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EFFECT OF DIFFERENT FAT SOURCES AND ENERGY LEVELS ON GROWTH PERFORMANCE, NUTRIENT DIGESTIBILITY AND MEAT QUALITY IN BROILER CHICKS

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ABSTRACT

This experiment was conducted to evaluate different oil sources and energy density in broiler. Two vegetable oil sources (canola and palm oil), two animal oil sources (fish oil and refined poultry oil) and two levels of energy were: ***recommended energy (RE)***; 3000 and 3200 kcal/kg according to manual of Ross 308 and ***low energy (LE)***; 2850 and 3050 kcal/kg used in starter and finisher phases, respectively. Four hundred and sixteen (416) day-old broiler birds were distributed in eight treatments (four replicates containing 13 birds in each) in 2 x 4 factorial arrangement. Feed intake, body weight and mortality were recorded. At the end of experiment, two birds from each replicate were slaughtered for carcass characteristics and meat quality parameters. Nutrient digestibility was determined using Celite® as marker. Data were subjected to statistical analysis using analysis of variance technique by completely randomized design under factorial arrangement using Minitab 17 and treatment means were compared using Tukey's Test. Results revealed that weight gain, protein efficiency ratio (PER), European production efficiency factor (EPEF), Feed efficiency (FE) and FCR were improved ($P \leq 0.05$) in birds given recommended energy diet than those fed low energy diet. Feed intake was lower ($P \leq 0.05$), whereas weight gain, PER, EPEF, FE and FCR were improved in birds given canola and poultry oil than those received fish and palm oil. Dressing percentage was higher ($P \leq 0.05$) in birds fed RE and poultry oil and it was lower ($P \leq 0.05$) in birds fed LE and fish oil. Water holding capacity of broiler breast meat was higher ($P \leq 0.05$) in birds fed RE diet. Different energy levels had no effect ($P > 0.05$) on dry matter (DM), ether extract (EE) and crude protein (CP) digestibility (%) at 21st day. Birds fed diet having poultry and canola oil had greater ($P \leq 0.05$) DM, CP and EE digestibility on 35th day than those fed diet having palm and fish oil. Production cost per kg live weight was lower ($P \leq 0.05$) in birds receiving recommended energy and poultry oil based diets. In conclusion, refined poultry oil in recommended energy had improved growth performance, meat quality and economics efficiency in broilers.

Keywords: energy density, oil sources, growth performance, meat quality, nutrient digestibility, economics efficiency

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INTRODUCTION

In poultry production enterprises, feed cost accounts for around 70% of the total costs involved in production (Fan *et al.,* 2008). Optimizing the dietary energy level, therefore, is important for lowering the feed cost per unit of poultry products (Classen, 2017). Dietary energy can be optimized for both growth performance and for enhanced meat quality. Dietary nutrient levels alter meat color, energy content, and histological makeup as well as the metabolic characteristics of broiler muscles (Zhao and Kim, 2017).

Lipids (oils and fats) are energy-rich compounds. Chemically lipids are triglycerides i.e., tri-esters of fatty acids and glycerol. Birds cannot synthesize essential fatty acids, hence; essential fatty acids are obtained from dietary fat and it must be added in poultry feed. Fat addition in broiler diet improves growth performance and also provides extra caloric effect to meet the requirements of fast-growing broilers in a short time (Baião and Lara, 2005). Digestion and absorption of nutrients are also improved by fat addition in the broiler diet. In the broiler diet, both vegetable and animal fats are used to increase the energy value (Long *et al.,* 2018). The addition of fat in the broiler diet improves absorption of fat-soluble vitamins and enhances the likeness of bird towards feed (Liu *et al.,* 2017).

Digestibility of fat depends on multiple properties of fat, like chain length, composition of fatty acids, ratio of saturated/unsaturated fatty acids and free fatty acids (Allahyari-Bake and Jahanian, 2017). Vegetable oils are recognized for their high content of monounsaturated fatty acids (Kiani *et al.,* 2017). Vegetables sources are high in price and less available due to their consumption in human. Palm oil, which comes from the fruit of the *Elaeis guineensis* tree, is the second most common vegetable oil produced globally following soybean oil. According to Skrivan *et al.* (2018), palm oil is a common supplement in poultry diets. However, due to the negative impact on the environment, i.e., deforestation, extinction of endangered species and loss of biodiversity consumers are looking for an alternative energy source (Skrivan *et al.,* 2018). In replacement of vegetable oil, animal oils, like poultry and fish oil, are the byproduct of rendering plants and after refining, they can be used in poultry diets as an energy source. Compared to plant source, they contain a higher degree of saturated fatty acids and omega-6 fatty acids (Liu *et al.,* 2017). On the other hand, chicks have the ability to utilize fatty acids from unsaturated fat sources more efficiently than from saturated fat sources (Smits *et al.,* 2000). Poultry fat contains approximately same energy than soybean oil (8220 vs 8196 kcal/kg) (Firman *et al.,* 2008). However, some authors stated that birds fed diet having higher saturated fatty acid had higher abdominal fat. Therefore, the present study was planned to examine the effect of different oil sources and energy levels on growth performance, nutrient digestibility and meat quality in broilers.

MATERIALS AND METHODS

The present study was conducted at Research House, Animal Nutrition Center, University of Agriculture, Faisalabad with prior approval from the animal care and use committee of the university via letter no. 15497-500.

House cleaning and preparation: Before chick arrival, the house was cleaned, washed, fumigated and closed to minimize the microbial load. Feed was offered to birds in round bottom feeder while water was available in nipple lines. House temperature was sustained at 95°F at first week of trial with following reduction of 5°F every week. Birds were vaccinated with ND+IB (day 1), IBD (day 8), IBD (day 18) and ND (day 25) vaccine. Saw dust was used as bedding material. Birds were reared maintaining all standard conditions like temperatures, relative humidity, and ventilation etc.

Experimental birds and diet: Four hundred and sixteen (416) day-old broiler birds were distributed into eight treatments with four replicates containing 13 birds in each. Eight iso-nitrogenous diets (CP 22% in starter and 20% in finisher phase) were formulated according to the manual of ROSS-308. Two levels of Metabolizable energy ***Recommended energy*:** 3000 kcal/kg in starter (1-21 days), 3200 kcal/kg in finisher (22-35 days) and ***Low energy*:** 2850 kcal/kg in starter, 3050 kcal/kg in finisher diet) and four sources (canola oil, palm oil, poultry oil and fish oil) were tested in a 2 x 4 factorial arrangement under complete randomized design. First seven days were considered as adaption period in this experiment (Table 1 and 2).

Table 1. Ingredient and nutrient composition of experimental diets during starter phase (1-21 days).

	LOW ENERGY				RECOMMENDED ENERGY			
Ingredients	**Canola Oil**	**Palm Oil**	**Fish Oil**	**Poultry Oil**	**Canola Oil**	**Palm Oil**	**Fish Oil**	**Poultry Oil**
Corn	55.36	54.86	54.99	54.93	52.51	52.50	52.34	52.42
Soybean Meal 45%	37.05	38.42	38.41	38.42	38.93	38.93	38.96	38.95
Molasses	1.70	0.81	0.70	0.75	0.00	0.00	0.00	0.00
Canola oil	1.00	0.00	0.00	0.00	3.66	0.00	0.00	0.00
Palm Oil	0.00	1.00	0.00	0.00	0.00	3.67	0.00	0.00
Fish Oil	0.00	0.00	1.00	0.00	0.00	0.00	3.79	0.00
Poultry Oil	0.00	0.00	0.00	1.00	0.00	0.00	0.00	3.73
Calcium Carbonate	0.90	0.89	0.89	0.89	0.90	0.90	0.90	0.90
DCP	2.15	2.17	2.17	2.17	2.17	2.17	2.17	2.17
Sodium Chloride	0.39	0.37	0.37	0.37	0.39	0.39	0.39	0.39
Sodium Biocarbonate	0.30	0.32	0.31	0.31	0.30	0.30	0.30	0.30
L-Lysine Sulphate	0.38	0.37	0.37	0.37	0.35	0.35	0.35	0.35
DL-Methionine	0.36	0.37	0.37	0.37	0.37	0.37	0.37	0.37
L. Threonine	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
Vitamin Premix*	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mineral Premix**	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100	100	100
Nutrient composition (Calculated)								
Dry Matter Fed	87.35	87.20	87.22	87.21	87.61	87.61	87.62	87.62
Metab. Energy	2850.00	2850.00	2850.00	2850.00	3000.00	3000.00	3000.00	3000.00
Crude Protein	22.00	22.00	22.00	22.00	22.00	22.00	22.00	22.00
Ether extract	3.32	3.30	3.30	3.30	5.87	5.87	5.98	5.94
Crude Fiber	3.09	2.98	2.98	2.98	2.94	2.94	2.94	2.94
Ash	4.92	4.96	4.95	4.96	4.93	4.91	4.91	4.93
Calcium	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.96

Avail. Phos.	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
Sodium	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Potassium	0.87	0.91	0.90	0.90	0.88	0.88	0.88	0.88
Chlorine	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DEB	245.43	255.84	254.92	255.35	249.53	249.53	249.53	249.53
Dig. Lysine	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28
Dig. Methionine	0.66	0.67	0.67	0.67	0.67	0.67	0.67	0.67
Dig. Met + Cys	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Dig. Threonine	0.86	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Dig. Tryptophan	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Dig. Arginine	1.39	1.40	1.40	1.40	1.41	1.41	1.41	1.41
Dig. Leucine	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70
Dig. Isoleucine	0.85	0.86	0.86	0.86	0.86	0.86	0.86	0.86
Dig. Valine	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
Dig. Histidine	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Nutrient composition (Analyzed)								
Moisture	89.1	89.0	88.8	88.5	88.9	88.1	88.2	88.0
Ash	5.4	5.2	4.8	4.3	4.4	4.1	4.6	4.7
CP	22.2	22.1	21.8	21.9	22.1	22.02	22.21	21.89
EE	3.2	2.9	3.23	3.12	5.5	5.3	5.32	5.1
Crude fiber	3.52	3.43	2.9	3.2	3.6	2.89	3.45	3.12
Calcium	0.91	0.9	0.92	0.93	0.94	0.91	0.93	0.92
Total phosphorus	0.58	0.58	0.55	0.56	0.58	0.56	0.57	0.56

Table 2. Ingredient and nutrient composition of experimental diets during finisher phase (22-35 days).

	LOW ENERGY				RECOMMENDED ENERGY			
Ingredients	**Canola Oil**	**Palm Oil**	**Fish Oil**	**Poultry Oil**	**Canola Oil**	**Palm Oil**	**Fish Oil**	**Poultry Oil**
Corn	59.22	59.21	59.08	59.14	55.70	55.68	55.43	55.55
Soybean Meal 45%	33.99	33.99	34.02	34.01	34.64	34.64	34.69	34.67
Canola oil	3.13	0.00	0.00	0.00	6.03	0.00	0.00	0.00
Palm Oil	0.00	3.14	0.00	0.00	0.00	6.04	0.00	0.00
Fish Oil	0.00	0.00	3.25	0.00	0.00	0.00	6.25	0.00
Poultry Oil	0.00	0.00	0.00	3.19	0.00	0.00	0.00	6.15
Calcium Carbonate	0.73	0.73	0.73	0.73	0.72	0.72	0.72	0.72
DCP	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Sodium Chloride	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
Sodium Biocarbonate	0.13	0.13	0.13	0.13	0.12	0.12	0.12	0.12
L-Lysine Sulphate	0.10	0.10	0.10	0.10	0.08	0.08	0.08	0.08
DL-Methionine	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
Vitamin Premix*	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Mineral Premix**	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Total	100	100	100	100	100	100	100	100
Nutrient composition								
Dry Matter Fed	87.80	87.79	87.81	87.81	88.11	88.10	88.13	88.13
Metab. Energy	3050.00	3050.00	3050.00	3050.00	3200.00	3200.00	3200.00	3200.00
Crude Protein	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Ether extract	5.53	5.53	5.62	5.59	8.29	8.29	8.47	8.41
Crude Fiber	2.84	2.84	2.83	2.84	2.80	2.80	2.79	2.80
Ash	4.40	4.38	4.38	4.40	4.42	4.39	4.39	4.41
Calcium	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Avail. Phos.	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Sodium	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Potassium	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Chlorine	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
DEB	210.11	210.11	210.11	210.11	210.25	210.25	210.26	210.26
Dig. Lysine	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
Dig. Methionine	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
Dig. Met + Cys	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Dig. Threonine	0.69	0.69	0.69	0.69	0.69	0.69	0.69	0.69
Dig. Tryptophan	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
Dig. Arginine	1.28	1.28	1.28	1.28	1.28	1.28	1.28	1.28

Dig. Leucine	1.60	1.60	1.60	1.60	1.59	1.59	1.59	1.59
Dig. Isoleucine	0.78	0.78	0.78	0.78	0.79	0.79	0.79	0.79
Dig. Valine	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Dig. Histidine	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Nutrient composition (Analyzed)								
Moisture	88.9	88.92	90.7	89.7	89.4	90.23	88.5	89.1
Ash	5.52	5.6	5.3	5.76	5.23	5.3	5.7	5.8
CP	19.78	19.6	19.65	19.65	19.54	19.45	19.65	19.45
EE	4.77	4.87	5.12	5.23	7.45	7.32	7.8	7.92
Crude fiber	3.65	3.23	3.76	3.45	3.55	3.12	3.54	3.77
Calcium	0.78	0.76	0.75	0.78	0.74	0.76	0.75	0.77
Total phosphorus	0.54	0.52	0.52	0.55	0.51	0.53	0.54	0.54

*Vitamins premix provides 10000 IU Vitamin A, 5 mg Riboflavin, 12 mg Ca Pantothenate, 2.2 mg thiamin, 1.55 mg Folic acid, 44 mg nicotinic acid, 2.2 mg Vitamin B6, 12.1 µg Vitamin B12, 250 mg Choline chloride, 0.11 mg d-biotin, 1100 IU Vitamin D3, 11.0 IU Vitamin E, 1.1 mg Vitamin K per kg of diet.

**Mineral premix provides 30 mg Fe, 50 mg Zn, 5 mg Cu, 60 mg Mn, 0.1 mg Co, 0.3mg I and 1 mg Se per kg of diet.

Data collection

Growth performance

- ***Body weight***

Body weight of birds was measured at the end of each subsequent week.

- ***Feed intake***

Feed intake was calculated as follow:

$$\text{Feed intake} = \text{Feed offered} - \text{Feed refused}$$

- ***Feed conversion ratio***

Feed conversion ratio was calculated week-wise using the following relationship.

$$\text{FCR} = \frac{\text{Feed intake (g)}}{\text{Weight gain (g)}}$$

- ***Feed efficiency***

Feed efficiency was calculated using the following relationship.

$$\text{Feed eficency} = \frac{\text{Weight gain (g)}}{\text{Feed intake (g)}}$$

- ***Protein efficiency ratio***

The PER was calculated as grams of weight gain per gram of protein intake (Kamran *et al.,* 2008).

$$\text{Protein efficiency ratio} = \frac{\text{Weight gain}}{\text{Protein consumed}}$$

- ***European Production Efficiency Factors***

The EPEF was calculated according to the following formula (Marcu *et al.,* 2013).

$$\text{European Production Efficiency Factors} = \frac{\text{Liveability x Liveweight (kg)}}{\text{FCR x Age (days)}}\, x\ 100$$

Nutrient digestibility: Indirect marker method was used for determining nutrient digestibility (Dourado *et al.,* 2010). For this purpose, acid insoluble ash (Celite®) was included in experimental diets @ 1%. Feces were collected at 21st and 35th day of the experiment. Flex sheets were placed under each pen and droppings were collected three times a day. Proximate analysis of feed and feces were determined (AOAC, 2000). Nutrient digestibility was determined using following formula.

$$\text{Digestibility coefficient (\%)} = 100 - \left(100 \times \frac{\text{\% marker in feed}}{\text{\% marker in ileal}} \times \frac{\text{\% nutrient in ileal}}{\text{\% nutrient in feed}}\right)$$

Slaughter parameters: At 35th day, 2 birds from each replicate were slaughtered to determine the relative weights of organs including heart, gizzard and liver. Breast and thigh yield were calculated percent to carcass weight and relative organ (liver, gizzard and heart) weights and abdominal fat weight was calculated percent to live weight.

Meat quality parameters: Meat samples from breast meat were collected at the end of trial and freeze for further analysis.

pH determination: To measure pH of breast muscles approximately 1.5 g of ground breast meat was homogenized in 10 mL water and then measure the pH using pH meter (Milwaukee MW102) (Jeacocke, 1977) at 3 h post slaughtering.

Water holding capacity: A weighed meat sample (15gm) was centrifuged at 5000 rpm for 15 mints at 4ºC in a stainless tube. Water was decanted off as early to stop its re-absorption after released from meat. Meat sample was reweighed to determine liquid loss (Pearson and Dutson, 1995).

$$\%\text{WHC} = \left(\frac{\text{W1} - \text{W2} - \text{Sample weight}}{\text{Sample weight}}\right) \times 100$$

Cooking Loss: Approximately 40 gm or 2 x 5 cm meat cut was taken and cooked to an internal temperature of 75 ± 1ºC in water bath (80 ± 0.5ºC) for 30 to 35 minutes. After cooling the meat, cooking loss was calculated as weight loss from meat (Ahmed *et al.,* 2015).

Quality test of oil: Quality of oil was measure in term of moisture, percentage of free fatty acids and peroxide values (Butolo, 2002) (table 3).

Table 3. Lab analysis of oil used in experimental diets.

	Moisture (%)	Free fatty acid (%)	Per oxidize value (%)
Canola oil	0.02	0.94	1.81
Palm oil	0.06	0.84	2.09
Refined poultry oil	1.08	0.82	2.91
Fish oil	0.08	25.2	21.9

Statistical Analysis: The obtained data was subjected to statistical analysis using analysis of variance technique under completely randomized design factorial arrangement using Minitab 17 and treatment means were compared using Tukey's Test (Steel *et al.,* 1997).

RESULTS

Effect of energy levels and oil sources on growth performance in broiler

Starter phase: Weight gain, feed intake (FI), FCR, PER, FE and EPEF of starter phase are given in table 4. Feed intake, WG, FCR, PER, FCR, FE and EPEF were not influenced ($P > 0.05$) by different oil sources and energy levels. There was no interaction ($P > 0.05$) between energy levels and oil sources on growth performance and nutrient utilization in starter period.

Finisher phase: Fed intake, WG, FCR, PER and EPEF of finisher phase are given in table 5. Weight gain, PER, FE, EPEF and FCR were improved ($P \leq 0.05$) in birds fed RE diet than those fed LE diet. Feed intake was lower ($P \leq 0.05$), whereas, PER, EPEF, FE and FCR were improved ($P \leq 0.05$) in birds received diet having canola oil and refined poultry oil than those fed palm and fish oil. However, WG was not influenced ($P > 0.05$) different oil sources. Improved ($P \leq 0.05$) FCR, PER, FE and EPEF were recorded in birds received diet having poultry oil and recommended energy diet and poor FCR, PER and EPEF was observed in birds received diet having low energy and palm oil.

Whole life: The results of total FI, WG, FCR PER, FE and EPEF are given in table 6. Weight gain, PER, EPEF, FE and FCR were improved ($P \leq 0.05$) in birds received RE diet than those fed LE diet. Feed intake was lower ($P \leq 0.05$), WG, PER, EPEF, FE and FCR were improved ($P \leq 0.05$) in birds fed canola and poultry oil based diet than those received diet having fish and palm oil. There was an interaction ($P \leq 0.05$) between energy level and oil sources on growth performance. Birds fed diet having refined poultry oil in RE diet had higher ($P \leq 0.05$) weight gain, PER, FE, EPEF and better ($P \leq 0.05$) FCR, while, higher ($P \leq 0.05$) feed intake, lower ($P \leq 0.05$) PER and poor ($P \leq 0.05$) FCR was observed in birds having palm oil in low energy diet.

Table 4. Effect of energy levels and oil sources on growth performance during starter phase (8-21 days).

	Feed Intake (g)	Weight gain (g)	FCR (FI:WG)	Feed efficiency (WG:FI)	PER	EPEF
Energy Density						
RE	1112.25	601.27	1.866	0.54	2.46	286.15
LE	1135.18	611.78	1.864	0.54	2.46	286.30
SEM	***20.5***	***13.3***	***0.06***	***0.02***	***0.07***	***12.7***
P Value	***0.438***	***0.583***	***0.976***	***0.902***	***0.945***	***0.993***
Oil Sources						
Canola Oil	1123.72	611.72	1.852	0.55	2.46	287.82
Fish Oil	1117.72	602.69	1.853	0.54	2.45	285.55
Palm Oil	1147.62	592.70	1.942	0.52	2.35	269.58
Poultry Oil	1105.80	618.99	1.812	0.57	2.58	301.96
SEM	***29.0***	***18.9***	***0.08***	***0.02***	***0.09***	***18.0***
P Value	***0.777***	***0.780***	***0.687***	***0.463***	***0.420***	***0.657***
Energy Density x Oil Sources						
RE Canola Oil	1117.92	602.37	1.869	0.54	2.44	280.70
RE Fish Oil	1124.36	606.35	1.851	0.54	2.46	284.15
RE Palm Oil	1120.95	573.23	1.966	0.51	2.30	263.57
RE Poultry Oil	1085.78	623.13	1.778	0.58	2.65	316.17
LE Canola Oil	1129.52	621.06	1.834	0.55	2.49	294.94
LE Fish Oil	1111.08	599.03	1.855	0.54	2.44	286.94
LE Palm Oil	1174.29	612.18	1.918	0.52	2.39	275.59
LE Poultry Oil	1125.81	614.85	1.847	0.55	2.51	287.74
SEM	***41.1***	***26.7***	***0.11***	***0.03***	***0.14***	***25.4***
P Value	***0.852***	***0.781***	***0.952***	***0.889***	***0.853***	***0.825***

SEM, standard error of the mean;
P>0.05: Non-Significant, P≤0.05: Significant

Table 5. Effect of energy levels and oil sources on growth performance during finisher phase (22-35 days).

	Feed Intake (g)	Weight gain (g)	FCR (FI:WG)	Feed efficiency (WG:FI)	PER	EPEF
Energy Density						
RE	2067.91	1219.23[a]	1.704[b]	0.59[a]	3.03[a]	494.88[a]
LE	2094.85	1156.26[b]	1.811[a]	0.56[b]	2.82[b]	458.37[b]
SEM	***28.9***	***16.4***	***0.02***	***0.01***	***0.04***	***12.5***
P Value	***0.516***	***0.012***	***0.003***	***0.003***	***0.001***	***0.050***
Oil Sources						
Canola Oil	1978.78[b]	1202.11	1.647[b]	0.61[a]	3.09[a]	522.48[a]
Fish Oil	2187.21[a]	1186.48	1.845[a]	0.54[b]	2.78[b]	435.59[b]
Palm Oil	2131.27[ab]	1148.84	1.855[a]	0.54[b]	2.75[b]	437.99[b]
Poultry Oil	2028.27[ab]	1213.54	1.683[b]	0.60[a]	3.07[a]	510.43[a]
SEM	***40.9***	***23.2***	***0.03***	***0.01***	***0.06***	***17.7***
P Value	***0.006***	***0.246***	***0.0001***	***0.0001***	***0.0001***	***0.002***
Energy Density x Oil Sources						
RE Canola Oil	2095.95[abc]	1264.15	1.661[bcd]	0.60[ab]	3.09[ab]	545.31[ab]
RE Fish Oil	2185.74[ab]	1185.86	1.846[ab]	0.54[bc]	2.79[bc]	410.73[c]
RE Palm Oil	2030.49[abc]	1147.37	1.771[abc]	0.57[bc]	2.88[bc]	452.29[bc]
RE Poultry Oil	1959.47[bc]	1279.52	1.537[d]	0.65[a]	3.36[a]	571.18[a]
LE Canola Oil	1861.60[c]	1140.07	1.633[cd]	0.61[ab]	3.10[ab]	499.66[bc]
LE Fish Oil	2188.68[ab]	1187.10	1.843[abc]	0.54[bc]	2.77[bc]	460.45[abc]
LE Palm Oil	2232.04[a]	1150.31	1.939[a]	0.52[c]	2.63[c]	423.68[c]
LE Poultry Oil	2097.08[abc]	1147.56	1.829[abc]	0.55[bc]	2.79[bc]	449.68[abc]
SEM	***57.8***	***32.8***	***0.05***	***0.01***	***0.08***	***25.0***
P Value	***0.005***	***0.074***	***0.005***	***0.004***	***0.004***	***0.02***

SEM, standard error of the mean;
P>0.05: Non-Significant, P≤0.05: Significant

Table 6. Effect of energy levels and oil sources on growth performance (8-35 days).

	Feed Intake (g)	Weight gain (g)	FCR (FI:WG)	Feed efficiency (WG:FI)	PER	EPEF
Energy Density						
RE	3187.10	1820.49[a]	1.755[b]	0.57[a]	2.81[a]	389.80[a]
LE	3230.02	1768.04[b]	1.827[a]	0.55[b]	2.68[b]	369.60[b]
SEM	***30.3***	***12.6***	***0.02***	***0.001***	***0.03***	***6.82***
P Value	***0.326***	***0.007***	***0.013***	***0.015***	***0.005***	***0.047***
Oil Sources						
Canola Oil	3116.37[b]	1813.83[a]	1.719[b]	0.58[a]	2.85[a]	414.49[a]
Fish Oil	3304.92[a]	1789.17[ab]	1.848[a]	0.54[b]	2.66[b]	351.11[b]
Palm Oil	3278.88[ab]	1741.54[b]	1.883[a]	0.53[b]	2.60[b]	355.28[b]
Poultry Oil	3134.07[b]	1832.53[a]	1.715[b]	0.59[a]	2.88[a]	397.91[a]
SEM	***42.8***	***17.8***	***0.03***	***0.001***	***0.04***	***9.65***
P Value	***0.007***	***0.008***	***0.0001***	***0.0001***	***0.0001***	***0.0001***
Energy Density x Oil Sources						
RE Canola Oil	3241.62[abc]	1866.52[ab]	1.738[bc]	0.58[abc]	2.84[ab]	422.60[ab]
RE Fish Oil	3310.10[ab]	1792.21[abc]	1.848[ab]	0.54[bc]	2.67[bc]	327.51[d]
RE Palm Oil	3151.44[abc]	1720.59[c]	1.835[ab]	0.55[bc]	2.66[bc]	367.67[bcd]
RE Poultry Oil	3045.25[bc]	1902.65[a]	1.601[c]	0.63[a]	3.08[a]	441.40[a]
LE Canola Oil	2991.12[c]	1761.13[bc]	1.700[bc]	0.59[ab]	2.85[ab]	406.38[abc]
LE Fish Oil	3299.75[ab]	1786.13[abc]	1.847[ab]	0.54[bc]	2.65[bc]	374.72[bcd]
LE Palm Oil	3406.33[a]	1762.49[bc]	1.932[a]	0.52[c]	2.54[c]	342.88[cd]
LE Poultry Oil	3222.89[abc]	1762.41[bc]	1.829[ab]	0.55[bc]	2.68[bc]	354.42[cd]
SEM	***60.5***	***25.1***	***0.04***	***0.01***	***0.06***	***13.6***
P Value	***0.002***	***0.004***	***0.008***	***0.005***	***0.01***	***0.001***

SEM, standard error of the mean;
P>0.05: Non-Significant, P≤0.05: Significant

Effect of energy levels and oil sources on carcass characteristics in broiler: The results of carcass characteristics are given in table 7. Dressing percentage was higher (P ≤ 0.05) in birds fed RE diet than those fed LE diet. However, dressing percentage was not affected (P > 0.05) by different oil sources. There was no interaction (P > 0.05) between energy levels and oil sources on dressing percentage. Breast yield (including wings and neck), thigh yield (included drumstick), heart weight and gizzard weight were not different in birds fed different energy levels and oil sources. Birds received diet containing fish oil had higher (P ≤ 0.05) liver weight and abdominal fat deposition than those fed diet having canola, palm and poultry oil. Abdominal fat deposition and liver weight were higher (P ≤ 0.05) in birds received diet having low energy and fish oil.

Table 7. Effect of energy levels and oil sources on carcass characteristics.

	Dressing percentage (%)	Breast yield (%)*	Thigh yield (%)*	Heart weight (%)**	Gizzard weight (%)**	Liver weight (%)**	Abdominal fat (%)**
Energy Density							
RE	63.34[a]	61.83	38.17	0.66	1.45	2.51	1.53
LE	61.44[b]	61.43	38.57	0.60	1.49	2.64	1.50
SEM	***0.51***	***0.25***	***0.25***	***0.03***	***0.06***	***0.07***	***0.06***
P Value	***0.011***	***0.26***	***0.26***	***0.16***	***0.56***	***0.16***	***0.711***
Oil Sources							
Canola Oil	62.75	61.58	38.42	0.64	1.49	2.54[ab]	1.50[ab]
Palm Oil	61.83	61.59	38.41	0.58	1.42	2.32[b]	1.35[b]
Fish Oil	61.59	61.67	38.33	0.60	1.45	2.84[a]	1.68[a]
Poultry Oil	63.38	61.69	38.31	0.69	1.52	2.61[ab]	1.54[ab]
SEM	***0.73***	***0.35***	***0.35***	***0.04***	***0.08***	***0.09***	***0.08***
P Value	***0.28***	***0.99***	***0.99***	***0.19***	***0.79***	***0.003***	***0.045***
Energy Density x Oil Sources							
RE Canola Oil	62.91	61.61	38.39	0.64	1.43	2.66[ab]	1.51[ab]
RE Palm Oil	62.68	62.00	38.00	0.60	1.47	2.30[b]	1.46[ab]
RE Fish Oil	63.56	61.86	38.14	0.65	1.45	2.53[b]	1.59[ab]
RE Poultry Oil	64.19	61.86	38.14	0.73	1.45	2.55[b]	1.57[ab]
LE Canola Oil	62.58	61.54	38.46	0.63	1.56	2.42[b]	1.49[ab]
LE Palm Oil	60.99	61.18	38.82	0.56	1.38	2.34[b]	1.25[b]
LE Fish Oil	59.62	61.47	38.53	0.55	1.44	3.15[a]	1.77[a]
LE Poultry Oil	62.57	61.53	38.47	0.66	1.60	2.67[ab]	1.50[ab]
SEM	***1.03***	***0.50***	***0.50***	***0.06***	***0.11***	***0.13***	***0.11***
P Value	***0.37***	***0.90***	***0.90***	***0.85***	***0.67***	***0.018***	***0.38***

SEM, standard error of the mean;
P>0.05: Non-Significant, P≤0.05: Significant
*Breast and thigh yield (% to carcass weight)
**Relative organ (liver, gizzard and heart) weight and abdominal fat (% to live weight)

Effect of energy levels and oil sources on meat quality parameters in broiler: Results of breast meat quality parameters are given in table 8. Water holding capacity or broiler breast meat was higher (P ≤ 0.05) in birds fed diets with RE compared to those fed LE diet. Higher (P ≤ 0.05) water holding capacity was observed in birds fed diet containing canola oil. There was an interaction (P ≤ 0.05) between energy levels and oil sources on water holding capacity. Cooking losses and pH of the breast meat were not affected (P > 0.05) by energy levels and different oil sources. There was no interaction (P > 0.05) between energy levels and different oil sources in cooking loss and pH.

Effect of energy levels and oil sources on nutrient digestibility in broiler at 21 day: Results of nutrient digestibility at 21st day are given in table 9. Birds fed diet having recommended and lower energy had no effect (P > 0.05) on DM, EE and CP digestibility (%). Further, different oil sources (canola, palm, poultry and fish oil) had no effect (P > 0.05) on DM, EE and CP digestibility (%) at 21st day. However, DM digestibility (%) was higher (P ≤ 0.05) in birds fed poultry oil and recommended energy while it was lower (P ≤ 0.05) in birds received diet having poultry oil and low energy.

Effect of energy levels and oil sources on nutrient digestibility in broiler at 35 day: Results of nutrient digestibility at 35th day are given in table 9. Birds fed diet having recommended and lower energy had no effect (P > 0.05) on DM, EE and CP digestibility (%). However, birds fed diet having poultry and canola oil had greater (P ≤ 0.05) DM, CP and EE digestibility (%) at 35th day than those fed diet having palm and fish oil. Highest (P ≤ 0.05) DM and EE digestibility were observed in birds received diet having poultry oil with recommended energy. Highest

($P \leq 0.05$) CP digestibility was observed in birds offered diet having canola oil with recommended energy and lowest ($P \leq 0.05$) CP digestibility was shown in birds offered diet having palm oil with low energy.

Effect of energy levels and oil sources on economics performance in broiler: Poultry oil-based diet had lower ($P \leq 0.05$) production cost per kg than others oils (Table 10). Further, birds fed diet having recommended energy and poultry oil had lower ($P \leq 0.05$) production cost per kg than fish oil and recommended energy (Table 11).

Table 8. Effect of energy levels and oil sources on meat quality parameters.

	WHC (%)	Cooking loss (%)	pH
Energy Density			
RE	60.38[a]	25.27	6.05
LE	55.45[b]	27.33	6.03
SEM	***1.12***	***0.89***	***0.03***
P Value	***0.005***	***0.124***	***0.681***
Oil Sources			
Canola Oil	63.31[a]	25.88	6.11
Fish Oil	53.31[c]	27.60	6.09
Palm Oil	54.93[bc]	24.60	5.96
Poultry Oil	60.11[ab]	27.13	6.00
SEM	***1.59***	***1.27***	***0.05***
P Value	***0.001***	***0.364***	***0.120***
Energy Density x Oil Sources			
RE Canola Oil	65.89[a]	24.97	6.17
RE Fish Oil	56.13[abc]	25.72	6.04
RE Palm Oil	57.04[abc]	23.63	6.02
RE Poultry Oil	62.46[ab]	26.76	5.97
LE Canola Oil	60.73[abc]	26.78	6.05
LE Fish Oil	50.49[abc]	29.48	6.14
LE Palm Oil	52.82[bc]	25.57	5.91
LE Poultry Oil	57.75[c]	27.50	6.03
SEM	***2.25***	***1.80***	***0.07***
P Value	***0.990***	***0.864***	***0.278***

SEM, standard error of the mean; WHC: water holding capacity
P>0.05: Non-Significant, P≤0.05: Significant

Table 9. Effect of energy levels and oil sources on nutrient digestibility in broiler.

	21 day			35 day		
	DM %	EE %	CP %	DM %	EE %	CP %
Energy Density						
RE	73.57	70.29	63.71	69.32	66.42	65.07
LE	72.00	70.05	63.14	68.35	65.59	63.76
SEM	***0.61***	***0.93***	***1.04***	***0.34***	***0.71***	***0.59***
P Value	***0.081***	***0.855***	***0.703***	***0.057***	***0.414***	***0.133***
Oil Sources						
Canola Oil	73.17	71.67	63.89	70.18[ab]	66.75[ab]	66.51[a]
Fish Oil	72.20	70.34	61.51	68.31[b]	64.42[b]	64.28[ab]
Palm Oil	71.59	67.66	62.69	66.28[c]	63.84[b]	61.08[b]
Poultry Oil	74.18	70.99	65.60	70.56[a]	69.00[a]	65.79[a]
SEM	***0.86***	***1.32***	***1.48***	***0.49***	***0.99***	***0.84***
P Value	***0.189***	***0.178***	***0.267***	***0.001***	***0.005***	***0.001***
Energy Density x Oil Sources						
RE Canola Oil	74.53[ab]	73.73	64.43	70.74[ab]	66.18[ab]	66.89[a]
RE Fish Oil	72.04[ab]	70.29	63.00	68.82[abc]	65.92[ab]	65.84[ab]
RE Palm Oil	70.32[b]	64.99	60.02	66.38[c]	63.16[b]	61.50[ab]
RE Poultry Oil	77.39[a]	72.14	67.38	71.33[a]	70.41[a]	66.04[ab]
LE Canola Oil	71.80[ab]	69.61	63.35	69.63[ab]	67.33[ab]	66.12[ab]

LE Fish Oil	72.36^{ab}	70.39	60.02	67.80^{bc}	62.92^{b}	62.73^{ab}
LE Palm Oil	72.86^{ab}	70.33	65.36	66.19^{c}	64.51^{ab}	60.65^{b}
LE Poultry Oil	70.96^{b}	69.85	63.82	69.78^{ab}	67.59^{ab}	65.55^{ab}
SEM	***1.22***	***1.86***	***2.09***	***0.69***	***1.41***	***1.19***
P Value	***0.007***	***0.09***	***0.155***	***0.795***	***0.253***	***0.668***

SEM, standard error of the mean;
P>0.05: Non-Significant, P≤0.05: Significant

Table 10. Effect of energy levels and oil sources on economics efficiency (Main effect).

Production Cost (Rs.)	**Energy levels**		**SEM**	**P-value**	**Oil Sources**				**SEM**	**P-value**
	Recommended Energy	**Low Energy**			**Canola Oil**	**Fish Oil**	**Palm Oil**	**Poultry Oil**		
Starter Phase (8-21 days)										
Bird cost	34.0	34.0	-	-	34.0	34.0	34.0	34.0	-	-
Average feed intake (g)	1112.3	1135.2	20.5	0.438	1123.7	1117.7	1147.6	1105.8	29.0	0.777
Feed cost / kg	55.9	52.7	-	-	54.1	56.0	54.0	53.1	-	-
Feed cost / bird	62.2	59.8	1.12	0.140	60.8	62.6	61.9	58.7	1.58	0.342
Finisher Phase (22-35 days)										
Average feed intake (g)	2067.9	2094.8	28.9	0.516	1978.8^{b}	2187.2^{a}	2131.3^{ab}	2028.3^{ab}	40.9	0.006
Feed cost / kg	55.7	52.6	-	-	54.3	57.3	53.3	51.6	-	-
Feed cost / bird	115.3^{a}	110.1^{b}	1.53	0.026	107.5^{bc}	125.3^{a}	113.6^{b}	104.5^{c}	2.17	0.0001
Overall Period (8-35 days)										
Feed cost / bird	177.5^{a}	169.9^{b}	1.68	0.004	168.3^{bc}	187.9^{a}	175.5^{b}	163.2^{c}	2.38	0.0001
Miscellaneous[1]	25.0	25.0	-	-	25.0	25.0	25.0	25.0	-	-
Production cost / bird[2]	236.5^{a}	228.9^{b}	1.68	0.004	227.3^{bc}	246.9^{a}	234.5^{b}	222.2^{c}	2.38	0.0001
Average body weight (g)	1964.4^{a}	1914.2^{b}	12.4	0.008	1958.0^{a}	1935.7^{ab}	1887.4^{b}	1976.2^{a}	17.5	0.009
Production cost / kg	120.7	119.6	1.02	0.451	116.1^{b}	127.6^{a}	124.3^{a}	112.6^{b}	1.44	0.0001

[1] Miscellaneous cost include vaccination cost, farm preparation and brooding expenditures
[2] Production cost per bird = Bird cost + Feed cost per bird + Miscellaneous
a-c values of superscript different in row differ significantly

Table 11. Effect of energy levels and oil sources on economics efficiency (Simple effect).

Production Cost (Rs.)	**Recommended Energy**				**Low Energy**				**SEM**	**P-value**
	Canola Oil	**Fish Oil**	**Palm Oil**	**Poultry Oil**	**Canola Oil**	**Fish Oil**	**Palm Oil**	**Poultry Oil**		
Starter Phase (8-21 days)										
Bird cost	34	34	34	34	34	34	34	34	-	-
Average feed intake (g)	1117.9	1124.4	1121.0	1085.8	1129.5	1111.1	1174.3	1125.8	41.1	0.852
Feed cost / kg	56.0	58.4	55.3	53.9	52.2	53.5	52.7	52.3	-	-
Feed cost / bird	62.6	65.7	62.0	58.5	58.9	59.5	61.9	58.9	2.24	0.417
Finisher Phase (22-35 days)										
Average feed intake (g)	2096.0^{abc}	2185.7^{ab}	2030.5^{abc}	1959.5^{bc}	1861.6^{c}	2188.7^{ab}	2232.0^{a}	2097.1^{abc}	57.8	0.005
Feed cost / kg	55.8	59.8	54.6	52.3	52.7	54.7	52.0	50.8	-	-
Feed cost / bird	117.1^{ab}	130.8^{a}	111.0^{bcd}	102.5^{cd}	98.0^{d}	119.8^{ab}	116.1^{bc}	106.6^{bcd}	3.06	0.001
Overall Period (8-35 days)										
Feed cost / bird	179.7^{b}	196.5^{a}	172.9^{bc}	161.0^{cd}	157.0^{d}	179.3^{b}	178.0^{b}	165.4^{bcd}	3.37	0.0001
Miscellaneous[1]	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	-	-
Production cost / bird[2]	238.7^{b}	255.5^{a}	231.9^{bc}	220.0^{cd}	216.0^{d}	238.3^{b}	237.0^{b}	224.4^{bcd}	3.37	0.0001
Average body weight (g)	2009.6^{ab}	1939.1^{abc}	1865.4^{c}	2043.3^{a}	1906.3^{bc}	1932.2^{abc}	1909.3^{bc}	1909.2^{bc}	24.7	0.005
Production cost / kg	118.8^{bc}	131.8^{a}	124.5^{ab}	107.7^{d}	113.4^{cd}	123.3^{ab}	124.1^{ab}	117.6^{bc}	2.04	0.001

[1] Miscellaneous cost include vaccination cost, farm preparation and brooding expenditures
[2] Production cost per bird = Bird cost + Feed cost per bird + Miscellaneous; a-d values of superscript different in row differ significantly

DISCUSSION

Weight gain, PER, EPEF, FE and FCR were improved ($P \leq 0.05$) in birds received diet having poultry oil and canola oil as compared to those fed diets having fish and palm oil due to the highest level of unsaturated fatty acids in canola oil which are converted by birds to omega-3 fatty acids. Further, lower level of FFA and POV in poultry oil increased its digestion and absorption unlike fish oil which had higher value of FFA and POV leads to poor performance (table 3). In accordance with present study, it was reported that the addition of poultry fat and canola oil at 3% in broiler diet had higher weight gain and better FCR than those receiving 6% canola oil and poultry fat alone or in combination (Shahryar *et al.,* 2011). This might be due to the higher amount of metabolizable energy in canola oil and the highest capability of digestion and absorption of unsaturated fatty acids that exists in canola oil (as a high content) is the main factor that birds can keep their energy received with reduction of feed consumption. Likewise, use of vegetable oil like sunflower oil in broiler diet had greater WG and improved FCR than those fed palm oil (Khatun *et al.,* 2018). Broiler birds fed diet containing soybean oil had higher WG and better FCR than those fed poultry fat and tallow oil (Zhang *et al.,* 2011). Contrarily, no effect of chicken tallow and soybean oil in broiler were observed on FI, WG and FCR (Polycarpo *et al.,* 2014). Birds fed diet containing beef tallow and canola oil had similar WG, FI and FCR (Meng *et al.,* 2004).

Higher ($P \leq 0.05$) dressing % was observed in birds fed recommended energy diet than those fed low energy diet. Probably birds fed diet having low energy diet had higher proportion of visceral organs resulting in lower dressing percentage. Breast yield, thigh weight, heart weight and gizzard weight were similar in birds fed different energy levels and oil sources. Addition of poultry fat and canola oil in broiler diet had lower gizzard weight and higher abdominal fat, while, breast yield, thigh yield and liver weight were no affected by oil sources (Shahryar *et al.,* 2011). Different fat sources (chicken tallow and soybean oil) in broiler diet had similar effect on carcass yield; drumstick and chest yield (Polycarpo *et al.,* 2014). Soybean oil and poultry fat in broiler diet had similar effect on carcass, breast and thigh yield (Neto *et al.,* 2011). Use of palm oil, sunflower oil and their combination in broiler diet had similar effect on breast muscle pH, cooking loss and breast meat color (Khatun *et al.,* 2018). Liver weight was higher in birds fed fish oil-based diet. This might be due to that fish oil contains higher content to free fatty acid which causes oxidation in liver which cause increase in size.

Different oil sources (canola, palm, refined poultry and fish oil) had no effect on DM, EE and CP digestibility at 21 day. Similar outcomes were noted by Abdulla *et al.* (2016) who revealed that different fat sources (soybean, palm and linseed) in broiler diet had similar organic matter, ether extract, crude protein and ash digestibility. Further, different oil sources (beef tallow and canola oil) in broiler diet had similar effect on fat, starch and nitrogen digestibility (Meng *et al.,* 2004).

Birds fed diet having poultry and canola oil had higher DM, CP and EE digestibility at 35th day than those fed diet having palm and fish oil. This is due to that canola and poultry oil had lower adulteration and higher caloric value unlike fish oil which had higher value of FFA and POV value and lower digestibility. Results are in line with the outcome of Polycarpo *et al.* (2014) who observed that vegetable oil like soybean oil in broiler diet resulted in greater digestibility coefficient of nitrogen in broiler birds than those fed chicken tallow. Apparent digestibility coefficient of fat in birds fed soybean oil was higher than those received tallow oil (Tancharoenrat *et al.,* 2014). Higher net profit in birds fed diet having poultry oil is due to higher body weight and low price or poultry oil as compared to canola, palm and fish oil.

Conclusion: It was concluded from the results that birds fed diet having canola and poultry oil had improved growth performance, dressing percentage and meat quality than those fed palm oil and fish oil. However, in term of economics, addition of refined poultry oil in recommended energy diet is beneficial.

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