Heliyon 7 (2021) e08297

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Effect of dietary replacement of soybean meal with linseed meal on feed intake, growth performance and carcass quality of broilers

Negasa Tamasgen [a,*], Mengistu Urge [b], Meseret Girma [b], Ajebu Nurfeta [c]

[a] Department of Animal Science, Wollega University, P. O. Box 395, Nekemte, Ethiopia
[b] School of Animal and Range Sciences, Haramaya University, P.O. Box 138, Dire-Dawa, Ethiopia
[c] School of Animal and Range Sciences, Hawassa University, P.O. Box 5, Hawassa, Ethiopia

ARTICLE INFO

Keywords:
Broilers
Carcass parameters
Linseed meal
Soybean meal

ABSTRACT

To increase the chicken's productivity and performance it is imperative to exploit underutilized oil crops such as linseed meal as protein source. This study evaluated the effect of replacing soybean meal with graded levels of linseed meal on feed intake, growth performance and carcass parameters of broiler chickens. A total of 180 day-old Cobb500 broilers were distributed to five treatment diets in a completely randomized design replicated three times with 12 chicks each. Isocaloric and isonitrogenous treatment diets formulated were T1 (0%, diet with no linseed meal), T2 (25%), T3 (50%), T4 (75%) and T5 (100%, soybean meal in the diet was replaced by linseed meal). The feeding experiment lasted for 44 days. The total feed intake, mortality rate and feed conversion ratio (FCR) during starter phase were similar ($P > 0.05$) among treatments. High ($P < 0.05$) starter phase body weight was recorded for T3 compared to T1, T2, T4 and T5 treatments but T2, T4 and T5 had similar average daily gain. The feed intake, body weight change, FCR and mortality during finisher phase and entire period were similar ($P > 0.05$) among treatment groups. The weight of most carcasses were similar ($P > 0.05$) among treatment except the weight of kidney, heart, breast, liver and abdominal fat. Kidney weight for T1 and T3 were higher ($P < 0.05$) than for T2, T4 and T5. The weight of heart for T3 was higher than T2 and T5 while T1, T3 and T4 were similar ($P > 0.05$). High ($P < 0.05$) breast weight were observed for T3 than T2 and T4. Liver weight for T3 was greater ($P < 0.05$) than T2 and T5. The total feed cost decreased with increasing levels of linseed meal. High net return was obtained from T3 followed by T4 and T2. The results showed that although linseed meal can replace 100% soybean meal in the ration without detrimental effect on the health, replacement at 50% (T3) is recommended for better performance of broilers.

1. Introduction

The prominence of poultry production is primarily due to the short generation interval and relatively quick turn over on investment and high quality protein from products (Dessie et al., 2017). Large numbers of chickens across the world are reared under commercial poultry production systems. But, this production system in developing countries like Ethiopia is not a common practice and limited to urban areas (Habte et al., 2017). Even though chicken production in Ethiopia is based mainly on the scavenging village production system, there are a growing number of commercial poultry producers (Habte et al., 2017). The capacity of commercial poultry producers varies according to the area they are located, technical know-how and the resources required to start intensive poultry production. Therefore, most commercial chicken production in Ethiopia are comprised of small and medium-scale producers (Habte et al., 2017).

Chicken is the largest livestock species accounting for more than 30% of all animal protein consumption in Ethiopia (Getu and Birhan, 2014). The estimated annual production of chicken meat in Ethiopia is 61,840 tons, which account for a 1.3% share of a production in Africa and an 11.7% share in East Africa (FAOSTAT, 2017; Teshome et al., 2019). Poultry meat account for about 33% of the world meat consumption (Ahmed et al., 2018) and consumers' demand for poultry meat is ever increasing. Chicken meat is generally regarded as better than red meat because it is a white meat which contains less fat and cholesterol, easy to handle portions and has no religious restrictions unlike pork and beef (Liu et al., 2012; Ahmed et al., 2018).

* Corresponding author.
E-mail address: seenaashee@gmail.com (N. Tamasgen).

https://doi.org/10.1016/j.heliyon.2021.e08297
Received 11 May 2021; Received in revised form 3 July 2021; Accepted 27 October 2021

Recently linseeds by-products have attracted considerable attention due to the presence of bioactive compound poly-unsaturated fatty acids such as omega-3 fatty acid and conjugated linoleic acid (Meherunnisa et al., 2017). Additionally, linseed contains all essential amino acid of the protein. It is an excellent source of fiber, lecithin, vitamins and minerals. Moreover, linseed is of fastidious significance for its role in lowering the risk of breast and colon cancers in humans (Diederichsen and Richards, 2003; Anjum et al., 2013). Most of the feed crops consumed by poultry are also staple food of human which make competitive. Hence, replacing highly demanded crops and less available agro-industrial by-products by more available unconventional source of protein and energy is one of the solutions to reduce cost of production and contribute to increased supply of animal protein to reach of poor people (Amin and Cheah, 2010; Melese et al., 2017).

Soybean meal is crucial protein sources in poultry diet. But its high cost and less availability compared with linseed drive producers to look for alternative affordable feed resources. One of such feed could be linseed meal. The potential of linseed production in Ethiopia is related to the presence of different socio-cultural conditions, diverse tropical and sub-tropical and mountainous topography which support high genetic diversity of linseed (Worku and Heslop-Harrison, 2018). Linseed is produced in different parts of Ethiopia in which stakeholders particularly farmers are widely involved in its production along other cereal and oil crops. Indeed, consumers including small processing plants are utilizing linseed as input for oil production with linseed meal (cake) as a by-product. Despite its benefits, linseed meal by-product is not widely utilized as poultry diet in Ethiopia. Therefore, the objectives of this study were to evaluate the effect of replacement of soybean meal with linseed meal on feed intake, growth performance, carcass parameters and its economic feasibility in broilers.

2. Materials and methods

2.1. Description of the study area

The experiment was conducted at Haramaya University Poultry farm located at 42° 3′ East Longitude and 9° 26' North Latitude at an altitude of 1980 m above sea level. The mean annual rainfall of the area amounts to 780 mm and the average minimum and maximum temperatures are 8 and 24 °C, respectively (Samuel, 2008).

2.2. Management of experimental animals

The experimental house was thoroughly cleaned, washed and the floor was covered with grass hay and was disinfected before the placement of the experimental birds in the pens. Infra-red lamp providing 250 W was fitted for each pen. Circular plastic feeders and waterers were also placed in the pens. A total of one hundred and eighty (180) day-old unsexed Cobb 500 chicks were purchased from Alema Private Farms, Bishoftu and were used for feeding trial. Feed was offered *ad libitum* (10% refusal). The daily offer was presented in two portions at 0800 and 1600 h. Water was available all time. Vitamin premix was provided with water for seven consecutive days following the arrival of day old chicks to the farm. Body weight was measured at the beginning and at the end and at a weekly interval during the experiment using sensitive balance. Chickens were vaccinated against Newcastle disease (HB1) at day 7 and Lasota a booster dose at day 21 through eye drop.

2.3. Design of the experiment and ingredients

The ingredients used for experimental ration preparation were nougseed cake (NSC), wheat short, linseed meal (LM), soyabean meal (SBM), salt, vitamin premix and limestone. The SBM, NSC and Vitamin and mineral premix were purchased from GASCO Trading PLC, Addis Ababa. Maize, wheat short and salt was purchased from local market of Haramaya town. Limestone was taken from Haramaya University poultry farm. Linseed meal was purchased from Adama edible oil factory. Treatment rations were formulated to be isocaloric and isonitrogenous using Win Feed 2.8 software to meet the nutrient requirement standards for broilers (NRC, 1994). Accordingly, each of the starter treatment rations contained about 3100 Kcal/kg DM of metabolisable energy and 22% of crude protein, while the finisher ration had 3200 kcal/kg DM of metabolisable energy and 20% crude protein. The treatment rations designated as T1, T2, T3, T4 and T5, were formulated with T1 containing 26 g (100% SBM), which is recommended as an economic maximum level of inclusion in chicken ration (Senayt, 2011). Then the treatments T1, T2, T3, T4 and T5 were formulated with the percentage of replacement of Soybean meal by Linseed meal at 0%, 25%, 50%, 75% and 100%, respectively (Table 1). The five treatment rations were assigned to the pens with three replicates consisting 12 chicks per replicate. The design of the experiment was completely randomized design (CRD). The experiment lasted for a 44 days of feeding trial.

2.4. Feed intake, body weight gain and feed conversion ratio

The measured quantity of feed offered and refused per replication was recorded daily and amount of feed consumed was determined as a difference. The following formula was employed to calculate the daily intake.

$$\text{Feed intake} / \text{chick}/\text{day} = \frac{\text{Total offered} - \text{Total Refusal}}{\text{No.of experimental days x No.of chicks}} \quad (1)$$

The average daily body weight gain was computed as body weight change divided by the number of experimental days. Mean feed conversion ratio was determined by dividing the mean daily feed intake to the average daily weight gain of chicks. Mortality was recorded when occurred and general health status was monitored during the whole experimental period.

Table 1. Ingredients proportion of starter and finisher broiler chickens ration.

Phase	Ingredients (%)	Treatments				
		T1	T2	T3	T4	T5
Starter phase	Maize	44.5	43.2	36.3	33.8	30.5
	Wheat short	13.25	12.26	17.35	17.92	18.84
	Linseed meal	0	6.5	13	19.5	26
	Soybean meal	26	19.5	13	6.5	0
	Nougseed cake	13.25	15.54	17.35	19.28	21.66
	Vitamin and mineral premix	1	1	1	1	1
	Salt	0.5	0.5	0.5	0.5	0.5
	Limestone	1.5	1.5	1.5	1.5	1.5
Finisher phase	Maize	45	40.2	36.2	34.1	35.5
	Wheat short	13	15.4	17.4	18.45	18.75
	Linseed meal	0	6.5	13	19.5	26
	Soybean meal	26	19.5	13	6.5	0
	Nougseed cake	13	15.4	17.4	18.45	18.75
	Vitamin and mineral premix	1	1	1	1	1
	Salt	0.5	0.5	0.5	0.5	0.5
	Limestone	1.5	1.5	1.5	1.5	1.5

T1, T2, T3, T4 and T5 = 0%, 25%, 50%, 75% and 100% of replacement of Soybean meal by Linseed meal, respectively, Vitamin premix 50 kg contains, Vit A 1000000iu, Vit D3 200000iu, Vit E 10000 mg, Vit K3 225 mg, Vit B1 125 mg, Vit B2 500 mg, Vit B3 1375 mg, Vit B6 125 mg, Vit B12 1 mg, Vitpp (Niacin) 4000000 mg, Folic acid, 100 mg, Choline chloride 37500 mg, Anti-oxidant (BTHT) 0.05%, Manganese 0.60%, Zinc 0.70%, Iron 0.45%, Copper 0.05%, Sodium 0.01%, Selenium, 0.004%, Calcium 2.7%.

2.5. Carcass yield characteristics

At the end of the experiment a total of 30 birds, 6 per treatment and 2 per replication were randomly taken for carcass evaluation. Slaughtering procedure was approved by Haramaya University Animal Welfare Ethical Committee formed from School of Animal and Range Sciences and Research Affairs. The birds were starved for 12 h, and weighed just before slaughter. Birds slaughtered were de-feathered by hand plucking, eviscerated and carcass cuts and non-edible offal components were determined according to the procedure described by Kekeocha (1985). Dressed weight was measured after the removal of blood, feathers, lower leg, head, kidney, lungs, pancrease, crop, proventriculus, small intestine, large intestine, cloaca and urogenital tracts were removed. Dressed percentage was determined following FAO (2001).

$$\text{Dressing }\% = \frac{\text{Dressed weight}}{\text{Slaughter weight}} * 100 \tag{2}$$

From eviscerated carcass weight, drumstick, thigh and breast meat were separated and weighed, then their respective percentage weights was determined by dividing slaughter weight and multiplied by 100. Fat trimmed from proventriculus up to cloaca was weighed. The edible offal's (giblets), which include the heart, gizzard and liver were weighed in relation to slaughter weight. Non edible offal's, which include spleen, lung, crop proventriculus, small and large intestine, and ceca weights were also measured.

2.6. Chemical analysis

Dried feed samples were milled to pass through 1 mm sieve screen. Samples of feed ingredients were analyzed for dry matter, ether extract, crude fibre and ash following the proximate analysis method (AOAC, 2000). Nitrogen content was determined by Kjeldahl method (Elinge et al., 2012) and crude protein was calculated as N x 6.25. Calcium and phosphorus content was analyzed by atomic absorption spectroscopy and spectrophotometer method, respectively (AOAC, 1998) at Haramaya University Laboratory. Dry matter based metabolisable energy (Kcal/kg) content of the experimental diets was calculated by indirect method from the equation proposed by Wiseman (1987).

$$ME\left(\frac{Kcal}{kg}DM\right) = 3951 + 54.4EE - 88.7CF - 40.8ash \tag{3}$$

ME = metabolisable energy, EE = ether extraxt, CF = crude fiber.

2.7. Economic analysis

Economic efficacy of feeding ration containing graded levels of linseed meal as soybean meal replacement was evaluated by calculating European Broiler Index (EBI) and Production Efficiency Factor (PEF) (Marcu et al., 2013).

$$EBI = \frac{\text{Viability}(\%) \text{ x ADG } (g/chick/d)}{\text{FCR}(kg\ feed/kg\ gain) \text{ x } 10} \tag{4}$$

$$PEF = \frac{\text{Viability } (\%) \text{ x BW } (kg)}{\text{Age}(d) \text{ x FCR}(kg\ feed/kg\ gain) \text{ x } 10} \tag{5}$$

where: Viability (%) = chicks alive at the end of the period (%), Age (day) = the age of the chick at slaughter, BW = final live body weight of the broilers, ADG = Average daily gain.

Partial budget of replacing soybean meal with linseed meal was computed according to the principles developed by Upton (1979).

$$NI = TR - TVC \tag{6}$$

NI = net income, (TR = total return, TVC = total variable cost).

$$\Delta NI = \Delta TR - \Delta TVC \tag{7}$$

ΔNI = change in net income, ΔTR = change in total return, ΔTVC = change in total variable cost

$$MRR = \Delta NI/\Delta TVC * 100 \tag{8}$$

MRR = marginal rate of return, ΔNI = change in net income, ΔTVC = change in total variable cost.

2.8. Statistical analysis

All the data collected were subjected to statistical analyses using general linear model procedure of SAS software (SAS, 2009). Differences between treatment means were separated using Duncan's multiple range tests. The following model was used for data analysis. $Yij = \mu + T_i + e_{ij}$, Where: Yij = is an observation (response variable), μ = Over all means, T_i = treatment effect of i^{th} treatment and e_{ij} = error term. A two-way ANOVA was performed to determine effects of sex and sex by treatment interactions.

3. Results

3.1. Chemical composition of feed ingredients and treatment diets

The soybean meal CP content (39.8%) was high compared to linseed meal (31%) (Table 2). But, soybean meal ME (2678.4Kcal/kg DM) content was low as compared to linseed meal (3449.0Kcal/kg DM). A slight increase in ether extract content of ration was observed as level of linseed meal increased. The calcium content ranged from 1.0-1.9% and 0.78–0.99% whereas phosphorus ranged from 0.38-0.53% and 0.33–0.45% in starter and finisher diets, respectively and it is within the range recommended for broiler ration (NRC, 1994).

3.2. Feed intake and body weight gain

Total feed intake, mortality rate and feed conversion ratio during starter phase were similar ($P > 0.05$) among treatments (Table 3). High ($P < 0.05$) starter body weight gain was recorded for T3 compared to T1, T2, T4 and T5 treatments but T2, T4 and T5 had similar ($P > 0.05$) average daily gain. The feed intake, body weight change, FCR and mortality during finisher phase and entire period were similar ($P > 0.05$) among treatment groups.

3.3. Carcass characteristics

The weight of most carcasses and offal's were similar ($P > 0.05$) among treatments, while kidney, heart, breast and liver weights in T3 tend to be higher than most of the other treatments ($P < 0.05$). The abdominal fat weight of T1, T2 and T3 were higher ($P < 0.05$) than T5. High ($P < 0.05$) fat weight was observed in female whereas there was no effect of sex by treatment interaction (Table 4).

3.4. Non-edible offal parameters of broiler chickens

Spleen, large intestine and ceaca weights and large intestine and ceaca length were similar ($P > 0.05$) among treatments (Table 5). Treatment three had greater ($P < 0.05$) lung, crop, proventriculus and small intestine weight than most of the other treatments. There was no effect ($P > 0.05$) of sex and sex by treatment interaction on non-edible offal.

3.5. Production efficiency and economic return

Both European broiler index (EBI) and Production efficiency factor (PEF) of starter, finisher and entire period were similar ($P > 0.05$) among treatments (Table 6). The total feed cost decreased with increasing levels of linseed meal. High value of net return of broilers was recorded in T3

Table 2. Chemical composition of ingredients and treatment diets (% on DM bases).

Ingredients	% DM	CP	CF	EE	Ash	Ca	P	ME (Kcal/kg DM)
Maize	91.4	9.3	3.8	3.9	3.2	0.14	0.3	3696
Wheat short	91.8	15.7	6.8	3.3	4.6	0.13	0.3	3339.7
Soybean meal	91.9	39.8	12.4	1.4	6.1	0.32	0.7	2678.4
Linseed meal	90.8	31	7.3	8.9	8.3	0.26	0.56	3449.0
Nougseed cake	92.3	29.8	15.2	7.2	12.5	0.31	0.6	2484.4
Starter phase								
T1	91.38	22.95	7.5	9.2	10.8	1.1	0.52	3102.3
T2	90.74	22.94	8.3	9.1	11.7	1.0	0.53	3117.9
T3	91.08	22.43	9.2	10.4	9.32	1.5	0.52	3148.7
T4	92.47	22.20	8.9	11.01	8.05	1.4	0.38	3130.1
T5	90.70	22.01	9	11.05	8.7	1.9	0.46	3105.5
Finisher phase								
T1	91.98	21.01	8.4	9.8	8.07	0.99	0.42	3209.4
T2	91.72	20.86	7.9	9.5	7.54	0.95	0.33	3230.5
T3	90.61	20.29	8.9	10.2	8.01	0.89	0.45	3203.6
T4	92.71	20.06	9.7	11.1	7.02	0.85	0.38	3207.7
T5	90.39	19.92	9.5	11.3	6.12	0.78	0.35	3215.8

T1, T2, T3, T4 and T5 = 0%, 25%, 50%, 75% and 100% of replacement of Soybean meal by Linseed meal, respectively, DM = dry matter, CP = crude protein, EE = ether extract, CF = crude fiber, Ca = calcium, P = phosphorous, ME = metabolisable energy, Kcal = kilocalorie, Kg = kilogram.

Table 3. Effect of replacing soybean meal with linseed meal on feed intake and body weight gain in broilers ration.

Parameters	Treatments					SEM	P-Value
Starter Phase (1–22 days)	T1	T2	T3	T4	T5		
Feed intake/Chick (g/bird)	952.6	873.4	1279.5	1127.2	1115.8	66.08	0.352
Initial body weight (g/bird)	45.89	49.78	52.33	49.56	46.33	1.27	0.530
Final body weight (g/bird)	511.67[b]	448.33[bc]	670.0[a]	495.0[bc]	391.67[c]	28.01	0.002
Body weight change(g/bird)	465.78[b]	398.56[bc]	617.67[a]	445.44[bc]	345.33[c]	27.75	0.002
Average gain (g/day)	21.17[b]	18.12[bc]	28.1[a]	20.25[bc]	15.7[c]	1.26	0.003
Feed conversion ratio	2.11	2.20	2.10	2.64	3.41	0.24	0.364
Mortality (%)	25	11.11	11.11	19.44	22.22	2.68	0.368
Finisher Phase (23–44 days)							
Feed intake/chick (g/bird)	2954.5	2638.2	3105.6	2801.9	2837.9	106.59	0.768
Final body weight (g/bird)	1816.1	1768.3	1743.0	1767.5	1606.5	37.2	0.511
Bodyweight change (g/bird)	1304.4	1319.9	1073.0	1272.5	1214.8	34.9	0.139
Average gain (g/day)	59.3	59.9	48.8	57.8	55.2	1.58	0.138
Feed conversion ratio	2.27	2.01	2.91	2.20	2.41	0.14	0.306
Mortality (%)	2.78	5.56	0	5.56	5.56	1.11	0.452
Entire Experiment (1–44days)							
Feed intake/chick (g/bird)	3907.0	3511.6	4385.1	3929.2	3953.7	139.61	0.463
Initial body weight (g/bird)	45.9	49.8	52.3	49.6	46.3	1.274	0.531
Final body weight (g/bird)	1816.1	1768.3	1743.0	1767.5	1606.5	37.19	0.511
Body weight change (g)	1770.2	1718.5	1690.7	1717.9	1560.2	37.45	0.526
Average gain(g/day)	40.23	39.06	38.42	39.05	35.46	0.85	0.526
Feed conversion ratio	2.23	2.10	2.61	2.28	2.63	0.13	0.606
Mortality (%)	27.78	16.67	11.11	25.0	27.77	2.91	0.274

[a, b, c] Means within a row with different superscripts are significantly different, T1, T2, T3, T4 and T5 = 0%, 25%, 50%, 75% and 100% of replacement of Soybean meal by Linseed meal, respectively, g = gram, SEM = standard error of the mean.

followed by T 4 and T2. High marginal rate of return was observed in T4 followed by T3 and T5.

4. Discussion

4.1. Chemical composition

The CP value of linseed meal was within the range reported in other studies (Geremew et al., 2015; Meherunnisa et al., 2017; Ndou et al., 2018). Little variation in CP contents of linseed meal between studies might be related to variety of linseed, growing agro-ecology and linseed oil processing methods. The calculated metabolisable energy content of linseed meal was higher than the value (2724.67 kcal/kg DM) reported by Ndou et al. (2018). The high metabolisable energy content of linseed meal indicates that it can also be considered as energy source in broilers diets in addition to a source of protein. The metabolisable energy and protein content of treatment rations were within the requirements of starter and finisher broilers (NRC, 1994). The calcium and phosphorous

Table 4. Effect of replacing soybean meal with linseed meal in broilers ration on carcass parameters.

Parameters	Treatments							Sex		T*Sex	
	T1	T2	T3	T4	T5	SEM	P-Value	M	F	P-Value	P-Value
Slaughter weight (g)	1617.5	1657.5	1640.0	1640.8	1460	58.47	0.144	1618.7	1587.7	0.560	0.717
Dreseed weight (g)	1143.7	1217.8	1128.0	1182.5	1107.2	59.91	0.676	1184.5	1127.1	0.280	0.660
Dressing%	70.9	73.5	69.0	72.2	75.5	2.509	0.452	73.23	71.19	0.375	0.585
Kidney weight (g)	9.3^{a}	6.2^{b}	10.7^{a}	6.6^{b}	5.2^{b}	0.824	0.001	7.43	7.73	0.688	0.727
Heart weight (g)	7.8^{abc}	5.3^{c}	9.2^{a}	8.5^{ab}	5.8^{bc}	0.946	0.037	7.5	7.2	0.756	0.387
Gizzard weight (g)	40.5	40	45.5	42.5	40.5	3.62	0.809	42.0	41.6	0.903	0.216
Drumstick weight (g)	128.67	141.33	132.83	125.67	110.33	11.06	0.402	124.4	131.13	0.504	0.657
Drumstick%	7.9	8.5	8.1	7.7	8.1	0.836	0.965	7.81	8.32	0.508	0.880
Thigh weight (g)	147.5	138.17	153.5	122.5	139.17	9.032	0.194	141.67	138.67	0.714	0.403
Thigh%	9.1	8.3	9.4	7.4	9.8	0.606	0.091	8.82	8.76	0.903	0.818
Breast weight (g)	333.8^{ab}	213.7^{cd}	380.3^{a}	279.8^{bc}	194.7^{d}	23.72	0.0007	264.8	196.13	0.155	0.367
Breast%	20.5^{ab}	12.9^{d}	23.0^{a}	16.9^{bc}	13.7^{cd}	1.275	0.0001	16.32	18.55	0.065	0.334
Liver weight (g)	29.8^{ab}	24.3^{cb}	31.3^{a}	27.2^{abc}	21.8^{c}	2.006	0.019	25.87	27.93	0.263	0.850
Abdominal fat weight(g)	18.2^{a}	14.0^{a}	15.5^{a}	11.5^{ab}	2.8^{b}	3.006	0.018	8.67^{b}	16.13^{a}	0.012	0.547

[a, b, c, d] Means within the row with different superscripts are significantly different, SEM = standard error of the mean,T1, T2, T3 T4, and T5 = 0%, 25%, 50%, 75% and 100% of replacement of Soybean meal by Linseed meal, respectively, M = male, F = female, T*S = treatment-sex interaction, g = gram.

Table 5. Effect of replacing soybean meal with linseed meal in broilers ration on non-edible offal.

Parameters	Treatments							Sex		T*Sex	
	T1	T2	T3	T4	T5	SEM	P-Value	M	F	P-Value	P-Value
Spleen weight (g)	1.5	1.17	1.67	1.25	1.17	0.22	0.417	1.37	1.33	0.867	0.766
Lung weight (g)	6.8^{a}	5.3^{ab}	7.2^{a}	6.7^{a}	4.3^{b}	0.58	0.012	6.13	6.0	0.801	0.668
Crop weight (g)	8.2^{ab}	7.83^{ab}	9.3^{a}	5.7^{b}	5.8^{b}	0.87	0.032	7.27	7.47	0.800	0.110
Proventriculus weight (g)	7.7^{ab}	6.3^{bc}	8.7^{a}	6.7^{bc}	5.2^{c}	0.54	0.003	6.6	7.2	0.235	0.564
Small intestine weight (g)	62.5^{ab}	73.8^{a}	74.5^{a}	58.5^{b}	48.5^{b}	4.64	0.004	63.3	63.9	0.887	0.907
Small intestine length (cm)	156.3^{ab}	175.0^{a}	176.3^{a}	144.3^{b}	149.0^{b}	7.42	0.016	160.6	159.8	0.909	0.726
Large intestine weight(g)	3.3	3.0	3.8	2.5	3.2	0.57	0.588	2.87	3.47	0.255	0.526
Large intestine length(cm)	8.27	5.35	7.48	6.75	7.17	0.95	0.311	6.77	7.24	0.585	0.234
Ceca weight (g)	9.17	8.5	9.83	10.3	7.33	1.43	0.621	9.27	8.8	0.720	0.993
Ceca length(cm)	14.1	9.67	13.5	13.5	11.6	1.10	0.057	11.6	13.3	0.095	0.050

[a, b, c, d] Means within the row with different superscripts are significantly different, SEM = standard error of the mean,T1, T2, T3 T4, and T5 = 0%, 25%, 50%, 75% and 100% of replacement of Soybean meal by Linseed meal, respectively, M = male, F = female, T*S = treatment-sex interaction, g = gram, cm = centimeter.

concentration of the ration meets the recommended concentration of 1% Ca, 0.9% Ca; 0.45%P and 0.35%P during starter and finisher phases, respectively (NRC, 1994).

4.2. Feed intake, body weight gain, feed conversion ratio and mortality

The absence of influence of levels of linseed meal on feed intake during starter, finisher and entire phase agreed with Mir et al. (2018) who found no dietary effect on overall (0–42 days) feed intake when 10% linseed meal was fed to broilers. In the contrary, Anjum et al. (2013) reported decreased feed intake with an increase in extruded linseed levels which they attributed to anti-nutritional factors such as cyanide, linatine and mucilages. The high body weight gain noted for starter phase at 50% linseed meal replacement level for soybean was not in accordance with that reported by Anjum et al. (2013) who found significant decrease in body gain with increasing levels of extruded linseed (0, 5, 10 and 15%) fed to broilers. The variation in intake and average daily gain reported in different literature may be related to the ability of different processing methods in reducing the contents of anti-nutritional factors of the seed. The similarity in body weight change during the finisher phase and entire experiment period is consistent with the findings of Liversidge et al. (1997) and Meherunnisa et al. (2017) who reported that cyanide toxicity in linseed can be reduced when properly processed and linseed meal can be used effectively at the level of more than 5%. Similarly, Mir et al. (2018) reported no significant difference on body weight gain and feed intake of broilers up on feeding 10% linseed meal in the compound ration.

The similarity in feed conversion ratio in all phases among different levels of linseed meal agree with the findings of Shafey et al. (2014) who observed that diet with up to 8% of flaxseed meal did not affect the feed conversion ratio. Additionally, Meherunnisa et al. (2017) reported that linseed meal can be utilized efficiently when treated properly to lower its anti-nutritional substance. However, contrary to the current study, Mridula et al. (2015) and Mir et al. (2018) observed significant increase in feed conversion ratio when linseed meal was fed to broilers. The variation in feed conversion ratio is likely related to the linseed processing methods employed to reduce anti-nutritional content to increase nutrient availability and efficiency of utilization to the birds (Anjum et al., 2013). Mortality occurred was greater than the normal range recommended in broiler production, but it did not relate to the level of linseed meal because Chiroque et al. (2018) noted lack of detrimental effects of linseed meal when used in guinea fowls. Aguilar et al. (2011) and Ahmad et al. (2013) have not also observed significant morbidity and mortality in the birds fed linseed meal up to 10% in the ration. The contributing factors for the high loss encountered are associated to ascites due to poor ventilation and high feed intake, fast growth rate and predator mainly rat during the experiment.

Table 6. Production efficiency and economic return of broiler chickens fed linseed meal as a replacement to soybean meal.

Parameters	Treatments						
Production Efficiency	T1	T2	T3	T4	T5	SEM	P-Value
Starter EBI	85.03	73.09	130.38	71.39	40.47	10.766	0.089
Starter PEF	93.17	82.29	141.18	78.74	45.73	11.471	0.094
Finisher EBI	264.62	289.08	169.99	257.06	135.25	18.906	0.364
Finisher PEF	370.14	386.18	275.32	354.81	311.82	23.255	0.612
Entire EBI	139.99	161.82	135.21	128.41	106.02	10.341	0.613
Entire PEF	143.58	166.46	139.31	132.09	109.10	10.564	0.608
Partial Budget Cost (Birr)							
Day old chick cost (Et.Birr)	30	30	30	30	30		
Total feed consumed/bird (kg)	3.91	3.51	4.39	3.93	3.95		
Per unit feed cost (Et.Birr)	13.25	14.27	10.91	11.83	11.48		
Total feed cost (birr/bird)	51.79	50.11	47.88	46.51	45.34		
Revenue (Et.Birr)							
Average carcass weight (kg)	1.14	1.21	1.20	1.18	1.10		
Carcass price (supermarket)	95	95	95	95	95		
Total return (Et.Birr)	108.3	114.95	114	112.1	104.5		
Net return/bird (Et.Birr)	56.51	64.84	66.12	65.59	59.16		
Marginal rate of return	1.09	1.29	1.38	1.41	1.30		

EBI = European broiler index, PEF = Production efficiency factor; T1, T2, T3 T4, and T5 = 0%, 25%, 50%, 75% and 100% of replacement of Soybean meal by Linseed meal, respectively, Kg = kilogram, Et. Birr = Ethiopian Currency, SEM = standard error of the mean.

4.3. Carcass yield and internal organs

The dressed weight observed in the current study is similar with Chiroque et al. (2018) who observed no significant effect on carcass weight up on inclusion of 20% linseed meal in guinea fowls diet. Chiroque et al. (2018) reported improved dressed percentage when 10% linseed meal was fed to guinea fowls. The drumstick and thigh weight of the current study is similar with work of Mridula et al. (2015) who reported similar weight among treatments up to 10% levels of linseed to broilers. But, thigh weight in this study is not similar with Beheshti Moghadam et al. (2017) who reported higher thigh weight when linseed was fed to broilers at 20% compared with 10% inclusion. The breast weight of the present study inconsistently increased in control and 50% LM and then decreased in 25%, 75% and 100% LM fed groups. In their findings, Mridula et al. (2011) reported higher breast yield in group fed flaxseed meal up to 10%, and then decreased at 15% levels of linseed meal in the diet. On the other hand, Chiroque et al. (2018) fed 0, 10 and 20% linseed and observed improvement in breast weight and thigh yield up on inclusion of 10% and 20% linseed compared with the control. Additionally, Aguilar et al. (2011) reported that diets such as linseed which is rich in polyunsaturated fat improved the carcass and breast yields. However, the non-linear increase in breast weight observed among treatment groups with increased levels of linseed meal in the current study might be due to dissimilar growth patterns by different body parts of the chicken as suggested by Alkan et al. (2011). Also it might be related to the rate variation to which body organs increases in size (Koops and Grossman, 1991). The similar kidney and heart weight observed between 0%LM and 50% LM fed groups were consistent with Meherunnisa et al. (2017) who reported no kidney and heart weight difference with increased levels of linseed meal. Farran et al. (2005); Mushtaq et al. (2014) reported that the presence of anti-nutritional substances in the diet affects internal organ size. High heart weight observed in the control and T3 might be due to the fact that heavier values of internal organs of animals probably indicate increase in size (Koong et al., 1985). The similarity observed for gizzard and spleen weight among treatments agreed with Meherunnisa et al. (2017) who reported no change of gizzard and spleen weight with increased levels of linseed meal fed to broilers. On the other hand, high-fiber diets cause an increase in the gizzard weight due to the fact that fiber is more difficult to grind than other nutrients and accumulated in the gizzard (Hetland et al., 2003; Martínez et al., 2015). The high liver weight observed at 0%, 50% and 75% linseed meal fed groups might be indicator of higher metabolic activity (Zaefarian et al., 2019).

Abdominal fat content decreased with increasing levels of linseed meal. According to Ferrini et al., (2008) and Kartikasari et al. (2018) chickens fed diets containing high levels of alpha linolenic acid (ALA) have less abdominal fat pad accumulation compared with chickens fed diets containing high levels of saturated fatty acids or monounsaturated fatty acids. Other findings also confirmed that feeding linseed at 20% led to decreased fat deposition in chickens (Najib and Al-Yousef, 2011; Beheshti Moghadam et al., 2017) compared to non-linseed fed group. The reduction is ascribed to the poly-unsaturated fatty acid content (n-3) of linseed which activates fatty acid beta-oxidation (El-Senousey et al., 2013) and also probably due to the suppression of fatty acid synthesis (Fouad and El-Senousey, 2014) leading to the reduction of abdominal adipose tissue deposition. The higher abdominal fat content of female in this study indicates the fact that females have a higher rate of fat deposition than males (Silva, 2012), possibly due to metabolic and hormonal differences (Tumova and Teimouri, 2010) and also fatty acids synthesis gene expression related to lipids synthesis is higher in female than male (de Souza Khatlab et al., 2018).

Majority of non-edible offals such as spleen, large intestine and ceaca weight was not influenced by dietary treatments. Although, the variation observed in crop weight among treatment groups might be related to feed particles remained in crop. The high proventriculus weight observed in the current study might implied that broilers responded to dietary treatment by increasing enzymatic secretion in the proventriculus to compensate for rapid passage rate (Satid, 2015). The large lung weight is associated with metabolic activity of the broilers. Namakparvar et al. (2014) reported that large lung supports the supply of sufficient oxygen for body metabolic requirements. The length of small intestine in broilers was assumed to be related to more efficient digestion of feed and provide a greater surface area for nutrient absorption and the increase in small intestine weight allows broiler chickens to reach a heavier body weight (Jamroz, 2005; Al-Marzooqi et al., 2019).

4.4. Production efficiency and economic return

The performance of broiler birds was also evaluated in terms of European broiler index (EBI) and production efficiency factor (PEF), which includes daily weight gain and survival percentage. A higher value of EBI and PEF indicates that the bird's body weight gain is uniform and the flock is in a good health (Bhamare et al., 2016). In the current study, both EBI and PEF value for starter phase, finisher phase and entire experiment were similar among the treatment groups. The total cost of production decreased with increasing levels of linseed meal replacement. The highest net income was observed for T3 (50% LM) followed by T4 (75% LM). The highest marginal rate of return with a unit cost of production was seen in 75% linseed meal fed broilers.

5. Conclusion

The current study revealed that replacement of linseed meal for soybean meal in broilers ration had no adverse effect on feed intake, feed conversion ratio and mortality of broilers. Body weight gain and carcass yield tend to be greater in group consumed ration that consists 50% each of soybean and linseed meals. The total feed cost decreased with increasing replacement levels of linseed meal. The highest net return and marginal rate of return was recorded in T3 (50% LM) and T4 (75% LM) groups. The result showed that although linseed meal can replace the 100% soybean meal in the ration without detrimental effect on the health, replacement at 50% (T3) is recommended for better performance of broilers.

Declarations

Author contribution statement

Negasa Tamasgen: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mengistu Urge; Meseret Girma; Ajebu Nurfeta: Conceived and designed the experiments; Performed the experiments, Contributed reagents, materials, analysis tools or data.

Funding statement

This work was supported by Haramaya University Research Office, Ethiopia.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

Haramaya University Poultry Farm and Farm workers are highly recognized for the assistance rendered during the entire research work.

References

Aguilar, Y.M., Yero, O.M., Navarro, M.V., Hurtado, C.B., López, J.C., Mejía, M.G., 2011. Effect of squash seed (*Cucurbitamoschata*) meal on broiler performance, sensory meat quality, and blood lipid profile. Brazil. J. Poultr. Sci. 13 (4), 219–226.

Ahmed, H.O., Hassan, Z., Abdul Manap, M.N., 2018. Physico-chemical changes and microbiological quality of refrigerated broiler chicken meat slaughtered by two different method. Int. Food Res. J. 25 (3), 913–920.

Ahmad, S., Yousaf, M., Kamran, Z., Sohail, M.U., 2013. Effect of feeding whole linseed as a source of polyunsaturated fatty acids on performance and egg characteristics of laying hens kept at high ambient temperature. Brazil. J. Poultr. Sci. 15 (1), 21–25.

Alkan, S., Mendes, M., Karabag, K., Balcioglu, M.S., 2011. Allometric growth of body components in 11 generations selected Japanese quails of different lines. Arch Geflugelkd 75 (1), 13–19.

Al-Marzooqi, W., Al-Maskari, Z.A.S., Johnson, E.H., Al-Kharousi, K., Mahgoub, O., Al-Saqri, N.M., Tahir, Y.E., 2019. Comparative evaluation of growth performance, meat quality and intestinal development of indigenous and commercial chicken strains. Int. J. Poultr. Sci. 18, 174–180.

Amin, I., Cheah, S.F., 2010. Determination of vitamin C, β-carotene and riboflavin contents in five green vegetables organically and conventionally grown. Malays. J. Nutr. 9 (1), 31–39.

Anjum, F.M., Haider, M.F., Khan, M.I., Sohaib, M., Arshad, M.S., 2013. Impact of extruded flaxseed meal supplemented diet on growth performance, oxidative stability and quality of broiler meat and meat products. Lipids Health Dis. 12, 13–24.

AOAC, 1998. Official Methods of Analysis, 16thEdition. Washington, DC.

AOAC, 2000. Official Methods of Analysis of the Association of Official Analytical Chemists. Gaithersburg, MD, USA.

BeheshtiMoghadam, M.H., Rezaei, M., Behgar, M., Kermanshahi, H., 2017. Effects of irradiated flaxseed on performance, carcass characteristics, blood parameters, and nutrient digestibility in broiler chickens. J. Poultr. Sci. 5 (2), 153–163.

Bhamare, K.S., Dildeep, V., Senthil, M.S., Chavan, S.J., 2016. Nutritive evaluation of cashew apple waste in broilers. Int. J. Sci. Nature 7, 629–632.

Chiroque, G., Vásquez, G., Vásquez, E., Vásquez, E., Más, D., Betancur, C., Ruiz, C., Botello, A., Martínez, Y., 2018. Growth performance, carcass traits and breast meat fatty acids profile of helmeted Guinea Fowls (*Numida meleagris*) fed increasing level of linseed (*LinumUsitatissimum*) and pumpkin seed (*CucurbitaMoschata*) meals. Brazil. J. Poultr. Sci. 20 (4), 665–674.

de Souza Khatlab, A., Del Vesco, A.P., Gasparino, E., de Oli-veira Neto, A.R., 2018. Gender and age effects on the expression of genes related to lipid metabolism in broiler liver. Czech J. Anim. Sci. 63, 103–109.

Dessie, A., Alemayehu, A., Fekadu, B., Alayu, T., Misba, A., 2017. Growth performance, feasibility and carcass characteristics of Cobb 500 commercial broiler under small-scale production in western Ethiopia. Asian J. Poultr. Sci. 11 (1), 49–56.

Diederichsen, A., Richards, K.W., 2003. Cultivated flax and the genus linum L.-taxonomy and germplasm conservation. In: Muir, A., Westscott, N. (Eds.), Flax, the *Genus Linum*. Taylor & Francis, London, UK, pp. 22–54.

Elinge, C.M., Muhammad, A., Atiku, F.A., Itodo, A.U., Peni, I.J., Sanni, O.M., 2012. Proximate mineral and antinutrient composition of pumpkin (*Cucurbitapepo* L) seeds extract. Int. J. Plant Res. 2 (5), 146–150.

El-Senousey, H.K., Fouad, A.M., Yao, J.H., Zhang, Z.G., Shen, Q.W., 2013. Dietary alpha lipoic acid improves body composition, meat quality and decreases collagen content in muscle of broiler chickens. Asian Aust. J. Animal Sci. 26, 394–400.

FAO, 2001. Food Balance Sheet: A Hand Book. Rome, Italy. http://www.fao.org/DOCREP/003/X9892E/X9892e06.htm.

FAOSTAT, 2017. FAO Statistics Database. http://apps.fao.org.

Farran, M.T., Halaby, W.S., Barbour, G.W., Uwayjan, M.G., Sleiman, F.T., Ashkarian, V.M., 2005. Effects of feeding ervil (*Viciaervilia*) seeds soaked in water or acetic acid on performance and internal organ size of broilers and production and egg quality of laying hens. Poultr Sci. 84, 1723–1728.

Ferrini, G., Baucells, M.D., Esteve-García, E., Barroeta, A.C., 2008. Dietary polyunsaturated fat reduces skin fat as well as abdominal fat in broiler chickens. Poultr Sci. 87, 528–535.

Fouad, A.M., El-Senousey, H.K., 2014. Nutritional factors affecting abdominal fat deposition in poultry: a Review. Asian Australas. J. Animal Sci. 27, 1057–1068.

Geremew, A., Getahun, A., Rana, K., 2015. Digestibility of soybean cake, Niger seed cake and linseed cake in Juvenile Nile Tilapia, *Oreochromisniloticus* L. J. Aquacult. Res. Dev. 6, 333.

Getu, A., Birhan, M., 2014. Chicken production systems, performance and associated constraints in North Gondar Zone, Ethiopia. J. Fisher. Livest Prod. 2.

Habte, T., Amare, A., Bettridge, J., Collins, M., Christley, R., Wigley, P., 2017. Guide to chicken health and management in Ethiopia. In: ILRI Manual, 25. International Livestock Research Institute (ILRI), Nairobi, Kenya.

Hetland, H., Svihus, B., Krogdahl, A., 2003. Effects of hoat hulls and wood shavings on digestion in broilers and layers fed diets based on whole or ground wheat. Br. Poultr. Sci. 44 (2), 275–282.

Jamroz, D., 2005. Comparative characteristic of gastrointestinal tract development and digestibility of nutrients in young chickens, ducks and geese. In: Proceedings of the 15th European Symposium on Poultry Nutrition, September 25-29, 2005. Balatonfured, Hungary, pp. 74–85.

Kartikasari, L.R., Hertanto, B.S., Nuhriawangsa, A.M.P., 2018. Carcass and cut yields of broiler chickens fed diet containing purslane meal rich in omega-3 fats. International Symposium on Food and Agro-biodiversity (ISFA) 2017. IOP Conf. Ser. Earth Environ. Sci. 102 (2018), 012088.

Kekeocha, C.C., 1985. Introduction to poultry keeping. In: Poultry Production Hand Book. Pfizer Corporation, Nairobi, pp. 1–15.

Koong, L.J., Farcell, C.L., Nienaber, J.A., 1985. Assessment of interrelationship among levels of intake and production, organ size and fasting heat production in Animals. J. Nutr. 115 (10), 1383–1390.

Koops, W.J., Grossman, M., 1991. Application of a multiphasic growth functions to body composition in pigs. J. Anim. Sci. 69, 3265–3273.

Liu, X.D., Jayasena, D.D., Jung, Y., Jung, S., Kang, B.S., Heo, K.N., Lee, J.H., Jo, C., 2012. Differential proteome analysis of breast and thigh muscles between Korean native chickens and commercial broilers. Asian Aust. J. Animal Sci. 25, 895–902.

Liversidge, R.M., Lloyd, G.J., Wase, D.A.J., Forster, C.F., 1997. Removal of basic blue 41 dye from aqueous solution by linseed cake. Process Biochem. 32 (6), 473–476.

Marcu, A., Vacaru-Opris, I., Dumitrescu, G., Ciochina, L.P., Marcu, A., Nicula, M., Pet, I., Dronca, D., Kelciov, B., Maris, C., 2013. The influence of genetics on economic efficiency of broiler chickens growth. Anim Sci. Biotechnol. 46 (2), 333–346.
Martínez, Y., Carrión, Y., Rodríguez, R., Valdivié, M., Olmo, C., Betancur, C., Liu, G., Al-Dhabi, N.A., Duraipandiyan, V., 2015. Growth performance, organ weights and some blood parameters of replacement laying pullets fed with increasing levels of wheat bran. Brazil. J. Poultr. Sci. 17 (3), 347–354.
Meherunnisa, L., Leghari, I.H., Sethar, A., Sethar, G.H., Sethar, F.M., 2017. Effect of linseed meal on broiler performance and fat content. J. Dairy Vet. Sci. 4 (1), 555628.
Melese, Temesgen, Retta, Nugussie, Tesfaye, Etalem, 2017. Nutrient composition and digestibility of taro leaf in the diets of chicken and effects on the meat quality. J. Nutr. Health Food Eng. 7 (3), 00238.
Mir, N.A., Tyagi, P.K., Biswas, A.K., Tyagi, P.K., Mandal, A.B., Wani, M.A., Deo, C., Biswas, A., Verma, A.K., 2018. Performance and meatquality of broiler chicken fed a rationcontaining flaxseed meal and higher dietarylysine levels. J. Agric. Sci. 156, 291–299.
Mridula, D., Kaur, D., Nagra, S.S., Barnwal, P., Sushma, G., Singh, K.K., 2011. Growth performance, carcass traits and meat quality in broilers fed flaxseed meal. Asian-Australas. J. Anim. Sci. 24 (12), 1729–1735.
Mridulaa, D., Kaurb, D., Nagrab, S.S., Barnwala, P., Sushma, G., Singh, K.K., 2015. Growth performance and quality characteristics of flaxseed-fed broiler chicks. J. Appl. Anim. Res. 43 (3), 345–351.
Mushtaq, M.M.H., Parvin, R., Kim, J., 2014. Carcass and body organ characteristics of broilers supplemented with dietary sodium and sodium salts under a phase feeding system. J. Anim. Sci. Technol. 56 (4), 1–7.
Najib, H., Al-Yousef, Y.M., 2011. Performance and essential fatty acids content of dark meat as affected by supplementing the broiler diet with different levels of flaxseeds. Annu. Rev. Res. Biol. 1, 22–32.
Namakparvar, R., Shariatmadari, F., Hossieni, S.H., 2014. Strain and sex effects on ascites development in commercial broiler chickens. Iran. J. Vet. Res. 15 (2), 116–121.
Ndou, S.P., Kiarie, E., Walsh, M.C., Nyachoti, C.M., 2018. Nutritive value of flaxseed meal fed to growing pigs. Anim. Feed Sci. Technol. 238, 123–129.
NRC, 1994. Nutrient Requirements of Poultry. Ninth revised edition, pp. 19–23.
Samuel, Sahle, 2008. The Epidemiology and Management Options of Chocolate Spot Disease (*Botrytis Fabaesard*) on Faba Bean (*Vicia faba* L.) in Northern Ethiopia. Ph.D Dissertation, Haramaya University, Ethiopia, p. 175.
SAS (Statistical Software System), 2009. SAS User's Guide, Statistics. SAS Institute, Inc., Cary, NC. USA.
Satid, A., 2015. Impact of ground corn particle size and distribution on pellet quality, live performance of broilers, and proventriculus and gizzard weights. In: A Dissertation Submitted to the Graduate Faculty of North Carolina State University in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy. Animal Science and Poultry Science. Raleigh, North Carolina.
Senayt, Abraha, 2011. The effect of feeding different levels of soybean meal on egg production, quality, fertility and hatchability of White Leghorn Layers. In: A Thesis Submitted to the School of Graduate Studies (School of Animal and Range Sciences). Haramaya University.
Shafey, T.M., Mahmoud, A.H., Hussein, E.S., Suliman, G., 2014. The performance and characteristics of carcass and breast meat of broiler chickens fed diets containing flaxseed meal. Ital. J. Anim. Sci. 13, 3514.
Silva, C.R., 2012. Performance and Deposition of Nutrients of Broiler Chickens Fed with Different Lysine Levels. Ph.D. Thesis. Federal University of Viçosa, Minas Gerais, Brazil (in Portuguese).
Teshome, T., Bekele, E., Million, B., Hagos, S., Eshetie, T., 2019. Assessment of broiler production; processing and marketing practices in Ethiopia: identifying the root causes for poultry products importation to Ethiopia and way forward. Appro. Poult. Dairy Vet. Sci. 7 (2), 620–625.
Tumova, E., Teimouri, A., 2010. Fat deposition in the broiler chicken.a review. Czech Agricul. Sci. 41, 121–128.
Upton, M., 1979. Farm Management in Africa: the Principle of Production and Planning. Oxford University Press, Great Britain, pp. 282–298.
Wiseman, J., 1987. Feeding of Non-ruminant Livestock. Butter worth and C.Ltd, p. 370.
Worku, N.M., Heslop-Harrison, J.S., 2018. Biodiversity in Ethiopian linseed (*Linum usitatissimum* L.): molecular characterization of landraces and some wild species. Genet. Resour. Crop Evol. 65, 1603–1614.
Zaefarian, F., Abdollahi, M.R., Cowieson, A., Ravindran, V., 2019. Review avian liver: the forgotten organ. Animals 9 (2), 63.