

Effects of crude glycerin from waste vegetable oil in diets on performance and carcass characteristics of feedlot goats

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Objective: This experiment was conducted to investigate the effects of crude glycerin from waste vegetable oil (CGWVO) on performance, carcass traits, meat quality, and muscle chemical composition.

Methods: Twenty-four crossbred (Thai Native×Anglo Nubian) uncastrated male goats (16.8±0.46 kg body weight [BW]) were assigned to a completely randomized design and subjected to four experimental diets containing 0%, 2%, 4%, and 6% of CGWVO (63.42% of glycerol and 47.78% of crude fat) on a dry matter (DM) basis. The diets were offered *ad libitum* as total mixed rations twice daily. The feed intake, feeding behavior, growth performance, carcass and meat traits, and muscle chemical composition were evaluated.

Results: Based on this experiment, there were significant differences ($p>0.05$) among groups regarding DM intake, growth performance, and carcass traits where goats receiving 6% of CGWVO had lower daily DM intake, growth performance, and carcass traits than those fed on 0%, 2%, and 4% of CGWVO. There were no effects of CGWVO on carcass length, carcass width, *Longissimus* muscle (LM) area, Warner-Bratzler shear force, pH and color of LM at 45 min after slaughter, as well as on other carcass cut and muscle chemical composition.

Conclusion: In conclusion, the addition of up to 4% of DM in the diets for crossbred finishing goats seems to be the most interesting strategy, since it promotes greatest animal performance. Moreover, this study was a suitable approach to exploit the use of biodiesel production from waste vegetable oil for goat production.

Keywords: By-product; Crude Glycerin; Waste Vegetable Oil; Growth Performance; Carcass Characteristic; Goat

INTRODUCTION

Rapid growth in biofuel production has led to increased prices of several agricultural commodities, including corn. Its high market price is driving livestock producers to search for alternative feed sources. Crude glycerin (CG) is the major byproduct of the conversion of vegetable oils, animal fats (first-use oil) and/or waste greases (second-use oil) into biodiesel [1]. Approximately 10% of the total volume of biodiesel produced becomes CG [1]. Rapid growth in biofuel production of Thailand has led to increasing feedstocks of CG, with a subsequent price reduction, making glycerin a potential high energy feed source for ruminants [2]. The use of CG as a substitute for energetic ingredients in animal feed has shown promising results for livestock in many species including swine, poultry, beef cattle, dairy cattle, goats, and sheep.

The inclusion of glycerin in ruminant diets modifies ruminal fermentation such as the acetate: propionate ratio, because CG is preferentially converted to propionate in the rumen, absorbed directly by ruminal epithelium or goes directly to the small intestine and is then converted to glucose in the liver [3]. Similarly, AbuGhazaleh et al [4] reported that CG was

an appealing byproduct in feedlot diets because it was primarily converted to propionate in the rumen and acted as a precursor for glucose synthesis. However, recent studies have evaluated the effects of the inclusion of CG (up to 86% of glycerol) in diets on feed intake, performance, carcass, and meat quality of beef, dairy, goat and sheep with acceptable inclusions of 15% to 21% dry matter (DM), respectively [2,5,6]. Furthermore, most of the CG used in those studies was derived from vegetable oils (first-use oil) of castor bean, soybean, cottonseed, sunflower, rapeseed, canola, and palm oil. At present, a limited number of studies have evaluated the effects of CG originating from waste vegetable oils (CGWVO) that (second-use oil) contained high crude fat and a low content of glycerin in diets fed to goats. Thompson and He [1] reported that nutritional data generated for the glycerin of the first-use oil samples showed that it was mostly carbohydrate and could reasonably be mixed with high protein meal and used as a feed supplement. They also found that giving the higher fat content of CGWVO could be used as a supplement for energy or fat in animal diets particularly in goats. The authors hypothesized that CGWVO containing 63.42% of glycerol and 47.78% of crude fat in DM basis [7] might be used as an energy source in the diet of feedlot finishing goats at concentrations of up to 6% on a DM basis without compromising animal performance, or carcass and meat quality traits of goats. Lage et al [8] noted linear decreases in feedlot performance and carcass characteristics of lambs when fed 6 and 12% CG; however, no differences were noted between 0% and 6% CG supplementation. To further evaluate the optimal amount of CGWVO in the diet of goats. Therefore, the objectives of this study were to evaluate the effects of CGWVO on animal performance, and carcass and meat quality traits while establishing an optimal feeding amount in goats fed diets containing corn grain.

MATERIALS AND METHODS

The trials were conducted at the Department of Animal Science, the Faculty of Natural Resources, Prince of Songkla University (PSU), Hat Yai Campus. All procedures involving animals in the metabolism and finishing studies were approved by the Animal Ethics Committee of Prince of Songkla University (record no. AEPSU 16/2558), based on the Ethical of Animal Experimentation of National Research Council of Thailand (NRCT).

Animals, housing and experimental diets

Twenty-four crossbred (Thai Native×Anglo Nubian) uncastrated male goats (16.8±0.46 kg body weight [BW]) and an initial average age of eight months were used in a completely randomized design and subjected to four experimental diets containing 0%, 2%, 4%, and 6% of CGWVO/kg DM (Table 1). Animals were housed in individual pens (1.0×1.0 m) indoors,

Table 1. Ingredient proportion and chemical composition of the experimental diets

Item	Dietary CGWVO (% DM)			
	0	2	4	6
Ingredients (%)				
CGWVO ¹⁾	0.00	2.00	4.00	6.00
Ground corn	43.00	41.00	39.00	37.00
Soybean meal	20.93	21.56	21.83	22.78
Fish meal	1.00	1.00	1.00	1.00
Leucaena leave meal	4.87	4.24	3.50	3.02
Plicatulum hay ²⁾	25.00	25.00	25.00	25.00
Molasses	3.50	3.50	3.97	3.50
Salt	0.20	0.20	0.20	0.20
Dicalcium phosphate	0.30	0.30	0.30	0.30
Urea	0.20	0.20	0.20	0.20
Mineral and vitamin mix ³⁾	1.00	1.00	1.00	1.00
Analyzed nutrient content ⁴⁾ (% DM)				
DM	95.13	95.77	95.97	94.69
Ash	5.32	5.57	5.62	5.98
OM	94.68	94.43	94.38	94.02
CP	16.65	16.67	16.49	16.51
EE	1.95	3.61	4.71	6.06
NFC	30.00	29.90	32.92	30.43
NDF	46.08	44.25	40.26	41.02
ADF	19.36	18.13	18.41	18.00
ADL	6.63	5.50	5.59	5.46
ME (Mcal/kg DM)	2.65	2.66	2.67	2.67

CGWVO, crude glycerin waste vegetable oil; DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NFC, non-fiber carbohydrate; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; ME, metabolizable energy.

¹⁾ Contained 63.42% glycerol, 13.93% water, 0.47% sodium, and 4.38% methanol (Colorless, odorless, viscous liquid obtained from Specialized Research and Development Center for Alternative Energy from Palm Oil and Oil Crop, Faculty of Engineering, Prince of Songkla University, Hat Yai Campus, Songkhla Province, 90110, Thailand).

²⁾ *Paspalum plicatulum* Michx.

³⁾ Minerals and vitamins mix (each kg contains): Vitamin A, 10,000,000 IU; Vitamin E, 70,000 IU; Vitamin D, 1,600,000 IU; Fe, 50 g; Zn, 40 g; Mn, 40 g; Co, 0.1 g; Cu, 10 g; Se, 0.1 g; I, 0.5 g.

⁴⁾ Based on analysis of composite feed sample.

with individual feed bunks and collective waterers. Animals were submitted to one of the four experimental treatments for 14 d adaptation period.

The experimental total mixed rations (TMR) diets were formulated to be isonitrogenous at 16% DM of crude protein (CP) and isocaloric at 2.7 Mcal/kg DM (on a metabolizable energy basis) to meet or exceed the NRC [9] requirements of growing goats (Table 1). The CGWVO used in this study originated from waste vegetable oils of rice bran, soybean, palm oil, and sunflower. CGWVO was produced by methylic route and obtained from the Faculty of Engineering, Prince of Songkla University, Songkhla Province, Thailand. The composition of the CGWVO is presented in Table 2. CGWVO from single batch was added to the total TMR as liquid.

Table 2. Physical-chemical composition of crude glycerin from waste vegetable oil (CGWVO^{1,2}) included in the experimental diets

Items	Content	Analytical method
Glycerol (%)	63.42	ASTM D 6584-00E01, titration assay
Methanol (%)	4.38	Gas chromatography
Water (%)	13.93	AOAC ³) method 984.20
Crude protein ⁴) (%)	0.03	AOAC method 990.03
Ash ⁴) (%)	7.41	AOAC method 942.05
Ether extract ⁴) (%)	47.78	AOAC method 920.39 (A)
Gross energy (kcal/kg)	6,290.83	Adiabatic bomb calorimeter
Sodium ⁴) (%)	0.47	AOAC methods 956.01, 9.15.01
Calcium ⁴) (%)	0.0053	AOAC method 2.019, 9.15.01
Phosphorus ⁴) (%)	0.0022	AOAC method 2.019, 2.095-7.098
Viscosity (cs) at 40°C	11.75	Viscometer (MJ 800S), ASTM D445 (ASTM, 2006)
pH	9.57	Orion 230A pH meter with 9107 BN probe, (ISO 12185)

¹) CGWVO was obtained from Specialized Research and Development Center for Alternative Energy from Palm Oil and Oil Crop, Faculty of Engineering, Prince of Songkla University, Hat Yai Campus, Songkhla Province, 90110, Thailand.

²) Analysis by Central Laboratories (Songkhla, SK), Co., Ltd., Songkhla 90110, Thailand.

³) AOAC [10].

⁴) Expressed as a percentage of crude glycerin dry matter.

Feed intake and growth performance

Feed was offered for *ad libitum* consumption twice daily in two equal portions at 0800 and 1600 h for 90 days. The amount of TMR offered and orts was recorded daily for each goat and the offered amount was adjusted to ensure approximately 10% of orts after feeding. Before morning feeding, 10% of orts of each animal were sampled in order to monitor dry matter intake (DMI). The feed efficiency was calculated as the ratio between average daily gain (ADG, kg) and DMI (kg). To evaluate growth performance, animals were weighed upon arrival, at the end of adaptation period, and every 14 d until slaughter.

Chemical analyses

Samples of feed and orts were composited and at the end of the experiment and dried in a forced-air oven at 55°C for 72 h and ground to a mesh size of 1 mm [10]. The DM concentration was determined by drying the material in an oven at 105°C for 24 h, and ash content was obtained by sample combustion in a muffle furnace at 600°C for 3 h [9] to determine the organic matter (OM). Nitrogen concentration was determined using the micro-Kjeldahl method [9] and CP content was estimated multiplying N content by 6.25. The EE content was determined by extraction with petroleum ether in a Soxhlet apparatus for 4 h. The acid detergent lignin (ADL), acid detergent fiber (ADF), and neutral detergent fiber (NDF) content were estimated according to recommendations of Van Soest et al [11], using a heat stable alpha-amylase, without the use of sodium sulfite and expressed inclusive of residual ash.

Slaughter, carcass evaluation, and sample collection

At the end of the 90-d experiment, four goats from each treatment were randomly selected for slaughter after a 16-h solid fasting period and BWs were recorded to determine the

slaughter BW. Animals were transported to Prince of Songkla University Goat Unit's experimental abattoir and were slaughtered according to the standard slaughter procedures described in Thai Agricultural Standard TAS 6006 [12]. Bleeding was performed by severing the carotid arteries and jugular veins immediately after stunning. After evisceration, carcasses were weighed to determine the hot carcass weight (HCW). Directly after slaughter, noncarcass components (skin, head, feet, lung, heart, liver, spleen, kidneys, kidney fat, and gastrointestinal tract fat) were removed and weighed. The stomach (rumen, reticulum, omasum, and abomasum) and post-ruminal tract (small intestine and large intestine) were removed and weighed separately. The contents of the stomach and post-ruminal tract were removed, washed, and weighed to obtain the weight of the empty stomach and post-ruminal tract. The carcass yield percentage was calculated as 100 (hot carcass weight/slaughter weight). Carcasses were refrigerated at approximately 4°C for 24 h. After the post mortem chill period, the cold carcass weight (CCW) and cold carcass yield were determined. Carcass length and width were measured. The carcasses were split longitudinally in two parts. The right sides of the carcasses were cut into eight pieces (loin, hind leg, chump, rack, should, fore leg, breast, and neck) according to Thai Agricultural Standard TAS 6006 [11] and were weighed, separately. Individual parts were then dissected into lean meat, bone, trimmings and weighed, separately. The muscular *longissimus dorsi* (LD) area was made on the left cut surface (of the chilled carcass) between rib 12 and 13. The LD (the section between the last lumbar and the first sacral vertebrae) were collected. These cuts of meat and two per animal were labeled and frozen immediately after collection for later measurement of the chemical composition, meat color and shear force characteristics.

Meat color and pH

The initial pH was measured between the 12th and 13th ribs in the center of the *Longissimus* muscle (LM), approximately 45 min after slaughter, using a digital penetration pH meter model AG 8603 (Mettler Toledo, AG 8603, Greifensee, Switzerland). Muscle surface color was measured objectively using a Hunter Lab Miniscan Plus Spectrocolorimeter on the same cut surface the LD. Instrumental color measurements were recorded for L* (measures darkness to lightness; lower L* indicates a dark color), a* (measures redness; higher a* value indicates a redder color), and b* (measures yellowness; higher b* value indicates a yellower color) at 3 locations of exposed lean to obtain a representative reading. To determine shear force, samples were defrosted at room temperature until their internal temperature reached 2°C to 5°C. After weighing, samples were trimmed, and thin sections from the lateral and extremities were removed; 4 samples, parallel to the muscle fibers and having 1 cm of thickness and 5 cm of length were obtained, to measure the shear force in a texture analyzer (TA-XTPlus-Texture Analyzer, with a Warner-Bratzler Blade probe, Texture Expert Exponent-Stable Micro Systems software, Ltd in Godalming, Surrey, UK. SMS). For each sample, 6 shear force results were obtained. Samples of LD muscle were subjected to proximate analysis following the standard methods of AOAC [11].

Statistical analysis

All data were analyzed using SAS (SAS Institute, Inc., Cary, NC, USA) software. The GLM procedure was used to analyze the fixed effects of treatment on intake, performance, carcass and meat quality traits, with animal serving as the experimental unit. Data were analyzed using the model:

$$Y_{ij} = \mu + M_i + \varepsilon_{ij}$$

Where Y_{ij} is dependent variable; μ is the overall mean, M_i is effect of the level of CGWVO ($i = 0\%, 2\%, 4\%$, and 6% DM), and ε_{ij} is the residual effect. Results are presented as mean values with the standard error of the means. The significant differences ($p \leq 0.05$) between means were determined by Duncan's multiple comparison tests. Orthogonal polynomials for CGWVO responses were determined by linear, quadratic, and cubic effects.

RESULTS AND DISCUSSION

Chemical composition of feeds

The ingredients and chemical compositions of the experimental diets and CGWVO are presented in Table 1 and Table 2, respectively. Experimental diets contained similar concentrations of DM, OM, CP, NFC, ADF, and ADL but varying amount of ether extract (EE) and NDF. The amount of EE was

slightly higher as the level of CGWVO increased in the diets, ranging from 1.95% to 6.06%, whereas NDF content decreased as the proportion of CGWVO in diets increased due to feeding less corn grain, ranging from 40.26% to 46.08% DM, respectively. The differences among concentrate mixed diets in EE and NDF concentrations can be related to differences in the ingredients used in diet formulation (Table 1) especially high contents of EE in CGWVO (47.78%) (Table 2).

Intake and growth performance

The effects of CGWVO substitution of corn grain in the diets on growth performance of finishing goats are presented in Table 3. Overall mean final BW, weight gain, feed intakes, and nutrient intake for the four diets in terms of total DMI (% BW and g/kg BW^{0.75}), OMI, CPI, NDFI, and ADFI were significantly altered ($p < 0.05$) by levels of CGWVO; goats receiving 6% of CGWVO had linearly lower final BW, weight gain, daily DMI (% BW and g/kg BW^{0.75}) and nutrient intake than those treatments. Likewise, ADG and feed efficiency of goats were changed ($p < 0.05$) by inclusion of CGWVO in the diets; goats receiving 6% of CGWVO had lower ADG and feed efficiency than other those fed of CGWVO. This is supported by previous studies [13,14]. Most of the studies regarding the evaluation of inclusion of CG in diets of ruminant animals [5,15] had used CG with concentrations of fatty acids and methanol lower than 1%. In the present study, CGWVO had 47.78% of lipids and 4.38% of methanol. However, the high-risk to health associated to methanol consumption due to inclusion of CG in diets of ruminant animals was not expected since methanol was naturally produced in the ruminal environment as a result of pectin digestion [16]. These authors had demonstrated that a continuous infusion of methanol (1 mol/L) at a rate of 10 mL/h into the rumen of ovine was completely converted to methane. Our results are in agreement with a study by Lage et al [8] also reported DMI was not altered when lambs fed 3% DM of CG with high fat and methanol (46.5% of lipids and 8.7% of methanol), but a linear decrease when CG increased from 6% to 12% DM. This may result from the greater concentration of lipid in diets with the higher concentration of CGWVO was likely to be the main factor that contributed for a reduction of DMI and nutrient digestibility. Ruminant animals are relatively intolerant to high concentrations of fat and feed intake usually decreases as fat content of the diets exceeds 6% on a DM basis [9]. The study observed that EE content was 6.06% in diet containing concentration 6% of CGWVO higher than 4% DM of CGWVO. Lipids represent a potential stimulator of cholecystokinin which is an appetite suppressant through the gastric emptying inhibition. High lipid diets increase plasma levels of cholecystokinin while the decrease of passage rate of the digesta increases the reticulo-rumen distention leading to a stimulation of cholecystokinin receptors in these gastrointestinal compartments reducing appetite con-

Table 3. Effects of dietary crude glycerin waste vegetable oil on feed intake and nutrient intake of goats

Item	Dietary CGWVO (% DM)				SEM	Contrasts (p-value)		
	0	2	4	6		Linear	Quadratic	Cubic
Day on test	90	90	90	90	-			
Pen replicates	6	6	6	6	-			
Initial BW (kg)	16.88	16.60	16.83	17.10	0.18	0.33	0.15	0.56
Final BW (kg)	27.38 ^a	28.13 ^a	27.91 ^a	24.30 ^b	0.42	0.001	0.0001	0.20
Weight gain (kg)	10.50 ^a	11.53 ^a	11.08 ^a	7.20 ^b	0.36	0.001	0.001	0.23
DMI (kg/d)								
Total DMI kg/d	0.716 ^{ab}	0.768 ^a	0.784 ^a	0.648 ^b	0.02	0.08	0.001	0.27
DMI (% BW)	3.24	3.43	3.50	3.13	0.11	0.63	0.02	0.52
DMI (g/kg BW ^{0.75})	70.23 ^{ab}	74.74 ^{ab}	76.27 ^a	66.85 ^b	2.32	0.41	0.01	0.45
Nutrient intake (kg/d)								
OMI (kg/d)	0.670 ^{ab}	0.721 ^a	0.737 ^a	0.606 ^b	0.02	0.08	0.001	0.25
CPI (kg/d)	0.110 ^{ab}	0.117 ^a	0.120 ^a	0.100 ^b	0.003	0.07	0.001	0.27
NDFI (kg/d)	0.315 ^a	0.325 ^a	0.299 ^a	0.253 ^b	0.009	0.0001	0.001	0.73
ADFI (kg/d)	0.139 ^{ab}	0.153 ^a	0.156 ^a	0.123 ^b	0.004	0.04	0.0001	0.22
ADG (kg/d)	0.118 ^a	0.128 ^a	0.125 ^a	0.080 ^b	0.004	0.0001	0.0001	0.14
G:F (kg/kg)	0.164 ^a	0.167 ^a	0.157 ^a	0.124 ^b	0.006	0.001	0.01	0.74

CGWVO, crude glycerin from waste vegetable oil; DM, dry matter; SEM, standard error of the mean (n = 6); BW, body weight; DMI, dry matter intake; OMI, organic matter intake; CPI, crude protein intake; NDFI, neutral detergent fiber intake; ADFI, acid detergent fiber intake; ADG, average daily gain; G:F, gain-to-feed.

^{a,b} Means within rows followed with different superscript letters are statistically different (p < 0.05).

sequently. According to Doreau et al [17], the fatty acids may reduce the nutrient digestibility in the ruminal environment and thus reduce the DMI. Jenkins [18] reported that inclusion of lipids in ruminant diets could negatively affect the NDF digestibility and animal performance. In addition, glycerol supplementation affects negatively the digestion of the more fibrous fraction of the feed [19]. Thus, the association of CGWVO with higher content of crude fat in diets decreased the DMI and digestibility by the animals. Indeed, substituting corn with high levels of glycerin was reported to adversely affect ruminal fermentation through reducing fiber digestion, acetate production, and bacterial populations [20]. Moreover, Roger et al [21] demonstrated that introducing glycerol to the ruminal ecology reduced cellulolytic activity of ruminal bacteria.

Carcass characteristics and meat traits

The effects of treatment diets on carcass characteristics are presented in Table 4. A significant effect was observed for the HCW, CCW, and dressing percentage (p < 0.05); goats receiving 6% of CGWVO had lower HCW, CCW and dressing percentage than 4% of CGWVO (quadratic; p < 0.01), while the differences among the diets 0%, 2%, and 6% of CGWVO were not different. Our results are in agreement with a study by Lage et al [8] reported a negative linear effect of CG concentrations on HCW and CCW of lambs when CG with high fat and methanol (46.5% of lipids and 8.7% of methanol) increased from 6% to 12% DM. However, there are no information about the feeding trial of CGWVO were evaluated by goats. Carcass yield is directly affected by carcass weight [22]. Thus, animals

fed diets with higher concentrations of CGWVO had lighter carcasses and consequently lower carcass yield. On the other hand, diets with low fat levels may increase the dressing percentage, quality and yield grade of the carcass while the high fat content diets tend to decrease these carcass traits [22] as observed in the present study.

However, no effects of CGWVO concentrations were observed on cold carcass dressing percentage, carcass length, carcass width, LM area, and Warner-Bratzler shear force (WBSF), which presented average values of 49.3%, 60.2 cm, 25.8 cm, 12.2 cm, 3.4 kg/cm² respectively (Table 4). Cold carcass dressing percentage was similar in all goats and within the previously published range of 37% to 55% [23]. For the warm dressing percentage in this study was similar to the one reported for crossbred male (Thai Native × Anglo Nubian) goats [2] who reported that warm dressing percentage in the ranges of 48.9% to 50.3% of crossbred male goats. Likewise, the area and WBSF of LM were not affected by treatments. Similarly, Bartoň et al [24] found that a long-term dietary treatment with CG as a replacement of barley meal up to the level of 10% DM had no significant effect on any of the bull carcass and meat quality traits studied. Nevertheless, the obtained WBSF results (<4.0 kg) ensure a tenderness that should result in high consumer acceptance [25]. Considering that the Warner-Bratzler force values exceeding 5.5 kg would often be considered objectionably tough by both trained panel and consumers [26]. In addition, inclusion with CGWVO did not affect back fat thickness (0.7 ± 0.1), 45 min pH (6.6 ± 0.04), 24 h pH (6.1 ± 0.1), 45 min temperature (34.2 °C ± 0.4 °C), and also colorimetric

Table 4. Effects of dietary crude glycerin waste vegetable oil on carcass characteristics of finishing goats

Item	Dietary CGWVO (% DM)				SEM	Contrasts (p-value)		
	0	2	4	6		Linear	Quadratic	Cubic
HCW (kg)	13.00 ^{ab}	13.55 ^{ab}	13.72 ^a	11.85 ^b	0.44	0.12	0.02	0.40
CCW (kg)	12.85 ^{ab}	13.40 ^{ab}	13.57 ^a	11.60 ^b	0.43	0.09	0.01	0.38
Warm dressing percentage (%)	49.92 ^{ab}	50.31 ^{ab}	50.69 ^a	49.19 ^b	0.43	0.34	0.04	0.34
Cold dressing percentage (%)	49.25	49.76	50.14	48.13	0.52	0.22	0.03	0.34
Carcass length (cm)	60.25	61.23	60.25	59.01	0.82	0.21	0.19	0.64
Carcass width (cm)	26.25	26.50	25.75	24.51	0.64	0.07	0.26	0.86
LM area (cm ²)	11.65	12.37	12.32	12.29	0.79	0.60	0.63	0.82
WBSF (kg/cm ²)	3.59	3.41	3.18	3.43	0.36	0.20	0.40	0.17
Back fat thickness (cm)	0.68	0.73	0.78	0.69	0.19	0.18	0.37	0.34
pH ^{45 min 1)}	6.61	6.54	6.57	6.63	0.07	0.22	0.25	0.19
pH ^{24 h 2)}	6.12	6.05	6.00	6.02	0.03	0.21	0.26	0.20
Temperature ^{45 min}	34.21	33.58	34.60	34.35	0.52	0.31	0.42	0.50
Color of LM ³⁾								
<i>L</i> [*]	37.21	37.20	36.75	37.95	1.04	0.87	0.25	0.54
<i>a</i> [*]	12.11	11.88	11.11	11.83	0.50	0.24	0.80	0.48
<i>b</i> [*]	9.54	9.46	9.15	9.29	0.77	0.39	0.24	0.35

CGWVO, crude glycerin from waste vegetable oil; DM, dry matter; SEM, standard error of the mean (n = 4); HCW, hot carcass weight; CCW, cold carcass weight; LM, *Longissimus* muscle area, cm² from *Longissimus dorsi*; WBSF, Warner-Bratzler shear force.

¹⁾ pH measurements taken at 45 min after slaughter.

²⁾ pH measurements taken at 24 h after slaughter.

³⁾ *L*^{*} values are a measure of lightness (higher value indicates a lighter color); *a*^{*} values are a measure of redness (higher value indicates a redder color); *b*^{*} values are a measure of yellowness (higher value indicates a more yellow color), by CIE = Complete international commission on illumination (Hunter color flex).

^{a,b} Means within rows followed with different superscript letters are statistically different (p < 0.05).

parameters of LD (37.3±0.5, 11.7±0.4, and 9.4±0.2, for *L*^{*}, *a*^{*}, and *b*^{*}, respectively) among treatments. The pH 45 min and 24 h of LM muscle, within the range recorded in the studies reviewed by Webb et al [27], was not affected by dietary treatments. The pH value of the muscle after slaughter is one of the most important factors that affect meat quality, because the pH can influence the tenderness, color and water retention capacity. This process involves the depletion of muscle glycogen stores with the production and accumulation of lactic acid. This process also triggers *rigor mortis*, which in sheep or goat carcasses occurs when the pH is between 5.6 and 5.8 for the *Longissimus* muscle. In this study, the pH of *Longissimus* muscle 45 min and 24 h after slaughter averaged 6.6 and 6.1. It can be inferred from these low values that no DFD meat (dry, firm and dark muscle) was observed, proving also by the high *L*^{*} values found 45 min after slaughter, reflecting on high values of *a*^{*} and *b*^{*}. Color is an important meat quality trait because the first impression consumers have on any meat product is based on its color [28]. The average values observed in the current study for each of these variables were 36.7 to 37.2, 11.1 to 12.1 and 9.1 to 9.5, respectively for *L*^{*}, *a*^{*}, and *b*^{*}. Similar value for color have been previously reported by Chanjula et al [2]; Adeyemi et al [29] who was observed in goats meat usually presents values from 30.6 to 39.9 for *L*^{*}, 11.8 to 18.0 for *a*^{*}, and 3.3 to 11.54 for *b*^{*}. Postmortem ageing did not affect (p>0.05) the *L*^{*}, *a*^{*}, and *b*^{*} values of LM muscle from goats.

The lack of differences in carcass characteristics (Table 4) can be explained by the uniformity of the animals in the beginning of feedlot period and the similar slaughter weight.

The effects of treatment diets on the carcass cuts of the goats are presented in Table 5. Percentage of the chilled carcass weight, loin, chump, rack, shoulder, breast, fore leg, and neck were similar (p>0.05) for all treatments. However, hind leg was greater (quadratic; p<0.01) in goats that received the 6% of CGWVO treatment (22.8%) than in those that received the 2% of CGWVO (21.0%). It remains unclear whether this was due to the dietary treatment. The present results cannot be compared with other results, because there are few reports on the effects of CGWVO supplementation on carcass cuts. Nevertheless, data from the current study demonstrate that feeding CGWVO up to 6% of dietary DM may have not a negative impact on commercial cut of goats. By design, no significant effect of dietary CGWVO was observed on chemical composition of LD (Table 6). The mean values of chemical composition of *Longissimus* muscle, within the range recorded in the studies by Beserra et al [30] reporting DM, ash, CP, and EE levels ranging 22.3 to 24.0, 20.5 to 21.9, 1.5 to 2.7, and 1.0 to 1.1, respectively. However, it is noteworthy that LD petroleum ether extract was numerically greater in the animals fed CGWVO. Glucose was previously shown to be quantitatively the primary lipid precursor in intramuscular adipose tissue whereas the relative contribution of acetate to lipogenesis was

Table 5. Effects of dietary CGWVO crude glycerin waste vegetable oil on carcass cuts of finishing goats

Items	Dietary CGWVO (% DM)				SEM	Contrasts (p-value)		
	0	2	4	6		Linear	Quadratic	Cubic
Carcass cuts ¹⁾								
Loin (%)	11.24	12.50	11.34	11.22	0.54	0.61	0.21	0.16
Hind leg (%)	22.18 ^{ab}	21.01 ^b	21.68 ^{ab}	22.82 ^a	0.33	0.10	0.01	0.37
Chump (%)	7.38	7.35	6.75	6.74	0.26	0.07	0.98	0.33
Rack (%)	10.10	10.91	10.68	10.49	0.51	0.33	0.97	0.56
Shoulder (%)	12.36	13.82	13.71	11.98	0.90	0.76	0.10	0.98
Fore leg (%)	20.50	19.67	20.29	20.65	0.60	0.69	0.32	.51
Breast (%)	10.96	9.72	10.08	10.68	0.48	0.82	0.08	0.53
Neck (%)	5.35	5.63	5.82	5.39	0.26	0.79	0.19	0.64

CGWVO, crude glycerin from waste vegetable oil; DM, dry matter; SEM, standard error of the mean (n = 4).

¹⁾ Carcass cuts, as a percentage of chilled carcass weight.

^{a-b} Means within rows followed with different superscript letters are statistically different (p < 0.05).

greatest in subcutaneous adipose tissue [31]. As glycerin is an important glucogenic substrate, this might give an explanation of the slightly higher levels of intramuscular fat. Unlike in our study, it has been previously reported that glycerin increased ruminal propionic and butyric acid concentrations at the expense of acetic acid concentration [3]. Therefore, lower concentrations of acetic acid as a lipogenic precursor could have been the reason why glycerin supplemented diets reduced in both subcutaneous fat and marbling scores in feedlot heifers fed increasing quantities of CG [13] and decreased LD ether extract values in finishing lambs [6].

IMPLICATIONS

Based on the results of this experiment, substituting corn grain with CGWVO (63.42% glycerol and 47.78% crude fat) up to 4% of DM in the diets of goats had no effect on feed intake and none on growth performance, carcass, and meat quality traits studies when compared to the control group. However, increasing CGWVO levels at 6% DM would result more in a slightly lower daily DMI, nutrient intake, and carcass characteristics than in those goats fed on 0% to 4% of CGWVO. Thus, in the case of competitive prices, CGWVO may be ef-

fectively used as an alternative energy source to substitute for cereals in the diets of goats. However, further research and long-term studies should be conducted to validate the effects of supplementing of CGWVO on milk production and to determine the optimal feeding rates in dairy goats.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Table 6. Effects of dietary crude glycerin waste vegetable oil on chemical composition of LD (*Longissimus dorsi*) muscle of finishing goats

Item	Dietary CGWVO (% DM)				SEM	Contrasts (p-value)		
	0	2	4	6		Linear	Quadratic	Cubic
Nutritional composition								
DM (%)	26.39	25.56	26.31	26.16	0.38	0.69	0.58	0.31
Ash (%)	1.50	1.55	1.63	1.65	0.11	0.57	0.85	0.56
Protein (%)	22.30	22.19	22.25	22.12	0.29	0.61	0.50	0.98
Ether extract (%)	1.48	1.58	1.89	1.72	0.18	0.11	0.69	0.32
Calcium (%)	0.10	0.11	0.10	0.11	0.01	0.90	0.86	0.88
Phosphorous (%)	0.66	0.64	0.63	0.69	0.07	0.78	0.25	0.67

CGWVO, crude glycerin from waste vegetable oil; DM, dry matter; SEM, standard error of the mean (n = 4).

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