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Feeding behavior, nutrient digestibility, feedlot performance, carcass traits, and meat characteristics of crossbred lambs fed high levels of yellow grease or soybean oil

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ABSTRACT

Twenty-four crossbred (Santa Inês × Dorper) non-castrated male lambs (initial body weigh 24.9 kg ± 2.4 kg), were used to evaluate the effects of lipid sources (soybean oil or frying soybean oil) on feeding behavior, feedlot performance, digestibility of dry matter and nutrients of finishing lamb diets. The animals were distributed in a randomized block design and assigned to one of the isonitrogenous (18.4% CP, DM basis) diets which were formulated in forage:concentrate ratio of 40:60. The control treatment (CTL) was composed of corn silage, corn grain, sunflower meal, soybean hulls, urea, limestone and minerals. The other two treatments contained 6% soybean oil (SO) or 6% residual soybean frying oil (YG) on DM basis, mainly replacing corn grain and soybean hulls. Animals were offered total mixed rations twice daily *ad libitum*. Animals were harvested at 35 kg BW, and carcass characteristics data were recorded. Samples of *Longissimus* muscle were collected for centesimal composition analysis. The feeding behavior was observed for 3 consecutive days (12 h period each). The apparent digestibility of DM and nutrients of experimental diets were estimated using the internal marker indigestible acid detergent fiber. The oil supplementation, regardless of the source, did not change feeding behavior and carcass characteristics. Dry matter and nutrient intake and digestibility were decreased when animals were fed oil, except for ether extract, which increased. Animals fed YG presented lesser average daily weight gain (177.7 g) than SO-fed lambs (205.3 g). In conclusion, the addition of soybean oil or yellow grease at 6% in diet DM for feedlot crossbred lambs has minimal effects on feeding behavior and increases feed efficiency, however decreases digestibility of DM, NDF and ADF, and tends to increase intramuscular fat. The use of yellow grease as an alternative energy source increases lambs' days on feed.

1. Introduction

Costs of feeding limit the feedlot activity in many countries around the world (*i.e.* Brazil). The use of alternative feed ingredients aims to minimize production costs without altering the production of animal products such as meat, milk or wool. Food industry residues may be economical alternative energy sources in ruminant diets, especially when the prices of conventional ingredients, such as corn and soybean hulls, are high. In addition to economic constraints, competition between humans and animals for grains limits the level of grain inclusion, and negatively affects the sheep industry (Awawdeh et al., 2009a).

Vegetable oils and animal fat are used in animal feed to increase energy density of the diets (NRC, 2007), as well as to serve as carriers of fat-soluble ingredients (vitamins and essential fatty acids), to facilitate the digestion process of these ingredients, and to improve the physical nature of the ration (Palmquist, 1987).

According to OCDE/FAO (2015), vegetable oil production in Brazil is approximately 8 Mt l, and the demand for human consumption is about 5 Mt l, with perspective to expand the oil production by up to 31% by 2024. Also, according to the PNBE (National Thought of Entrepreneurs Bases) only 2.5–3.5% of disposed edible oil is recycled (Yoshida and Morcatti, 2010).

Because of the benefits of using oil in animals' diets coupled with the possibility of decreasing feeding costs, previous researchers

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investigated the inclusion of residual frying oil (yellow grease) in diets for beef cattle (Plascencia et al., 1999), dairy cattle (Chow et al., 1990), and sheep (Awawdeh et al., 2009b) with promising results. This by-product is most commonly used in biodiesel, soap, or ink production, but it still requires a quality standardization and specific regulation of using it as an animal feed ingredient.

Moreover, data from studies using yellow grease as an energy source in ruminants' diets are still rare in the literature. Thus, the objectives of this study were to evaluate the effects of yellow grease or soybean oil on feeding behavior, feedlot performance, nutrient digestibility, and meat quality of crossbred lambs.

2. Materials and methods

The study was carried out at the Animal Unit of Digestive and Metabolic Studies from the Department of Animal Science of São Paulo State University (Unesp), Jaboticabal, São Paulo, Brazil. The São Paulo State University Institutional Animal Care and Use Committee approved all experimental protocols adopted in the current study (approval number: 00719711).

2.1. Animals, diets and management

Twenty-four Santa Inês × Dorper male lambs (initial BW = 25 ± 2.4 kg) were housed in individual shaded pens (1.2 m^2), and used in a complete randomized block design. Upon arrival, all lambs were offered *ad libitum* access to corn silage and water before processing. Animals were blocked by initial BW and randomly assigned, within block, to one of the three treatments (n = 8), for a total of 24 pens. Animals were tagged, vaccinated for clostridiosis (Sintoxan Polivalente T, Merial Saúde Animal Ltda, Paulínia, Brazil), and supplemented with vitamins A, D, and E (Valléevita ADE, Vallée S/A Produtos Veterinários, Montes Claros, Brazil).

Lambs were transitioned from a 70:30 roughage:concentrate diet to a 40:60 finishing diet over a period of 21 days, using three step-up diets. Three Isonitrogenous (18.4% CP) finishing diets were formulated according to NRC (2007) for a minimum average daily weight gain of 0.250 kg (Table 1). The control treatment (CTL) was composed of corn silage, corn grain, sunflower meal, soybean hulls, urea, limestone and mineral-vitamin premix. In yellow grease (YG) and soybean oil (SO) treatments, corn grain and soybean hulls were partially replaced, and antioxidant butylated hydroxytoluene (BHT) was added. Yellow grease was obtained from restaurants of Jaboticabal City, Brazil, and soybean oil was obtained from commercial sources. Diets were mixed weekly to avoid oil rancidity. Feed samples were collected weekly for determination of DM, OM, CP (AOAC, 2005), ADF and NDF (Goering and Van Soest, 1970), using thermostable α-amylase and an autoclave [0.5 kgf/cm^2, 110 °C, for 40 min], according to Senger et al. (2008).

Animals were fed total mixed rations (TMR) twice daily (0700 and 1700 h) *ad libitum*, and before access to the morning feed was allowed, the feed was spread out in the bunk according to Pritchard (1993), to present feed bunk with score 1 (thin uniform layer of feed across bottom of bunk). Samples of refused feed were collected weekly from each bunk, and composited for each animal to calculate DM and nutrient intakes.

Lambs were weighed upon arrival, at the end of adaptation period, and every seven days of the experimental period, for monitoring weight gain. At the end of the experimental period, the average daily gain (ADG) as well as feed efficiency (F:G) were calculated. When animals reached 35 kg BW, they were harvested at São Paulo State University Goat Unit experimental abattoir, where carcass data were collected.

Table 1
Ingredient and chemical composition of experimental diets.

Item	Treatments		
	Control (CTL)	Soybean oil (SO)	Yellow grease (YG)
Ingredient composition (%)			
Corn Silage	40.0	40.0	40.0
Corn cracked grain	10.8	7.5	7.5
Sunflower meal	37.5	40.9	40.9
Soybean hulls	9.8	3.6	3.6
Soybean oil	–	6.0	–
Frying residual oil	–	–	6.0
Urea	0.5	0.5	0.5
Limestone	0.4	0.5	0.5
Butylated hydroxytoluene	–	0.02	0.02
Mineral-vitamin premix[a]	1.0	1.0	1.0
Nutrient composition			
Dry matter, %	66.7	67.4	67.4
Crude protein, % DM	18.4	18.4	18.4
Ether extract, % DM	2.4	8.2	8.2
Neutral detergent fiber, % DM	46.2	43.0	43.0
Acid detergent fiber, % DM	30.7	28.6	28.6
Non-fibrous carbohydrates[b], % DM	29.2	26.5	26.5
Calcium, % DM	0.8	0.9	0.9
Phosphorus, % DM	0.6	0.6	0.6
Metabolizable energy[c], kcal/kg	2.5	2.5	2.5

[a] Composition per 1 kg contained (vitamin A, 2,000,000 IU; vitamin D3, 35,000 IU; vitamin E, 300 mg; Ca, 100 g; P, 60 g; Mg, 10 g; S, 25 g; Na, 195 g; Cl, 300 g; Co, 100 mg; Fe, 1.2 g; Se, 12 mg; Zn, 4 g; F, 600 mg; Cu, 600 mg.
[b] NFC = 100 – (% CP + % NDF + % ash + % EE).
[c] Calculated based on TDN contents, considering TDN = %DCP + %DNDF + %DEE × 2.25 + %DNFC; 1 kg TDN = 4409 kcal DE; ME = DE × 0.82.

2.2. Feeding behavior

To evaluate feeding behavior, animals were observed for 3 consecutive days (day 30 to day 32) in a 12 h period (0700 to 1900 h). Data collection was performed by two trained observers, which observed 12 animals each, and recorded, each 5 min, the following activities: interaction with feed bunk (IF), when animal positioned the head toward the feed bunk, without specifying whether ingested, smelled or played with the feed; interaction with waterer (IW), when animal positioned the head toward the waterer, without specifying whether ingested, or played with the water; standing still (SS), when the animal was with four feet in contact with pen's floor without moving the body; stand ruminating (SR); laid ruminating (LR); laid (LD); stereotypes (ST—when the animal was chewing pen's wood, biting, repetitively licking or butting), and other activities (OA). Time (expressed in minutes) expended in each activity was calculated by the number of observations recorded multiplied by 5.

2.3. Total tract apparent digestibility

The apparent digestibility of dry matter and nutrients of experimental diets were estimated by using the internal marker indigestible acid detergent fiber (iADF). Diets and refused feed were sampled daily during the feedlot period, and fecal samples were collected each 4 h during 3 consecutive days (day 40 to day 42) in order to obtain representative fecal samples of 24 h periods. Subsequently, samples were composited by animal, pre-dried in a 55 °C oven for 72 h, ground (2 mm) using a Wiley-type mill, and approximately 4 g of each sample were placed into pre-weighed nylon bags (7 × 14 cm), and incubated in a bovine rumen for 264 h (Casali et al., 2008). After incubation period, bags were dried at 55 °C in a forced air-circulation oven for 72 h, and samples were ground (1 mm) using a Wiley-type mill and analyzed for ADF contents. ADF analysis was performed according to Goering and Van Soest

Table 2
Feeding behavior of feedlot crossbred lambs fed diets containing different sources of lipid.

Item[a]	Treatments[b]			SE	Contrast[c], *P*-value	
	CTL	SO	YG		Oil	Source
Interaction with waterer	13.2	11.5	11.3	3.6	0.25	0.91
Interaction with feed bunk	169.4	183.8	155.0	42.7	0.99	0.19
Stand still	111.9	128.1	112.6	42.8	0.65	0.48
Stand ruminating	14.6	20.0	8.2	10.4	0.90	0.04
Laid ruminating	156.3	162.5	182.5	43.6	0.40	0.37
Laid	149.4	143.8	149.4	51.6	0.90	0.83
Events	6.9	8.8	5.6	5.7	0.90	0.29
Stereotypes	33.1	32.5	32.3	11.9	0.89	0.97
Other activities	57.5	30.0	44.4	32	0.16	0.38

[a] Expressed in min/12 h-period of observation.
[b] CTL = Control diet; SO = addition of 6% soybean oil; YG = addition of 6% frying oil.
[c] Oil = effect of oil addition (CON × [SO + YG]); Source = effect of oil source (SO × YG).

Table 3
Performance and nutrient intakes of feedlot crossbred lambs fed diets containing different sources of lipid.

Item	Treatments[a]			SE	Contrast[b], *P*-value	
	CTL	SO	YG		Oil	Source
Lambs, *n*	8	8	8	–	–	–
Initial BW, kg	25.7	24.2	24.5	1.7	0.17	0.62
Final BW	34.8	35.0	34.8	1.2	0.91	0.73
ADG, g/day	177.7	205.3	161.5	26.7	0.63	<0.01
Nutrient intake, g/day						
Dry matter	1286	1136	969	125.7	<0.01	0.02
Crude protein	213	166	143	23.0	<0.01	0.07
Neutral detergent fiber	542	496	427	50.1	<0.01	0.02
Acid detergent fiber	352	316	261	33.2	<0.01	<0.01
Ether extract	27	93	78	7.1	<0.01	<0.01
Gain to feed, g/g	0.14	0.18	0.17	0.03	0.02	0.30
Days on feed	53.5	54.1	67.4	12.2	0.19	0.04

[a] CTL = Control diet; SO = addition of 6% soybean oil; YG = addition of 6% frying oil.
[b] Oil = effect of oil addition (CTL × [SO + YG]); Source = effect of oil source (SO × YG).

(1970), using an autoclave set to 0.5 kgf/cm^2, 111 °C, for 50 min. Digestibility coefficients (DC) were calculated using the following equation: DC (%) = 100 − 100 × [(% diet iADF/% fecal iADF) × (% nutrient in feces/% nutrient in diet)].

2.4. Carcass, non-carcass components and meat characteristics

After reaching 35 kg BW, animals were harvested after a solid-fasting period of 16 h, at Goat Unit facility experimental abattoir (Faculdade de Ciências Agrárias e Veterinárias—Unesp/Jaboticabal). Moments before the slaughter, animals were evaluated for body conformation, considering the muscle mass distribution (Osório et al., 1998), and body condition score ranging from 1 to 5 (Silva Sobrinho, 2001). Pre-harvest handling followed good animal welfare practices, and slaughtering procedures followed the Sanitary and Industrial Inspection Regulation for Animal Products (Brasil, 1997). Lambs were slaughtered by cerebral concussion followed by jugular and carotid venesection.

After bleeding, non-carcass components (head, feet, skin, gastrointestinal tract, spleen, liver, respiratory tract, tongue, esophagus, reproductive tract, bladder, pancreas, kidneys and omental, perirenal and mesenteric fat) were collected and weighed individually. Hot carcass weight (HCW) was calculated by the difference between slaughter weight (SW) and non-carcass components weights. Empty body weight (EBW) was calculated as the difference between SW and the weight of the gastrointestinal content. After 24 h chill (4 ± 1 °C), carcasses were reweighed for determination of the cold carcass weight (CCW) and cooling loss (CL% = (HCW − CCW)/HCW × 100). Hot carcass dressing (HCD% = HCW/SW × 100), cold carcass dressing (CCD% = CCW/SW × 100), and true dressing (TD% = HCW/EBW × 100) were also calculated. Carcasses were visually evaluated by three trained observers and graded from 1 to 5 for conformation, considering the carcass shape (muscularity; 1 = straight and 5 = concave), and fatness, based on the degree of fat deposit (1 = very lean and 5 = excessively fat), according to Silva Sobrinho (2001).

Total edible non-carcass components yield (TENCC) was obtained as the sum of weights of blood, tongue, lungs + trachea, liver + gall bladder, heart, kidneys, gastrointestinal tract (reticulum, rumen, omasum, abomasum and intestines), and abdominal and kidney fats. Total yield of usable products (TUP) was calculated as the sum of hot carcass weight and TENCC.

Carcasses were split longitudinally into two parts and left half carcasses were transversely sectioned between the 12th and the 13th ribs, exposing the transverse section of the *Longissimus* muscle. Back fat thickness (BF) was measured using a digital caliper and loin eye area (LM) was estimated using the formula: $(A/2 \times B/2) \times \pi$, where A is the maximum length and B is the maximum depth of muscle, according to Silva Sobrinho (1999). Samples of *Longissimus* muscle were collected and freeze-dried for 72 h, to determine moisture, crude protein, ether extract and minerals, according to AOAC (2005).

Table 4
Dry matter and nutrient total tract digestibility of diets containing different sources of lipid estimated by indigestible acid detergent fiber method.

Item	Treatments[a]			SE	Contrast[b], *P*-value	
	CTL	SO	YG		Oil	Source
Digestibility coefficients (%)						
Dry matter	57.4	49.5	47.1	4.1	<0.01	0.28
Crude protein	69.6	66.3	66.4	5.2	0.17	0.97
Neutral detergent fiber	37.9	33.0	31.5	2.6	<0.01	0.27
Acid detergent fiber	31.4	26.5	26.1	3.3	<0.01	0.82
Ether extract	74.4	76.6	76.7	2.3	0.03	0.95

[a] CTL = Control diet; SO = addition of 6% soybean oil; YG = addition of 6% frying oil.
[b] Oil = effect of oil addition (CTL × [SO + YG]); Source = effect of oil source (SO × YG).

2.5. Statistical analysis

Intake, performance, carcass and meat characteristics data were analyzed as a randomized complete block design by using the MIXED procedure (SAS Inst. Inc., Cary, NC). Animal was the experimental unit for all the variables studied. The statistical model was as follows: $Y = \mu + B_i + D_j + E_{ij}$, where μ is the overall mean, B_i is the block effect (i = 1–3), D_j is the diet effect (j = 1–3), and E_{ij} is the residual error. The block was included as a random effect. Feeding behavior data were analyzed as repeated measures by using the MIXED procedure of SAS. The statistical model for this trial was: $Y = \mu + B_i + D_j + S_{ij} + T_k + (DT)_{jk} + E_{ijk}$, where μ is the overall mean, B_i is the block effect (i = 1–3), D_j is the diet effect (j = 1–3), S_{ij} is the residual error associated with sheep effect (block × diet), T_k is the day of observation effect (k = day 30, day 31, or day 32), $(DT)_{jk}$ is the interaction of diet × day of observation, and E_{ijk} is the residual error. The block was included as random effect. The covariance structure with the best fit was the unstructured (UN). Contrasts were used to determine the effect of oil addition (CTL × [SO + YG]) and the effect of source of oil (SO × YG). Treatment means were computed with the LSMEANS option and significance was defined as $P < 0.05$ and trends as $0.05 \leq P \leq 0.10$.

3. Results

3.1. Feeding behavior

No day × treatment interaction was observed for any behavioral parameters evaluated in this trial. The oil supplementation, regardless the source, did not change time spent interacting with waterer or feed bunk (12 and 169.4 min, respectively; Table 2). Treatments also did not affect time that animals spent standing still (117.5 min). Animals fed YG diet spent less time standing ruminating compared with SO-fed animals ($P = 0.04$), which did not occur when animals were laying ruminating (167.1 min), or just lying (147.5 min). No changes were observed among treatments for events (7.1 min), stereotypes (32.6 min), or other activities (44 min).

3.2. Nutrient intake and performance

Dry matter intake was decreased when animals were fed oil ($P < 0.01$), regardless of the source, and the decrease was more pronounced when animals were fed the YG diet ($P = 0.02$; Table 3). Consequently, CP, ADF and NDF intakes followed a similar effect ($P < 0.01$). Ether extract intake was greater for the average of SO and YG compared with CTL ($P < 0.01$), and when oil diets were compared, YG promoted the least EE consumption ($P < 0.01$).

Initial and final body weights were similar among treatments ($P > 0.17$; Table 3). Average daily gain of CTL-fed lambs was similar to the average of SO and YG-fed animals ($P = 0.63$), while animals fed YG had ADG 21.3% lower than SO-fed lambs ($P < 0.01$), resulting in more days on feed for animals fed YG ($P = 0.04$). Animals fed CTL diet were more efficient (0.14) compared with SO and YG-fed animals (0.18 and 0.17, respectively; $P = 0.02$), which were not different between them ($P = 0.30$). Considering the cumulative days on feed, it was observed that the total dry matter intake follows the descending order CTL > YG > SO (69 kg, 66 kg, 61.5 kg, respectively), which possibly resulted in greater efficiency (0.14, 0.17, and 0.18 respectively) of animals fed oil, even if they had greater energy maintenance requirement.

3.3. Dry matter and nutrient total tract digestibility

Dry matter digestibility was reduced when animals were fed diets containing oil ($P < 0.01$), and no differences were observed between YG and SO diets ($P = 0.28$; Table 4. A similar effect was observed for NDF and ADF digestibilities. On the other hand, regardless of the oil sources, oil supplementation increased EE digestibility ($P = 0.03$), while CP digestibility was unaffected by treatments ($P > 0.17$).

3.4. Carcass traits, non-carcass edible components, and meat composition

Oil supplementation did not change hot carcass weight ($P = 0.53$), and YG-fed lambs tended to have a heavier hot carcass compared with SO-fed ones ($P = 0.06$). Dressing percentage was similar between animals fed CTL and the average of SO and YG ($P = 0.35$), however dressing percentage of YG-fed animals was greater than animals fed SO. No differences were observed among treatments on fat thickness ($P = 0.38$), *Longissimus* muscle area ($P = 0.77$), carcass conformation score ($P = 0.81$) or carcass fat score ($P = 0.91$) (Table 5).

Regarding edible non-carcass components, the liver was the only component that tended to be affected by treatments. Animals fed oil, regardless of the source, presented lighter liver ($P = 0.03$). Blood ($P = 0.82$), digestive tract ($P = 0.68$), spleen ($P = 0.44$), tongue ($P = 0.95$), esophagus ($P = 0.52$), heart ($P = 0.97$), kidneys ($P = 0.40$), perirenal fat ($P = 0.65$), omental fat ($P = 0.71$), also TENCC ($P = 0.55$) and TUP ($P = 0.37$) did not change with inclusion of oil sources in the diets (Table 6).

Longissimus muscle moisture (73.5%, $P = 0.78$), ash (1.2%, $P = 0.30$), and crude protein (23.0%, $P = 0.29$) were unaffected by oil supplementation. However, regardless of the source, treatments with oil, tended to have greater concentrations of ether extract ($P = 0.07$) (Table 7).

Table 5
Carcass characteristics of crossbred feedlot lambs fed diets containing different source of lipid.

Item	Treatments[a]			SE	Contrast[b], *P*-value	
	CTL	SO	YG		Oil	Source
Hot carcass weight, kg	15.7	15.0	15.8	0.8	0.53	0.06
Dressing percentage, %	45.0	43.0	45.5	1.7	0.35	0.01
12th rib fat thickness, mm	2.1	1.8	1.7	0.8	0.38	0.90
Longissimus area, cm[b]	9.6	9.3	9.6	1.2	0.77	0.64
Carcass conformation score[c]	3.1	2.9	3.1	0.3	0.81	0.29
Carcass fat score[c]	2.9	2.9	2.8	0.4	0.91	0.85

[a] CTL = Control diet; SO = addition of 6% soybean oil; YG = addition of 6% frying oil.
[b] Oil = effect of oil addition (CTL × [SO + YG]); Source = effect of oil source (SO × YG).
[c] Visual score scale 1–5.

Table 6
Edible non-carcass components and total usable products of crossbred lambs fed diets containing different source of lipid.

Item	Treatments[d]			SE	Contrast[e], *P*-value	
	CTL	SO	YG		Oil	Source
ENCC[a] yield, kg						
Blood	1.37	1.40	1.37	0.15	0.82	0.74
Digestive tract	2.66	2.69	2.51	0.32	0.68	0.31
Spleen	0.07	0.07	0.06	0.01	0.44	0.17
Liver	0.66	0.60	0.61	0.06	0.03	0.89
Tongue	0.09	0.09	0.09	0.01	0.95	0.50
Esophagus	0.05	0.05	0.06	0.01	0.52	0.35
Heart	0.22	0.22	0.22	0.03	0.97	0.92
Kidneys	0.11	0.10	0.11	0.01	0.40	0.30
Perirenal fat	0.19	0.21	0.18	0.07	0.65	0.41
Omental fat	0.54	0.49	0.53	0.18	0.71	0.62
TENCC[b], kg	6.62	6.57	6.43	0.16	0.55	0.56
TUP[c], kg	22.27	21.62	22.27	0.28	0.37	0.13

[a] Edible non-carcass components.
[b] Total edible non-carcass components.
[c] Total usable products = TENCC + HCW.
[d] CTL = Control diet; SO = addition of 6% soybean oil; YG = addition of 6% frying oil.
[e] Oil = effect of oil addition (CTL × [SO + YG]); Source = effect of source of oil (SO × YG).

Table 7
Proximate composition of meat from crossbred lambs fed diets containing different source of lipid.

Item, %	Treatments[a]			SE	Contrast[b], *P*-value	
	CTL	SO	YG		Oil	Source
Moisture	73.4	73.5	73.6	1.7	0.78	0.93
Ash	1.3	1.2	1.2	0.2	0.30	0.99
Crude protein	23.4	22.7	22.9	1.3	0.29	0.80
Ether extract	2.2	3.0	2.9	0.8	0.07	0.70

[a] CTL = Control diet; SO = addition of 6% soybean oil; YG = addition of 6% frying oil.
[b] Oil = effect of oil addition (CTL × [SO + YG]); Source = effect of source of oil (SO × YG).

4. Discussion

4.1. Feeding behavior, dry matter and nutrient intake

Data from feeding behavior observations show that all the animals were in a good state of welfare and comfort, spending most of the time (approximately 44%) lying down. According to Krohn and Munksgaard (1993), animals that are unstressed, spend most of the time lying down, in lateral decubitus, ruminating or not.

The shortest time ruminating standing observed in animals fed YG could be related to acceptability and intake of this oil. All the animals spent the same time interacting with the feed bunk (23.8%), however the intake of DM, NDF, and ADF were lowest for animals fed YG. This fact could be attributed to the greater selectivity of these animals trying to separate particles rich in frying oil from feed delivered.

When in excess in the rumen, unsaturated fatty acids reach the small intestine without complete biohydrogenation, which can increase the concentration of these metabolites in the blood stream, activating receptors of satiety in the hypothalamus, thereby inhibiting appetite and reducing feed consumption (Obici et al., 2002; Harvatine and Allen, 2006). According to Krehbiel et al. (2006), the chemical effect keeps the energy ingestion constant with changing DM intake. Thus, when the energy requirements are satisfied, animals start reducing DM intake. DMI observed in the current study was also reported by Nelson et al. (2008), who fed crossbred beef steers 0, 3, or 6% yellow grease, and attributed this effect to the greater energy content of oil-supplemented diets. However, previous studies did not show any change in overall DM intake when Holstein or crossbred yearling steers were fed 5 or 4% yellow grease, respectively (Brandt et al., 1992; Plascencia et al., 1999). Moreover, Awawdeh et al. (2009a, 2009b) feeding 3.2% yellow grease to Awassi ewes and lambs did not find any change in DMI. These authors also observed a greater intake of ether extract, due to the increase of this nutrient in oil-supplemented diets. The decreased intake of CP, ADF and NDF in the current study was due to the pronounced decrease in DMI observed in YG-fed lambs.

4.2. Feedlot performance

The effect of oil supplementation in diets on the performance of ruminants are variable, and such variability could be associated with differences among experiments in terms of composition of the basal diet (*i.e.*, energy density and level of grain), level of oil inclusion, oil composition (*i.e.*, contents of free and saturated fatty acids), and whether diets were formulated to be isoenergetic (Awawdeh et al., 2009b).

The initial and final BW were not different among treatments because animals were blocked by initial weight in the beginning of the experiment and all animals were harvested upon reaching 35 kg. Although the final BW were similar, animals fed YG diet took 13 days longer to be harvested when compared with CTL or SO-fed animals, primarily due to the these having the least ADG.

Average daily gain in the current study for CTL and the average of oil-fed lambs were similar, but animals fed YG showed the worst daily gain, probably due to palatability or to the greater contents of free and saturated fatty acids. Controversially, Awawdeh et al. (2009b) observed improvements in ADG with inclusion of YG or SO and attributed the result to a better utilization efficiency of ME from these sources and/or greater efficiencies of conversion of dietary fat to body fat than conversion of carbohydrates. Plascencia et al. (1999), supplementing Holstein steers with 5% yellow grease, observed greater ADG and feed efficiency compared with control-fed animals, while Zinn (1988) observed a greater feed efficiency for crossbred steers fed 4% yellow grease. The results from the current study suggest lambs are more sensitive to high concentration of yellow grease (6%), and a high content of ether extract (8%) than cattle are.

4.3. Dry matter and nutrient total tract digestibility

The supplementation of high concentrations of oil in the diets for ruminants usually causes a reduction in the growth of fibrolytic bacteria, thereby decreasing degradation of dietary fiber (Van Soest, 1994). Indeed, fiber fraction (ADF and NDF) digestibility was highly decreased in the current study, decreasing DM digestibility. However, previous studies showed no effect of YG supplementation at 5 or 6%, on digestibility of OM or ADF (Plascencia et al., 1999; Zinn, 1992; respectively). Awawdeh et al. (2009b), feeding Awassi finishing lambs 3.2% YG, also observed no difference in digestibility of DM, OM, ADF, NDF, or CP, but showed a higher ether extract digestibility in oil supplemented diets, similar to results of the current study. Yamamoto et al. (2005); Maia et al. (2012), and Morgado et al. (2014), also observed an increased ether extract digestibility when oil was added in diets for lambs.

4.4. Carcass, non-carcass edible components and meat characteristics

The tendency of improvement in hot carcass weight, and consequently in dressing percentage, in response to YG diets, was probably due to more days on feed observed for lambs fed this diet, resulting in older animals, which had different tissue deposition in the carcasses (Butterfield, 1988). Awawdeh et al. (2009b) feeding finishing Awassi lambs 3.2% yellow grease or soybean oil reported no oil source effect on hot carcass weight, cold carcass weight or dressing percentage. These authors slaughtered all animals on the same day, and the heavier carcasses obtained in the present study were due to the heavier fasting live weights of animals fed oil.

The lack of effect of oil addition or oil source obtained in the present study for 12th rib fat thickness and *Longissimus* muscle area is in agreement with previous studies using 4% (Brandt et al., 1992), or up to 6% (Nelson et al., 2008) yellow grease in diets for crossbred steers. Carcass conformation and carcass fat score were unaffected probably because animals were slaughtered at the same body weight at the same stage of relative maturity.

The lighter livers observed for animals fed oil sources in the current study are in contrast with data reported by Awawdeh et al. (2009b), which probably are due to the reduction of the digestibility of these diets, decreasing the activity of the organ. Scarpino et al. (2014) reported greater concentrations of liver enzyme (AST—aspartate aminotransferase) for oil-fed animals that may indicate some degree of tissue damage, contributing to loss of liver weight.

The lack of effect of oil supplementation and oil source on individual edible non-carcass components, total edible non-carcass components or total usable products indicate that either oil source can be used as energy ingredient to obtain satisfactory results in terms of edible products.

The average values observed for centesimal composition of *Longissimus* muscle is consistent with results from studies evaluating meat composition from crossbred (Santa Inês × Dorper) lambs, which present average values for moisture, ash, CP, and ether extract of 73.3, 23.0, 1.3 and 2.4%, respectively (Bezerra et al., 2012; Moreno et al., 2011; Peixoto et al., 2011). The greater concentrations of ether extract observed in treatments with addition of oil (YG and SO), could be partially explained by the greater consumption of energy (2.7 Mcal/kg for oil-rich treatments × 2.5 Mcal/kg for CTL treatment), especially in form of ether extract, compared with controls (8.2 × 2.4%). Possibly, the greater consumption allowed better metabolic efficiency of anabolic reactions in adipose tissue. According to Chilliard (1993), unsaturated fatty acids are readily available for fat deposition, reducing the energy cost of fat synthesis from short chain fatty acids, such as acetate and butyrate. The direct oxidation of fatty acids is 10% more efficient than the oxidation of acetate (Palmquist, 1994), promoting energy saving for the animal.

5. Conclusions

The addition of soybean oil or yellow grease at 6% in diet DM of feedlot crossbred lambs has minimal effects on feeding behavior and increases feed efficiency, however decreases digestibility of DM, NDF and ADF, and tends to increase intramuscular fat. The use of yellow grease as alternative energy source increases lambs' days on feed, but depending on the price and availability it can be economically feasible, especially for small family farmers.

Conflict of interest

The authors declare no known conflict of interest.

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