1 (*MMP-1*), lysyl oxidase and α-subunit of prolyl 4-hydroxylase (*α-subunit P4H*) in *rectus abdominis* muscle of finishing pigs. The expression levels were normalized against that of Ribosomal 18s (*R18s*) reference gene. Each column represents the means ± SED of 32 pigs. The results were considered significant when $P < 0.05$ and as trends when $0.05 \le P \le 0.10$. SED = standard error of the difference; F = female; IC male = immunocastrated male.

(2008) also demonstrated improvement in feed efficiency in finisher pigs fed lecithin in diets containing 2.5% tallow. In contrast to the present study, lecithin had no effect on feed efficiency but it improved dressing percentage in finisher pigs supplemented lecithin in diets containing 4.5% tallow (Akit et al., 2014). Lecithin, as an emulsifier, was proposed to increase the capacity of bile salt micelles to solubilise long chain saturated fatty acids thus improving animal fat digestion and absorption (Freeman, 1969; Reynier et al., 1985). However, Kim et al. (2008) did not observe any improvements in nutrient digestibility. The degree of fatty acid saturation in the diet is an important factor in determining fat digestibility in pigs (Eusebio et al., 1965). Lecithin is high in unsaturated fatty acid, particularly linoleic acid. Therefore, it was hypothesised that rather than being due to lecithin's emulsifying effect, the benefits on digestibility might be due to an indirect increase in fatty acid unsaturation (Soares and Lopez-Bote, 2002). However, the same authors found that addition of lecithin increased the unsaturated to saturated fatty acid ratio of diets containing lard but lecithin had no effect on fat digestibility of weaning piglets. Effect of lecithin on feed efficiency of pigs fed diets containing vegetable oils was also inconsistent. A few studies showed no changes in the feed efficiency of pigs fed lecithin in diets containing canola oil (D'Souza et al., 2012, 2015). Another study on the other hand, showed lecithin improved feed efficiency in growing-finishing pigs fed diets containing soy oil (Overland et al., 1993b). They suggested that different sources of lecithin as well as varying type and level of dietary fats contribute to inconsistent responses of growth performance to lecithin.

Generally, muscles with higher collagen content possess higher cross-link concentrations per unit of collagen than muscles with lower collagen content (Shimokomaki et al., 1972; Light et al., 1985). A more tender meat was suggested to be as a consequence of reduced collagen content, and therefore reduced cross-links levels (Ngapo et al., 2002). Lecithin in the present experiment had no effect on meat texture and collagen content. In contrast, dietary lecithin decreased longissimus muscle chewiness and hardness (Akit et al., 2014; D'Souza et al., 2015) and this improvement was suggested to be due to decreased muscle collagen content (Akit et al., 2014). Dietary lecithin also decreased hardness and chewiness of semitendinosus muscle (D'Souza et al., 2012). Longissimus muscle had relatively lower collagen content compared with other muscles such as *Biceps femoris, Triceps bricii* and semitendinosus (Nold et al., 1999; Wheeler et al., 2000). Collagen content (0.64 to 0.69 mg/kg) was much lower in the present experiment than in a previous experiment (1.07 to 1.51 mg/kg) reported by Akit et al. (2014). Because of the already relatively low longissimus muscle collagen content in the present study, it was less likely to detect any changes caused by dietary lecithin. In addition, the shear force values in the present study (3.04 to 3.43 kg) were lower compared with the values reported by Channon et al. (2001). Their study reported longissimus muscle shear force values were in a range of 3.72 to 5.13 kg. The meat from the present experiment was already tender which may have made it difficult to further improve its tenderness. Moreover, it was suggested to supplement lecithin in the diet of pigs as early as the grower stage through to the finisher stage (D'Souza et al., 2012) because meat becomes tougher as the animal grows in age due to the progressive maturation of collagen (Kauffman et al., 1964; Fang et al., 1999). Hence, lecithin in the present study could perhaps influence meat texture and collagen content if the pigs were fed lecithin for longer duration or if pigs with tougher muscle with higher collagen content was used.

Cooking loss was increased by lecithin in the present study. However, it should be noted that the cooking loss was much lower than the normal range of 25.8% to 27.3% (Akit et al., 2014). During cooking, denaturation and shrinkage of endomysial and perimysial collagen sheaths resulted in loss of water and reduced tenderness (Bailey, 1988; Avery et al., 1996). Cooking loss was shown to be positively correlated with meat total collagen and heat-insoluble collagen (Okeudo and Moss, 2005). This may explain the low values of cooking loss and total collagen in the present study.

As expected, IC males in the present experiment grew faster than the gilts and this was in agreement with previous studies (Gispert et al., 2010; Morales et al., 2011; Font-i-Furnols et al., 2012). Immunocastrated males also had more superior growth performance compared with boars and barrows (Dunshea et al., 2001, 2011). Immunocastration of male pigs decreased testosterone levels after the second immunisation against gonadotropin-releasing hormone (Dunshea et al., 2001; Zeng et al., 2002; Claus et al., 2007). Testosterone has a negative influence on appetite of pigs thus reduced levels of testosterone resulted in increased feed intake (Weiler et al., 1996). Reduced testosterone level also reduced aggression and mounting behaviours leading to increased growth rate because more feed was utilised for live weight gain rather than the non-beneficial behaviours in IC male pigs (Cronin et al., 2003; Dunshea et al., 2011).

Variation in meat characteristics due to sex effect can be explained by its influence on protein and body fat depositions in the carcass (Franco et al., 2008; Peinado et al., 2008; Serrano et al., 2009). However, carcass backfat depth at the P2 site was not affected by sex in the present study. When comparing IC male and gilt, backfat depth did not differ by much as reported by Gispert et al., (2010), and Fabrega et al. (2010) found backfat depth values of IC male and gilt were in between barrow and boar. Another study found that backfat depth did not differ between IC male and gilt but

was lower than barrow (Morales et al., 2011). Testosterone was suggested to contribute to high muscle collagen content in bulls because of its anabolic effects on collagen synthesis (Boccard et al., 1979). This coincides with a study that found muscle total collagen was greater in boars than barrows and gilts (Nold et al., 1999). A few studies comparing barrows and gilts found no effect of sex on muscle collagen content (Correa et al., 2006; Maiorano et al., 2007; Corino et al., 2008). However, one study found that collagen content and shear force values were lower in muscle of barrows than gilts (Kim et al., 2016). The lack of differences in backfat depth and collagen content correspond with the lack of differences in meat texture between IC male and gilt in the present study. Including boars and measuring the effect of testosterone on meat collagen synthesis could be worthy of further investigation.

Intramuscular collagen had less contribution to beef toughness from cattle slaughtered after a period of rapid growth (Fishell et al., 1985; Harper et al., 1999). Increased growth rate following a period of feed restriction showed variable responses on meat tenderness and collagen characteristics in pigs (Therkildsen et al., 2002; Kristensen et al., 2002, 2004). In the present experiment, IC male that had faster growth rate did not show any differences in the muscle collagen content and meat texture compared with the gilt. It is known that other than growth rate, type of muscle, animal age and management practices can also affect collagen synthesis and maturation (McCormick, 1994; Purslow, 2005). Apart from intramuscular collagen, growth rate prior to slaughter also affects postmortem proteolytic degradation of myofibrillar proteins and thus meat texture (Kristensen et al., 2002; Sazili et al., 2004; Therkildsen et al., 2004). However, myofibrillar protein degradation may have been levelled out in all samples in the present experiment because the meat were left to age for 5 days prior to analysis. Moreover, muscle ultimate pH was similar in both IC male and gilt therefore any differences in the meat texture due to myofibrillar protein degradation may have been minimised.

Intramuscular connective tissues composed of extracellular matrix molecules such as collagens, proteoglycans, and glycoproteins. Collagen is synthesised as intracellular precursors known as procollagens. Type I and type III collagens make up the major components of intramuscular connective tissue. Extracellular matrix plays an important role in muscle cell growth and the organization of intramuscular connective tissue during skeletal muscle development (Nishimura, 2015). Faster growth rate was associated with greater rate of collagen synthesis (McCormick, 1994). The *COL3A1* and *COL5A3* (collagen type V, alpha 1) genes which have functions in collagen development were down-regulated in tissue of pigs fed low protein diets that had reduced growth rate (Hamill et al., 2013). The expression levels of several important genes involved in collagen synthesis including *COL3A1* and *COL1A1* were up-regulated in intact male cattle compared with the castrates (Zhang et al., 2011). They suggested that this was because intact males have a vigorous collagen anabolism and turnover rates compared with the castrates. The substantial difference in growth rate between IC male and gilt may explain the increase of *COL1A1* expression and the trend in increase of *COL3A1* expression in IC males in the present study. Although it should be kept in mind that this explanation should be supported by other genes involved in growth and development functions.

Lecithin was shown to prevent collagen accumulation as evidenced by down-regulation of *COL1A1* expression in hepatocyte cell culture (Poniachik et al., 1999; Cao et al., 2002a, 2002b) as well as to enhance breakdown of existing collagen (Lieber et al., 1994) in liver fibrosis. In a study using gilts, lecithin down-regulated skeletal muscle expression of *COL1A1*, *COL3A1* and *MMP-1* genes, and it tended to down-regulate the expression of α-subunit *P4H* (Akit et al., 2016). In contrast, lecithin did not show any changes in the expression of genes involved in collagen synthesis in the present study. This lack of lecithin effect may partly be explained by the low level of muscle collagen content.

5. Conclusions

Dietary lecithin improved feed efficiency in both IC males and gilts without impacting pork quality. Hence, lecithin could be useful to improve feed efficiency in finisher pigs fed high amount of fat during the summer period. Lecithin and sex had no effect on meat texture, collagen content as well as gene expression of key genes involved in collagen synthesis and degradation. The lack of lecithin effect maybe because of the low collagen content and shear force values across treatments. Immunocastrated males had faster growth rate and higher *COL1A1* expression levels than gilts. Further investigation on the relationship between growth rate and collagen synthesis may be worth considering.

Conflicts of interest

The authors declare that they have no conflict of interest.

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