Influence of different sources of oil on performance, meat quality, gut morphology, ileal digestibility and serum lipid profile in broilers

J. Khatuna, T. C. Lohab, H. Akita, H. L. Foo and R. Mohamadd

1. Introduction

Fat and oil are commonly used in poultry diets to increase the energy density as they yield 2.25 times more calories than carbohydrates and protein. Fat-supplemented diets increase the feed efficiency and profitability in poultry. Besides, oil improves the palatability of diets, reduces the dustiness of feeds and decreases the passage rate of feed through the intestinal tract of poultry, which gives more time for the adequate absorption of all nutrients present in the diet (Baião and Lara 2005; Chwen et al. 2013).

The digestibility of dietary fats is influenced by the fatty acid profile. Diets containing oil rich in unsaturated fats have higher metabolizable energy values due to better intestinal absorption compared to saturated fats (Celebi and Utlu 2006). During fat digestion, the free fatty acids may form a complex with minerals such as calcium (Ca) and form insoluble or soluble soaps, which may reduce the availability of the fatty acids and Ca for absorption (Leeson and Attte 1995; Leeson and Summer 2005). Chicken digesta contains more saturated fatty acids (SFAs) as unutilized soap compared to unsaturated fatty acids (UFAs) (Atteh and Leeson 1983). Thus, the combination of SFAs and UFAs could have a synergistic effect on fatty acid digestion and absorption (Baião and Lara 2005). In addition, Khatun et al. (2017) reported that the inclusion of 6% combination of palm oil (PO) (rich in SFA) and sunflower oil (SO) (rich in UFA) would have a synergistic effect on fatty acid digestion and absorption in broilers.

In chickens, dietary lipid is reflected in the tissue fatty acid composition (Abdulla et al. 2015; Khatun et al. 2017) and can alter the levels of triglycerides (TG) and lipoproteins in blood (Wongsuthavas et al. 2007; Viveros et al. 2009; Alzawqari et al. 2016). Usually, fats rich in UFAs reduce TG and low density lipoprotein in blood compared to fats rich in SFAs. The use of unsaturated fats in poultry diets improves product quality (UFA content such as ω-3 and ω-6) which is concordant with the demand of consumers (Raza et al. 2016). However, such products are liable to oxidative spoilage, which could reduce product quality and have detrimental effects on consumers (Adeyemi et al. 2015). Contrarily, saturated fats are stable against lipid oxidation. The dietary blend of saturated and unsaturated fats in birds could be an effective strategy to enhance the product quality and minimize oxidative spoilage. Although some information is available on the effect of the use of individual oils on broiler performance and blood lipid profile (Wongsuthavas et al. 2007; Velasco et al. 2010), information on the effect of the combination of SFA and UFA on the performance and apparent digestibility and meat quality is limited. Thus, in this study, the hypothesis was that feeding broilers various combinations of vegetable oils rich in SFA
(PO) and UFA (SO) may have a positive effect on their performance, meat quality and serum lipid profile. Therefore, the aim of this study was to evaluate the effect of feeding diet containing PO, SO and their combination on the performance, meat quality, intestinal morphology, apparent digestibility and blood lipid profile of broilers.

2. Materials and methods

2.1. Animals, husbandry and diets

The experiment was conducted following the guidelines approved by the Institutional Animal Care and Use Committee of Research Policy at Universiti Putra Malaysia (UPM/IACUC/AUP-R081/2016).

A total of 144-day-old male broiler chicks (Cobb-500) were purchased from a commercial hatchery in Negeri Sembilan, Malaysia. Immediately after arrival, the chicks were individually wing-banded, weighed and randomly distributed into four dietary treatments. Each treatment consisted of six replications, with six broilers per replication. The birds were vaccinated with infectious bronchitis (IB) and Newcastle disease (ND) live vaccine against IB and ND after 7 days followed by 14 days through the intraocular route. Throughout the experimental period, water and feed were provided ad libitum to the birds.

Starter and finisher diets were fed to the broiler chickens from 0 to 21 and from 22 to 42 days, respectively. The birds were provided a basal diet containing corn and soybean meal with four different oil supplements. The dietary treatments were T1, basal diet containing 6% PO (control); T2, basal diet containing 4% PO + 2% SO; T3, basal diet containing 2% PO + 4% SO and T4, basal diet containing 6% SO. The diets were formulated to maintain a constant ratio of energy and protein in order to meet the requirements of broilers. The dietary compositions and nutritive value of the starter and finisher diets are presented in Tables 1 and 2, respectively.

2.2. Sample and data collection

Body weight of each bird and feed intake (FI) were recorded per replication weekly. Live weight gain and feed conversion ratio (FCR) were calculated. At 21 and 42 days of age, 6 and 12 broilers were randomly selected from each dietary treatment and slaughtered. The right pectoralis major (breast muscle) was collected, snap-frozen in liquid nitrogen and stored at −80°C to analyse meat quality. Ileal digesta and intestinal samples were collected to study the gut morphology and apparent digestibility. Blood samples were collected at 42 days to measure the plasma lipid profile.

2.3. Meat quality

For meat quality assessment, the muscle pH, drip loss, cooking loss, meat tenderness and meat colour were determined using the procedure described by Abdulla et al. (2017) and Kareem.

### Table 1. Composition and calculated nutrient content of starter diet of broilers.

| Ingredient (%) | T1 | T2 | T3 | T4 |
|----------------|----|----|----|----|
| Corn           | 44.14 | 43.20 | 42.77 | 41.50 |
| Soybean meal   | 31.23 | 33.20 | 33.62 | 33.40 |
| PO             | 6.00 | 4.00 | 0.00 | 0.00 |
| SO             | 0.00 | 2.00 | 0.00 | 0.00 |
| Wheat bran     | 3.85 | 3.95 | 5.13 | 5.30 |
| Wheat pollard  | 7.64 | 7.65 | 6.65 | 7.80 |
| Fish meal      | 3.95 | 2.52 | 2.16 | 2.20 |
| L-Lysine       | 0.20 | 0.20 | 0.20 | 0.20 |
| dl-Methionine  | 0.20 | 0.20 | 0.20 | 0.20 |
| DCP            | 1.50 | 1.80 | 1.83 | 1.86 |
| Calcium carbonate | 0.46 | 0.45 | 0.58 | 0.70 |
| Choline chloride | 0.08 | 0.08 | 0.06 | 0.08 |
| Salt           | 0.30 | 0.30 | 0.30 | 0.30 |
| Mineral premix | 0.15 | 0.15 | 0.15 | 0.15 |
| Vitamin premix | 0.15 | 0.15 | 0.15 | 0.15 |
| Antioxidant    | 0.02 | 0.02 | 0.02 | 0.02 |
| Toxin binder   | 0.13 | 0.13 | 0.13 | 0.13 |
| Total          | 100 | 100 | 100 | 100 |

#### Chemical composition for starter diet (calculated)

| ME (MJ/kg) | 12.86 | 12.86 | 12.86 | 12.86 |
| CP (%)     | 21.01 | 21.01 | 21.01 | 21.01 |
| Fat (%)    | 8.23  | 8.23  | 8.23  | 8.23  |
| Fibre (%)  | 4.30  | 4.41  | 4.47  | 4.51  |
| Calcium (%)| 1.00  | 1.00  | 1.00  | 1.10  |
| Avail. P for poultry (%) | 0.46 | 0.46 | 0.46 | 0.46 |

Note: T1: 6% PO (control); T2: (4% PO + 2% SO); T3: (2% PO + 4% SO); T4: (6% SO). *Di-calcium phosphate.

### Table 2. Composition and calculated nutrient content of finisher diet of broilers.

| Ingredient (%) | T1 | T2 | T3 | T4 |
|----------------|----|----|----|----|
| Corn           | 49.58 | 48.78 | 47.82 | 46.63 |
| Soybean meal   | 29.17 | 28.97 | 29.09 | 29.27 |
| PO             | 6.00 | 4.00 | 0.00 | 0.00 |
| SO             | 0.00 | 2.00 | 0.00 | 0.00 |
| Wheat bran     | 3.40 | 4.55 | 5.29 | 5.75 |
| Wheat pollard  | 5.05 | 4.90 | 5.20 | 6.00 |
| Fish meal      | 2.77 | 2.77 | 2.54 | 2.26 |
| L-Lysine       | 0.20 | 0.20 | 0.20 | 0.20 |
| dl-Methionine  | 0.20 | 0.20 | 0.20 | 0.20 |
| DCP            | 1.80 | 1.80 | 1.83 | 1.86 |
| Calcium carbonate | 1.00 | 1.00 | 1.00 | 1.00 |
| Choline chloride | 0.08 | 0.08 | 0.08 | 0.08 |
| Salt           | 0.30 | 0.30 | 0.30 | 0.30 |
| Mineral premix | 0.15 | 0.15 | 0.15 | 0.15 |
| Vitamin premix | 0.15 | 0.15 | 0.15 | 0.15 |
| Antioxidant    | 0.02 | 0.02 | 0.02 | 0.02 |
| Toxin binder   | 0.13 | 0.13 | 0.13 | 0.13 |
| Total          | 100 | 100 | 100 | 100 |

#### Chemical composition for finisher diet (calculated)

| ME (MJ/kg) | 13.00 | 13.00 | 13.00 | 13.00 |
| CP (%)     | 19.51 | 19.51 | 19.51 | 19.51 |
| Fat (%)    | 8.32  | 8.36  | 8.38  | 8.38  |
| Fibre (%)  | 4.04  | 4.11  | 4.19  | 4.27  |
| Calcium (%)| 1.22  | 1.22  | 1.22  | 1.22  |
| Avail. P for poultry (%) | 0.45 | 0.45 | 0.45 | 0.45 |

Note: T1: 6% PO (control); T2: (4% PO + 2% SO); T3: (2% PO + 4% SO); T4: (6% SO). *Di-calcium phosphate.

Vitamin premix contains retinol 2 mg, α-tocopherol 0.02 mg, cholecalciferol 0.03 mg, menadione 1.33 mg, thiamine 0.83 mg, cobalamin 0.03 mg, riboflavin 2.0 mg, biotin 0.03 mg, folate acid 0.33 mg, niacin 23.30 mg, pantothenic acid 3.75 mg and pyridoxine 1.33 mg.

Mineral premix contains iron120 mg, Zn 100 mg, Mn 150 mg, Cu 20 mg, Mg 12 mg, Co 0.6 mg and Se 0.20 mg.

Antioxidant contain butylated hydroxyanisole.

Toxin binder contains natural hydrated sodium calcium aluminium silicates.
et al. (2015); however, a brief description of the procedure of all the above tests/measurements are given below.

2.3.1. Muscle pH measurement
The pH of breast muscles at 24 h post-slaughter was measured using a portable pH meter (Mettler Toledo, AG 8603, Switzerland). About 0.5 g of crushed sample was taken and homogenized for 10 s in 10 ml cold deionized water at maximum speed by using a homogenizer (Wiggen Hauser® D-500, Germany). The pH of each sample was measured in triplicate and average reading was computed for each replication according to American Meat Science Association (AMSA 2012).

2.3.2. Measurement of drip loss
Approximately 40 g of fresh breast muscle sample at day 0 was taken, weighed and the weight recorded as the initial weight ($W_1$). The meat sample was kept in a plastic bag, vacuum-packaged and stored in a refrigerator at 4°C. After a particular post-mortem storage was reached, the samples were removed from the bags, gently blotted with tissue to dry and the final weight ($W_2$) was measured. The percentage of drip loss was calculated according to Honikel (1998) as:

\[
\text{Drip loss}\% = \frac{(W_1 - W_2)}{W_1} \times 100.
\]

2.3.3. Cooking loss
The breast muscle samples were weighed and the weight recorded as initial weight ($W_1$). Then the muscle samples were placed in a plastic bag, vacuum-packaged and cooked in a water bath at 80°C for 20 min. The samples were then dried using tissue paper without pressing and weighed ($W_2$). Cooking loss was calculated as:

\[
\text{Cooking loss}\% = \frac{W_1 - W_2}{W_1} \times 100.
\]

2.3.4. Measurement of meat tenderness
Meat tenderness was determined from the sample of breast muscle used for the determination of cooking loss. The sample was stored in the refrigerator (4°C) overnight in a plastic bag to prevent evaporation. On the next day, the cooked sample was cut into at least three subsamples (blocks) 1 cm high × 1 cm thickness × 2 cm length (± 0.5 mm) with the long axis accurately aligned with the muscle fibre direction (Kareem et al. 2015). Each subsample was sheared perpendicular to the muscle fibres using a TA.HD plus® texture analyser fitted out with a Volodkevitch blade set according to the procedure of Cavitt et al. (2004). Shear force values were documented as the average of all block values of each individual sample.

2.3.5. Measurement of colour
Breast muscle samples were bloomed (27°C) for 25–30 min prior to the colour analysis. The colour coordinates were determined according to the method of AMSA using a Colour Flex spectrophotometer (Hunter Lab Reston, VA, USA). The device was calibrated against black and white reference tiles prior to use. A total of three readings for each sample (the cup rotates 90 degrees in the second and third reading) of L*(lightness), a* (redness) and b*(yellowness) were recorded and then the average value was calculated for each sample (Hunt 1980).

2.4. Intestinal histomorphology
Intestinal morphology was determined according to the procedure of Choe et al. (2012). About 5–5.5 cm long segments from the central part of the duodenum, jejunum and ileum were collected and physiological saline was used to flush the sample. Intestinal segments were excised about 3.5 mm and transferred into plastic cassettes and kept in neutral buffered formalin solution overnight. Then the samples were dehydrated and embedded in paraffin wax. After trimming, 4 μm section of the samples was cut using a rotary microtome machine (Leica RM 2155, Japan) and fixed on a glass slide. The slide was then stained using haematoxylin and eosin, mounted and examined under light microscopes. Villi height and crypt depth of 12 villi were recorded from every segment and then the average value was calculated for each bird.

2.5. Nutrient digestibility
Titanium dioxide (TiO2) was added as an indigestible marker at 3 g/1000 g to the starter and finisher diets, provided at 18–21 and 39–42 days of age, respectively, four days before slaughtering. After slaughtering, the ileal digesta was collected and stored at −20°C until further analyses. The ileal digesta was frozen, freeze-dried, homogenized and analysed for the nutrient content. The dry matter (DM), crude protein (CP), ether extract (EE) and ash content of the feed and digesta were analysed according to the method of Association of Official Analytical Chemist (AOAC 1995). The TiO2 contents of the feed and digesta were determined by digesting the sample in sulphuric acid (7.4 M) and reacting with hydrogen peroxide, and the absorbance was measured using a spectrophotometer at 410 nm (Abdulla et al. 2016b).

Intestinal digestibility (AID) of DM, CP, EE and Ash was estimated using titanium marker ratios in the diet and ileal content according to Hashemi et al. (2014) using the following formula:

\[
\text{AID of nutrient} = 100 - \left( \frac{\% \text{TiO}_2 \text{ in feed}}{\% \text{TiO}_2 \text{ in ileal content}} \right) \times \left( \frac{\% \text{nutrient in ileal content}}{\% \text{nutrient in feed}} \right) \times 100.
\]

2.6. Plasma lipid profile
The total cholesterol (Tch), TG and high density lipoprotein (HDL-C) from blood plasma were analysed using an Automatic analyser 902 (Hitachi, Germany). Serum very low density lipoprotein cholesterol (VLDL-C) and low density lipoprotein cholesterol (LDL-C) were determined using the Friedewald Equation described by Loh et al. (2014):

\[
\text{LDL cholesterol} = \text{total cholesterol} - (\text{HDL cholesterol} + \text{VLDL cholesterol}),
\]

where VLDL cholesterol = triglycerides/5.
3. Results and discussion

3.1. Bird performance

The impact of feeding different sources of oil on bird performance at 1–21 days and 22–42 days is shown in Table 3. The body weight gain (BWG) increased and FCR decreased at 1–21 days with an increasing level of UFA sources of oil (SO) compared to the control group (PO). Significantly higher (p < 0.05) BWG and superior feed efficiency (1.51) were found in broilers fed dietary treatment T3 (2% PO + 4% SO) at 1–21 days; however, no differences were observed among the dietary treatments T2–T4. The dietary treatments had no influence on the FI of the birds. Higher BWG was observed in birds fed different combinations of PO and SO, and SO alone, which supports the findings of Velasco et al. (2010) who observed better feed efficiency in chicks fed diet containing unsaturated sources of fat than in chicks fed saturated fat diet. Better performance of the broilers might be due to better intestinal absorption of unsaturated fats compared to saturated fats at the starter phase. Insufficient bile secretion and lower lipase activity are responsible for the low fat utilization in the first week of age of chickens (Mossab et al. 2000). Thus, fats containing higher UFAs enhance bile secretion and lipase activity, which promotes the digestibility of young chickens (Noy and Sklan 1996).

No significant differences were observed in the BWG, FCR and FI of birds at 22–42 days of age. These results corroborate the findings of De Witt et al. (2009) and Febel et al. (2008), who reported that diet supplemented with SO, lard, soybean oil and linseed oil had no significant effect on the growth of birds. The FI at the starter and finisher phases observed in the present study agrees with the findings of Azman et al. (2004) and Abdulla et al. (2016a) who reported that supplementation of different dietary fats did not influence the FI in broilers.

| Parameter                  | Treatments | SEM |
|----------------------------|------------|-----|
| 1–21 days                  | T1         |     |
| Initial body weight (g)    | 38.06      |     |
| Body weight (g)            | 672.02b    | 39.61 |
| BWG (g)                    | 633.96b    | 39.69 |
| Feed intake (g)            | 1069.73    | 39.69 |
| FCR                       | 1.68b      | 39.69 |
| 22–42 days                 | T2         |     |
| Body weight (g)            | 2126.83b   |     |
| BWG (g)                    | 1454.82    |     |
| Feed intake (g)            | 2530.71    |     |
| FCR                       | 1.74       |     |

Note: ^b,c^ means with different superscripts in the same row differ significantly (p < 0.05). T1: 6% PO (control); T2: (4% PO + 2% SO); T3: (2% PO + 4% SO); T4: (6% SO).

3.2. Meat quality

3.2.1. Meat pH, drip loss and cooking loss

The effects of different oil sources on breast muscle pH, drip loss and cooking loss are presented in Table 4. Dietary treatments had no significant effect on the meat pH, drip loss and cooking loss. However, a numerically higher drip loss and cooking loss were observed in the diet containing 6% SO (T4) than in other dietary treatments. The pH of the breast muscle ranges from 5.80 to 5.78 for dietary treatments T1–T4. These values are within the ranges of normal pH reported for breast meat (Fernandez et al. 1994; Alvarado et al. 2007).

There was no significant differences observed in cooking loss among the dietary treatments; this might be due to the similarity in the pH value for all treatments. The present findings agreed with that of DalleZotte et al. (1995) who reported that cooking loss is negatively correlated with pH value. In addition, the present findings are in line with those of Jankowski et al. (2012) who reported no significant differences in the drip and cooking loss of breast muscles after 1-day post-mortem in chicken fed different dietary oils.

3.2.2. Meat colour and shear force value

Colour is an important meat quality trait as it affects consumer acceptability of meat (Adedyemi et al. 2016). Meat colour is influenced by sex, age, muscle pigments, meat pH, pre-slaughter condition and processing (Sabow et al. 2016; Salwani et al. 2016). Table 4 shows the effect of different dietary oils on the colour coordinates of breast muscles of broilers. Dietary oil had no significant (p > 0.05) influence on L* (lightness), a* (redness) and b* (yellowness) value of breast meat at 1-day post-mortem among the treatment groups. The current results are similar to the reports of Oliveira et al. (2012) in cattle and Jankowski et al. (2012) in chickens, who found that meat colour did not change with the dietary supplementation of oils. However, this observation contradicts the findings of Qi et al. (2010) who reported that dietary supplementation of different oils influenced the colour of broiler meat.

Tenderness is one of the vital parameters that regulates consumers’ satisfactoriness of cooked meat (Miller et al. 2001). No significant difference (p > 0.05) was found in the shear force value of breast meat of broiler chickens among the dietary treatments (Table 4). This could be due to the similarity in the cooking loss and pH among the treatments. This result is consistent with that of Jankowski et al. (2012) who found that
different dietary oils did not affect the shear force value of broiler meat.

### 3.3. Intestinal histomorphology

Intestinal villi in the digestive tract act as a vital site for the absorption of nutrients. The efficiency of the absorption is controlled by the surface area available for the nutrients. Increased villus height of the intestine is paralleled by increased digestive and absorptive functions of the intestine due to enhanced absorptive surface area (Amat et al. 1996). The effects of different oil sources on villus height and crypt depth at 21 and 42 days are presented in Tables 5 and 6, respectively. Supplementation of UFA oil sources increased duodenal and jejunum villus length at both 21 and 42 days. On day 21, broilers fed dietary treatment T3 had significantly longer (p < .05) duodenum and jejunum villus compared to the control (PO) birds. Nonetheless, ileum villus height, crypt depth and villus: crypt ratio were not affected by different dietary oils. At 42 days, birds fed treatment T3 had significantly higher (p < .05) villus height in duodenum, jejunum and ileum than treatment those fed T1, while there were no significant differences among the other treatments. The lower duodenum villus height observed in birds fed PO is consistent with the findings of Xie et al. (2013), who reported lower duodenum villus height using supplemented PO in squabs diets related to less activity of leucine aminopeptidase and alkaline phosphatase in duodenum. Changes in the villus height by the supplementation of different oils were also reported by Abdullah et al. (2015).

### 3.4. Nutrient digestibility

Results regarding the apparent ileal nutrient digestibility of starter and finisher diets are presented in Table 7. The apparent digestibility of EE and crude fat in starter and finisher diets and ash in starter diets was affected by the dietary treatments. Significantly (p < .05) higher EE and ash digestibility were found in birds fed dietary treatment T3 compared with that in the control birds. There were no differences found among treatments T2–T4. The higher digestibility of fat in birds fed diet supplemented with SO and the combination of SO and PO might be due to the higher content of UFA, which enhanced higher lipase activity. This finding agrees with that of Baiao and Lara (2005) who reported that a higher amount of long chain UFAs in diet or mixed with SFAs increases the ability to form micelles, which enhance the digestibility and absorption of fats. On the other hand, CP digestibility was not affected by the dietary treatments. The present findings are in agreement with that of Kavouridou et al. (2008), who observed that nitrogen efficiency (%) did not differ significantly, but affected fat digestibility in broilers fed diet containing different fat sources (PO, soybean oil and linseed oil). Kavouridou et al. (2008) also stated that diet containing PO had the lowest digestibility of fat. The lower ash digestibility in the PO diet could be due to the higher amount of SFA in this diet, which binds with Ca phytate complexes and forms soluble or insoluble soap in the gut lumen (Selle et al. 2009) and hence decreases ash and fat digestibility. However, further study is needed to measure Ca phytate to confirm this statement. The similarity in CP, DM and Ash digestibility in the finisher diet in the current study supports the findings of Abdulla et al. (2016b), who found that the supplementation of PO, SO and linseed oil in broiler diet had no effect on the apparent ileal digestibility of nutrients in the birds.

### 3.5. Plasma lipid profile

Values for the plasma lipid profile in broilers fed dietary treatments are presented in Table 8. Tch and LDL-C were

---

**Table 5.** Effect of diets containing different sources of oil on villus height and crypt depth of broilers at 21 days of age.

| Parameter | T1 | T2 | T3 | T4 | SEM |
|-----------|----|----|----|----|-----|
| Villus height (μm) | | | | | |
| Duodenum | 859.99<sup>b</sup> | 979.42<sup>a</sup> | 1026.25<sup>a</sup> | 994.45<sup>a</sup> | 21.35 |
| Jejunum | 541.65<sup>b</sup> | 636.64<sup>a</sup> | 689.93<sup>a</sup> | 632.13<sup>a</sup> | 15.48 |
| Ilium | 507.57 | 520.26 | 531.39 | 518.53 | 8.30 |
| Crypt depth (μm) | | | | | |
| Duodenum | 213.52<sup>b</sup> | 130.84<sup>b</sup> | 142.21<sup>ab</sup> | 157.11<sup>a</sup> | 3.22 |
| Jejunum | 99.78 | 107.17 | 101.39 | 102.89 | 3.82 |
| Ilium | 8.43 | 9.57 | 9.60 | 9.63 | 0.27 |

Note: <sup>a,b,c</sup> means with different superscripts in the same row differ significantly (p < .05). T1: 6% PO (control); T2: (4% PO + 2% SO); T3: (2% PO + 4% SO); T4: (6% SO).

**Table 6.** Effect of diets containing different sources of oil on villus height and crypt depth of broilers at 42 days of age.

| Parameter | T1 | T2 | T3 | T4 | SEM |
|-----------|----|----|----|----|-----|
| Villus height (μm) | | | | | |
| Duodenum | 894.98<sup>b</sup> | 1009.00<sup>a</sup> | 1057.25<sup>a</sup> | 1064.20<sup>a</sup> | 16.72 |
| Jejunum | 753.08<sup>b</sup> | 831.47<sup>ab</sup> | 865.53<sup>a</sup> | 938.63<sup>ab</sup> | 22.42 |
| Ilium | 594.73<sup>b</sup> | 629.42<sup>ab</sup> | 658.45<sup>a</sup> | 654.62<sup>a</sup> | 7.66 |
| Crypt depth (μm) | | | | | |
| Duodenum | 133.52<sup>b</sup> | 130.84<sup>b</sup> | 142.21<sup>ab</sup> | 157.11<sup>a</sup> | 3.22 |
| Jejunum | 111.90 | 114.28 | 126.38 | 122.48 | 2.45 |
| Ilium | 8.43 | 9.57 | 9.60 | 9.63 | 0.27 |

Note: <sup>a,b,c</sup> means with different superscripts in the same row differ significantly (p < .05). T1: 6% PO (control); T2: (4% PO + 2% SO); T3: (2% PO + 4% SO); T4: (6% SO).

**Table 7.** Effect of different sources of oil on apparent ileal nutrient digestibility of broiler chickens.

| Parameter | T1 | T2 | T3 | T4 | SEM |
|-----------|----|----|----|----|-----|
| DM | 63.54 | 63.96 | 65.04 | 64.72 | 0.40 |
| Ether extract | 67.97<sup>b</sup> | 71.02<sup>a</sup> | 72.72<sup>a</sup> | 72.13<sup>a</sup> | 0.62 |
| Crude Protein | 72.92 | 78.01 | 78.40 | 77.94 | 0.27 |
| Ash | 46.39<sup>b</sup> | 53.77<sup>a</sup> | 54.38<sup>a</sup> | 53.19<sup>a</sup> | 1.01 |

Note: <sup>a,b,c</sup> means with different superscripts in the same row differ significantly (p < .05). T1: 6% PO (control); T2: (4% PO + 2% SO); T3: (2% PO + 4% SO); T4: (6% SO).
significantly \((p < .05)\) lower in birds fed diet containing SO and the combination of PO and SO compared to the control diet. No significant differences were observed in the HDL-C values among the dietary treatments. The TG and VLDL-C levels were significantly higher in birds fed T1 compared to other dietary treatments, whereas no differences were observed for all values among the treatments \(T_2-T_4\). Generally, SFA increased the serum VLDL-C and LDL-C and reduced the HDL level compared with dietary poly-UFAs (Kinsella et al. 1990; Duraisamy et al. 2013). The current findings are consistent with that of Velasco et al. (2010) who observed higher concentrations of serum LDL-C and VLDL-C in broilers fed PO-containing diets than in those fed SO-containing diets. Viveros et al. (2009) and Sanz et al. (1999) demonstrated that different degrees of saturation of dietary fats modify the level of serum lipids in chickens. Dietary PUFAEs decrease chylomicron secretion from intestinal cells and suppress hepatic fatty acid synthesis and TG production. Broilers fed SO diet and the combination of PO and SO diet contain a higher PUFA:SFA ratio and had significantly \((p < .05)\) lower plasma cholesterol, TG, VLDL-C and LDL. This observation agrees with the findings of Shearer et al. (2012) who reported that the inclusion of PUFA-rich oil in broiler diet reduced serum Tch, TG and VLDL compared to the control diet.

**4. Conclusions**

The results of this study revealed that no significant differences were found in birds’ performance, digestibility and plasma lipid profile among the two types of oil combination and SO alone. Therefore, considering the availability and cost of PO, it can be suggested that the supplementation of PO and SO at the ratio of 4:2 (PO:SO) in broiler diets seemed to be beneficial for the better development of gut morphology. The combination of oil increased the absorption and digestibility of nutrients, resulting in good performance of broilers. The result also supports that this dietary treatment had a favourable effect on meat quality and improved the blood serum lipid profile by decreasing the concentration of Tch.

**Acknowledgements**

The authors are grateful to the Organization for Women in Science and Technology for the developing world (OWSDI), Trieste, Italy, for providing a PhD Fellowship to the first author.

**Disclosure statement**

No potential conflict of interest was reported by the authors.

**Funding**

The research fund was supported by the Long-Term Research Grant Scheme (LRGS NO. 5526000) from the Ministry of Higher Education Malaysia.

**References**

Abdulla NR, Loh TC, Akit H, Sazili AQ, Foo HL. 2016a. Effect of dietary oil sources and calcium: phosphorus levels on growth performance, gut morphology and apparent digestibility of broiler chickens. S Afr J Anim Sci. 46:42–53.

Abdulla NR, Loh TC, Akit H, Sazili A, Foo HL, Mohamad R, Rahim RA, Ebrahim M, Sabow A. 2015. Fatty acid profile, cholesterol and oxidative status in broiler chicken breast muscle fed different dietary oil sources and calcium levels. S Afr J Anim Sci. 45:153–163.

Abdulla NR, Loh TC, Akit H, Sazili A, Foo HL, Mohamad R, Rahim RA, Ebrahim M, Sabow A. 2016b. Effects of dietary oil sources, calcium and phosphorus levels on growth performance, carcass characteristics and bone quality of broiler chickens. J Appl Anim Res. doi:10.1080/09712119.2016.1206903.

Abdulla NR, Zamri ANM, Sabow AB, Kareem KY, Nurzhahiz S, Foo HL, Sazili AQ, Loh TC. 2017. Physico-chemical properties of breast muscle in broiler chickens fed probiotics, antibiotics or antibiotic–probiotic mix. J Appl Anim Res. 45:64–70. doi:10.1080/09712119.2015.1124330.

Addeymi KD, Sabow AB, Shittu RM, Karim R, Sazili AQ. 2015. Influence of dietary canola oil and palm oil blend and refrigerated storage on fatty acids, myofibrillar proteins, chemical composition, antioxidant profile and quality attributes of semimembranosus muscle in goats. J Anim Sci Biotech. 6:1–13.

Addeymi KD, Shittu RM, Sabow AB, Ahmed AA, Karim R, Karsani SA, Sazili AQ. 2016. Comparison of myofibrillar protein degradation, antioxidant profile, fatty acids, metmyoglobin reducing activity, physicochemical properties and sensory attributes of glutens medius and infraspinatus muscles in goats. J Anim Sci Tech. 5:1–17.

Alvarado CZ, Richards MP, O‘Keefe SF, Wang H. 2007. The effect of blood removal on oxidation and shelf life of broiler breast meat. Poult Sci. 86:156–161.

Alzawqari MH, Al-Baddany AA, Al-Badani, HH, Alhidary IA, Khan RU, Aqil GM, Abdurab A. 2016. Effect of feeding dried sweet orange \((Cymbopogon citratus)\) peel and lemon grass \((Cymbopogon citratus)\) leaves on growth performance, carcass traits, serum metabolites and antioxidant status in broiler during the finisher phase. Environ Sci Pollut Res. 23:17077–17082.

Amat C, Planas JM, Moreto M. 1996. Kinetics of hexose uptake by the small intestine of the chicken. Am J Physiol. 271:1085–1089.

Atteh J, Leeson S. 1983. Effects of dietary fatty acids and calcium levels on performance and mineral metabolism of broiler chickens. Poult Sci. 62:2412–2419.

Azman M, Konar V, Seven P. 2004. Effects of different dietary fat sources on growth performances and carcass fatty acid composition of broiler chickens. Revue de Med Vet. 155:278–286.

Baiao NC, Lara L. 2005. Oil and fat in broiler nutrition. Revista Brasil Ciênc Avic. 7:129–141.

Cavitt LC, Youm GW, Meullenet JF, Owens CM, Xiong R. 2004. Prediction of poultry meat tenderness using razor blade shear, allo Kramer shear and sarcomere length. J Food Sci. 69:11–15.

Celebi S, Utlu N. 2006. Influence of animal and vegetable oil in layer diets on performance and serum lipid profile. Int J Poult Sci. 5:370–373.

Choe D, Loh TC, Foo H, Hair-Bejo M, Awis Q. 2012. Egg production, fecal pH and microbial population, small intestine morphology, and plasma and

**Table 8. Effect of different sources of oil on the plasma lipid profile of broilers.**

| Parameter | \(T_1\) | \(T_2\) | \(T_3\) | \(T_4\) | SEM |
|-----------|-------|-------|-------|-------|-----|
| Cholesterol | 3.26a | 2.67b | 2.64b | 2.49b | 0.96 |
| Triglycerides | 0.68a | 0.51ab | 0.52ab | 0.42b | 0.03 |
| HDL-C | 1.62 | 1.64 | 1.63 | 1.69 | 0.04 |
| VLDL-C | 0.14a | 0.102ab | 0.110b | 0.085b | 0.01 |
| LDL-C | 1.51a | 0.93b | 0.90b | 0.72b | 0.10 |

Note: \(^{ab}\) means different superscripts in the same row differ significantly \(p < .05\). \(T_1\): 6% PO (control); \(T_2\): (4% PO + 2% SO); \(T_3\): (2% PO + 4% SO); \(T_4\): (6% SO); HDL-C: high density lipoprotein cholesterol; VLDL-C: very low density lipoprotein-cholesterol; LDL-C: low density lipoprotein cholesterol.
