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Original research article

Effects of the ratio of unsaturated fatty acid to saturated fatty acid on the growth performance, carcass and meat quality of finishing pigs

Wandee Tartrakoon [a, *], Tinnagon Tartrakoon [b], Nattporn Kitsupee [a]

[a] Department of Agricultural Science, Faculty of Agriculture, Natural Resource and Environment, Naresuan University, Phitsanulok 65000, Thailand
[b] Faculty of Sciences and Agricultural Technology, Rajamangala University of Technology Lanna, Phitsanulok Campus, Chiang Mai 50300, Thailand

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ABSTRACT

The effects on finishing pigs (80–100 kg BW) fed diets supplemented with oil sources containing different ratios of unsaturated to saturated fatty acids (UFA:SFA ratio) were evaluated in 15 barrows and 15 gilts (Duroc × Large White × Landrace). Three experimental diets were evaluated using a randomized complete block design, with broken rice, soybean meal and rice bran as the main feedstuffs in the control diet. Diets 2 and 3 consisted of the control diet supplemented with 3% oil, with UFA:SFA ratios of 2.5:1 and 5:1, respectively. Overall, there was no significant difference ($P > 0.05$) found in the average daily gain (ADG) of the pigs fed the treatment diets; however, the pigs fed the control diet and diet 3 had better ($P < 0.05$) feed conversion ratios (FCR) than the pigs fed diet 2. The pigs fed diets 2 and 3, which were supplemented with oil at UFA:SFA ratios of 2.5:1 and 5:1, had greater ($P < 0.05$) average daily feed intakes (ADFI) than the pigs in the control group. Additionally, it was found that the gender of the pigs had an effect ($P < 0.05$) on the FCR. Interaction effects between the experimental diets and the gender of the pigs ($P < 0.05$) were found in the ADFI and FCR. There were no significance differences ($P > 0.05$) among the treatment groups with regard to the carcass quality of the pigs; however, it was found that the gilts had greater ($P < 0.01$) loin eye areas than the barrows fed diets 2 and 3 and the loin eye area of pig fed diet 2 was the largest ($P < 0.05$). In the case of the meat quality parameters, it was clearly found that the pigs fed the control diet had a greater ($P < 0.05$) lightness (L^*) in the meat colour, and the lowest cooking loss was found in the pigs fed the diet supplemented with fat containing the UFA:SFA ratio of 5:1. Overall, the dietary treatment did not significantly affect the drip loss, thawing loss and shear force of the pork. In conclusion, the supplementation of oil with UFA:SFA ratios of 2.5:1 and 5:1 has the potential to improve pork quality.

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1. Introduction

The goal of the production of high-quality pork in the pig industry has been focused on for decades (Dokmanovic et al., 2015). However, feeding during the finishing period (80–100 kg BW), not only to obtain the optimum feed efficiency (FE) and growth rate, also effects on the carcass and meat quality should be considered. The composition of the diet directly affects the carcass and meat quality of finishing pigs, and interest in the fatty acid composition of the meat stems mainly from the need to find ways to produce healthier meat (Wood et al., 2003). Recent studies have demonstrated that dietary arginine supplementation beneficially promotes muscle gain and reduces body fat accretion in growing-finishing pigs (Tan et al., 2009). Due to arginine differentially regulates expression of fat-metabolic genes in skeletal muscle and white adipose tissue, therefore favouring lipogenesis in muscle but lipolysis in adipose tissue (Tan et al., 2011).

The components of the technological meat quality influenced by fatty acids include the fat tissue firmness (hardness) and flavour. Although it has been suggested that dietary fatty acids influence

* Corresponding author.
E-mail address: wandeeta@nu.ac.th (W. Tartrakoon).
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tenderness and juiciness, they are more likely to be affected by the total amount of fatty acids rather than the individual ones. The effects of the fatty acids on firmness are due to the different melting points of the fatty acids in the meat (Enser, 1984), and many researchers have studied the effects of diets supplemented with different sources or levels of fat on pig performance and fatty acid composition (Mitchaothai et al., 2007; Olivares et al., 2009; Apple et al., 2009; Realini et al., 2010; Duran-Montgé et al., 2010; Kim et al., 2014; Ivanovic et al., 2015). In addition, some research has been done on pork eating quality (Corino et al., 2002; Teye et al., 2006; Tikk et al., 2007; Alonso et al., 2012). Overall, there are a number of other fat sources and combinations of fat sources which may affect the pig carcass composition and meat quality. For example, Powles et al. (1994) determined that the increase in the unsaturated fatty acid to saturated fatty acid ratio (UFA:SFA ratio) is accompanied by a curvilinear increase in the digestible energy (DE) values. Improvement in the DE with an increasing UFA:SFA ratio occurred up to the maximum ratio studied (5.71), which is in contrast with previous observations of growing/finishing pigs, where the greatest improvement in the fat utilization occurred up to ratios of 2.08, with little improvement thereafter (Powles et al., 1993; Wiseman et al., 1990). This may reflect the age of the pigs, since young pigs may require more UFA in the diet for the efficiency of fat utilization than the growing/finishing pigs (Gu and Li, 2003). In addition, Li et al. (2015) found the maintaining of the dietary n-6:n-3 polyunsaturated fatty acid (PUFA) ratios of 1:1–5:1 would facilitate the absorption and utilization of fatty acids and free amino acids, and result in improved muscle and adipose composition. Not only energy sources from the fatty acid composition in feed should be considered, but also the protein:energy ratio is important for the production performance and utilization of available feed resources by animals. Increased protein consumption by mammals leads to elevated feed costs and increased nitrogen release into the environment. However, Liu et al. (2015) found the dietary protein:energy ratio did not affect the growth performance of Bama mini-pigs and suggested that, in swine production, low dietary protein:energy ratio may be useful for reducing feed costs and minimizing the adverse effects of ammonia release into the environment. More information about the effect of muscle and fat deposition such as, soy isoflavones regulated the BW gain and fat percentage of Chinese *Guangxi* minipigs, which also showed changes in insulin-like growth factor-I (IGF-I) system and Peroxisome proliferator activated receptor-ϒ (PPAR-$_{\gamma}$) (Li et al., 2011a). More reference concerned muscle or adipocyte development demonstrating the metabolic mechanism by molecular biology methods. Li et al. (2011b) reported that myostatin suppressed 3T3-L1 preadipocyte differentiation and regulated lipid metabolism of mature adipocyte via activation of extracellular-regulated kinase 1/2 (ERK 1/2) signalling pathway.

As far as we know, no previous work has dealt with the effects of the UFA:SFA ratio of the diet on the productive performance, carcass or meat quality. Therefore, the objectives of this study were to evaluate the effects of adding a 3% combination of oil sources containing ratios of 2.5:1 and 5:1 (UFA:SFA), compared with a diet with no added oil, on the growth performance, carcass and meat quality of finishing pigs.

2. Materials and methods

2.1. Animals and diets

This experiment was conducted with 15 barrows and 15 gilts (Duroc × Large White × Landrace), which were divided into three groups of 10 pigs each. Each group was fed one of the three experimental diets in a randomized complete block design, using broken rice, soybean meal and rice bran as the main feedstuffs in the control diet. Diets 2 and 3 consisted of the control diet supplemented with 3% oil, which contained a mixture of coconut and canola oil to UFA:SFA ratios of 2.5:1 and 5:1, respectively. The composition and proximate analysis of the diets are shown in Table 1 and Table 2. All of the diets contained gross energy equal to 3,250 ± 100 kcal/kg and 13 ± 0.5% CP. Broken rice was used to adjust metabolizable energy value in the control diet to have calculated ME equal to 3,164 kcal/kg. The pigs were housed in individual pens with concrete floors, equipped with nipple drinkers and single feeders, allowing the pigs *ad libitum* access to feed and water.

2.2. Growth performance and sampling procedures

The pigs' body weights and feed consumption were recorded and measured from the beginning of the trial to a final average live weight of 100 ± 5 kg to calculate the average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (feed: gain; FCR). The proper care and use of the animals in this research procedure was performed by trained researcher under Naresuan University animal care and use committee. The animals were killed in a DLD (Department of Livestock Development, Thailand) licensed abattoir in the Phitsanulok Province. The pigs had access to water, but were fasted for 24 h prior to slaughter. They were transported to the slaughterhouse, located 30 km from the experimental facilities, and killed by bleeding after electrical stunning, according to industry standards. The initial pH (pH_{45}) in the muscularis longissimus was measured at the last rib position, after slaughtering, with a digital pH meter (Oakton waterproof pH spear pocket pH tester, Virginia, USA). The ultimate (final) pH ($pH_{24\ h}$) was measured at 24 h after slaughter. In addition, the back fat thickness (P2) was measured 6.5 cm from the dorsal midline at the last rib position. The right muscularis longissimus muscle was removed, and chops of about 2.5 cm in thickness were cut from the anterior end for

Table 1
Composition of the three experimental diets.

Item	Diets[1]		
	Control	Diet 2	Diet 3
Ingredients, g/kg (as fed basis)			
Broken rice	670	640	640
Rice bran	200	200	200
Soybean meal	110	110	110
Coconut oil	–	8.9	3.7
Canola oil	–	21.1	26.3
Di-calcium phosphate	7.0	7.0	7.0
$CaCO_3$	7.0	7.0	7.0
$NaCl_2$	3.5	3.5	3.5
Vitamin and mineral premix[2]	2.5	2.5	2.5
Chemical analysis composition, g/kg (DM basis)			
Gross energy, kcal/kg	3,540	3,655	3,647
Crude protein	132.8	130.5	130.5
Ether extract	10.7	39.3	39.1
Calculated composition, g/kg (DM basis)	0.63	0.62	0.62
Metabolizable energy, kcal/kg	3,164	3,313	3,315
Lysine	6.3	6.2	6.2
Methionine	2.4	2.3	2.3
Tryptophan	1.6	1.6	1.6
Threonine	4.6	4.5	4.5

[1] Control, diet without oil supplementation; diets 2 and 3 consisted of the control diet supplemented with 3% oil, which contained a mixture of coconut and canola oil to UFA:SFA ratios of 2.5:1 and 5:1, respectively.

[2] Vitamin and mineral premix provided per kilogram of diet: 450 mg Fe; 400 mg Cu; 250 mg Zn; 150 mg Mn; 0.5 mg I; 0.25 mg Se; 8,000 IU vitamin A; 2,000 vitamin D_3; 37.5 mg vitamin E; 0.925 mg vitamin K-3; 8.43 mg vitamin B_2; 0.04 mg vitamin B_{12}; 34.5 mg nicotinic acid; 26 mg pantothenic acid.

Table 2
Calculated fatty acid composition[1] in the experimental diet.[2]

Fatty acids, % of total fatty acids	Control	Diet 2	Diet 3
Linolenic (18:3)	3.24	6.27	7.78
Linoleic (18:2)	41.29	21.68	24.55
Oleic (18:1)	38.55	43.35	50.83
Pamitonic (16:1)	0.07	0.14	0.16
Stearic (18:0)	2.9	2.41	2.12
Palmitic (16:0)	13.38	7.13	6.55
Myristic (14:0)	0.57	4.33	1.88
Lauric (12:0)	0	11.16	4.66
Capric (10:0)	0	3.53	1.47
Others	1.09	6.64	7.02
UFA	83.15	71.44	83.32
MUFA[3]	38.62	43.49	50.99
PUFA[4]	44.53	27.95	32.33
SFA	16.85	28.56	16.68
PUFA:MUFA ratio	1.15	0.64	0.63
UFA:SFA ratio	4.93:1	2.50:1	5.00:1

UFA = unsaturated fatty acids; SFA = saturated fatty acids.
[1] Broken rice, rice bran and soybean meal were analyzed for ether extract, and then they were calculated for fatty acid composition in ether extract as rice bran oil and soybean oil, including of coconut oil and canola oil using standard composition recommended by NRC (1998).
[2] Control, diet contained without oil supplementation; Diets 2 and 3 consisted of the control diet supplemented with 3% oil, which contained a mixture of coconut and canola oil to UFA:SFA ratios of 2.5:1 and 5:1, respectively.
[3] MUFA: monounsaturated fatty acid (C16:1, C18:1).
[4] PUFA: polyunsaturated fatty acid (C18:2, C18:3).

evaluating the muscle colour (MiniScan E24500S spectrophotometer, HunterLab, Virginia, USA).

The drip loss evaluation was conducted on slices (approximately 100 g, with a thickness of 2.54 cm) sectioned from each sample, and used for exudate determination. Each slice was weighed and sealed in a polyethylene bag, and the samples were stored at 4 ± 1 °C for 24 h. After this, the bags were opened, the drip was decanted, and the meat was reweighed. The drip loss was expressed as a percentage of the initial weight adapted from Alonso et al. (2012). In addition, a thawing loss evaluation was conducted using slices (approximately 100 g, with a thickness of 2.54 cm) sectioned from each sample. Each slice was weighed and sealed in a polyethylene bag, and the samples were stored at −20 °C for more than 48 h. After this, the bags were opened and stored at 4 °C for 24 h, the drip was decanted, and the meat was reweighed.

To evaluate the cooking loss, the meat samples (approximately 200 g, with a thickness of 2.54 cm) were water-cooked (in vacuum-pack bags) at 80 °C to an internal temperature of 72 °C. The samples were then cooled and held at room temperature (25 °C) before weighing. The cooking loss was expressed as a percentage of the initial sample weight (adapted from Vergara et al., 2003). The evaluation of the shear force value of pork, the samples (in vacuum-pack bags) were cooked in a preheated circulating water bath operating at 80 °C to an internal temperature of 80 °C. The samples were then cooled and held at room temperature (25 °C). Five 1 cm × 1 cm rectangular blocks cut along the direction of the muscle fibres were cut from each cooked sample. The force required to shear each block of muscle was determined by using a texture analyzer (QTS25, Brookfield, New York, USA). Each block was sheared at a constant speed of 0.5 mm/s.

2.3. Statistical analysis

All data were subjected to statistical analysis by one-way analysis of variance (ANOVA) using the SPSS statistical software (Ver. 15 for windows, SPSS Inc., Chicago, IL, USA). Differences among treatments were examined using Duncan's multiple range tests, which were considered significant at $P < 0.05$. The means and standard errors of the means are presented.

3. Results

3.1. Growth performance and carcass quality

All of the animals remained in good health throughout the experiment, and adapted well to the experimental diets. As shown in Table 3, there were significant differences ($P < 0.05$) in experimental period, ADFI and FCR between the groups over the experimental period. The pigs fed diets 2 and 3, which were supplemented with oil to contain 2.5:1 and 5:1 UFA:SFA ratios, had greater ($P < 0.05$) ADFI than pigs in the control group, resulting in their taking one less day ($P < 0.05$) to reach the final weight. Even though the experimental period showed a significant difference ($P < 0.05$), the ADG of the pigs were not significant ($P < 0.05$) among the treatment groups. There were no differences in the FCR between the pigs fed the control diet and diet 3; however, the highest FCR was found in those pigs fed diet 2. With regard to the carcass quality parameter (Table 4), there were no significant differences ($P > 0.05$) between the treatment groups in the hot carcass weight, carcass yield, carcass length or back fat thickness. Additionally, the pigs fed diets 3, which was supplemented with oil to contain 5:1 UFA:SFA ratios, had the greatest ($P < 0.05$) loin eye area.

Gender had no effect on the ADFI, ADG or parameters of carcass quality, with the exception of the loin eye area. The gilts fed the control diet took only 26 days to reach their final weight, which was shorter ($P < 0.05$) than the barrows (29 days). The barrows fed diet 2 had better ($P < 0.05$) FCR than the gilts; however, a better ($P < 0.05$) FCR was found in the gilts than the barrows fed the control diet. A gender effect was clearly shown in the loin eye area, which was larger in the gilts ($P < 0.05$) than in the barrows in all treatment groups; however, there was no significant interaction between the gender and diet found in this case.

Interactions ($P < 0.05$) between the treatment diets and genders of the pigs were found in the experimental period, ADFI and FCR. In addition, an interaction was found between the treatment diets and genders of the pigs fed diets 2 and 3.

3.2. Meat quality traits

In the parameters of meat quality (Table 4), no influence of diet was detected in the longissimus dorsi muscle pH, redness (a^*), water holding capacity (drip loss), thawing loss or shear force of the pork. However, greater meat lightness (L^*) ($P < 0.05$) was found in the pigs fed the control diet. In the pigs fed diet 2, which contained 3% oil supplemented with a 2.5:1 UFA:SFA ratio, the highest value ($P < 0.05$) of yellowness (b^*) was found. Moreover, the cooking loss was the lowest ($P < 0.05$) in the pork fed diet 3, which was supplemented with 3% oil at a 5:1 UFA:SFA ratio.

The gender of the pigs affected ($P < 0.05$) the longissimus dorsi muscle pH (at 45 min post-slaughter), all pork colour parameters and all parameters of the water holding capacity, with the exception of the shear force. The gilts fed the control diet had a higher value ($P < 0.05$) of meat redness (a^*) and yellowness (b^*) than the barrows; and the gilts fed diets 2 and 3 had higher values ($P < 0.05$) of meat lightness (L^*) than the barrows. A lower ($P < 0.05$) drip loss from the barrows was found, with the exception of the pigs fed diet 3, which had a lower ($P < 0.05$) drip loss from the gilts than the barrows. There was a lower ($P < 0.05$) cooking loss and thawing loss from the barrows fed the control diet and diet 3. Overall, interactions ($P < 0.05$) between the treatment diets and genders of the pigs were found in the meat quality with regard to the lightness (L^*), yellowness (b^*) and cooking loss of the pork.

Table 3
Effect of dietary treatments[1] on the growth performance of finishing pigs.

Item	Control			Diet 2			Diet 3			*P*-value[2]		
	B	G	$\bar{x}$	B	G	$\bar{x}$	B	G	$\bar{x}$	T	S	T × S
Initial weight, kg	80.03	80.15	80.09	80.12	80.00	80.06	79.97	80.05	80.01	ns	ns	ns
Final weight, kg	101.64	101.33	101.49	101.35	101.33	101.34	101.63	101.45	101.54	ns	ns	ns
Weight gain, kg/d	21.61	21.18	21.40	21.23	21.33	21.28	21.66	21.40	21.53	ns	ns	ns
Experimental period, d	29.00^{a}	26.00^{b}	27.50^{A}	26.00	27.00	26.50^{B}	27.00	26.00	26.50^{B}	*	*	*
Average daily feed intake, kg/d	2.66	2.52	2.59^{B}	2.67	2.87	2.77^{A}	2.63	2.64	2.64^{A}	*	ns	*
Average daily gain, kg/d	0.75	0.81	0.78	0.82	0.79	0.81	0.80	0.82	0.81	ns	ns	ns
Feed conversion ratio (feed: gain)	3.56^{a}	3.09^{b}	3.33^{B}	3.27^{b}	3.63^{a}	3.45^{A}	3.28	3.20	3.24^{B}	*	*	*

B = Barrows; G = Gilts.
^{a,b,A,B} Means within rows with different superscripts differ ($P < 0.05$).
[1] Control, diet contained without oil supplementation; diets 2 and 3 consisted of the control diet supplemented with 3% oil, which contained a mixture of coconut and canola oil to UFA:SFA ratios of 2.5:1 and 5:1, respectively.
[2] T = effect of treatment diet; S = effect of the gender of the pigs. *($P < 0.05$).

Table 4
Effect of dietary treatments[1] on carcass and meat quality.

Item	Control			Diet 2			Diet 3			*P*-value[2]		
	B	G	$\bar{x}$	B	G	$\bar{x}$	B	G	$\bar{x}$	T	S	T × S
Hot carcass weight, kg	78.25	76.16	77.21	78.25	76.16	77.21	75.98	75.91	75.95	ns	ns	ns
Carcass yield, %	76.99	75.16	76.08	77.21	75.16	76.19	74.76	74.83	74.80	ns	ns	ns
Carcass length, cm	76.33	77.98	77.17	76.33	77.98	77.17	77.32	80.01	78.66	ns	ns	ns
Back-fat thickness, cm	2.59	2.54	2.57	2.59	2.54	2.57	2.72	2.34	2.54	ns	ns	ns
Loin eye area, cm^2	45.68^{b}	52.85^{a}	49.28^{B}	45.68^{b}	52.85^{a}	49.28^{B}	54.41^{b}	59.48^{a}	56.94^{A}	*	**	ns
Longissimus dorsi muscle pH												
pH_{45} (at 45 min post−slaughter)	5.89^{b}	6.41^{a}	6.15	6.17	6.15	6.16	5.83^{b}	6.41^{a}	6.12	ns	*	ns
$pH_{24\ h}$ (at 24 h post−slaughter)	5.23	5.52	5.38	5.44	5.30	5.37	5.14	5.38	5.26	ns	ns	ns
Color parameters												
Lightness (L*)	46.39	46.08	46.24^{A}	41.61^{b}	43.04^{a}	42.33^{B}	40.99^{b}	43.27^{a}	42.13^{B}	*	*	*
Redness (a*)	8.99^{b}	11.91^{a}	10.45	11.81	10.54	11.18	9.49	9.32	9.41	ns	*	ns
Yellowness (b*)	7.46^{b}	9.35^{a}	8.41^{B}	8.90	8.56	8.73^{A}	7.55	8.34	7.96^{B}	*	*	*
Water holding capacity												
Drip loss, %	5.48^{b}	7.36^{a}	6.42	4.81^{b}	6.13^{a}	5.47	7.00^{a}	6.15^{b}	6.58	ns	*	ns
Cooking loss, %	30.96^{b}	33.40^{a}	32.18^{A}	32.16	33.04	32.60^{A}	29.99	30.10	30.05^{B}	*	*	*
Thawing loss, %	11.71	12.90	12.31	11.89	11.65	11.77	10.66^{b}	13.89^{a}	12.28	ns	*	ns
Shear force, kg/cm^2	6.24	7.34	6.79	6.21	6.57	6.39	6.64	6.76	6.70	ns	ns	ns

B = Barrows; G = Gilts.
^{a,b,A,B} Means within rows with different superscripts differ ($P < 0.05$).
[1] Control, diet contained without oil supplementation; Diets 2 and 3 consisted of the control diet supplemented with 3% oil, which contained a mixture of coconut and canola oil to UFA:SFA ratios of 2.5:1 and 5:1, respectively.
[2] T = effect of treatment diet; S = effect of the gender of the pigs * ($P < 0.05$), **(P < 0.01).

4. Discussion

4.1. Growth performance and carcass quality

According to previous assumptions, replacing part of the metabolizable energy of the basal diet with different fat mixtures will not change the nutritional value or energy content of the diet and, consequently, will not influence the performance or carcass quality. In the current study, the inclusion of 3% oil (containing coconut and canola oil) in the diets of finishing pigs did not affect the ADG; however, there was a significant difference in the experimental period in pigs fed diets supplemented with oil (diets 2 and 3), compared with the pigs fed diets without oil supplementation (control). This means that the pigs fed the diets with oil supplementation tended to grow faster, because greater ADFI were found in the pigs in both treatment groups, compared with the controls. Similar final live and carcass weights occurred in all of the treatments, because the pigs were fed *ad libitum* and allowed to achieve a target live weight before slaughtering. Moreover, higher ADFI and poorer FCR were observed in the pigs fed diet 2 (Table 3).

The present findings are in agreement with the data reported by Wiecek et al. (2010), who observed that the dietary supplementation of 4% linseed oil increased the ADG, ADFI and FE. In contrast to the findings presented herein, Engel et al. (2001), Glaser et al. (2002), Eggert et al. (2007), Apple et al. (2009), Bertol et al. (2013) and Kim et al. (2014) observed no effects of fat sources in the diet on the ADG, ADFI or FE of finishing pigs. This variation in results may be due to differences in the diet compositions and fat inclusion levels. Additionally, the dietary treatments in this study did not affect the carcass yield, carcass length or back-fat thickness, with the exception of loin eye area. This is in agreement with the observations of Nuernberg et al. (2005), Teye et al. (2006), Mitchaothai et al. (2007), Martin et al. (2008), Olivares et al. (2009), Benz et al. (2011), Bertol et al. (2013) and Ivanovic et al. (2015), who assessed different fat sources in isocaloric diets for finishing pigs, and reported no effects on the carcass traits.

Effects of the genders of the pigs on the experimental period and FCR were found in the current study, in which the barrows in the control group took longer (3 days) to reach the final weight and showed a lower FCR than the gilts. This is in agreement with most published research (Leach et al., 1996; Latorre et al., 2003a; Serrano et al., 2013). In addition, the better growth rate and poorer FE of the barrows were consistent with greater ADFI and higher carcass fat contents (Serrano et al., 2013). However, with regard to the pigs fed diet 2 with the 3% oil supplement containing the 2.5:1 UFA:SFA ratio, the barrows had better FCR than the gilts. The different results

found in the current study might be related to the oil supplementation, in which an interaction between the gender and diet was found for the FCR.

No interactions between the gender and dietary treatment were observed for the hot carcass weight, carcass yield, carcass length or back-fat thickness, in agreement with the data reported by Brumm (2004) and Serrano et al. (2013), comparing gilts and barrows kept in different spaces. Additionally, the gender did not influence the carcass yield, which was consistent with the data reported by Latorre et al. (2003a); however, Langlois and Minvielle (1989) observed higher yields for the gilts than for the barrows. The reasons for the discrepancies among the authors are not known, but might be related to the differences in the methods used for trimming the reproductive system at the abattoir (Latorre et al., 2003b). In addition, the different final body weights between the sexes could have been affected by the carcass yields, since these parameters were correlated. The barrows had higher back-fat depths, measured *in vivo* at different ages than the gilts, which is consistent with the results of Cisneros et al. (1996), Peinado et al. (2008) and Lammers et al. (2008). In the current study, a significant difference was found in the loin eye area, which was larger in the gilts in all treatment groups. This suggests that the gilts tended to have more lean meat than the barrows. These results are similar to those reported by Leach et al. (1996), which found that the proportion of the primal lean cuts was greater for the gilts than for the barrows.

4.2. Meat quality traits

The meat quality results, which include the pH, colour measurement, drip loss, cooking loss, thawing loss and shear force, are presented in Table 4. There was no effect of the treatment diets on the pH_{45} and $pH_{24\ h}$ values; however, the $pH_{24\ h}$ in all of the groups was lower than 5.5, meaning that the pork tended to be pale, soft, exudative (PSE) meat. In the case of PSE meat, the rapid muscle tissue acidification immediately after the slaughter leads to changes in the muscle proteins and, consequently, to their partial denaturation and loss of cell membrane impermeability (Chmiel et al., 2014). The research results of many scientists indicate that there is a correlation between the meat pH and the lightness (L^*) of its colour. For example, PSE meat is lighter than normal meat (Joo et al., 1999; Van Oeckel et al., 1999). A similar trend was also observed in the current study in the control group (Table 4), in which the greatest lightness (L^*) was found. The occurrence of meat defects has recently received attention from scientists and processors, since PSE meat has been shown to have poor processing parameters, and decreased consumer acceptance (O'Neill et al., 2003). The incidence of PSE meat is, primary, associated with rapid post-mortem glycolysis, which results in the fast and abnormal accumulation of excess lactic acid in the muscles. The high post-mortem acidification rate of muscle tissue and increased carcass temperature (even up to 40 °C) lead to changes in the muscle proteins, that is, to their partial denaturation and loss of cell membrane impermeability (Joo et al., 1999; Huff-Lonergan et al., 2010). The partial protein denaturation decreases the meat's water-holding capacity (WHC), and leads to a lighter colour accompanied by a higher drip loss and higher electrical conductivity (Torley et al., 2000; Barbut et al., 2008). Karamucki et al. (2013) stated that the colour of PSE meat (even with a lower pigment content), when compared with normal meat, may be characterized by higher redness (a^*); although this can be indiscernible during the visual evaluation of the meat colour. However, in this study, mild PSE was found in all groups, with the lower $pH_{24\ h}$ only affecting the lightness (L^*) of the pork in the control group (without oil supplementation). Similar findings were observed by Tikk et al. (2007) and Patrick et al. (2013), who found that the feedstuff, lipid type and supplementation had little to no impact on the pork quality characteristics. However, the pH_{45} was affected by gender, and was lower in the barrows than the gilts fed the control diet and diet 3 (3% oil supplementation with UFA:SFA ratio of 5:1). When the pH was measured at 24 h, there was no difference between the genders, which agrees with Peinado et al. (2012) and Egea et al. (2016) who found no pH difference between the genders in Iberian and Iberian × Duroc pigs. In the present study, although the initial pH_{45} differed between the genders, the fall in the pH led to similar pH values at 24 h.

In this study, the dietary treatment influenced the muscle colour. The meat became paler (higher L^*) in the pigs fed the control diet (without oil supplementation), the $pH_{24\ h}$ decreased when compared with the pH_{45}, cooking losses increased and no significant difference was seen in the shear forces among the treatment groups. It is known that a lower pH causes the water in the meat to be released, the structure to become denser and light rays to be reflected from the surface layers, making the muscle appear lighter in colour (Patrick et al., 2013). In addition, if the meat becomes paler (higher L^*), as the ultimate pH decreases the amount of expressed juice, the cooking losses will increase and shear forces will decrease.

There was a higher degree of yellowness (b^*) in the meat colour in treatment 2, which contained a high level of coconut oil (Table 1) to obtain the 2.5:1 UFA:SFA ratio. A significantly higher colour saturation, which could be related to the higher concentration of the C12:0 and C14:0 fatty acids from the coconut oil (Table 2) in the marbling fat of the pork, which makes the constituent lipids less translucent and, therefore, less bright. In agreement with the report of Teye et al. (2006), who found this same conclusion using a palm kernel diet containing a high level of C12:0 and C14:0 fatty acids.

Gender had a statistically significant effect on the colour values, in which the colour lightness (L^*), redness (a^*) and yellowness (b^*) values were higher for the gilts. Some previous studies have reported no effect of gender on the colour values (Renaudeau and Mourot, 2007), while other authors have found that the meat from the barrows was darker (Cisneros et al., 1996; Latorre et al., 2003a), or more pale (Unruh et al., 1996). Mas et al. (2011) found that the meat quality characteristics were similar for the barrows and gilts, with the exception of the loin colour (L^*) values, which were higher, indicating a lighter colour for the gilts. In addition, some research has reported that castrated males had more intramuscular fat and more intense meat colour than female pigs (Alonso et al., 2009). Although not statistically significant, the finishing pigs fed a dietary supplementation of 3% oil from coconut and canola oil (2.5:1 and 5:1 UFA:SFA ratios) did appear to have an improved water holding capacity with regard to the drip loss, thawing loss and shear force, when compared to the finishing pigs fed a control diet without oil supplementation. However, the results shown in Table 4 suggest that there were negative effects from the control diet without oil supplementation and the diet supplemented with 3% oil (2.5 UFA:SFA ratio), and positive effects from the diet supplemented with 3% oil (5:1 UFA:SFA ratio) on the cooking loss. Cooking led to a systematic and significant loss of matter, and the cooking yields differed depending on the muscle and cooking process (Gerber et al., 2009). In this study, the cooking loss was greater in the muscles from the pigs fed the control diet and from the pigs fed the 2.5:1 UFA:SFA ratio, and statistically significant differences in this parameter were found for all of the analyzed meat samples (Table 3). According to Ouali (1990), the meat tenderness is affected by the origin and the age of the animals, gender, breed, environmental conditions associated with pre-slaughter stress, the slaughter itself, as well as the time of meat ageing. One objective measure of the tenderness is the force required to shear a piece of meat, with low shear values being

desirable. In this study, the treatment diets had no significant effect on the shear force values of the cooked meat samples (Table 4). Overall, the meat shear force values were approximately the same between the groups and between the genders of the pigs.

5. Conclusion

The results obtained in the current study indicate that the supplementation of 3% oil (from coconut and canola oil) using UFA:SFA ratios of 2.5:1 or 5:1 in the diets of finishing pigs has the potential to improve pork quality.

Conflict of interest

The authors have no conflict of interest relating to this manuscript.

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