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Carcass quality traits and omega-3 content in different pork cuts from pigs fed a diet supplemented with linseed

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Abstract A total of 300 crossbred pigs were divided into three groups to evaluate the optimal slaughter weight for pig fed with linseed diet. The control pigs (C) were fed a commercial feed mixture with slaughter weight of 100-105 kg. The linseed fed pigs were fed a diet supplemented with 5% ground linseed during the growing-finishing periods and slaughtered with 100-105 kg (designed as low weight group, L) or with 110-115 kg (designed as height weight group, H). Four animals per groups were randomly selected for analysis of carcass quality traits, omega-3 (*n*-3) content, and lipid oxidation among different pork cuts. The results showed that feeding with linseed diet in H group seem to be higher Lenden-speck quotient (LSQ) index than L and C groups. There were no significant differences in lean cutting yields and percentage of retail cuts among treatments ($P>0.05$). Regarding *n*-3 contents, especially in form of alpha-linolenic acid (ALA, C18:3*n*3), ham, belly, boston butt, fore and hind legs, and backfat were higher in L and H groups than in control ($P<0.05$), which approximately 2.6−3.2 times greater than that in the control, depending on pork cuts. The oxidative stability of muscle lipids as indicated by TBARS values were not significantly differences among treatments ($P>0.05$). Due to the positive effects on higher *n*-3 content related to human health, linseed supplementation can be recommended in pig diet with commercial slaughter weight with 100-105 kg.

Keywords: Omega-3 pork, Healthy meat, Linseed, Linolenic acid

Introduction

Pork meat is one of the most widely consumed protein sources, which accounts for 36% of the world's meat consumption (Bula *et al.*, 2019). But at the same time, it was found that the world's population has an increased rate of morbidity due to meat consumption (Department of Health, 1994). The trend of healthy meat has been an increase in the interest of producers and consumers with lower saturated fatty acids (SFA) and a higher proportion of monounsaturated (MUFA) and polyunsaturated fatty acids (PUFA), especially

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omega-3 (*n*-3), which decrease the incidence of coronary heart diseases and blood cholesterol levels (Voet and Voet, 1990). Fatty acids are categorized as the *n*-3 PUFA including alpha-linolenic acid (ALA, C18:3*n*3) and several types of the long-chain *n*-3 PUFA such as eicosapentaenoic acid (EPA, C20:5*n*-3), docosapentaenoic acid (DPA, C22:5*n*-3) and docosahexaenoic acid (DHA, C22:*6n*-3), which protect against heart disease and stroke, atherosclerosis, cancer, and metabolic disorders (Dugan *et al*., 2015; Trombetta *et al*., 2019).

A study by Coates *et al.* (2009) found that *n*-3 fatty acids in meat can be supplemented by providing a diet that is a source of *n*-3 to monogastric animals. The *n*-3 fatty acids will be deposited in tissues, and it is a convenient way to increases the nutritional value of pork. The most common sources of *n*-3 are fish and plant oils (Corino *et al*., 2014). Fish oil is increased *n*-3 PUFA in pork meat, consistent with Otten *et al.* (1993). They found that fish oil supplementation over 13 weeks resulted in increased significantly (higher than 40%-165% or 0.4-1.65 times) of *n*-3 PUFA (EPA and DHA) in skeletal muscle and adipose tissues as compared to the control group (fed with 5% coconut oil). However, fish oil is quite expensive and if consumed in large quantities, can lead to the accumulation of heavy metal toxins and also negatively effects on sensory and meat quality (Ma *et al*., 2015). Jaturasitha *et al.* (2002), reported that supplementing tuna oil in pork diets is a promising way to enrich pork with *n*-3 fatty acids, but tuna oil supplementation was found to be associated with significant adverse effects on taste as well as decreased shelf life. For this reason, linseed is an alternative source of *n*-3 for supplementation in pig feeds. It is inexpensive and rich of *n*-3 PUFA, especially ALA, without negatively effects on sensory quality (Hoz *et al*., 2003). Consistent with Nuernberg *et al.* (2005) reported that supplementing the pig diets with 5% linseed oil increased the amount of *n*-3 PUFAs in muscle, heart, and backfat, which significantly increased the level of ALA, decreased content of SFA without adversely affecting carcass and meat quality (Hogberg *et al*., 2003; Czyż *et al*., 2021). Trombetta *et al.* (2019) reported, the addition of 3% linseed to the pig diet for crossbred swine showed that daily weight gain was unchanged compared to the control group (based on soybean and corn meal), although the backfat was thicker. Supplementation with 3% extruded linseed did not affect growth while improving the fatty acid profile of meat. In addition, when *n*-3 PUFA (ALA, EPA, DPA and DHA) increased, it related to evidence for the health-promoting effects (Tarricone *et al*., 2019).

However, the accumulation of *n*-3 PUFA content in pork from research studies were inconstancy. Both positive and/or negative effects depend on several factors such as the amount, frequency or time consumed as well as factors from *n*-3 sources, species, age, sex, feeding, and length of raising

(Kajla, 2015; Czyż *et al*., 2021). Crossbred swine [(Yorkshire × Landrace) × Duroc] was often used in studies and usually evaluated in only one or two pork cuts, specifically loin or ham portion (Coates *et al*., 2009; Ma *et al*., 2015). There are a limit studies on the optimum slaughter weight of pig raised by the linseed supplementation in swine diets. Moreover, the *n*-3 content in commercial pork cuts has not been studied. Therefore, the objective of this study was to investigate the effect of slaughter weight of pig fed with linseed on carcass and meat qualities as well as *n*-3 PUFA content among different commercial pork cuts.

Materials and methods

Animal and sample collection

A total of 300 crossbred pigs [(Large white × Landrace) × Duroc] were divided into three groups to evaluate the optimal slaughter weight for pig fed with linseed diet. The control pigs (C) were fed a commercial feed mixture with slaughter weight of 100-105 kg. The linseed fed pigs were fed a diet supplemented with 5% ground linseed during the growing-finishing periods and slaughtered with 100-105 kg (designed as low weight group, L) or with 110-115 kg (designed as height weight group, H). Approximately 6 months for raising in a private farm, Surin province, twelve selected pigs from barrows and gilts (4 pigs per treatment) were sampled. After slaughtering process, carcasses were chilled overnight until the temperature of carcass were lower than 0-4˚C and then were transported to cutting laboratory for further evaluate.

Carcass quality traits

Chilled carcass weight and pH were measured. The pH measurement on the left side of carcass at the loin and ham portions with triplicate determination for each sample were recorded. Lenden-speck quotient (LSQ) index was performed on the left side of carcass in which two positions of the backfat thickness and the width of *M. gluteus medius* of all carcasses were measured by using vernier calipers according to Sethakul *et al.* (2003).

Carcass fabrication parameters

Carcasses (left sides) were fabricated into 9 commercial primal cuts (tenderloin, loin, ham, boston butt, picnic shoulder, belly, spare ribs, legs (fore and hind legs), and backfat), and weighted. The percentage (%) of lean cutting yield was calculated as percentages of the chilled carcass weight according to Boler *et al.* (2012) as shown in the equation below:

% Lean cutting yield =

$$\frac{(trimmed\ ham + trimmed\ loin + boston\ butt + picnic)}{chilled\ carcass\ weight} \times 100$$

In addition, percentage of retail cuts was calculated from all retail cuts including groups of deboned retail cuts (boston butt, picnic shoulder, loin, tenderloin, ham and jowl and belly) and bone-in retail cuts (fore leg, hind leg and spare ribs) as percentages of the chilled carcass weight with the equation below:

% Retail cuts =

$$\frac{deboned\ retail\ cut\ or\ bone\ in\ retail\ cuts}{chilled\ carcass\ weight} \times 100$$

Meat quality traits

Pork cuts sampling

Among of various retail pork cuts, there are five retail cuts with high fat content were focused. Therefore, backfat, belly, leg (fore and hind legs), boson butt, and ham were selected for determinations of fatty acid composition and lipid oxidation. These chilled pork cuts at 1 day of refrigerated storage were individually packaged and then frozen at (-18)–(-20) ℃ until analysis.

Fatty acids composition

Fatty acid composition was determined according to AOAC (2019) method and the results were expressed as the percentage (%) of SFA, MUFA, and PUFA as well as the summation of *n*-3 PUFA and *n*-6 PUFA.

Lipid oxidation

Lipid oxidation of selected pork cuts were performed by thiobarbituric acid reactive substances (TBARS) method according to Buge and Aust (1978). This method started by reacting with TBA in an acidic solution (0.0375% (w/v) TBA, 15% (w/v) TCA and 0.25 M HC) and absorbance was measured at a wavelength of 532 nm.

Statistical analyses

The differences in carcass and meat quality traits among treatments (C, L, and H) were analyzed by one-way analysis of variance (ANOVA) and the mean difference was compared by Duncan Multiple Rank Test (DMRT) by SPSS program (IBM SPSS Inc.).

Results

Carcass quality

Carcass quality of pig fed with linseed supplement with different slaughter weight and control are shown in Table 1. The linseed fed treatment of H was significantly higher slaughter weight than in L group as well as in control (P<0.05). The results of LSQ index were not statistically significantly differences (P>0.05) among C, H, and L treatments. Each treatment was 0.21, 0.21 and 0.25, respectively, but H group seem to be a higher LSQ index than C and L group. Indeed, consideration on each carcass grade based on the range of LSQ value, treatment H exhibited a high number of “grade B” with nothing “grade A” as compared with other groups.

The pH values after 24 hours (h) of post-mortem (pm) were not statistically significantly differences (P>0.05) for all treatments both at the loin and ham portions. The pH value of loin region ranged from 5.55 to 5.67 and the ham region pH value between 5.65 to 5.82.

Table 1. Effect of linseed on carcass quality traits of pig from different weight of slaughter

Items	Treatment group[1/]			***P*-value**
	C	L	H	
Slaughter weight (kg)	104.00 ±1.58[b]	104.10 ±0.43[b]	112.50 ±0.86[a]	0.023
LSQ				
LSQ index	0.21 ±0.08	0.21 ±0.06	0.25 ±0.02	0.645
Each carcass grade[2/]	A, A, B, C	A, A, B, C	B, B, B, C	
$pH_{24h\ pm}$				
Loin	5.61 ±0.03	5.67 ±0.13	5.55 ±0.53	0.725
Ham	5.65 ±0.03	5.82 ±0.21	5.74 ±0.48	0.563

[abc:] Means with different superscript in the same row differed significantly (P<0.05).

[1]/: C=Control group (100-105 kg); L= Low slaughter weight group (100-105 kg.) and supplemented with 5% ground linseed; H, High slaughter weight group (110-115 kg.) and supplemented with 5% ground linseed

[2]/: Grade of each carcass based on LSQ value (Grade A = LSQ< 0.20, Grade B = 0.21-0.26, and Grade C= 0.27-0.32)

Carcass traits

Lean cutting yields and percentage of retail cuts of pork from different treatments are shown in Table 2. Chilled carcass weight from left side of H group was higher than C and L group (P<0.05). However, the percentage of lean cutting yield when comparing all treatments was not statistically significant difference (P>0.05), with values range from 46-48%. Regarding percentage of retail cuts, linseed supplementation in pig diet had no statistically significant impact as compared to all treatments in all pork cuts.

Table 2. Effect of linseed on cutting yield and percentage of retail cuts of pork from different weight of slaughter

Items	Treatment group[1/]			*P*-value
	C	L	H	
Chilled carcass (kg)	38.85 ±0.54[b]	40.12 ±1.21[b]	43.18 ±0.33[a]	0.001
Lean cutting yield (%)	46.79 ±1.81	48.31 ±0.65	47.39 ±1.74	0.501
Deboned retail cuts				
Ham				
Weight (kg.)	7.54 ±0.07	8.33 ±0.32	7.94 ±0.32	0.328
% Retail cuts	19.41 ±0.42	20.77 ±0.47	19.30 ±2.02	0.328
Picnic shoulder				
Weight (kg.)	5.23 ±0.08	5.03 ±0.18	5.84 ±0.29	0.432
% Retail cuts	13.45 ±0.39	12.54 ±0.22	12.59 ±1.49	0.432
Loin				
Weight (kg.)	3.06 ±0.44	3.22 ±0.34	3.77 ±0.61	0.543
% Retail cuts	7.88 ±1.18	8.01 ±0.74	8.91 ±1.48	0.543
Belly				
Weight (kg.)	5.78 ±0.50	5.42 ±0.49	5.78 ±0.02	0.640
% Retail cuts	8.44 ±1.06	8.06 ±0.78	7.81 ±0.36	0.640
Boston butt				
Weight (kg.)	1.90 ±0.10	2.36 ±0.21	2.14 ±0.28	0.217
% Retail cuts	4.89 ±0.28	5.88 ±0.52	5.59 ±0.91	0.217
Jowl				
Weight (kg.)	0.24 ±0.05	0.22 ±0.03	0.28 ±0.05	0.307
% Retail cuts	2.12 ±0.29	1.88 ±0.11	2.19 ±0.27	0.307
Tenderloin				
Weight (kg.)	0.57 ±0.03	0.57 ±0.05	0.62 ±0.07	0.890
% Retail cuts	1.47 ±0.10	1.43 ±0.10	1.49 ±0.22	0.890
Bone-in retail cuts				
Fore leg				
Weight (kg.)	1.05 ±0.37	1.35 ±0.10	1.30 ±0.01	0.405
% Retail cuts	3.57 ±0.93	4.20 ±0.18	3.78 ±0.02	0.405
Hind leg				
Weight (kg.)	2.10 ±0.14	2.21 ±0.03	2.28 ±0.15	0.744
% Retail cuts	5.41 ±0.28	5.53 ±0.11	5.41 ±0.23	0.744
Spare ribs				
Weight (kg.)	1.27 ±0.15	1.28 ±0.04	1.51 ±0.12	0.811
% Retail cuts	3.28 ±0.39	3.23 ±0.21	3.37 ±0.14	0.811

[abc:] Means with different superscript in the same row differed significantly ($P<0.05$).
[1]/: C=Control group (100-105 kg); L= Low slaughter weight group (100-105 kg.) and supplemented with 5% ground linseed; H, High slaughter weight group (110-115 kg.) and supplemented with 5% ground linseed

Fatty acid composition

Fatty acid composition of selected pork cuts with linseed supplemented diet and control are shown in Table 3. Although MUFA was the most abundant class of fatty acid in pork in present study, there were no statistically significant differences among treatments (P>0.05). In addition, the second-most abundant content was SFA, but the significant impact of linseed treatment was only shown in backfat, especially in which L group was lower SFA than control (P<0.05).

Table 3. Effect of linseed on fatty acid composition of pork in different pork cuts and weight of slaughter

Items	Fatty acid (%)	Treatment group[1/]			*P*-value
		C	L	H	
Backfat	SFA	34.19 ± 1.54^{a}	29.77 ± 0.80^{b}	31.97 ± 1.37^{ab}	0.016
	MUFA	42.00 ± 0.83	40.75 ± 1.02	41.68 ± 0.70	0.261
	PUFA	23.81 ± 0.72^{c}	29.47 ± 1.29^{a}	26.36 ± 1.15^{b}	0.002
	- *n*-3	1.52 ± 0.07^{b}	4.88 ± 0.03^{a}	4.40 ± 0.58^{a}	0.000
	- *n*-6	22.29 ± 0.65^{ab}	24.59 ± 1.28^{a}	21.96 ± 1.38^{b}	0.061
Belly	SFA	35.97 ± 1.72	33.14 ± 1.80	33.013 ± 1.18	0.107
	MUFA	42.59 ± 0.71	42.23 ± 0.95	42.24 ± 0.48	0.797
	PUFA	21.44 ± 1.01	24.63 ± 2.03	24.76 ± 1.65	0.077
	- *n*-3	1.48 ± 0.16^{b}	4.17 ± 0.45^{a}	4.11 ± 0.33^{a}	0.000
	- *n*-6	19.99 ± 1.10	20.52 ± 1.68	20.64 ± 1.95	0.874
Leg	SFA	33.94 ± 1.36	31.68 ± 1.22	32.46 ± 0.99	0.143
	MUFA	44.34 ± 1.32	45.80 ± 2.76	44.10 ± 1.12	0.528
	PUFA	25.52 ± 6.07	22.76 ± 2.96	23.43 ± 0.99	0.688
	- *n*-3	1.36 ± 0.24^{b}	3.10 ± 0.20^{a}	3.36 ± 0.06^{a}	0.000
	- *n*-6	20.86 ± 2.08	19.41 ± 2.69	20.07 ± 1.02	0.703
Boston butt	SFA	38.37 ± 1.28	34.04 ± 1.94	35.28 ± 2.46	0.082
	MUFA	39.45 ± 0.68	39.57 ± 0.68	39.30 ± 0.14	0.910
	PUFA	22.19 ± 1.12	26.39 ± 2.44	25.35 ± 2.47	0.112
	- *n*-3	1.34 ± 0.10^{b}	4.16 ± 0.34^{a}	3.81 ± 0.16^{a}	0.000
	- *n*-6	24.16 ± 6.36	22.23 ± 2.20	21.47 ± 2.32	0.724
Ham	SFA	36.16 ± 0.58	33.41 ± 1.25	34.76 ± 1.25	0.104
	MUFA	38.43 ± 0.77	40.16 ± 3.00	38.68 ± 2.31	0.614
	PUFA	25.41 ± 0.68	26.43 ± 1.29	26.56 ± 3.36	0.776
	- *n*-3	1.17 ± 0.12^{b}	3.31 ± 0.27^{a}	3.06 ± 0.37^{a}	0.000
	- *n*-6	24.20 ± 0.64	23.11 ± 1.87	23.17 ± 3.50	0.815

[abc:] Means with different superscript in the same row differed significantly (P<0.05).
[1]/: C=Control group (100-105 kg); L= Low slaughter weight group (100-105 kg.) and supplemented with 5% ground linseed; H, High slaughter weight group (110-115 kg.) and supplemented with 5% ground linseed

Regarding PUFA, the results showed that the amount of *n*-3 in the linseed supplement group (L and H) had a statistically significantly higher *n*-3 content than the control group (C) (P>0.05), which was found to be different in all pork cuts. Moreover, it was found that the higher *n*-3 content in all pork cuts was mainly due to ALA, whereas EPA and DHA was found at very low content or not detection in pork cuts (data not shown). In the C group, the average content of ALA was 1.36% and found neither EPA nor DHA. The L group consisted of 3.82% ALA with not found both EPA and DHA. While H group consisted of 3.64% ALA, 0.1% EPA, and not found DHA.

Lipid oxidation

Lipid oxidation as indicated by TBARS values among samples are shown in Table 4. The results showed that both the control and linseed supplementation groups did not find a statistically significant difference in all pork cuts (P>0.05).

Table 4. Effect of linseed on TBARS values (mg MDA/kg meat) in different weight of slaughter and pork cuts

Items	Treatment group[1/]			*P*-value
	C	L	H	
Backfat	4.11 ± 1.15[2/]	4.43 ± 1.73	3.31 ± 2.36	0.747
Belly	3.53 ± 2.14	2.53 ± 1.78	1.58 ± 4.62	0.755
Leg	1.17 ± 0.26	1.34 ± 0.56	0.80 ± 0.35	0.325
Boston butt	1.22 ± 0.83	1.82 ± 0.29	1.41 ± 0.32	0.070
Ham	1.38 ± 1.13	2.69 ± 1.08	2.03 ± 2.44	0.294

[1]/: C=Control group (100-105 kg); L= Low slaughter weight group (100-105 kg.) and supplemented with 5% ground linseed; H, High slaughter weight group (110-115 kg.) and supplemented with 5% ground linseed

[2]/: Mean values ± SD obtained from 4 animals (n=4)

Discussion

Linseed-enhanced feeding to pigs with different slaughter weights in this study had no effect on LSQ index, pH value, carcass quality traits and lipid oxidation in all pork cuts compared to control groups. As reported, the LSQ index was not significantly different among treatments. However, the H group was higher found carcass with the B grade than the C and L groups, representing the higher fat thickness on the carcass. Sethakul *et al*. (2003) reported that LSQ values were correlated with backfat thickness. The increase in LSQ resulted in increased a percentage of backfat thickness and reduced a percentage of lean meat. Therefore, the higher slaughter weight of pig fed with linseed (H group) in present study seem to be increase the backfat thickness, leading to down quality grade of pig carcass.

According to pH value, Tarricone *et al.* (2019) and Horczyczak *et al.* (2020) had been studied the supplementation of pig feed with 3% linseed and showed that the pH value on 45 min and 24 h pm were not affected by diets. This finding consistent with that reported in other studies (Maiorano *et al*., 2007; Corino *et al*., 2008). Several studies frequently indicated the pH of meat was influenced by storage time (Horczyczak *et al*., 2020).

In the study of Corino *et al.* (2008), there was no difference in the percentage of retail cuts and carcass quality traits between pigs fed 5% linseed fortified diet with a slaughter weight of 110 kg and control. Consistent with the results of the De Tonnac *et al.* (2017), there were no differences in growth and carcass traits of pigs fed a 3.6% linseed diet and control diet. Including 3% extruded linseed added to pig feed on commercial pork cuts as reported by Tarricone *et al*. (2019) also showed similar results. In some report, lean yield of commercial pork cuts was increased by adding linseed to the pigs' diets (Juárez *et al*., 2011). Different results may depend on the percentage of linseed used, different production system and/or genetic differences in the pigs (Tarricone *et al*., 2019).

Fatty acid composition in this study demonstrated that linseed fed a diet (both L and H groups) achieved a pork with higher *n*-3 PUFA content, approximately 2.6-3.2 times greater than that in the control. The *n*-3 PUFA content was founded in the form of ALA, while long chain *n*-3 PUFA, EPA and DHA, was founded at very low content or not detection in pork cuts. In fact, linseed is a good source of *n*-3 due to high ALA content. It contained 55.75% ALA, 15.73% linoleic acid (C18:2*n*-6), 18.89% oleic acid (C18:1*n*-9c), 5.22% palmitic acid (C16:0) and 4.41% stearic acid (C18:0) (Upadhaya *et al*., 2016). When ALA from a plant oil was consumed by pig, the monogastric animal might be able to synthesize EPA, DPA and DHA via a desaturation and elongation pathways (Dugan *et al.*, 2015). In some studies linseed supplementation significantly increased *n*-3 PUFA in which ALA was the primary content, and also increased EPA and DPA, but not DHA (Horczyczak *et al*. 2020, Jiang *et al*. 2017). The variable of results attributed by the different of source, amount and type of *n*-3 fatty acids fed, feeding duration, and slaughter weight (Dugan *et al.*, 2015).

The results from TBARS in this study showed that the addition of linseed to the diet did not affect the lipid oxidation in all pork cuts. Horczyczak *et al.* (2020) reported that 3% linseed oil supplementation in pig feed had no lipid oxidation effect in pork from pig raised for 6 months. Generally, meat with high PUFA content had more susceptible to lipid oxidation. The oxidative susceptibility of porks derived from feeding pigs enriched with linseed should be monitored (Karolyi *et al*., 2012, Lahučký *et al*., 2004). It has been suggested that PUFA less than 23% for finishing pigs reduces oxidation problems (Bryhni *et al*., 2002). Some studies have used vitamin E in combination with linseed supplementation, which has been shown to reduce the deterioration of pork, reducing its oxidation due to vitamin E as an antioxidant (Upadhaya *et al*., 2016).

The present study showed the positive effect of pigs supplemented with linseed diet and slaughter weight of 100-105 kg. (L group) as compared to the control group and the H group. Because the amount of n-3 PUFA (ALA) in L group was higher than the C group but not different from H group. This result indicated the possible strategies to produce the *n*-3 enriched pork for beneficial health outcomes.

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