ORIGINAL RESEARCH

EFFECT OF LINSEED OIL BEADS AND VITAMIN-E SUPPLEMENTATION ON GROWTH, CARCASS CHARACTERS, AND BLOOD AND INTRAMUSCULAR LIPID PROFILE IN DAMASCUS GROWING MALE GOATS

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ABSTRACT

This study was conducted to evaluate the effects of dietary inclusion of linseed oil beads (LOB) and vitamin E supplementation on nutrient intake, nutrient digestibility, ruminal parameters, growth, feed conversion efficiency, blood biochemicals, carcass characters, and blood and intramuscular lipid profile of l*ongissimus lumborum* (LL) muscle in Damascus growing male goats. Fifteen Damascus growing male goats (120 days old) of 16.57 ± 2.03 kg average body weight were assigned to 3 groups of 5 animals each with three different dietary treatments on dry matter basis: (1) Control diet (CTRL / T1) with 50:50 of forage to concentrate ratio offered as a basal diet to all animals. (2) Experimental diet-1 (LOB / T2) comprised of control diet (T1) fortified with linseed oil beads (2.5 gm d^{-1} $goat^{-1}$) and (3) Experimental diet-2 (LOBE / T3) comprised of T2 diet fortified with 600 IU of vitamin E (α-tocopherol acetate) @ d^{-1} $goat^{-1}$. Diets were offered *ad libitum* daily once for a 95-day period. Digestibility trial was conducted for 10 days (4 goats / group), and at the end of the experiment, all animals were slaughtered for evaluation of carcass characters and determination of meat FAs profile of LL muscle. The results showed non-significant ($P \geq 0.05$) differences between the treatment groups (T1, T2, T3) in respect of nutrient intake, nutrient digestibility, growth, feed conversion efficiency, and ruminal parameters. LOB supplementation significantly ($P \leq 0.05$) depressed some plasma metabolites (cholesterol and total lipids) over the control, while total lipids in LOBE decreased ($P \leq 0.05$) over both the control and LOB. Some of the plasma unsaturated fatty acids (C12:0, Lauric acid; C15:0, Pentadecanoic acid; C16:0 and Heptadecanoic acid) were reduced in ($P \leq 0.05$) in LOB, while the latter two were reduced ($P \leq 0.05$) in LOB and LOBE. ∑MUFA and ∑n-3 were increased ($P \leq 0.05$), while ∑PUFA and ∑n-6 were decreased ($P \leq 0.05$) both in LOB and LOBE groups. There was no significant difference ($P \geq 0.05$) in carcass characters between the treatment groups, while chemical composition of LL muscle indicated decrease ($P \leq 0.05$) in fat (%) and increase ($P \leq 0.05$) in LL area in LOB compared to the control. Fatty acid composition of LL muscle showed increase ($P \leq 0.05$) of ∑n-3 and decrease ($P \leq 0.05$) of ∑n-6 / ∑n-3 ratio, in LOB, considered as nutritional value indicators for human health (WHO/FAO). It is concluded that LOB supplementation has positively contributed to production of healthy meat for human consumption, while LOBE had no advantage over LOB.

KEY WORDS

Carcass characteristics, Damascus goats, Fatty acids, Growth, Linseed oil beads, Vitamin-E

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INTRODUCTION

Ruminant meat is an important dietary component of human diets. Animal foods make a significant contribution to the daily diet in most of societies and dietary guidelines advise limiting the intake of animal fats, particularly meat and milk of ruminants, due to high content of saturated fatty acids (SFA), as it is linked to various cardiovascular diseases (AHA, 2015).

Animal fats represent about half of all human nutritional lipid intakes in developed countries (Girard et al., 1986). Moreover, blood lipid profile of meat eating individuals is influenced by the diets given to livestock (Morand-Fehr et al., 1986). Thus, the nutritional quality of lipids in ruminant meat may be enhanced through dietary manipulation strategies by minimization of biohydrogenation (BH) of ingested polyunsaturated fatty acids (PUFA) in the rumen.

The decrease of SFAs and increase of health-beneficial fatty acids, such as poly unsaturated fatty acids (PUFA), especially n-3 FA contents have been an important objective of ruminant meat studies (Miltkoet al., 2019), because researchers have become more aware about the health benefits of dietary n-3 long chain PUFA.

Nguyen et al. (2018) have reported that PUFA play an important role in decreasing the risk of cardiovascular diseases in humans (Watanabe and Tatsuno, 2017). Moreover, several studies have shown that supplementing farm animal diet with functional ingredients such as n-3 PUFA and / or antioxidants may improve the nutritional quality of meat products (Pieszka et al., 2017).

Dietary omega-3 has many benefits such as improving the absorption of liposoluble vitamins (A, D, E, K), reducing plasma triglycerides, and regulating the cholesterol metabolism (Ponnampalam et al., 2001).They are also essential for normal growth and metabolism (Kris-Etherton et al., 2002).

Miltko et al. (2019) have hypothesized that dietary supplementation of linseed oil is a good source of linolenic acid that can reduce the concentration of saturated fatty acids (SFA) and increase *n-3* PUFA. This can be achieved by oil encapsulation method using biopolymers to protect PUFA in linseed oil from rumen biohydrogenation, as described by Gawad et al. (2015) that may confer an opportunity to achieve a desired consistency in meat fatty acid composition.

The objectives of the present study were to investigate the effects of dietary inclusion of encapsulated linseed oil beads (LOB) with or without vitamin-E (LOBE) as feed additives on growth, carcass characteristics, intramuscular fatty acid composition of *Longissimus lumborum* (LL) muscle in male Damascus growing goats, and to investigate some of blood metabolites along with blood plasma fatty acids composition.

MATERIALS AND METHODS

Study Location: The present study was conducted at Maryout Research Station, Desert Research Center, Ministry of Agriculture, 35km south of Alexandria, Egypt.

Procurement of Experimental Materials: Linseeds were purchased from Manawate Company, Giza, Egypt, and linseed oil was extracted at Al hamzawy Squwisser, El-Azher, Egypt. Linseed oil was encapsulated using alginate/carrageenan polymers according to the method described by Gawad et al. (2015). The encapsulation method was optimized to get a final encapsulated linseed oil (82%) with maximum loading capacity (beads oil content).

Animals, Experimental Design and Feeding Trial: Fifteen growing (120 day-old) Damascus male goats of (16.57 ± 2.03 kg) as average initial live weight were assigned to 3 groups (5 each) according to initial body weight using a randomized complete block design. The feeding trial lasted 95 days, and digestibility trial took 10 days. At the end of the experiment, the animals were slaughtered and required information was collected.

The animals were housed in individual concrete pens with separate facilities for feeding. The Control group (CTRL / T1) was fed with a basal diet containing berseem hay and concentrate feed mixture (CFM) in 50:50 ratio. The first treatment group (LOB / T2) goats were fed the control (T1) diet supplemented with 2.5 gm encapsulated linseed oil (beads) / goat/ day. The second treatment group of goats (LOBE / T3) was fed on the control (T1) diet supplemented with 2.5 gm linseed oil beads + 600 IU vitamin E (α-tocopherol acetate) / goat /day. The experimental diets were adjusted to meet nutrient requirements of growing goats according to NRC (2007) recommendations.

Linseed oil beads (LOB) were stored away from direct sunlight and mixed with the concentrate immediately before feeding. Dietary compositions and chemical analysis are given in Table (1) and fatty acids profiles of linseed oil beads are presented in Table (2). Daily rations were offered in two equal portions at 8:00 h and at 16:00 h daily. The goats had free access to water and blocks of salt containing micronutrients.

Table (1): Nutrient composition of the basal diet (on DM basis %)

ITEMS	CONC. FEED MIXTURE	BERSEEM HAY
Dry matter	92.18	90.66
Organic matter	96.23	85.73
Crude protein	19.60	13.66
Ether extract	4.54	1.77
Ash	3.77	14.27
Neutral detergent fiber	17.94	57.71
Acid detergent fiber	8.98	36.79

CFM is composed of: 17% soybean meal, 52.5% yellow corn, 28% wheat bran, 0.9% salt, 1.1% limestone, 0.5% Vitamin mineral premix.

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Table (2): Fatty acids composition (%) of linseed oil (LO) and linseed oil beads (LOB)

FATTY ACIDS	LO	LOB		FATTY ACIDS	LO	LOB
(1) C6:0, Caproic	0.63	0.67		(14) C18:3ω3, Linolenic	51.4	50.40
(2) C8:0, Caprylic	0.33	0.37		(15) C20:0, Arachidic	0.33	0.24
(3) C14:0, Myristic	0.25	0.27		(16) C20:1ω9, Gadolic	0.30	0.27
(4) C15:0, Pentaenoic	0.18	0.20		(17) C20:1ω7, 9-eicosaenoic	nd	0.15
(5) C15:1ω6,10-Pentadecanoic	0.48	0.48		(18) C20:1ω5, 11-eicosaenoic	nd	0.25
(6) C16:0, Palmitic	7.46	7.98		(19) C22:0, Behenic	0.30	0.36
(7) C16:1ω7, Palmitoleic	0.10	0.21		(20) C22:1ω9, Erucic	0.21	0.45
(8) C17:0, Heptadecanoic	0.19	0.14		(21) Saturated fatty acids	14.67	14.13
(9) C18:0, Stearic	5.0	3.90		(22) Unsaturated fatty acids	51.4	85.87
(10) C18:1ω9, Oleic	18.43	18.41		(23) Mono unsaturated fatty acids	0.33	21.19
(11) C18:1ω7, Vaccinic	0.94	0.97		(24) Poly unsaturated fatty acids	0.30	64.68
(12) C18:2ω6, Linoleic	13.47	14.10		(25) Omega-3 FA	nd	50.40
(13) C18:2ω4,	n.d	0.18		(26) Omega-6 FA	nd	14.58

The goats were weighed just before morning feeding at every two weeks interval during fattening in order to adjust diets to body weight changes and to calculate the average daily gain (ADG) and feed conversion (FC: g of BW gain / kg of feed). Feed intake, utilization as well as daily live weight gains were recorded

Digestibility Trial: At the end of fattening period, 4 animals from each treatment group were subjected to digestibility trial to determine nutrient digestibility coefficients. Animals were kept in individual metabolic cages for 10 days during trial. The first 5 days were reckoned as adjustment period followed by 5 days of collection period. The weighed CFMs were offered daily at 8.00 am and berseem hay at 12.00 pm with the same additives described earlier. Drinking water consumption was determined daily for each animal. The daily feces were collected, weighed and 10% samples were dried and kept for further analysis.

Analysis of Feeds, Feces, Ruminal and Muscle Samples: The chemical composition of representative samples of feedstuffs, feces and muscles of sacrificed animals was determined according to standard methods of AOAC (2007). At the end of the digestibility trial, rumen liquor samples were collected 4 hours after the morning feeding from all animals using a stomach tube via the esophagus.

The ruminal pH of rumen liquid was measured immediately using a portable pH meter (Mettler-Toledo Ltd., England). Rumen liquid was filtered through double layers of cheese cloth, divided into subsamples, and kept in plastic bottles for determination of total volatile fatty acids (Warner, 1964) and ammonia: N (NH3-N) as per AOAC (1997).

Blood Biochemical Analysis: Blood samples were collected from all animals from the jugular vein into vacutainer tubes containing EDTA (anticoagulant) from all experimental animals at the end of the digestibility trial 4 hours post-feeding. Blood samples were centrifuged at 3000 rpm for 15 minutes, and the collected plasma was immediately frozen at -20˚C for subsequent analysis. Total protein, albumin, globulin (subtracting the total proteins values from the albumin values), urea–N, creatinine, cholesterol (TC), triglycerides, total lipids (TL), lipase, Alanine amino transferase (ALT), aspartate amino transferase (AST), and total antioxidant capacity (TAC) were determined using Biodiagnostic laboratory kits.

Fatty acids analysis of Linseed oil, Plasma and Muscles: Lipids from linseed oil and muscle were determined by using methyl esters boron trifluoride method (AOAC, 2000), where FAs were methylated with boron trifluoride in methanol, extracted with heptane. Fatty acids were quantified using a gas chromatograph (GC) with FID detector (PE Auto System XL) with auto sampler and Ezchrom integration system. Plasma lipids were extracted by using 100% ether, where sample was mixed with ether in the ratio of 1:10 (v/v) as detailed by Ferraz et al. (2004), then methylated and determined as described by AOAC (2000).

Carcass characteristics: At the end of the study, all of the goats were starved for 12 h and slaughtered in the slaughter house of the station. Afterwards, non-carcass components, gastrointestinal tracts and viscera were removed and weighted. Selected internal organs (liver, heart, and kidneys) were weighted. The contents of the digestive tract were removed and their weight was subtracted from the slaughter live weight to obtain the empty body weight (EBW). Dressing percentage was estimated as the percentage of hot carcass weight (HCW) relative to the EBW and as a percentage of HCW relative to EBW. Carcasses were kept at 4°C for 24 h and a dissection of their right halves was carried out. The samples of *Longissimus lumborum* (LL) muscle between 10th rib and 13th rib were taken to analyze the chemical composition and fatty acid (FA) profile. Muscle samples were minced, packed in polyethylene bags and stored at –30°C for further analysis. To obtain the (LL) area, the exposed area of the (LL) muscle was drawn on tracing paper, and measured three times with **Placom Digital Planimeter** (KP-82) to the nearest cm^2.The values obtained were used to calculate the mean of the LL area.

Statistical analysis: The data were analyzed using mixed procedure of Statistical Analysis System, version 9.2 for Windows (SAS Institute, Cary, NC, USA) with the following model:

$Yij = \mu + Ti + bj + eij$

Where, μ = the overall mean,

Ti = the treatment effect,

bi = effect of block,

eij = random effect.

Contrast statements were used to evaluate differences between means to compare the effect of linseed oil beads (LOB) over the control (CTRL) and linseed oil beads with vitamin E (LOBE) over LOB. The statistical significance between the groups was evaluated at $P \leq 0.05$.

RESULTS AND DISCUSSION

Dry matter intake and Nutrient digestibility: The results revealed that Total dry matter intake (DMI: g/d) was not different ($P \geq 0.05$) between CTRL, LOB and LOBE groups (Table 3). The nutrient intake and digestibility (DM, OM, CP, EE, NDF and ADF) of different groups were also not affected by treatments ($P \geq 0.05$).

Table (3): Nutrient intake and digestibility of Damascus growing male goats fed on linseed oil beads with and without vitamin E

ITEMS	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Nutrient Intake (g/d)						
Dry matter	1060.4	1019	1082.2	67.138	0.731	0.563
Organic matter	948.9	922.3	996.04	61.268	0.809	0.453
Crude protein	169.08	166.74	186.45	10.909	0.905	0.268
Ether extract	30.29	30.88	37.15	2.024	0.872	0.076
Neutral Detergent Fiber	442.39	403.63	366.05	31.557	0.493	0.486
Acid Detergent Fiber	271.72	245.92	217.4	19.784	0.467	0.407
Digestibility (%)						
Dry matter, %	69.44	70.39	69.07	0.508	0.122	0.135
Organic matter	70.53	71.73	71.75	0.724	0.252	0.988
Crude protein	66.41	67.69	68.39	0.799	0.206	0.597
Ether extract	65.59	66.93	67.65	0.764	0.269	0.411
Neutral Detergent Fiber	51.86	53.89	52.49	1.094	0.286	0.376
Acid Detergent Fiber	42.91	43.2	43.43	0.589	0.752	0.581

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3.

Nogueira et al. (2019) have reported similar results in respect of total DMI and digestibility of DM, OM, CP, NDF and ADF in animals fed with flaxseed alone or combined with vitamin E. They hypothesized that the capacity of microorganism to saturate the unsaturated fatty acids (UFA) did not exceed the threshold (8%). Therefore, UFA did not accumulate, resulting in regular microbial digestion and DMI (NRC, 2001).

The finding of Patra (2013) was also agreeable with the present results of digestibility based on oil seed supplementation. Jenkins and Lundy (2001) and Oliveira et al. (2007) supported the current results and they proved that whole oilseeds lessen the severity of digestion problem through encapsulation of anti-microbial FAs within their hard-outer seed coat.

On the other hand, previous studies of Martin et al. (2008) and Fiorentini et al. (2015) have reported negative effects of lipid supplementation as the cause of reduction of DMI and digestibility, and they attributed it to some factors such as low acceptance by animals and possible toxicity effect of lipid source causing reduction to BH process of UFA in the rumen (NRC, 2001), since inhibiting effect of lipids on bacterial growth increases with the degree of unsaturation of FAs (Giger-Reverdin et al., 2003). Wanapat et al. (2011) have also shown that the reduction in intake with inclusion of FAs may be associated with reduced digestibility.

Growth: Growth parameters of Damascus goats (Table 4) showed that initial body weight, final body weight, average daily body weight gains and feed conversion ratio during fattening were un-affected by dietary regimen.

The absence of effect of LOB or LOBE addition on final body weight and average daily gain could be attributed to similar DMI by the goats fed on the experimental diets. This is consistent with the previous studies of Radunz et al. (2009), Berthelot et al. (2012) and Facciolongo et al. (2018), who had observed that neither linseed nor linseed oil had influence on lamb growth performance.

Table (4): Growth and Feed conversion efficiency of the Damascus growing male goats fed linseed oil beads with and without vitamin E

ITEMS	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Dry matter intake, g/d	1044.09	998.91	1083.48	54.11	0.64	0.335
Initial body weight, kg	16.6	16.76	16.36	2.033	0.957	0.891
Final body weight, kg	30.35	32.04	32.08	2.469	0.659	0.991
Average daily gain, g/d	144.5	158.6	167.01	16.72	0.526	0.772
Feed conversion, kg/kg	7.27	6.57	6.8	0.574	0.367	0.816

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3.

Zhao et al. (2013) have proved that vitamin E levels over 100 IU day^{-1} $lamb^{-1}$ tended to suppress the growth of Tan sheep lambs. The same author as well as Maiorano et al. (2007) found that vitamin E supplementation to the diet of lambs had no significant effect on most of growth performance traits. Wulf et al. (1995) have also found that lambs fed on concentrates with 1000 mg α-tocopheryl acetate / day had a lower weight gain. Birch et al. (1994) showed that young lambs fed on vitamin E fortified diet exhibited beneficial effect on growth performance.

Ruminal characteristics: Addition of linseed oil beads with or without vitamin E in diet had no effect on rumen fermentation parameters (Table 5) and showed normal feed fermentability. These findings support the hypothesis that protected beads would have higher ruminal protection with variable dissociation.

Table (5): Rumen fermentation parameters in Damascus growing male goats fed linseed oil beads with or without vitamin E

ITEMS	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
pH	5.87	5.83	5.85	5.85	0.60	0.70
Volatile fatty acids, mg/dl	7.02	6.54	6.87	6.54	0.48	0.65
Ammonia- nitrogen, mg/dl	17.59	17.99	19.44	0.88	0.76	0.24

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3.

In the same line, Fiorentini et al. (2013 and 2015) have reported unchanged ruminal volatile fatty acids (VFA) with dietary addition of lipid sources. Ivan et al. (2001) have reported variable ruminal pH with vegetable oils due to high levels of free UFA that are more susceptible to hydrolysis by rumen bacteria than diets, so also with calcium salts (Wu et al., 1991) and oil seeds (Ueda et al., 2003). Non-significant ($P \geq 0.05$) decrease of ruminal NH3-N concentration may be attributed to protozoa action decreasing the number of de-aminating bacteria (Doreau and Ferlay, 1995), whereas higher GNH3-N levels (T2 and T3) may be due to a predominance of proteolytic protozoa which engulf the rumen bacteria and release NH3-N into the rumen environment (Doreauand Ferlay, 1995).

According to this scenario, ruminal ammonia concentration is a consequence of the balance between its production, absorption and utilization by microorganism (Fiorentini et al., 2015). In relation to vitamin E, normal ruminal parameters could be explained according to Vasquez-Anon and Jenkins (2007), who reported that the mechanism by which antioxidant compounds meliorate the toxic effect of excessive unsaturated fatty acids has not been well understood and might vary with the antioxidant compound and type of fat.

Blood Plasma Biochemical: The current results of plasma biochemical parameters (Table 6) revealed that the level of total cholesterol (TC) significantly ($P \leq 0.05$) decreased in goats fed on LOB, while total lipids (TL) significantly ($P \leq 0.05$) increased in goats fed on LOB compared to control goats. This indicated that lipase activity was not affected by treatments.

Table (6): Blood plasma biochemicals in Damascus growing male goats fed linseed oil beads with and without vitamin E

ITEMS	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Total protein, g/dl	5.74	5.83	5.86	0.13	0.62	0.88
Albumin, g/dl	4.89	5.01	4.56	0.18	0.53	0.34
Globulin, g/dl	0.73	0.94	1.31	0.21	0.34	0.37
Albumin/Globulin	8.72	5.41	8.39	2.64	0.17	0.59
Urea, mg/dl	49.89	38.59	36.45	5.22	0.08	0.82
Creatinine, mg/dl	1.17	0.99	1.13	0.14	0.44	0.44
Cholesterol, mg/dl	196.62	129.85	115.54	6.67	# 0.02	0.06
Triglycerides, mg/dl	83.96	85.16	81.27	1.33	0.51	0.09
Total lipids, mg/dl	793.98	987.95	934.94	51.13	# 0.02	# 0.05
Lipase,U/l	123.85	138.5	127.5	14.22	0.63	0.33
AST, U / ml	30.4	32.8	32.8	1.13	0.13	1.00
ALT, U / ml	20.4	21.6	24.2	1.02	0.47	0.08
TAC, mM /l	0.23	0.26	0.34	0.05	0.49	0.43

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3. # Significant at P ≤ 0.05.

Previous studies on reduced TC in growing Baladi goats supplemented with capsulated omega–3 plus (Teama and El-Tarabany, 2016) or supplemented with linseed (El-Essawy, 2019) and increased TL levels in response to feeding LOB rich in FA confirmed the present findings It is well known that omega–3 FA affects plasma lipids (Mattos et al.,2000).

Blood plasma cholesterol decreased (P ≤ 0.05) in LOB compared to the control, while total lipids increased (P ≤ 0.05) in LOB compared to control, and decreased (P ≤ 0.05) in LOBE compared to LOB, probably due to improved kidney functions. This is in agreement with Donadio et al. (1994), who have reported that addition of omega-3 FA improved kidney function and reduces hypertension in kidney.

Table (7): Blood plasma fatty acids profile in Damascus growing male goats fed on linseed oil beads with and without vitamin E (FA% of total)

FATTY ACID %	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Saturated fatty acids (SFA)						
C11:0, Undecanoic	2.64	2.36	1.48	0.440	0.692	0.232
C12:0, Lauric	3.63	0.00	0.00	0.127	#<0001	0.000
C13:0, Tridecanoic	1.19	1.52	0.00	0.481	0.712	0.122
C14:0, Myristic	1.34	1.76	2.12	0.343	0.416	0.462
C15:0, Pentadecanoic	2.16	1.83	1.32	0.101	#0.032	#0.030
C16:0, Palmitic	7.88	13.35	23.92	1.359	0.055	#0.010
C17:0, Heptadecanoic	13.78	10.21	2.67	0.379	#0.005	#0.000
C18:0, Stearic	7.21	7.16	8.11	0.491	0.952	0.320
∑SFA	39.82	38.19	39.63	0.858	0.230	0.362
Monounsaturated fatty acids (MUFA)						
C16:1ω7, Palmitoleic	nd	0.49	1.75	0.317	0.374	0.083
C18:1ω9, Oleic	5.62	9.70	20.52	1.135	#0.011	#0.005
C18:1ω7, Vaccinic	1.41	2.39	1.85	0.254	#0.053	0.280
∑MUFA	7.03	12.58	24.12	1.363	#0.028	#0.008
Polyunsaturated fatty acids (PUFA)						
C16:4ω3	15.66	16.82	15.73	0.804	0.426	0.306
C18:2ω6, linoleic	15.52	14.92	10.01	0.477	0.244	#0.004
C18:3ω3, Linolenic	1.71	5.01	3.83	0.239	#0.001	#0.020
C18:4ω3, Stearidonic	12.31	8.62	4.24	1.126	0.095	0.088
C20:2ω6	7.95	3.87	2.46	1.192	0.112	0.518
∑PUFA	53.15	49.24	36.26	2.076	#0.040	#0.021
∑UFA	60.18	61.82	60.38	0.858	0.230	0.362
∑n-3	29.67	30.45	23.80	1.264	#0.040	#0.027
∑n-6	23.47	18.78	12.46	1.210	#0.037	#0.036
∑n-6 / ∑n-3	0.79	0.62	0.53	0.041	0.067	0.204

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3. # Significant at P ≤ 0.05.

Blood plasma Fatty acids: Blood plasma fatty acids profile (Table 7) revealed changes in saturated fatty acids (SFA) levels. Feeding linseed oil beads alone (LOB) or with vitamin E (LOBE) resulted in decimation of lauric acid (C12:0), reduction ($P \leq 0.05$) of pentadecanoic acid (C15:0) and increase ($P \leq 0.05$) of palmitic acid, while ∑SFA remained unaffected. This finding is consistent with Fiorentini et al. (2015).

Monosaturated fatty acids (MUFA), such as Palmitoleic acid (C16: 1ω7) was not detected in blood of control goats and tended to increase with LOB (0.49%) followed by LOBE (1.75%), while Oleic acid (C18:1 ω9) significantly ($P \leq 0.05$) increased in LOB (9.7%) and LOBE (20.52%), compared to the control (5.62%). Vaccinic acid (C18:1 ω7) increased significantly ($P \leq 0.05$) in LOB only. ∑MUFA significantly ($P \leq 0.05$) increased in LOB (12.58%) and LOBE (24.12%) compared to the control (7.03%).

Harfoot and Hazlewood (1997) and Mckain et al. (2010) have stated that vaccinic acid is formed when an incomplete biohydrogenation (BH) process of linoleic (C18:2 ω6) and linolenic (C18:3 ω3) acids occurs because it is an intermediate product of BH, while stearic acid (C18:0) is the end product of these FAs. Chikunya et al. (2004) have also reported accumulation of vaccinic acid in duodenal digesta and plasma in animals fed on formaldehyde-treated linseed or linseed-fish oil supplemented diets. In this line, it is surmised that addition of linseed oil beads with or without vitamin E increased blood concentration of vaccinic acid and the increment of this acid is desirable because of its health benefits in relation to: Cardiovascular diseases, Cancer, Immune function and inflammation in humans (Field et al., 2009).

Fiorentini et al. (2015) have demonstrated that saturation or addition of hydrogen atoms by the action of isomerases and reductases of oleic acid, linoleic acids and stearic acid through ruminal biohydrogenation (BH) is done by specific microorganisms. The higher concentration of the total MUFA in blood plasma especially with vitamin E supplementation could be attributed to increased absorption and blood concentration of oleic acid which is the primary MUFA.

Polyunsaturated fatty acids (PUFA) such as C18:3 ω3, linolenic acid of control goats (1.71%) increased ($P \leq 0.05$) in LOB (5.01%) and decreased ($P \leq 0.05$) in LOBE (3.83%), while the concentration of Linoleic C18:2ω6 decreased numerically in LOB and significantly ($P \leq 0.05$) in LOBE (10.01%). ∑PUFA of control goats (53.15%) decreased significantly ($P \leq 0.05$) in LOB (49.24%) and LOBE (36.26%). Compared to control goats, the increases of vaccinic and linolenic acids and the decreases of stearic acid concentrations in the blood supply of goats fed on LOB suggest that the BH of linoleic and linolenic acids could have decreased due to the protective effect of encapsulation.

Moreover, the blood plasma concentration of linolenic acid was enhanced by linseed oil because it is very rich with this fatty acid, indicating that part of this FA is passed through rumen without exposure to BH. The present findings are in agreement with the report of Chikunya et al. (2004) on formaldehyde treated linseed, Liu et al. (2008) on roasted linseed and Almedia et al. (2019) on linseed oil.

There was significant decrease ($P \leq 0.05$) in the concentration ∑PUFA, ∑n-3 and ∑n-6 in blood plasma of LOB and LOBE goats compared to control goats Lower n-6/n-3 ratio ($P \geq 0.05$) in LOB and LOBE compared to the control is indicative of health benefits to the consumers. **Table**

Table (8): Carcass characters, carcass components of major cuts and internal organs weights in Damascus growing male goats

ITEMS	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Slaughter weight, kg	30.35	32.14	32.08	2.58	0.65	0.99
Carcass, kg	14.6	14.2	14.9	1.33	0.84	0.71
Dressing %	47.8	44.17	46.21	1.16	0.06	0.25
Shoulder, kg	3.38	3.27	3.36	0.27	0.59	0.81
Loin, kg	1.04	0.78	1.06	0.12	0.68	0.14
Leg, kg	4.6	4.82	5.08	0.37	0.49	0.65
Skin, kg	3.22	3.56	3.38	0.29	0.49	0.62
Head, kg	2.09	2.15	2.13	0.17	0.82	0.93
Feet, g	978	1067	1107	82.06	0.47	0.74
Digestive tract full, kg	4.9	6.78	6.19	0.56	#0.05	0.46
Digestive tract empty, kg	2.62	2.84	2.56	0.21	0.49	0.36
Abdominal fat, g	436	457	433	42.29	0.57	0.78
Kidney fat, g	137	163	180	32.29	0.58	0.73
9-10-11 rib, g	887	846	820	98.06	0.59	0.84
Fat, g	117	98	132	22.19	0.96	0.28
Fat %	13.01	12.81	15.79	2.85	0.92	0.47
Meat, g	522	511	448	70.25	0.83	0.49
Meat %	58.54	59.31	55.02	2.78	0.96	0.35
Bone, g	229	231	231	26.66	0.74	1.00
Bone %	26.51	27.27	28.14	1.18	0.62	0.46
Neck, kg	1.03	0.94	1.11	0.12	0.81	0.29
Ribs, kg	4.05	4.43	4.23	0.45	0.96	0.76
Flank, kg	0.56	0.57	0.51	0.08	0.14	0.63
Internal organs, g						
Lung	478	506	557	41.89	0.64	0.43
Heart	150	150	164	14.59	1.00	0.34
Liver	561	589	595	49.73	0.70	0.94
Spleen	61	70	96	7.19	0.50	0.01
Kidney	118	129	144	9.54	0.48	0.26
Testicles	228	251	285	23.15	0.46	0.37

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3. # Significant at P ≤ 0.05.

Moreover, it is beneficial for animals too because ruminants (cows and goats) have been found to suffer from heart disease (HD) without clinical signs of heart failure (HF) may ultimately succumb to premature death (Buczinski et al., 2010). Lower n-6/n-3 ratio in blood has also been reported previously in cows fed on flaxseed (Petit, 2003) and formaldehyde treated flaxseed or fish oil (Petit et al., 2002).

Carcass characters: LOB and LOBE goats did not reveal any significant ($P \leq 0.05$) change over the control in respect of the studied carcass characteristics (Table 8) except for increase ($P \leq 0.05$) in the weight of organs like spleen. Most important carcass characteristics like dressed carcass weight and dressing (%) remained unchanged ($P \geq 0.05$).

The present results are in line with the report of Czauderna et al. (2004) in sheep fed on diets rich in linseed oil with or without selenium, Lee et al. (2008) and Zhao et al. (2013) with vitamin E inclusion and Raes et al. (2004) with flaxseed inclusion also found no changes in animal performance or carcass quality.

Chemical composition of Logissimus lumborum (LL) muscle: The results (Table 9) indicated significant ($P \leq 0.05$) reduction in crude fat (%) in LOB compared to control goats, but no reduction ($P \leq 0.05$) in LOBE over LOB. The present results are in agreement with Lanza et al. (2011) and Facciolongo et al. (2018). The influence of dietary fat on the proportion of intramuscular fat seems to be controversial, because some researches attributed the incidence of intramuscular fat to be related to animal sex (Horcada et al., 1998).

Diaz et al. (2003) have reported a higher proportion of muscle fat in females. Horcada et al. (1998) have reported that sex differences are more evident in suckling lambs than in fat lambs. Zhao et al. (2013) had found that vitamin E supplementation (200 IU day^{-1} $lamb^{-1}$) had a suppressing effect on subcutaneous fat deposition as vitamin-E stimulates the immune system and inhibits lipid catabolism. However, lower fat (%) in muscle is welcome by the consumers.

Table (9): Chemical composition (%) and the area of *Longissimus lumborum* (LL) muscle of Damascus growing male goats fed linseed oil with and without vitamin E

ITEMS	CTRL (T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Dry matter	70.41	71.5	70.96	0.7958	0.42	0.55
Crude ash	3.36	3.08	3.32	0.3224	0.61	0.54
Crude protein	44.61	42.26	40.24	1.6443	0.33	0.44
Crude fat	51.85	37.48	37.09	1.5948	# 0.001	0.87
LL area (cm^2)	17.60	19.38	17.18	0.52	# 0.05	# 0.03

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3. # Significant at P ≤ 0.05.

Dimension of *longissimus lumborum* (LL) muscle: The LL muscle area (rib-eye area) was affected by feed treatments. It was higher ($P \leq 0.05$) in LOB compared to the control, and lower ($P \leq 0.05$) in LOBE compared to LOB (Table 9). Our results are in agreement with Maiorano et al. (2007) and Zhao et al. (2013), who did not observe significant differences for the main carcass indices such as hot carcass weight and LD muscle area with different levels of vitamin E supplementation. However, it is reported that selection of sires for longissimus muscle area could yield genetic progress in body weight, because it is the only group of muscles which develops at the same rate with that of body growth (Mirzaei et al., 2009).

Intramuscular fatty acid composition of longissimus lumborum (LL) muscle: The content and profile of specific fatty acids (FA) of intramuscular lipids in LL muscle are important factors in assessing its nutritional quality (Table 10).

However, growing animals may be less responsive to changes in tissue FA profile because supplemental fat may be used as energy source instead of being stored (Ferreira et al., 2014). Our results revealed the following.

Saturated Fatty acids (SFA): The concentration of $C_{18}H_{36}O_2$, stearic acid was lower ($P \leq 0.05$) in LOB compared to control.

Monounsaturated Fatty acids (MUFA): The concentration of c14:1ω5, tetradecenoic acid was higher ($P \leq 0.05$) in LOBE compared to LOB. The concentration of C20:1ω7, 9- Eicosaenoic acid and ∑MUFA were higher ($P \leq 0.05$) in LOB compared to the control.

Polyunsaturated Fatty acids (PUFA): The concentration of c18:2ω5, Vaccenic acid, was higher ($P \leq 0.05$), while the concentration of c18:2ω6, linoleic and c18:3ω3, linolenic acid, were lower ($P \leq 0.05$) in LOBE compared to LOB.

The concentration of ∑MUFA was higher ($P \leq 0.05$) in LOB compared to the control. The concentrations of ∑PUFA n-3 and PUFA n-6/ PUFA n-3 were lower ($P \leq 0.05$) in LOB than the control.

Our result agrees with Gallardo et al. (2015) in lambs receiving diets supplemented with linseed oil. The concentration of stearic acid (C18:0) was found to decrease significantly ($P \leq 0.05$) in goats fed on LOB compared to control goats and as a consequence the concentration of total SFA tended to decrease by LOB addition.

The reduction of the total SFA in ruminant's muscles was attributed to the de novo synthesis inhibition by a higher percentage of exogenous FA (Miltko et al., 2019) or may be due to oil stimulated peroxidation damage and /or catabolism of FA (Czauderna et al., 2004).

The current results are consistent with Ebrahimi et al. (2013) who didn't find significant changes in SFA concentration in the subcutaneous adipose tissue of goats fed diet with different levels of linseed oil. Insignificant decrease in concentration of total SFA in blood and in muscle with beads inclusion indicated decreased biohydrogenation process in the rumen.

A recent study (Miltko et al., 2019) has reported that increased SFA contents resulted from biohydrogenation by ruminal bacteria which converts unsaturated FA to SFA in the rumen that take part in the absorption as well as fat deposition in muscles.

Table (10): Fatty acid composition of *longissimus lumborum* muscle in Damascus growing male goats fed linseed oil beads with and without vitamin E (FA% of total)

Fatty acid %	CTRL(T1)	LOB (T2)	LOBE (T3)	SEM	P1	P2
Saturated fatty acids (SFA)						
C10, capric	0.16	0.16	0.17	0.055	0.966	0.849
c12, lauric	0.18	0.28	0.31	0.081	0.337	0.776
c14, myristic	2.52	2.69	2.63	0.250	0.660	0.845
c15, pentaenoic	0.72	0.78	0.90	0.086	0.475	0.402
c16, palmitic	21.68	22.17	22.08	0.184	0.071	0.296
c17, heptadecanoic	2.34	1.49	2.11	0.239	0.060	0.162
c18, stearic	17.25	14.67	16.73	0.816	#0.038	0.120
∑SFA	44.86	42.23	44.94	0.814	0.094	0.061
Monounsaturated fatty acids (MUFA)						
c14:1ω5, tetradecenoic	0.10	0.06	0.22	0.039	0.317	#0.030
C14:1ω7, Myristioleic	nd	0.14	0.22	0.064	0.061	0.526
c16:1ω7, palmitoleic	2.54	3.01	2.70	0.184	0.071	0.296
C16:1ω5	nd	0.08	0.20	0.049	0.153	0.192
c18:1ω9, oleic	41.03	41.62	42.83	0.890	0.612	0.366
c18:1ω7, vaccinic	2.12	2.42	2.08	0.175	0.309	0.174
c18:1ω5, 6-octadecosaenoic	1.04	0.86	0.79	0.081	0.135	0.638
C20:1ω7, 9- Eicosaenoic	nd	0.18	0.07	0.055	#0.024	0.288
c20:1ω11, Eicosaenoic	0.05	0.15	0.14	0.072	0.196	0.932
C20:1ω5, 11-Eicosaenoic	nd	0.31	0.18	0.126	0.133	0.586
c20:1ω9, Gadolic	0.46	1.06	0.187	0.250	0.163	0.023
∑MUFA	47.34	49.88	49.63	0.731	#0.031	0.818
Polyunsaturated fatty acids (PUFA)						
c16:2ω4,	0.04	0.11	0.11	0.060	0.332	1.000
c16:3ω4, hexadecatrienoic	0.83	0.91	1.09	0.087	0.591	0.132
c16:4ω3,	0.13	0.03	0.03	0.029	0.059	0.922
c18:2ω5,	0.13	0.25	0.29	0.026	#0.006	0.375
c18:2ω7,	0.31	0.28	0.18	0.057	0.584	0.304
c18:2ω6, linoleic	4.76	3.45	2.612	0.369	#0.045	0.034
c18:3ω3, linolenic	0.25	1.27	0.63	0.194	#0.010	0.092
c18:4ω3,alphaoctadecatetraenoic	0.46	0.21	0.12	0.100	0.136	0.392
c20:4ω6, Arachidonic	0.732	1.04	0.24	0.257	0.502	0.104
c20:5ω3, Eicosapentaenoic	0.14	0.34	0.14	0.137	0.333	0.333
∑PUFA	7.56	6.58	4.36	0.679	0.245	0.066
∑UFA	54.90	56.46	53.99	0.807	0.258	0.078
∑ PUFA n-3	0.98	1.85	0.92	0.248	#0.037	0.051
∑ PUFA n-6	5.49	4.49	2.85	0.500	0.231	0.029
Nutritional quality of meat						
∑n-6/ ∑n-3	5.60	2.42	3.09	2.01	#0.023	0.206
PUFA/SFA	0.17	0.16	0.10	0.017	0.660	0.053

CTRL (T1): Control Diet, LOB (T2): Control Diet: + Linseed oil-beads, LOBE (T3): Control Diet + Linseed oil-beads + Vitamin E, SEM: standard error of means, P1 = Probability between T1 &T2. (4) P2 = Probability between T2 &T3. # Significant at P ≤ 0.05.

Data of Table (10) further indicated that feeding LOB significantly increased (P ≤0.05) total MUFA deposition in muscle tissues. 9-Eicosaenoic (C20:1ω7) acid was increased (P ≤ 0.05) in meat with LOB addition compared to control goats and also tetradecenoic (C14:1 ω5) acid (P ≤ 0.05), while gadolic (C20:1 ω 9) acid was decreased (P ≤ 0.05) in meat of goats fed on LOBE that may be probably attributed to Δ^9– desaturase activity.

Aharoni et al. (2004), Barton et al. (2007) and Gallardo et al. (2015) have found an increase of MUFA levels in meat with linseed oil or linseed. On the other hand, oleic acid which is the main MUFA showed comparable values between experimental groups that agree with Facciolongo et al. (2018). In contrast, Bessa et al. (2007) and Miltko et al. (2019) found that linseed oil in diets reduced oleic acid in ruminants tissues because either of absence of stearic acid desaturated by Δ^9 – desaturase or inhibition of enzyme activity by high PUFA contents (Sampath and Ntambi, 2005).

In the present study, values of the plasma stearic acid in all treatments were comparable and plasma oleic acid increased with additives. The stearic acid concentration decreased in tissues while oleic acid was unaffected. These finding may be due to lower intake of oleic and stearic acids from blood (Facciolongo et al., 2018). Limited effect of vitamin E in the present study may be related to its susceptibility to degradation by rumen microbes when it is administered orally or due to impaired intestinal uptake of the vitamin or increased metabolism post absorption as reported in conflicting studies (Chikunya et al., 2004).

The concentration of C18:2 ω6 and C18:3w3 acids increased (P ≤ 0.05) in LOB compared to control goats and tended to decrease in LOBE indicating that vitamin E can somehow modify n-3 FA hydrogenation (Juarez et al., 2011). Pottier et al. (2006) and Juarez et al. (2010) have suggested that vitamin E could influence ruminal biohydrogenation pathways of PUFA acting either as bacterial inhibitor or as an electron acceptor. Indeed, eicosapentaentaenoic (C20:5 ω3) concentration was higher in LOB compared to CTRL and LOBE. Although, linoleic acid (C18:2 ω6) (n-6) decreased (P ≤ 0.05) in both the experimental groups (LOB and LOBE), the total n-6 PUFA was decreased (P ≤ 0.05) only in the meat of LOBE compared to LOB. Reduction of the percentage of total n-3 PUFA in LOBE maybe due to a decrease in arachidonic acid (C20:4 ω6) compared to those goats fed LOB only. The increased concentration of total n-3 PUFA may be attributed to its high dietary content.

The present results are in agreement with those of Ebrahimi et al. (2013) and Miltko et al. (2019) on lambs fed oils rich in n-3 FA. In the same line, Juarez et al. (2011) have concluded that inclusion of flaxseed or vitamin E to diet increased the level of total n-3 FA in intramuscular fat in response to higher levels of linolenic and EPA fatty acids. The present results of meat n-3 FA are in agreement with their corresponding data in plasma (Table 6) and the findings are supported by Raes et al. (2004) who proved that enzymes responsible for desaturating and elongatinglinoleic and linolenic acids to their longer chain metabolites are the same, but they had a higher affinity for n-3 FAs. Overall, the increase in n-3 FA and the decrease of n-6 FA in LL muscle of goats receiving LOB resulted in a reduction in n-6/n-3 ratio (P ≤ 0.05).

Nutritional quality of meat: According to the health indexes (Facciolongo et al. 2018), the n-6/n-3 and PUFA/SFA ratios are nutritional value indicators of fat for human consumption, and it has been reported in a recent study on lamb meat quality (Miltko et al., 2019). It is well known that ruminant meat is high in SFA. Hence, by increasing the dietary PUFA contents by enriching diets by n-3 or n-6 PUFA, there can be improvement in P: S ratio (Jeronimo et al. 2009).

The present results of P:S ratios in all the experimental groups were less than 0.045 which is the minimum recommended value for human diet by WHO/FAO (2003). Lowering the n-6/n-3 ratio in food products has been recommended for human health and it ranges from 1-4 (WHO/FAO, 2004). In the present study, LOB inclusion in diets of goats resulted in decrease ($P \leq 0.05$) in n-6/n-3 ratio (2.67) of muscle lipids compared to control goat's muscle (6.05) while vitamin E supplementation (LOBE) didn't affect this ratio ($P \geq 0.05$) compared to those fed on LOB.

CONCLUSIONS

In conclusion, LOB or LOBE inclusion influenced fewer dietary variables, didn't influence animal performance or carcass characteristics, but LOB addition to diets is more acceptable because they improve plasma and meat FA profile where they reduces the concentration of SFA and favorably decrease n-6/-n3 ratio in meat, and therefore achieving an important target that related to human health. Vitamin E had limited effect on plasma and meat FA composition. Consequently, the meat FA composition in LOBE was less satisfying than meat of goats fed on LOB only. Further studies are required to focus if FA profiles are influenced by longer duration of oil beads addition in diet with different levels of vitamin E.

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UNDERTAKING

It is certified that the research paper '**EFFECT OF LINSEED OIL BEADS AND VITAMIN-E SUPPLEMENTATION ON GROWTH, CARCASS CHARACTERS, AND BLOOD AND INTRAMUSCULAR LIPID PROFILE IN DAMASCUS GROWING MALE GOATS'** is an original research work carried out by the author in Animal and Poultry Nutrition Department, Animal and Poultry Division, Desert Research Center, Cairo, Egypt. It has neither been published nor contemplated for publication elsewhere.

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