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Supplemental effect of coated refined fish oil on the performance of finishing pigs fed diets containing soybean-meal as a partial alternative to barley or wheat feed ingredient

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Abstract

A total of 195 finishing pigs with an average body weight of 78.65 ± 0.09 kg were assigned to 1 of 3 dietary treatments in a 28 days trial. The designated nutritional diets were as follows: CON; TRT1- CON + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil. The inclusion of coated refined fish oil with the barley-based diet significantly increased body weight, average daily gain, and feed conversion ratio of finishing pigs throughout the experimental period. At the end of the experiment, pigs fed coated refined fish oil with the barley-based diet showed a significant improvement on nutrient digestibility of dry matter and nitrogen. Moreover, gas emission of NH_3 and H_2S concentration were significantly reduced. Also, drip loss during days 5 and 7 was significantly decreased in meat quality analysis of pigs fed coated refined fish oil supplemented to a barley-based diet. Furthermore, dietary coated refined fish oil with barley-based diet had significantly increased fatty acid profile of belly meat and reduced belly fat. In summary, the inclusion of coated refined fish oil with barley diet positively impacts on growth performance and nutritional values of meat quality in finishing pigs.

Key words: coated fish oil, meat quality, fatty acid, finishing pig.

Introduction

The feed cost plays a significant role for the successful pig production. Besides, fats and oils are used as a main energy supplements in animals' diets due to their high energy value and their beneficial role in nutrients absorption and maintaining the body temperature (Upadhaya et al. 2021). The most commonly used fat sources in the monogastric animals feed are vegetable oil (palm oil, soybean oil, coconut oil), animal fat (tallow), and marine fat (fish oil). Fish oil has a higher energy value compared to the animal fat source (Lauridsen et al. 2007). Moreover, fish oil is rich in polyunsaturated fatty acids (PUFA), particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) has been proved to prevent the cardiovascular disease and depressive disorders in humans (Ruxton et al. 2007). Though mammals are capable of synthesizing DHA from its precursor, alpha-linolenic acid (ALA) conversion to long-chain PUFA is still inadequate in pigs (Smink et al. 2013). Previously, many researchers have proved that the dietary supplement with fish oil and algae has enhanced the performance of monogastric animals (Irie and Sakimoto,1992; Kjos et al. 1999; Haak et al. 2008). Moreover, Haak et al. (2008) reported that supplementing the diet with 5% of fish oil have improved feed intake and growth performance of growing-finishing pigs during fattening stage. Similarly, Kew et al. (1992) stated that dietary supplement with fish oil and microalgae (which are rich in DHA and EPA) has improved the growth performance of weaning pigs. The studies by Liu et al. (2012) pointed out that dietary supplement with increased amount of DHA (fish oil) has enhanced the growth performance, intestinal health, immunity and bone strength of pigs. Furthermore, Rooke et el. (2000) stated that gestating sows fed diet supplemented with 3-5% of fish oil, positively increased the growth performance of their litters. Despite some advantages, PUFA can be easily oxidized, and the end product of oxidation as 2-alkenals may cause oxidative stress and leads to impair the health status of animals (Marschall and Beuers, 2013). In addition, the non-delayed significant release of lipids from unrefined fish oil may lead to digestive problems (Russell, 2003). To limit the usage of fish oil, some technical strategies have been found by the researchers, such as making oily material source of DHA into the powdered form of pharmaceutical composition or coating. Thus, coating was considered to be a feasible strategy to reduce the rancidity of polyunsaturated fatty acid, thereby improving the stability and usability (Crexi et al. 2010). To enrich fish oil with DHA, it is necessary to develop coated refined fish oil supplements cost-effectively, simultaneously that should be ideal for human and animal consumption.

In 2006, Newman and Newman, highlighted barley as a potential energy source to suit pigs' diet. It contains high levels of essential amino acids and contributes to the formulation of low-cost diets that are nutritionally effective in maximizing carcass quality (Harrold, 2010). Besides, it contains a higher level of non-starch polysaccharide (NSP), β-glucan (Skendi et al. (2003) compared to other alternative feed grains. Moreover, Lampe et al. (2006) pointed out that lower level of carotenoids and PUFA in barley-based has enhanced the whiter and firmer pork fat, thereby reducing the iodine values. The study by Kim et al. (2014) pointed out that the inclusion of 60% barley in the diet for finishing pig has obtained a desirable fat quality after 6 weeks, prior to slaughter. We hypothesized that supplementing the basal diet containing barley with coated refined fish oil has positive effect on meat quality and nutritional value of meat, and improving nutrient digestibility by regulating fecal microbiota, as well as enhances growth performance in finishing pigs. Therefore, the objective of the present experiment was to compare the supplementation of coated refined fish oil into corn-soybean-meal based diet moderately replaced either with barley or wheat as alternative feed ingredient on the growth performance, nutrient digestibility, fecal microbial counts, fecal gas emission, meat quality, and fatty acid composition of finishing pigs.

Materials and Methods

The experimental protocol was revised and approved (Approval no. DK-1-2027) by animal care and use committee of Dankook University, Republic of Korea

Source of coated fish oil

The fish oil/docosahexaenoic acid (DHA) used in this study was procured from commercial company Morning bio Co., Ltd., (Cheonan, Republic of Korea). As per the instruction of supplier, DHA was produced by purifying the fish oil through transesterification and molecular distillation processing methods of Hoque et al. (2011). The purified product (liquid oil) was rich in DHA, and it was coated in lipid matrix using spray drying method. The fatty acid composition of coated refined fish oil used in this study is shown in Table 2. The content of omega-3 PUFA in the coated refined fish oil was 18.64%; omega-6 PUFA was 2.90%. The ratio of omega-6 PUFA to omega-3 PUFA was 1:6.4.

Animal husbandry, experimental design, and dietary regimen

This experiment was carried out at the research facility of Dankook University (Gongju, Republic of Korea) with 195 crossbred [(Landrace × Yorkshire) × Duroc] finishing pigs. Based on the average body weight (BW) (78.65 ± 0.09 kg) and sex, pigs were randomly assigned 3 gilts and 2 barrows (5 pigs/pen) 13 pens/treatment to 1 of 3 dietary treatments for 4 weeks. The designated nutritional diets were as follows: CON, (corn-wheat-SBM basal diet, (no antibiotic or additive)); TRT1, CON +(10% Wheat) + 0.2% coated refined fish oil; TRT2, CON +(10% barley) + 0.2% coated refined fish oil. These supplements were formulated according to the recommendation of NRC (2012) (Table 1). Pigs were housed in an environmentally controlled, slatted-floor facility and mechanical ventilation system. To allow the pigs *ad libitum* access to feed and water throughout the experimental period, each pen accommodating the experimental animals was equipped with a 1-sided self-feeder and a nipple waterer.

Growth performance and nutrient digestibility

The dietary supplements were offered to pigs for 4 weeks. To calculate the performance variables, pigs (individual) BW was recorded at initial and end of each phase to determine the average daily gain (ADG). At the same time, the amount of feed consumption and left over (pen basis) were recorded to determine the average daily feed intake (ADFI) and gain to feed ratio (G: F).

From day 21-28, chromium oxide (Cr_2O_3, 0.5%) an indigestible marker was mixed in pigs' diet. On day 28, fresh fecal samples were randomly collected from 2 pigs /pen (1 gilt and 1 barrow) by rectal palpation, taken to the laboratory, and stored at -20°C. Prior to analysis, fecal samples were placed in a digital hot air-drying convection oven at 105℃ for 48-h. The samples were ground well, and sieved using 1mm screen sieve. The nutrient digestibility of dry matter (method 930.15), nitrogen (N) (method 984.13), and gross energy analysis were carried out according to the guidelines of AOAC (2000). The chromium absorption was identified by UV-1201 spectrophotometry (Shimadzu, Kyoto, Japan) and the results were recorded. Gross energy samples were measured by Parr 6400 (Parr Instrument Co., Moline, IL) oxygen bomb calorimeter. Nitrogen (protein) was determined using a Kjeltec8400 (Hoeganaes, Sweden) analyzer. The apparent total tract digestibility was calculated using: ATTD (%) = 100-[(NF/ND) ×(CrD/CrF)] ×100]. Hence NF, ND, CrD and CrF were referred as nutrient concentration in the fecal sample, nutrient concentration in the diet, chromium concentration in the diet, and chromium concentration in the fecal sample, respectively.

Fecal microbial count analysis

At the end of the trial, fresh fecal samples were collected from same pigs (using micro-tubes and placed in sterile plastic bags and immediately transferred to the laboratory for microbial analysis. To determine the count of *E. coli* and *Lactobacillus*,1g of fecal sample was taken, diluted with 9 mL of 1 % peptone broth, and mixed well with a vortex mixer. The serial dilution (10-fold in 1 % peptone) was performed, and 0.02% of the peptone solution was added to MacConkey agar plates and Lactobacilli medium III agar plates, respectively**.** *E. coli* count was enumerated in MacConkey agar for 24 h at 37°C. *Lactobacillus* was isolated on Lactobacilli medium III agar plates with an overnight incubation (20-24 h) and immediately counted after removing from the incubator. The counts of microbes were log-transformed and noted for statistical analysis.

Fecal gas emission

At the end of the trial, approximately 300 g of fecal sample was randomly collected and placed in a plastic box (2600 ml) with a small hole in the middle and sealed with plaster. The fecal samples were fermented at incubated for 72h (30^{o}C). After that, fermented samples were manually shaken for about 30 seconds to measure the crust formation on the surface. The concentration of NH_3 was determined using the procedure reported by Sampath et al. (2020). Finally, CO_2, acetic acid, H_2S, NH_3, and methyl mercaptans were measured using the scopes of 5.0 to 100.0 ppm (No. 3La, detector tube; Gastec Corp. Kanagawa, Japan) and 2.0 to 20.0 ppm (4LK, detector tube; Gastec Corp).

Meat quality and Fatty acid analysis

At the end of the experiment, 2pigs/pen were transported to the abattoir for slaughter. Then the samples were vacuum-packed and transported to the laboratory for further analysis. The carcasses were weighed individually and stored at 4 °C for 24 hr to measure pH, meat color, water-holding capacity, drip loss, cooking loss, the longissimus muscle area (LM), texture profile analysis and marbling. In addition, meat samples, which included lean and fat, were taken via perpendicular cut loins into 2-cm thick chop beginning from the 10th and 11th ribs region.

A portable digital pH meter was used to calculate the pH suspension with two buffers (pH 4.0 and 7.0) and the measurement process was repeated for 3 times. The color parameters such as lightness, redness, and yellowness values of each samples (surface) were measured at 3 locations using CR-410 colorimeter (Konica Minolta Sensing Inc., Osaka, Japan). Color, marbling, and firmness scores were measure according to the protocols of the National Pork Producers Council (2000). 0.2 g sample was placed in 125 mm (diameter) filter paper and pressed for 3 min. The moisture-exposure of the compressed areas were determined using a digitalized area line sensor (MT-10S, M.T. Precision Co. Ltd., Tokyo, Japan). The ratio of water: meat area was then calculated (a smaller ratio indicates increased WHC) and recorded. To estimate the cooking loss, 4g of raw meat samples was taken, packed into Ziplock bags, placed in a water bath for 30 min at 80°C, the samples were left to cool down for 1 hr and the boiled samples were re-weighed. For drip loos, 4 g meat sample was sliced and weighed at first. Then sliced samples were placed in a Ziplock bag, stored at 4°C and weighed at days 1, 3, 5, and 7 respectively, from the date of sample collection. The initial and final weight of each sample were used to determine the drip loss level. The (total fat) fatty acid analysis was extracted according to the method of Folch et al. (1957). The loin and belly fat, and muscle of carcass was extracted with hexane/isopropanol (3:2 v/v). Samples were analyzed for total fatty acids using a gas chromatograph with a flame ionization detector (HP 5890, Series II, USA). Supelcowax-10 fused silica capillary column (Supelco, Inc., Bellefonte, PA, USA) with a 1.2 ml/min of helium flow were used to separate the FAME. Fatty acid profile of palmitic acid (C16:0) and palmitoleic acid (C16:1) analyzed procedure were previously described by Li et al. (2018).

Statistical analysis

All data were statistically analyzed by analysis of variance, using the general linear model procedure of SAS/STAT® 9.2 (SAS Inst. Inc., Cary, NC, USA) as a randomized complete block design with the pen being considered as the experimental unit. The significance of differences between means were determined using Tukey's test. $p < 0.05$ was considered as significant, $p < 0.10$ was considered as a trend.

Result and Discussion

The effect of coated refined fish oil with barley/wheat-based diet on the growth performance of finishing pigs is presented in Table 3. The dietary inclusion of coated refined fish oil and a diet containing 10% barley as feed ingredient significantly increased the BW (p = 0.020) of pigs compared to other treatment groups at the end of the experiment, which is consistent with Upadhaya et al. (2021) who noted that the addition of (5 g/kg) fish oil or (2.99 g/kg coated) DHA to the diet of weaner pigs significantly increased the BW compared with the pigs fed the control diet.. Though fish oils have an odor and low antioxidant stability, they are considered as a good source of DHA in the diet of humans and animals (Lee and Whenham, 2019). Besides, the presence of long chain PUFA in the diet of animals improves their growth potential (Zhang et al.2010). During the experimental period, the inclusion of coated refined fish oil supplemented to barley-based diet significantly increased ADG (p = 0.023) and G:F (p = 0.021) of finishing pigs which agreed with Meadus et al.(2011) who observed a significant effect on ADG and G:F of finishing pigs fed diet containing 1.60% algae (18% DHA). Similarly, Schellingerhout (2002) stated that fish oil supplement improved the ADG of pigs. Furthermore, our previous study Upadhaya et al. (2021) indicated that unrefined fish oil dietary supplementation significantly increased the ADG, and overall G:F ratio of weaner pigs compared to the corn-based diet. Also, Samuel et al. (2014) noted that dietary supplement with

0.50 or 1.00 % algae (27 % DHA) in the diet of weaning pig increased the ADFI and decreased G.F. Likewise, Upadhya et al. (2017) pointed out that diet containing 0.75% coated linseed oil as a source of omega-3 fatty acid significantly increased the overall growth rate of finishing pig was agreed with our study which reveals that experimental diet had increased G:F and without effects on ADFI. The literature of Kim et al. (2014) suggested that dietary inclusion of barley may reduce growth performance of finishing pig due to its high fiber content. Moreover, it is important to determine the inclusion level of barley in finishing pigs' diet to improve the quality of meat without affecting growth efficiency. The possible reason for increased growth performance may be due the low concentration of barley. However, the discrepancies findings between ours and previous study may be due to the extrinsic factors such as animal'sage, diet density or stress.

The coated refined fish oil with basal diet containing 10% barley as one of the feed ingredients significantly increased the total tract digestibility of DM (p = 0.044) and N (p = 0.033) compared to pigs fed control diet at the end of the experiment (Table 4). However, our finding was not correlated with the study of Upadhaya et al. (2021) who noted an adverse effect on weaning pigs fed coated DHA/fish oil. Previously, Zhang et al (2008) stated that high concentration of unsaturation fatty acids is toxic towards the rumen microbes and reduce digestibility. Likewise, Nhan et al. (2007) pointed out that oil supplementation decreased the population of protozoa and increased the population of beneficial bacteria (*Lactobacillus*) that could increase nutrient digestibility. The gut microbiome plays a significant role in host nutrition and immunization by affecting the digestion and absorption of nutrients, preventing colonization from pathogens, and developing the immunological function (Munyaka et al. 2016). The growth of Lactobacilli in the gut reveals a positive impact on the host, whereas increased *E. coli* are considered as harmful to animals (Halas and Nochta, 2012). Puyalto et al.

(2016) suggested that sodium salts of distilled coconut fatty acids diet altered has increased intestinal *Lactobacillus* population and decreased *E. coli* counts in pigs, which is consistent with our result which showed a beneficial effect on the microbial population as significantly increased *lactobacillus* (p = 0.034) counts and decreased *E. coli* counts (p = 0.049) (Table 5) in pigs fed diet supplement with coated refined fish oil into diet containing 10% barley. With an opposing result, Holman et al. (2014) stated that dietary inclusion of linseed n-3 FA did not showed any detectable effect on the fecal microbiota of swine. Previously, Williams et al. (2014) stated that the composition of gut microflora of healthy adult host often remains remarkably stable. However, uneven distribution of fatty acids along the gut and the alterations in their metabolism may cause mucosal inflammation and other gastrointestinal disorder that mainly depends on the bioavailability of fatty acids that could eventually improve gut function via interaction with interaction with gut microbiota.

Earlier study has aimed to investigate a dietary manipulation strategy to lessen environmental hazards caused by the emission of the noxious gases such as NH_3, H_2S and methyl mercaptan (Okali et al. 2007). The present research, with coated refined fish oil supplemented to the barley-based diet significantly reduced the harmful gases of NH_3 and H_2S (p = 0.042, 0.036) but did not affect the concentration of methyl mercaptans, $CO_{2,}$ and acetic acid (Table. 6). Previously, Sun and Kim (2019) demonstrated that the increased nutrients digestibility would lead to less substrate for the microbial fermentation, and consequently reduces the noxious gas emission. However, adequate data on the literature of feeding coated refined fish oil supplemented to barley-based diet is not available on finishing pigs thus sufficient comparisons could not be made.

The meat quality traits were judged by the consumers on the basis of their appearance, flavor, and texture. Of all the sensory properties of meat, color is considered one of the most important physical properties (McKenna et al. 2005). This is because once a color is considered unacceptable, all other sensory traits are not so important to the consumer that influences the purchasing decision. Apart from this, Offer and Knight (1988) reported that the water-holding capacity (WHC) and intramuscular fat (IMF) are considered to be the most important traits of meat quality. In this present study, coated refined fish oil with the barley-based diet significantly reduced the drip loss at day 5 and 7 (p = 0.044, 0.037 respectively) post-slaughter However, no significant (p > 0.05) effects were found in meat color (redness and yellowness), sensory evaluation, water holding capacity, longissimus muscle area, and texture profile analysis (Table 7). Similarly, Jaturasitha et al. (2002) noted that pigs fed tuna oil supplementation failed to affect the pH, meat color, cooking loss, WHC of meat quality. In addition, Vossen et al. (2017) described that increasing level of freeze-dried *Schizochytrium* microalgae supplementation did not influence the pH and meat color in finishing pigs. Previously, Dang and Kim (2021) reported that the drip loss was dependent on the proteins and structures of binding and retaining water, especially myofibrillar proteins. Hossain et al. (2015) stated that meat pH is commonly seen as the direct effects of the consistency of muscle acid content and drip loss is another ordinary indicator in better meat quality (Balamuralikrishnan et al. 2017). The treatment diet decreased drip loss on day 7 which might be related to the enhancement of muscle protein biosynthesis. The fatty acid composition of pork is highly influenced by the fatty acid concentration of the lipids in the diet (Apple et al. 2007). Moreover, fatty acids composition may directly affect the adipose tissues of pigs. In 2003, Wood et al. demonstrated that monogastric animals are likely to modify the fatty acid content of adipose tissue and muscle when fed diets containing multiple oils. In the present study, dietary inclusion of coated refined fish oil with barley-based diet significantly increased the concentration of fatty acid C16:1, palmitoleic acid in belly meat (p = 0. 006) and increased belly fat of C16:1, palmitoleic acid (p

= 0.036) and reduced C16:0, palmitic acid (p = 0.004) (Table. 8). However, fatty acid composition of loin meat and loin fat (C16:1, palmitoleic acid and C16:0, palmitic acid) was not affected significantly. Similarly, Lampe et al. (2006) noted that the inclusion of barley supplement in the diet for finishing pig has not affected the loin muscle. Moreover, Li et al. (2016) reported that pigs fed kapok seed meal supplementation have significantly reduce the palmitic acid (C16:0) of fatty acid. The concentrations of linoleic acid and PUFA in belly fat were likely ranges from 14 and 15% (NPPC, 2000), because concentrations of linoleic acid and PUFA are less in belly fat than in backfat (Opapeju et al. 2006). However, Kim et al. (2014) reported that the fat quality issues of pigs was solved by the barley-based diet due to lower level of carotenoids and less PUFA compare than corn base diet. We assume that the higher concentration of palmitic acid and palmitoleic acid (belly fat, loin meat, and belly meat, respectively) in pigs receiving 10% barley with coated fish oil could enrich the pork meat quality and impart beneficial effects to consumers health.

Conclusions

Our findings showed that the inclusion of coated refined fish oil in the barley-based diet enhanced the growth performance as well as, total tract digestibility of dry matter and nitrogen and *lactobacillus* population in finishing pigs. The inclusion of 10% barely to the diet at the expense of corn resulted in acceptable pigs' performance and improved meat quality and fatty acid composition of fat and meat. The production of pork with decrease drip loss is highly desirable for the swine industry and consumers. Based on the positive findings, we believe that dietary inclusion of coated refined fish oil into a diet with barley as partial alternative source to promote growth performance and meat quality in finishing pigs.

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Conflicts of Interest

The authors affirm no conflict of interest.

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Table 1. Ingredients and chemical composition of complete diets

Item	CON	TRT1	TRT2
Ingredients (%)			
Corn	54.06	56.07	56.07
Wheat	10.00	10.00	0.00
Barley	0.00	0.00	10.00
Soybean meal 44%	8.39	6.28	6.28
Rapeseed meal	3.50	3.50	3.50
Palm kernel meal	8.00	8.00	8.00
DDGS	7.00	7.00	7.00
Limestone	0.63	0.63	0.63
TCP	0.98	0.88	0.88
Salt	0.40	0.40	0.40
Vitmin mix[1]	0.10	0.10	0.10
Mineral mix[2]	0.10	0.10	0.10
Tallow	4.71	4.70	4.70
Lysin-cms	1.30	1.30	1.30
Threonine 99%	0.11	0.11	0.11
Methionine 99%	0.03	0.03	0.03
Lysine-sulfate 54%	0.70	0.70	0.70
DHA	0.00	0.20	0.20
Total	100.00	100.00	100.00
Crude protein	13.80	13.80	13.80
Ca,%	0.70	0.70	0.70
P,%	0.50	0.50	0.50
LYS,%	0.90	0.90	0.90
MET,%	0.30	0.30	0.30
DE,kcal	3400.00	3400.00	3400.00

[1]Provided per kilogram of complete diet: vitamin A, 10 000 IU; vitamin D_3, 2000 IU; vitamin E, 48 IU; vitamin K_3, 1.5 mg; riboflavin, 6 mg; niacin, 40 mg; d-pantothenic, 17 mg; biotin, 0.2 mg; folic acid, 2 mg; choline, 166 mg; vitamin B_6, 2 mg; and vitamin $B_{12,}$ 28 mg.

[2]Provided per kilogram of complete diet: Fe (as $FeSO_4•7H_2O$), 90 mg; Cu (as $CuSO_4•5H_2O$), 15 mg; Zn (as $ZnSO_4$), 50 mg; Mn (as MnO_2), 54 mg; I (as KI), 0.99 mg; and Se (as $Na_2SeO_3•5H_2O$), 0.25 mg

Abbreviation: CON, (corn-wheat-SBM basal diet, no antibiotic or additive); TRT1, Basal diet (0% barley) + 0.2% coated docosahexaenoic acid; TRT2, Basal diet (10% barley) + 0.2% coated docosahexaenoic acid. DDGS- Distillers dried grains; TCP- Tricalcium Phosphate; DHA- Docosahexaenoic acid;

Table 2. Fatty acid composition of coated refined fish oil[1]

Items	Content, %
Caprylic acid, C8:0	0.0209
Capric acid, C10:0	0.0940
Lauric acid, C12:0	0.1000
Tridecylic acid, C13:0	0.0438
Myristic acid, C14:0	10.0720
Tetradecadienoic acid, C14:2	0.0227
Pentadecylic acid, C15:0	0.4337
Palmitic acid, C16:0	38.3533
Margaric acid, C17:0	0.8785
Stearic acid, C18:0	0.0284
Oleic acid, C18:1w9	20.4667
Linoleic acid, C18:2w6	2.2202
alpha-Linolenic acid, C18:3w3	0.8599
Eicosenoic acid, C20:1w9	1.8299
Docosanoic acid, C22:0	2.5253
Arachidonic acid, C20:4w6	0.6773
Eicosapentaenoic acid, C20:5w3	10.5974
Docosahexaenoic acid, C22:6w3	7.1816
Unknown	3.5943

[1]The refined fish oil was produced through the transesterification and molecular distillation process according to the method described by Hoque et al. (2011). In addition, in order to powder refined fish oil, it is coated with joint matrix coating method using silica as an adsorbent to protect unsaturated fatty acid from rancidity, thereby increasing its usability.

Table 3. The effect of dietary coated refined fish oil with barley-based diet on growth performance in finishing pigs[1]

Items	CON	TRT1	TRT2	SEM[2]	*p* -value
Body weight, kg					
Initial	78.65	78.65	78.64	0.06	1.000
Finish	102.97[b]	104.51[ab]	105.53[a]	0.52	0.020
Overall					
ADG, g	869[b]	877[ab]	882[a]	4.45	0.023
ADFI, g	2927	2922	2918	28.67	0.135
G:F	0.295[b]	0.314[ab]	0.325[a]	0.04	0.021

[1]Abbreviation: CON – (Corn-wheat, SBM based diet); TRT1- CON + 10% wheat + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil
[2]Standard error of means.
[ab] Means in the same row with different superscripts differ ($p < .05$).

Table 4. The effect of dietary coated refined fish oil with barley/wheat-based diet on nutrient digestibility in finishing pigs[1]

Items, %	CON	TRT1	TRT2	SEM[2]	*p* -value
Finish					
Dry matter	71.58 [b]	73.19 [a]	74.29 [a]	1.07	0.044
Nitrogen	69.18 [b]	71.68 [a]	71.92 [a]	1.06	0.033
Gross Energy	70.63	71.17	72.21	1.13	0.762

[1]Abbreviation: CON – (Corn-wheat, SBM based diet); TRT1- CON + 10% wheat + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil

[2]Standard error of means.

[ab] Means in the same row with different superscripts differ ($p < .05$).

Table 5. The effect of dietary coated refined fish oil with barley/wheat -based diet on fecal microbial in finishing pigs[1]

Items, $\log_{10}$cfu/g	CON	TRT1	TRT2	SEM[2]	*p* -value
Finish					
Lactobacillus	9.35^{b}	9.51^{ab}	9.63^{a}	0.07	0.034
Escherichia coli	7.53^{a}	7.47^{ab}	7.32^{b}	0.05	0.049

[1]Abbreviation: CON – (Corn-wheat, SBM based diet); TRT1- CON + 10% wheat + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil
[2]Standard error of means.

[ab] Means in the same row with different superscripts differ ($p < .05$).

Table 6 The effect of dietary coated refined fish oil with barley/wheat-based diet on gas emission in finishing pigs[1]

Items, ppm	CON	TRT1	TRT2	SEM[2]	*p* -value
Initial					
NH_3	0.7	0.8	0.8	0.30	0.859
H_2S	7.2	6.8	6.2	0.62	0.611
Methyl mercaptans	9.0	7.8	8.5	0.48	0.101
CO_2	15250	15500	15750	0.10	0.597
Acetic acid	5.6	6.0	6.7	1.06	0.887
Finish					
NH_3	1.5[a]	1.2 [ab]	0.8[b]	0.41	0.042
H_2S	6.2[a]	5.4 [ab]	4.1[b]	0.86	0.036
Methyl mercaptans	5.2	4.6	5.6	1.20	0.770
CO_2	15750	15000	15500	0.41	0.292
Acetic acid	7.7	6.7	7.9	0.59	0.550

[1]Abbreviation: CON – (Corn-wheat, SBM based diet); TRT1- CON + 10% wheat + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil

[2]Standard error of means.

[ab] Means in the same row with different superscripts differ ($p < .05$).

Table 7. The effect of dietary coated refined fish oil with barley/wheat-based diet on meat quality in finishing pigs[1]

Items	CON	TRT1	TRT2	SEM[2]	*p* -value.
pH	5.22	5.17	5.16	0.01	0.183
Longissimus muscle area, mm^2	5542	5819	6038	0.77	0.447
Water holding capacity, %	61.01	61.65	62.17	3.01	0.613
Meat color					
Lightness (*L**)	53.14	55.72	55.22	0.56	0.082
Redness (*a**)	14.89	14.70	14.75	0.35	0.133
Yellowness (b*)	6.13	6.55	6.30	0.22	0.360
Cooking loss, %	37.09	35.90	36.24	0.54	0.266
Sensory evaluation					
Color	3.46	3.44	3.58	0.07	0.439
Firmness	2.44	2.42	2.46	0.03	0.512
Marbling	3.00	2.81	2.81	0.11	0.082
Drip loss, %					
d1	2.98	2.63	2.91	0.34	0.625
d3	8.12	7.67	7.54	0.71	0.141
d5	8.93 [a]	7.53 [ab]	7.02[b]	0.80	0.044
d7	10.70 [a]	9.73 [ab]	7.84 [b]	0.77	0.037

[1]Abbreviation: CON – (Corn-wheat, SBM based diet); TRT1- CON + 10% wheat + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil
[2]Standard error of means.
[ab] Means in the same row with different superscripts differ ($p < .05$).

Table 8. The effect of dietary coated refined fish oil with barley/wheat-based diet on fatty acid in finishing pigs[1]

Items, %	CON	TRT1	TRT2	SEM[2]	*p* -value
Loin meat					
palmitic acid (C16:0)	23.74	24.01	24.85	0.36	0.097
palmitoleic acid	0.08	0.07	0.04	0.13	0.097
Belly meat (C16:1)					
palmitic acid (C16:0)	24.62	23.33	23.89	0.13	0.895
palmitoleic acid	2.65[b]	2.92[a]	3.02[a]	0.04	0.006
Loin fat (C16:1)					
palmitic acid (C16:0)	24.56	22.79	22.80	0.49	0.212
palmitoleic acid	2.44	2.57	2.69	0.13	0.317
Belly fat (C16:1)					
palmitic acid (C16:0)	25.34[a]	22.27[b]	23.62[ab]	0.36	0.004
palmitoleic acid (C16:1)	2.23[b]	2.50[b]	3.05[a]	0.13	0.036

[1]Abbreviation: CON – (Corn-wheat, SBM based diet); TRT1- CON + 10% wheat + 0.2% coated refined fish oil; TRT2- CON + 10% barley + 0.2% coated refined fish oil.

[2]Standard error of means.

[a,b] Means in the same row with different superscript differ significantly (p<0.05).