Use of dry citrus pulp or soybean hulls as a replacement for corn grain in energy and nitrogen partitioning, methane emissions, and milk performance in lactating Murciano-Granadina goats

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ABSTRACT

The aim of this study was to assess the effect of substitution of dietary corn grain by dry citrus pulp or soybean hulls on energy and nitrogen partitioning, substrate oxidation, methane emission, and milk performance in dairy goats during midlactation. Twelve multiparous Murciano-Granadina goats of similar body weight (41.7 ± 2.8 kg) were split in 3 groups in an incomplete crossover design. One group of 4 goats was fed a mixed ration with 605 g/kg of dry matter of corn grain (CRG), another group replaced corn grain with dry citrus pulp (CTP), and the last with soybean hulls (SYH). The goats were allocated to individual metabolism cages. After 14 d of adaptation, feed intake, total fecal and urine output, and milk yield were recorded daily over a 5-d period. Then, gas exchange measurements were recorded by a mobile open-circuit indirect calorimetry system using a head box. Dry matter intake was similar for all 3 groups (1.53 kg/d, on average). Total replacement of the concentrate with fibrous by-products increased fiber apparent digestibility. The metabolizable energy intake was significantly greater for diet CRG than SYH (1,193 vs. 1,079 kJ/kg of BW^{0.75}, respectively), CTP showed an intermediate value. The heat production was higher for the fiber diet than starchy diet (908 vs. 843 kJ/kg of BW^{0.75} for SYH and CRG, respectively). The efficiency of use of metabolizable energy for milk production obtained by regression was 0.59. Goats fed CTP and SYH diets produced similar CH₄ emissions (34.8 g/d, on average), significantly higher compared with goats fed the CRG diet (24.7 g/d). Goats of the 3 treatments were in negative energy balance, so the oxidation of fat was greater than for carbohydrates. No significant differences were observed for milk production (1.72 kg/d), and milk fat was significantly greater for a more fibrous diet compared with a starchy diet (6.57 vs. 4.95% in SYH and CRG, respectively).

Key words: lactating goat, cereal replacement, by-product, energy partitioning, methane emission

INTRODUCTION

In Mediterranean countries, ruminant production is limited by the poor quality and scarcity of pastures, especially during periods of drought. Consequently, farmers are forced to use cereal-based concentrates and the demand of cereals for animal feeding increases the price of concentrate. This justifies the need to develop feeding strategies based on cost-effective alternatives and local feed resources, which would increase the sustainability of livestock-production systems and improves farmers' income. Agricultural by-products may be of interest not only to reduce feed cost, but also to reduce environmental problems associated with by-product accumulation (Vasta et al., 2008).

Increasing interest in by-products has occurred as partial substitution of traditional feedstuffs in ruminant feeding has become more prevalent. From a nutritional point of view, by-products are included in the ration to supply energy and protein, but are often also characterized by high fiber content. This is the case with citrus pulp or soybean hulls, which are typically used as grain replacers. A large number of the citrus by-products feedstuffs, including citrus pulp, are suitable for inclusion in ruminant diets because of the ability of ruminants to ferment high-fiber feeds in the rumen (Grasser et al., 1995). According to FEDNA (2010), the NDF level of dry citrus pulp is intermediate (25%), between that of most concentrates and forages, and contains relatively large amounts of pectins (25%) and sugars (23%), a small amount of ADL (2%), and a very limited amount of available nitrogen (6% of CP). Soybean hulls are high in NDF (58%, high in cellulose) but low in ADL (2%) and NFC (24%).

Dietary composition affects the ruminal fermentation and, consequently, energy metabolism, CH₄ emissions, and milk composition. Methane is an undesirable end product of rumen fermentation as it represents an energy loss to the animal and because it is a major

Received May 30, 2014.

Accepted September 12, 2014.

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greenhouse gas. In ruminant nutrition, decreased production of CH₄ can represent an improvement in feed efficiency, because ruminants lose between 2 and 12% of the gross dietary energy in the form of CH₄ (Johnson and Johnson, 1995). Besides, ruminants contribute to global warming through N excretion from urine and feces. To reduce N excretion and improve N efficiency of ruminant, dietary levels of N and optimal balance between N and energy substrates in the diet should be targeted.

Our hypothesis was that citrus pulp and soybean hulls could replace cereal-based concentrate in goat diets without compromising energy and protein partitioning in lactating goats when mixed diets were formulated with similar amounts of energy and protein. The purpose of the present experiment was to study the effect of substitution of corn grain in the mixed diet by dry citrus pulp or soybean hulls on energy partitioning, CH₄ emissions, C and N balance, and milk performance in dairy goats during midlactation.

MATERIALS AND METHODS

Animals and Feeding

The experimental procedure was approved by the Animal Use and Care Committee of the Polytechnic University of Valencia (Spain) and followed the codes of practice for animals used in experimental works proposed by the European Union (2003). Twelve multiparous mature and nonpregnant Murciano-Granadina goats of similar BW (41.7 ± 2.8 kg) and in midlactation were randomly split into 3 groups (4 goats per treatment) in an incomplete crossover design. Treatments consisted of 3 different concentrate mixed rations (Table 1). Goats were fed daily 0.25 kg of cereal straw as forage and 1.5 kg of concentrate (forage:concentrate ratio = 14:86). The concentrate was mixed and pelleted along with the premix. One group was fed concentrate with 605 g/kg of DM of corn grain (**CRG**). The other 2 groups substituted corn grain with by-products: dry citrus pulp (**CTP**) and soybean hulls (**SYH**). Chemical composition shown in Table 1 is the whole mixed ration (forage and pelleted concentrate). The mean gross energy (**GE**) of the 3 diets was 17.6 MJ/kg of DM. The main difference among diets was the source of carbohydrates. Starch levels were 41.6, 6.4, and 1.5% (on a DM basis) for the CRG, CTP, and SYH diets, respectively. Neutral detergent fiber and neutral detergent soluble fiber (**NDSF**) values were 30.1 and 8.5% (respectively, DM basis) for CRG, 30.1 and 24.1% (respectively, DM basis) for CTP, and 59.0 and 17.1% (respectively, DM basis) for SYH. Mixed diets contained similar amounts of CP (15.8%, DM basis). Nutrient

requirements followed the recommendation of Lachica and Aguilera (2003) and Calsamiglia et al. (2009) for goats in lactation. Apparent total tract digestibility, gas exchange, energy partitioning, C and N balance, oxidation of nutrients, and milk composition and yield were determined. Moreover, ruminal fermentation parameters were determined in the second period of the experiment. Half the daily ration was offered at 0800 h and half at 1600 h. Goats had free access to water.

Experimental Schedule and Measurements

The experiment was conducted in an incomplete crossover design in two 31-d periods. During the adaptation, goats were fed experimental diets in pens for 7 d and then allocated in individual metabolism cages at thermoneutrality (20–23°C determined by a Hobo probe, Onset Data Loggers, Cape Cod, MA) for another 7 d. Next, data on the feed offered and refused

Table 1. Ingredients and chemical composition of the diets

Item	Diet ¹		
	CRG	CTP	SYH
Ingredient, g/kg of DM			
Barley straw (as a forage)	150.0	150.0	150.0
Corn	605.2	—	—
Soy hulls	—	—	610.0
Citrus pulp	—	605.2	—
Soy meal (44% CP)	202.4	221.7	173.9
Calcium carbonate	21.6	4.0	22.9
Salt	10.8	9.1	25.5
Bypass fat ²	5.0	5.0	12.7
Premix ³	5.0	5.0	5.0
Chemical composition, % of DM (unless otherwise noted)			
DM, %	88.36	88.41	90.15
OM	92.80	91.96	89.28
CP	16.66	15.80	14.79
Ether extract	2.66	2.10	2.03
NDF	30.11	30.08	58.97
ADF	8.55	16.69	37.55
Lignin	0.44	0.93	1.22
NDSF ⁴	8.51	24.09	17.07
NFC ⁵	45.30	43.98	13.50
Starch	41.63	6.36	1.45
Sugar + pectin ⁶	1.75	37.63	12.05
Gross energy, MJ/kg of DM	18.00	17.56	17.21

¹CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

²Bypass fat of palm FA distillate. Provided by Norel Animal Nutrition (Norel S.A., Madrid, Spain).

³Provided by Nacooop S.A. (Madrid, Spain). Premix composition: 40 mg of Se/kg, 250 mg of I/kg, 80 mg of Co/kg, 3,000 mg of Cu/kg, 6,000 mg of Fe/kg, 23,400 mg of Zn/kg, 29,000 mg of Mn/kg, 60,000 mg of S/kg, 60,000 mg of Mg/kg, 2,000,000 IU of vitamin A/kg, 400,000 IU of vitamin D₃/kg, 2,000 mg of vitamin E/kg, 10,000 mg of nicotinic acid/kg, and 20,300 mg of choline/kg.

⁴NDSF = neutral detergent-soluble fiber.

⁵NFC = 100 – (NDF + ash + CP + ether extract).

⁶Sugars + pectins = NFC – starch.

and the total fecal, urine, and milk output were recorded daily for each goat during a 5-d period, as well as BW at the beginning and end of the period. Feces were collected in wire-screen baskets placed under the floor of the metabolism crates and urine was collected through a funnel into plastic buckets containing an adequate amount of a solution of H_2SO_4 10% (vol/vol) to acidify the urine of each goat. The acidification of urine was necessary to prevent microbial degradation and the loss of volatile ammonia-N ($\text{NH}_3\text{-N}$). Representative samples (10%) of diet, feces, and urine were collected over 5 consecutive days, stored at -20°C , and pooled for chemical analysis. The goats were milked once daily at 0800 h with a portable milking machine (Flaco, model DL-170, J. Delgado S.A., Ciudad Real, Spain). Immediately after milking, the individual milk yield was measured and a sample of 10% was put in a bottle and frozen until analysis. In addition, samples were collected into a plastic vial that contained 20 mg of potassium dichromate as a preservative and taken to the Interprofessional Dairy Laboratory of the Valencia Community Region (Valencia, Spain) for compositional analysis. Ruminant fluid samples were collected by stomach tube before the morning feeding on the last day of apparent digestibility trial. Ruminant fluid pH was immediately determined using a model 265A portable pH meter (Orion Research Inc., Beverly, MA). A ruminant fluid sample was acidified with H_2SO_4 and frozen until later determination of $\text{NH}_3\text{-N}$. Samples for analysis of VFA were mixed with H_3PO_4 and kept frozen until analysis.

Next, gas exchange was measured for each goat during 24 h (4 goats/treatment) by an indirect calorimetric system based on a ventilated head-box designed for small ruminants. To this end, 12 d were taken for each period in the incomplete cross over design. The respirometry system has a head hood, a flow meter (Thermal Mass Flowmeter Sensyflow VT-S, ABB, Alzenau, Germany), and air suction provided by a centrifugal fan (CST60 Soler Palau Inc., Parets del Vallès, Barcelona, Spain). The CH_4 and CO_2 concentrations were measured using the infrared principle and O_2 was measured by the paramagnetic principle (Easyflow Gas Analyzer, model 3020, ABB). Although the unit was an autocalibrated model, the analyzers were calibrated with reference gases before each test. Fernández et al. (2012) described the mobile open-circuit respirometry system used for these measurements.

The whole system was calibrated injecting pure N_2 and CO_2 into the head box (McLean and Tobin, 1987) determined gravimetrically using a precision scale. Calibration factors were calculated according to Brockway et al. (1971). The CH_4 and CO_2 production and O_2

consumption were calculated as described by Aguilera and Prieto (1986). An initial atmospheric air sample was collected and the gas concentrations were used as reference for calculations.

Chemical Analysis

Feed, feed refusals, and feces samples were first dried in a forced-air oven at 55°C for 48 h then ground to pass a 1-mm screen before analysis. Urine and milk was dried by lyophilization. Chemical analyses of the diet, refusals, and feces were conducted according to methods of AOAC International (2000) for DM, ash, and ether extract. Dry matter of diets and feces was determined by oven-drying at $102 \pm 2^\circ\text{C}$ for 24 h. Ash concentration was measured by incineration in an electric muffle furnace at 550°C for 6 h to determine OM. Ether extract was extracted with petroleum ether after acid hydrolysis to recover saponified fat (Soxtec System HT Tecator, Hillerød, Denmark; 1047 Hydrolyzing Unit and 1043 Extraction Unit). The NDF and ADF were measured in an Ankom Fiber Analyzer (A220, Ankom Technologies, Fairport, NY) according to Mertens (2002) and AOAC International (2000), respectively. The NDF was determined using sodium sulfite and α -amylase. Lignin was determined according to Robertson and Van Soest (1981). The NDSF content was determined according to Hall et al. (1997) after adapting the method to the modifications proposed by Martínez-Valleespín et al. (2011). The NFC content of diets was calculated by the difference method based on chemical analysis of individual feeds (NRC, 2001) as $\text{NFC} = 100 - \text{NDF} - \text{ash} - \text{CP} - \text{ether extract}$. Gross energy content of the dried samples (feed, feces, urine, and milk) was analyzed by combustion in an adiabatic bomb calorimeter (Gallenkamp Autobomb; Loughborough, UK). Starch content was determined by enzymatic method (α -amylase obtained from Sigma-Aldrich, Steinheim, Germany) according to Batey (1982). The C and N were analyzed by the Dumas principle (TruSpec CN; Leco Corporation, St. Joseph, MI). Multiplying N by a factor of 6.25 converted the results to CP. Milk composition (fat, protein, lactose, and total milk solids content) was analyzed with infrared analyzer (MilkoScan FT120 Foss Electric, Hillerød, Denmark).

The $\text{NH}_3\text{-N}$ content of ruminant fluid samples was analyzed by the Kjeldahl procedure (2300 Kjeltac Analyzer Unit, Foss Tecator). Determination of ruminant VFA was based on the method described by Jouany (1982) using a gas chromatograph (Fisons 8000 series; Fisons Instruments SpA, Milan, Italy) equipped with a split/splitless injector and flame ionization detector.

Calculations

The ME intake (**MEI**) was calculated as the difference between GE intake and energy losses in feces, urine, and CH₄ (with an energy equivalent value of 39.5 kJ/L CH₄; Brouwer, 1965). The heat production (**HP**) was determined from measurements of O₂ consumption, CO₂ and CH₄ production, and urine N (**N_{urine}**), using the equation of Brouwer (1965):

$$\text{HP (kJ)} = 16.18 \times \text{O}_2 + 5.02 \times \text{CO}_2 \\ - 2.17 \times \text{CH}_4 - 5.99 \times \text{N}_{\text{urine}},$$

where gases were expressed in liters per day and N_{urine} in grams per day. The body tissue energy (**RE_{body}**) was calculated as MEI – HP – milk energy (**E_{milk}**).

The energy associated with the oxidation of protein (**OXp**), carbohydrate (**OXCHO**), and fat (**OXF**) was calculated by the method of Brouwer (1958) and Chwalibog et al. (1997) for ruminants. The CO₂ production from oxidation (**CO_{2x}**) was calculated as CO₂ – (1.7 × CH₄), according to Fahey and Berger (1988). The calculations were carried as follows:

$$\text{OXp} = 6.25 \times \text{N}_{\text{urine}} \times 18.42 \text{ (kJ/g)},$$

$$\text{OXCHO} = (-2.968 \times \text{O}_2 + 4.174 \times \text{CO}_{2x} \\ - 2.446 \times \text{N}_{\text{urine}}) \times 17.58 \text{ (kJ/g)},$$

$$\text{OXF} = (1.719 \times \text{O}_2 - 1.719 \times \text{CO}_{2x} \\ - 1.963 \times \text{N}_{\text{urine}}) \times 39.76 \text{ (kJ/g)}.$$

Then, the HP from oxidation (**HP_x**) was:

$$\text{HPx (kJ)} = 16.18 \times \text{O}_2 + 5.02 \\ \times \text{CO}_{2x} - 5.99 \times \text{N}_{\text{urine}}.$$

Again, gases were expressed in liters per day and N_{urine} in grams per day. Heat of fermentation (**HP_f**) was estimated subtracting HP from HP_x. The nonprotein respiratory quotient from oxidation of nutrients (**RQ_{npx}**) was determined as RQ_{npx} = [CO_{2x} – (N_{urine} × 6.25 × 0.774)]/[O₂ – (N_{urine} × 6.25 × 0.957)]. For C and N balance, we followed the equation and values proposed by McLean and Tobin (1987), and the grams retained in protein (**R_{protein}**) and fat (**R_{fat}**) were calculated.

The efficiency of use of ME for lactation (**k_l**) was calculated according to AFRC (1993). If the goat is in positive tissue energy balance, some of the MEI is being directed toward tissue energy retention and therefore

MEI is corrected [AFRC, 1993; value for efficiency of utilizing MEI for gain (**k_g**) is 0.6]. When the goat is in negative energy balance, some of the E_{milk} is derived from body stores and therefore E_{milk} is corrected [efficiency of utilizing body stores for milk production (**k_t**) is 0.84 according to AFRC, 1993]. Therefore, corrected E_{milk} was regressed on corrected MEI using a linear regression: k_l was the slope of the line and the ME for maintenance (**ME_m**) denotes the value of MEI when E_{milk} is zero. Net energy for lactation was computed as MEI × k_l.

Statistical Analysis

The effects of corn substitution with by-products on intake, digestibility, ruminal fermentation parameters, milk yield, energy and C-N balances, and oxidation of nutrients were analyzed using the PROC GLM of SAS (2001). The experiment was conducted as an incomplete crossover design and the model for the dependent variables included the fixed effect of diet and period and their interaction. The following statistical model was used: Y = μ + D + T + (D × T) + ε, where Y is the dependent variable; μ is the overall mean; D and T are the fixed effects of diet and period, respectively; D × T is the fixed interaction effect of diet × period; and ε is the random error. Effects were declared significant at P < 0.05 and P-values between 0.05 and 0.10 were considered as a trend. Tukey tests were used for multiple comparisons among diets and Student's *t*-test was used for the period.

RESULTS AND DISCUSSION

Feed Intake, Digestibility, and Rumen Fermentation

Intake and apparent total-tract digestibility of nutrients by Murciano-Granadina dairy goats are shown in Table 2. Dry matter, NDF, and starch digestibility were significantly (P < 0.05) affected by the period, being higher during the second digestibility than the first. No effect of interaction (diet × period) was found, with the exception of starch. In relation to the effect of the diet, DMI was similar for the 3 diets (1.54 kg/d, on average). Diet affected (P < 0.001) the apparent total-tract digestibility of most nutrients, as expected from a change in diet, which involves reducing starch and increasing fiber. The higher level of undigestible material for diet SYH compared with CRG and CTP (59% NDF, DM basis for SYH, and 30% NDF, DM basis for CRG and CTP, on average) appeared to be the main factor responsible for the decrease of DM, OM, NFC, and GE apparent digestibility in SYH. Consequently, goats fed high-concentrate diets are often associated

Table 2. Body weight, intake, and apparent digestibility coefficients of Murciano-Granadina goats ($n = 12$) during midlactation according to the type of diet

Item	Diet ¹			Period ²			<i>P</i> -value		
	CRG	CTP	SYH	A	B	SEM	Diet	Period	Diet × period
BW, kg	41.8	42.0	41.4	41.8	41.7	0.59	0.95	0.97	0.26
DMI, kg/d	1.508	1.528	1.570	1.519	1.552	0.0111	0.14	0.20	0.67
Digestibility, % of DM (unless otherwise noted)									
DM, %	77.36 ^a	77.62 ^a	71.29 ^b	74.42	76.42	0.768	0.0002	0.049	0.13
OM	79.87 ^a	80.70 ^a	74.00 ^b	77.21	79.17	0.777	0.0002	0.066	0.16
CP	74.64 ^a	70.76 ^b	64.69 ^c	68.95	71.10	1.062	0.0001	0.0504	0.13
Ether extract	70.67	69.95	75.26	69.84	74.07	1.667	0.45	0.23	0.11
NDF	59.82 ^b	65.45 ^b	74.00 ^a	64.18	68.67	1.729	0.0003	0.048	0.35
ADF	49.77 ^b	73.40 ^a	75.28 ^a	63.26	69.04	3.185	0.0001	0.13	0.49
NDSF ³	57.06 ^c	83.12 ^a	76.77 ^b	72.46	72.17	2.622	0.0001	0.86	0.61
NFC	94.58 ^a	94.85 ^a	84.00 ^b	91.32	90.97	1.097	0.0001	0.75	0.59
Starch	99.47 ^a	98.75 ^b	93.33 ^c	95.93	98.43	0.704	0.0001	0.0001	0.0001
Gross energy	78.50 ^a	79.35 ^a	73.55 ^b	76.39	77.87	0.725	0.0012	0.16	0.072

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

²A = first period; B = second period.

³NDSF = neutral detergent-soluble fiber.

with greater DM and OM and lower NDF digestibility (Kawas et al., 1991).

Rumen fermentation parameters obtained are shown in Table 3. It was not possible to assess the effect of period and interaction with diet because rumen liquid extraction was done only during the second period of the trial. The highest level of starch on diet CRG was the cause of the lower pH of CRG than CTP and SYH diet (6.9, 7.4, and 7.3, respectively). Goats fed with more starch also had a greater and significant ($P < 0.05$) $\text{NH}_3\text{-N}$ concentration (24.59 mg/dL for CRG) than other diets (12.69 and 17.74 mg/dL for CTP and SYH, respectively). Ariza et al. (2001) also obtained higher $\text{NH}_3\text{-N}$ concentration via the starch diet than high-NDSF diet, 14.2 versus 9.3 mg/dL in hominy feed versus dry citrus pulp diets, respectively, in continuous culture. Differences were found in most of the VFA studied. Greater ($P < 0.05$) total VFA was found for diet SYH than CRG and CTP (33.15 mM for SYH vs. 22.74 mM for the average of CRG and CTP), suggesting more fermentation activity for diet SYH than others and accompanied by greater NDF and ADF digestibility. An increase ($P < 0.05$) in acetic acid in the rumen was observed when fiber amount of diets increased (62.9, 68.7, and 71.2 mol/100 mol for CRG, CTP, and SYH, respectively). Conversely, the greater starch level of the CRG diet increased the production of propionic acid compared with the other diets (15.3 mol/100 mol for CRG vs. 13.4 mol/100 mol for the average of CTP and SYH) and butyric acid (15.1 mol/100 mol for CRG vs. 9.8 mol/100 mol for the average of CTP and SYH), although the differences were not significant.

Energy Balance

The average value obtained for the calibration factor, by releasing a known volume of N_2 or CO_2 into the respirometry system, was 1.0056 ± 0.00158 and 0.9924 ± 0.00915 for O_2 and CO_2 , respectively. Daily energy balance obtained with the 3 diets is shown in Table 4. A significant effect of period of time ($P < 0.05$) was observed in HP. The MEI, HP, and RE_{body} were significantly affected ($P < 0.05$) for the interaction diet and period. Regarding the effect of diet, no statistically significant differences were observed for GE intake (1,649 kJ/kg of $\text{BW}^{0.75}$, on average), but energy losses in feces were higher for SYH than CRG and CTP; in fact, GE digestibility of SYH was approximately 5.4% lower than other diets ($P < 0.05$). Therefore, we noted a reduction in digestible energy when feeding goats decreasing amounts of starch and soluble fiber. Urine energy losses were not different among treatments. Both CTP and SYH presented similar energy losses in CH_4 (118 kJ/kg of $\text{BW}^{0.75}$, on average) and were significantly higher ($P < 0.001$) than CRG (84 kJ/kg of $\text{BW}^{0.75}$), indicating that increasing the level of starch in the diet reduces the CH_4 production, as indicated by different authors and reviewed by Grainger and Beauchemin (2011). However, Romero-Huelva et al. (2012) found a reduction in CH_4 production (from 110 to 67 kJ/kg of $\text{BW}^{0.75}$) when 35% of a cereal-based concentrate was replaced with feed blocks containing wastes of tomato and cucumber. Those authors concluded that the feed blocks might also have the presence of secondary plant compounds, which could act as

Table 3. pH, ammonia-N (NH₃-N), and VFA of Murciano-Granadina goats (n = 12) during midlactation according to the type of diet

Item	Diet ¹			SEM	P-value
	CRG	CTP	SYH		Diet
pH	6.88	7.44	7.33	0.171	0.061
NH ₃ -N, mg/dL	24.59 ^a	12.69 ^b	17.74 ^b	3.447	0.048
Total VFA, mM	25.31 ^b	20.17 ^b	33.15 ^a	3.773	0.029
Individual VFA, mol/100 mol					
Acetic acid	62.94 ^b	68.69 ^a	71.19 ^a	2.441	0.035
Propionic acid	15.34	13.12	13.65	0.671	0.18
Butyric acid	15.06	9.80	9.70	1.772	0.075
Isobutyric acid	2.37	3.74	2.12	0.504	0.22
Isovaleric acid	2.88	3.53	2.25	0.370	0.25
n-Valeric acid	1.28	0.99	0.86	0.124	0.44
n-Caproic acid	0.11	0.13	0.22	0.034	0.56

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

a safe and natural antimethanogenic additive. Bava et al. (2001) did not observe significant differences, but the value of energy losses as CH₄ were 131 and 115 kJ/kg of BW^{0.75} for Saanen goats at midlactation fed a silage-based forage diet versus a nonforage diet. López and Fernández (2013) found no significant differences with midlactation Murciano-Granadina goats, obtaining an average value of 99 kJ of CH₄/kg of BW^{0.75} when fed 2 mixed diets that differed in carbohydrate source (corn grain or by-products) and starch level.

The MEI was ($P < 0.05$) greater for diet CRG than SYH (1,193 vs. 1,079 kJ/kg of BW^{0.75}, respectively), whereas CTP showed an intermediate value (1,147 kJ/kg of BW^{0.75}). The HP was higher ($P < 0.05$) for the more fibrous diet than the more starchy diet (908 vs. 843 kJ/kg of BW^{0.75} for SYH and CRG, respectively). Lachica et al. (1997) found that the act of eating accounts for an energy cost of about 0.05 of the MEI for long-dried forage in goats, with similar values between species, so the cost of eating is higher in fibrous diets.

The E_{milk} presented no statistically significant differences among diets (400 kJ/kg of BW^{0.75}, on average). The energy balance was negative for all treatments, indicating a mobilization of energy from reserves. Nevertheless, the higher starch content of the CRG diet decreased ($P < 0.01$) energy losses of tissues (−23.4 kJ/kg of BW^{0.75}) compared with CTP and SYH diet (−184.8 kJ/kg of BW^{0.75}, on average). The main reason this negative energy balance was found in our study is due to the quality of the forage and the level of feeding. The forage-to-concentrate ratio in our study was 14:86, with a low amount of forage (cereal straw) and of poor quality. Moreover, assuming an ME_m of 401 kJ/kg of BW^{0.75} (Aguilera et al., 1990), the value of level of feeding in our trial was 3.0, 2.9, and 2.7 for CRG, CTP, and SYH, respectively, lower than the recommendation for highly productive ruminants (ranging from 2 to more than 4 times maintenance, according to NRC, 2001). With our high-concentrate diets we expected greater DMI and, therefore, larger amounts of

Table 4. Daily energy partitioning (kJ/kg of BW^{0.75}) of Murciano-Granadina goats (n = 12) during midlactation according to the type of diet

Item ¹	Diet ²			Period ³		SEM	P-value		
	CRG	CTP	SYH	A	B		Diet	Period	Diet × period
GEI	1,659.9	1,628.6	1,657.4	1,629.3	1,667.9	23.56	0.87	0.49	0.24
E _{feces}	357.3 ^b	336.0 ^b	438.7 ^a	386.0	368.7	13.28	0.019	0.50	0.66
E _{urine}	25.7	27.6	22.5	32.7	17.8	3.57	0.89	0.083	0.30
E _{methane}	84.0 ^b	118.1 ^a	117.5 ^a	103.2	109.9	4.51	0.0001	0.20	0.096
MEI	1,192.9 ^a	1,146.8 ^{ab}	1,078.7 ^b	1,107.5	1,171.5	21.80	0.033	0.063	0.018
HP	842.7 ^b	862.5 ^{ab}	907.8 ^a	845.1	896.9	11.62	0.041	0.016	0.032
E _{milk}	373.6	445.0	379.9	435.2	363.8	21.45	0.28	0.092	0.39
RE _{body}	−23.4 ^a	−160.7 ^b	−208.9 ^b	−172.9	−89.2	30.71	0.0056	0.070	0.045

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹GEI = gross energy intake; E_{feces} = energy losses in feces; E_{urine} = energy losses in urine; E_{methane} = energy losses in methane; MEI = metabolizable energy intake; HP = heat production; E_{milk} = recovered energy in milk; RE_{body} = recovered energy in tissue (RE_{body} = MEI − HP − E_{milk}).

²CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

³A = first period; B = second period.

MEI, but it was not possible to reach higher DMI with the by-product diets. In ruminants, lipogenic nutrients originate either from fiber that stimulates the ruminal production of acetate and butyrate or from dietary fat, or are derived from body reserves. Glucogenic nutrients originate from starch escaped from rumen degradation or gluconeogenesis and include propionic acid, glucogenic amino acids, and lactic acid (van Knegsel et al., 2007). Lipogenic nutrients, which increase milk fat yield, increase the partitioning of ME into milk and consequently decrease the partitioning of ME into body reserves. These observations suggest that glucogenic nutrients (as in the CRG diet) stimulate body fat deposition and the partitioning of ME into body tissue so that less negative energy balance was observed. As mentioned previously, despite of the differences among diets in negative energy retention, no significant differences were found in E_{milk} .

The efficiency of use of ME for milk production obtained by regression was 0.59 (corrected $E_{\text{milk}} = -368.56 + 0.591 \times \text{corrected MEI}$; $R^2 = 0.86$; residual standard deviation = 60.2]. Different authors obtained greater values, such as Aguilera et al. (1990) with lactating Granadina goats ($k_1 = 0.67$) or Bava et al. (2001), who found values ranging from 0.60 to 0.73 for Saanen goats during lactation. Moreover, Tovar-Luna et al. (2010), with Alpine goats during lactation, found values ranging from 0.66 to 0.78. Those authors found variability when combining different stages of lactation with feed intake level, one of the reasons for differences in efficiencies being related to the complexity of biochemical transformation in tissues that are being synthesized or mobilized. López and Fernández (2013), with mixed diets and goats at midlactation and positive energy balance, found values around 0.63. Therefore, when we estimate the ME_m , we found values higher (624 kJ/kg of $BW^{0.75}$) than previous authors; Aguilera et al. (1990) found values of 401 kJ/kg of $BW^{0.75}$ for Granadina goats and Tovar-Luna et al. (2010) found ME_m values of 431 kJ/kg of $BW^{0.75}$, on average. In our study, most of the lactating goats were in negative energy balance and some of the reasons for the dissimilar findings for level of body fat reserves in goats were related to basal metabolism to support milk secretion. Moreover, when a linear model is used to regress energy recovered and MEI, the intercept of the relationship and the ME_m are determined using data obtained with animals receiving different MEI and they are then considered to be constant, irrespective of the ME supply to the animal. Therefore, the traditional assumption of a constant ME_m that is independent of the MEI may be wrong. In the review of Kebreab et al. (2003), using nonlinear regression approach with 652 lactating dairy cows, the calculated values of ME_m were higher (between 590 and

620 kJ/kg of $BW^{0.75}$, with average k_1 values of 0.55) than AFRC (1993) and NRC (2001) recommendations (490 and 510 kJ/kg of $BW^{0.75}$ for ME_m and k_1 values of 0.62 and 0.64, respectively).

Net energy for lactation was expressed as megajoules per kilogram of DM and no significant differences were found when substituting corn with fibrous by-products, although a lower value was found in soybean hulls diet (7.7 in CRG, 7.3 in CTP, and 6.6 in SYH). Diets were isoenergetic, and most of the variation observed in NE_L was due to changes from starch to fiber (NDF). Bava et al. (2001), with goats at midlactation, found values of 8.5 and 7.7 MJ/kg of DM for silage-based and non-forage diets, respectively. The average value obtained by López and Fernández (2013) in dairy goats at midlactation was 7.5 MJ/kg of DM when corn grain was replaced by a blend of soybean hulls and corn gluten feed.

Oxidation of Nutrients

The CO_2 production is derived from nutrient oxidation and rumen fermentation. The separation between these 2 components is necessary to calculate the substrate oxidation in ruminants and determine the proportion of substrate oxidation supporting the total HP associated with oxidative processes. The proportional contribution to HPx due to oxidation of nutrients is shown in Table 5. The significant ($P < 0.05$) effect of period was related to the stage of lactation. Although both periods were midlactation, first period was closer to the peak of lactation than the second period. Thus, higher oxidation of fat and lower RQ_{npx} were found during the first period, and greater oxidation of carbohydrates and RQ_{npx} were observed during the second period. Effect of interaction was significant ($P < 0.05$) for fat and carbohydrate oxidation and RQ_{npx} , and this interaction was not studied.

Diet had no significant effect on HPx (853 kJ/kg of $BW^{0.75}$, on average). However, more fibrous diets (CTP and SYH) were accompanied by greater ($P < 0.001$) HPf than the starch diet (CRG). A significant difference ($P < 0.05$) was observed for RQ_{npx} , being significantly lower for SYH (0.77) than CTP (0.81), and CRG (0.79) did not differ from the other 2 diets but in all cases was lower than 1. Chwalibog et al. (1997) reported that RQ_{npx} lower than 1 indicates predominance of OXF versus OXCHO, as we found in our study.

Due to the negative energy balance of goats, OXF was higher than OXCHO in all diets. The heat from OXP contributed about 8% of HPx on average for the 3 treatments. The CTP diet oxidized 58.2% of nutrients as OXF, but only 34.3% as OXCHO. However, the nutrient oxidation of OXF increased significantly

Table 5. Heat production (kJ/kg of BW^{0.75}) from oxidation and fermentation; daily oxidation (kJ/kg of BW^{0.75}) of protein, carbohydrate, and fat; and their contribution to the heat production from oxidation substrates (%) of Murciano-Granadina goats (n = 12) during midlactation according to the type of diet

Item ¹	Diet ²			Period ³			P-value		
	CRG	CTP	SYH	A	B	SEM	Diet	Period	Diet × period
HPx	829.2	843.5	888.9	828.5	879.2	11.49	0.059	0.017	0.030
HPf	13.5 ^b	19.0 ^a	18.9 ^a	16.6	17.7	0.73	0.0001	0.20	0.10
OXp	72.4	63.5	62.7	68.4	64.0	2.96	0.44	0.55	0.97
OXCHO	218.3 ^{ab}	288.7 ^a	168.3 ^b	133.0	317.2	28.88	0.044	0.0001	0.055
OXF	538.3 ^b	491.1 ^b	657.7 ^a	626.9	497.8	28.95	0.0095	0.0028	0.014
OXp/HPx, %	8.7	7.5	7.1	8.3	7.3	0.35	0.20	0.22	0.91
OXCHO/HPx, %	26.3 ^{ab}	34.3 ^a	18.5 ^b	16.1	36.6	3.39	0.024	0.0001	0.037
OXF/HPx, %	65.0 ^{ab}	58.2 ^b	74.4 ^a	75.6	56.1	3.34	0.018	0.0001	0.028
RQnp _x	0.79 ^{ab}	0.81 ^a	0.77 ^b	0.76	0.82	0.010	0.022	0.0001	0.030

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹HPx = heat production from oxidation of nutrients; HPf = heat production of fermentation [HPf = HP – HPx (Brouwer, 1958)]; OXP = heat production associated with the oxidation of protein; OXCHO = heat production associated with the oxidation of carbohydrates; OXF = heat production associated with the oxidation of fat; RQnp_x = nonprotein respiratory quotient (unitless) from oxidation of nutrients $\{[\text{CO}_{2x} - (\text{N}_{\text{urine}} \times 6.25 \times 0.774)]/[\text{O}_2 - (\text{N}_{\text{urine}} \times 6.25 \times 0.957)]\}$, where $\text{CO}_{2x} = \text{CO}_2$ production from oxidation and $\text{N}_{\text{urine}} = \text{N}$ in urine.

²CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

³A = first period; B = second period.

($P < 0.05$) to 74.4% in SYH and nutrient oxidation of OXCHO decreased significantly ($P < 0.05$) to 18.5%. The higher amount of NDSF in the CTP diet promotes the higher OXCHO compared with the SYH diet. Nevertheless, the CRG diet presented intermediate values compared with the other 2 diets. Few studies relating to oxidation of nutrients are available for ruminants, and especially for small ruminants. López and Fernández (2013) found higher oxidation of nutrients in OXCHO than OXF in goats in midlactation because the goats in their experiment were in a positive energy balance. Chwalibog et al. (1997), in calves with positive retained energy as fat, reported that part of OXF should originate from ingested carbohydrate, mainly fiber.

Carbon and Nitrogen Balance

The daily C and N balance and the calculated tissue recovered as protein and fat are displayed in Table 6. No effect of interaction between diet and period was observed. Effect of period was significant ($P < 0.05$) in carbon losses in CO_2 , recovered N in tissue, and R_{protein} , following the same tendency as observed during the energy balance. In relation to diet, no significant differences were observed in C intake among treatments (38.6 g/kg of BW^{0.75}, on average), but C losses in feces were 2.2 g/kg of BW^{0.75} greater in SYH than CRG and CTP due to the lower digestibility of DM of this diet. Carbon in urine tended ($P = 0.056$) to be higher with the CTP diet due to higher digestibility of DM and OM together with soluble fiber fractions (NDSF and NFC).

Following the trend observed for methane energy, the C losses in CH_4 were significantly lower with CRG

due to lower CH_4 production with this diet. Carbon losses in CO_2 show the same differences among diets as C in CH_4 . Carbon secreted into the milk was not significantly affected by treatment. The ratios between milk C output and C ingested were 0.21, 0.24, and 0.20 for CRG, CTP, and SYH, respectively. The CTP diet showed greater efficiency, with more C retained in milk in terms of intake. The 3 groups had negative balances, although CRG diet had significantly less negative balance (-0.42 g/kg of BW^{0.75}; $P < 0.05$) in comparison with the SYH diet (-3.94 g/kg of BW^{0.75}, on average).

Goats of the 3 groups ingested similar amounts of N (2.36 g/kg of BW^{0.75}, on average). The N losses in feces were greater for the SYH treatment (0.81 g/kg of BW^{0.75}) when compared with CRG and CTP (0.66 g/kg of BW^{0.75}, on average). Nitrogen losses in urine and N secreted into the milk were not affected by treatment. Therefore, the ratios between milk N output and N ingested were similar among groups and presented an average value of 0.27. The N balance was different ($P < 0.05$) between CRG and SYH, although CTP was not different from the others. The N balance was positive for all treatments. Although some authors (Kebreab et al., 2010) indicated a reduction in urinary N output when MEI increased; in our study, greater and nonsignificant values of urinary N were found for the CRG diet (diet with higher MEI). This was probably due to greater $\text{NH}_3\text{-N}$ found in CRG and, consequently, more urea N excreted in urine. Therefore, this numerically higher urinary N excretion in diet based on corn would indicate an inefficient use of ruminal $\text{NH}_3\text{-N}$ for ruminal proteosynthesis, even when rapidly degraded starch was available for ruminal microorganisms.

Table 6. Carbon and nitrogen balance (g/kg of BW^{0.75}) of Murciano-Granadina goats (n = 12) during midlactation according to the type of diet

Item ¹	Diet ²			Period ³			P-value		
	CRG	CTP	SYH	A	B	SEM	Diet	Period	Diet × period
C _{intake}	37.87	39.36	38.62	38.19	39.04	0.548	0.58	0.50	0.24
C _{feces}	8.41 ^b	8.50 ^{ab}	10.65 ^a	9.00	9.36	0.319	0.027	0.58	0.90
C _{urine}	1.02	1.39	1.12	1.16	1.19	0.058	0.056	0.80	0.84
C _{CO2}	19.47 ^b	20.92 ^a	21.06 ^a	19.37	21.59	0.348	0.019	0.0004	0.093
C _{CH4}	1.52 ^b	2.13 ^a	2.12 ^a	1.86	1.99	0.082	0.0001	0.20	0.096
C _{milk}	7.87	9.29	7.62	8.75	7.77	0.453	0.28	0.28	0.42
C retained body	-0.42 ^a	-2.89 ^{ab}	-3.94 ^b	-1.97	-2.87	0.608	0.023	0.38	0.079
N _{intake}	2.46	2.35	2.28	2.33	2.39	0.039	0.184	0.48	0.23
N _{feces}	0.63 ^b	0.69 ^b	0.81 ^a	0.73	0.69	0.021	0.0018	0.22	0.74
N _{urine}	0.63	0.55	0.54	0.59	0.56	0.026	0.44	0.55	0.97
Metabolizable N	1.20	1.10	0.93	1.01	1.15	0.050	0.061	0.13	0.32
N _{milk}	0.64	0.66	0.63	0.68	0.61	0.027	0.87	0.20	0.77
N retained body	0.56 ^a	0.44 ^{ab}	0.30 ^b	0.33	0.54	0.046	0.034	0.0098	0.43
R _{protein}	3.50 ^a	2.74 ^{ab}	1.89 ^b	2.03	3.39	0.287	0.034	0.0098	0.43
R _{fat}	-2.93 ^a	-5.62 ^b	-6.42 ^b	-3.95	-6.04	0.702	0.039	0.081	0.057

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹C_{intake} = C intake; C_{feces} = C losses in feces; C_{urine} = C losses in urine; C_{CO2} = C losses in CO₂; C_{CH4} = C losses in methane; C_{milk} = recovered C in milk; C retained body = recovered C in tissue; N_{intake} = N intake; N_{feces} = N losses in feces; N_{urine} = N losses in urine; Metabolizable N = N_{intake} - N_{feces} - N_{urine}; N_{milk} = recovered N in milk; N retained body = recovered N in tissue; R_{protein} = retained protein; R_{fat} = retained fat.

²CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

³A = first period; B = second period.

The values of N retained in the body were converted to grams of protein. Differences ($P < 0.05$) were found between CRG and SYH, whereas CTP showed a middle value. Therefore, R_{protein} was 3.5, 2.7, and 1.9 g/kg of BW^{0.75} for CRG, CTP, and SYH, respectively. Regarding R_{fat}, the CTP and SYH diets showed greater ($P < 0.05$) fat mobilization (-6.0 g/kg of BW^{0.75}, on average) than CRG (-2.9 g/kg of BW^{0.75}).

Milk Production

Table 7 reports the main productive results of the goats in the experiment. No effect of period was found for milk yield and composition. However, an effect of interaction was observed for DM, fat, and protein of milk. Diet had no effect on milk yield; average milk yield was 1.72 kg/d. However, a numerically higher milk yield was found for CTP than CRG and for CRG than SYH. Increased milk fat content is common when dietary fiber concentrations increase at the expense of starch. Significant differences ($P < 0.01$) were observed for milk fat between SYH and CRG (6.57 and 4.95%, respectively) and, consequently, milk DM was also higher (16.06 and 14.02% for SYH and CRG, respectively). This was because the SYH diet had greater fiber content (Table 1), greater NDF and ADF digestibility (Table 2), and higher values of acetic acid in rumen fluid than CRG (Table 3). The depression in milk fat with CRG diet can be explained by a shift from a high availability of fat precursors to glucose and by a shift from lipogenesis to gluconeogenesis (van

Knegsel et al., 2007). Moreover, milk fat content was higher for goats fed a fibrous diet and with greater fat mobilization (Table 6). Milk protein content differed between SYH and CTP (4.16 and 3.44%, respectively). Lactose content was not statistically different among treatments (4.55%, on average).

Methane Emissions

The effect of diet and period on CH₄ emissions are shown in Table 8. No effect of period and its interaction with diet was found. Goats fed CTP and SYH diets produced similar CH₄ emissions (34.8 g/d, on average) and were significantly higher ($P < 0.05$) compared with goats fed CRG diet (24.7 g/d). The type of carbohydrates in the diet influenced the proportion of individual VFA formed in the rumen and, thus, the amount of CH₄ produced. According to Johnson and Johnson (1995), fermentation of fibrous carbohydrates produces more CH₄ than fermentation of soluble sugars, which in turn produce more CH₄ than fermentation of starch. The similar CH₄ production that we found between CTP and SYH can be explained by the fact that CTP, although with a lower NDF content, has considerable amount of pectins, which, similar to hemicellulose and cellulose, are fermented to VFA and primarily to acetic acid, which promotes methanogenesis.

Methane emission as a percent of MEI and in grams per kilogram of DMI was greater ($P < 0.001$) for the CTP and SYH diets (10.6% and 22.4 g/kg, on average) than the CRG diet (7.0% and 16.4 g/kg). Methane con-

Table 7. Daily milk production and composition of Murciano-Granadina goats ($n = 12$) during midlactation according to the type of diet

Item	Diet ¹			Period ²		SEM	<i>P</i> -value		
	CRG	CTP	SYH	A	B		Diet	Period	Diet $\times$ period
Production, g/d	1,752.8	1,924.3	1,478.0	1,860.2	1,576.5	87.95	0.13	0.091	0.36
Composition, %									
DM	14.02 ^b	14.78 ^{ab}	16.06 ^a	15.21	14.70	0.283	0.0058	0.26	0.015
Fat	4.95 ^b	5.90 ^{ab}	6.57 ^a	6.15	5.46	0.226	0.0057	0.071	0.046
Protein	3.74 ^{ab}	3.44 ^b	4.16 ^a	3.63	3.93	0.113	0.0085	0.064	0.013
Lactose	4.53	4.61	4.51	4.57	4.54	0.044	0.76	0.77	0.86

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

²A = first period; B = second period.

version ratio, also called Ym factor, represents energy loss as CH₄ per unit of GE intake. Methane conversion ratio for CTP and SYH was 7.2%, on average, and CRG showed a value of 5.1% ($P < 0.001$). Kreuzer et al. (1986) also found significantly lower CH₄ loss (total as well as percent of GE) on rations with native starch than rations with cellulose. Although CH₄ emission is most commonly expressed in the literature relative to GE intake, the most meaningful expression is relative to intake of digestible OM because of its high correlation with ruminally fermented OM. On these bases, ruminal CH₄ emission was also greater ($P < 0.001$) with CTP and SYH as compared with CRG. The CH₄ production per kilogram of OM digested was 10.1 g higher in by-product diets, on average, than CRG.

When we report the CH₄ production related to the energy-to-protein ratio we found the same tendency. Thus, this ratio is MEI divided by metabolizable N [$\text{MJ/g} = \text{MEI}/(\text{N}_{\text{intake}} - \text{N}_{\text{feces}} - \text{N}_{\text{urine}})$] and the values obtained were 1.03, 1.05, and 1.17 for CRG, CTP and SYH, respectively. This means more CH₄ was produced when more MEI was available per unit of metabolizable N. Bava et al. (2001) found the same trend with lactating Saanen goats comparing a nonforage diet with a

forage diet; as more CH₄ was emitted, more energy and N ratio was observed (1.42 vs. 1.33 MJ/g of N for the forage and nonforage diet, respectively). As Dijkstra et al. (2013) indicated, integration between protein and energy metabolism is essential, and energy and protein should be considered together rather than as 2 distinct entities. When the relationship between CH₄ production and milk production was compared we found that goats fed SYH produced 8.0 g of CH₄/kg of milk more ($P < 0.01$) than goats fed CRG; conversely, the CTP diet presented intermediate values.

CONCLUSIONS

Our study provides data on energy partitioning, substrate oxidation, carbon and nitrogen balances, methane emissions, and milk performance in Murciano-Granadina goats during midlactation fed mixed diets. The replacement of 61% of corn in the diet by dry citrus pulp or soybean hulls did not affect milk yield (1.72 kg/d) and more fat content was observed for fibrous diets (6.57, 5.90, and 4.95% in SYH, CTP, and CRG, respectively). The MEI was greater for diet CRG than SYH (1,193 vs. 1,079 kJ/kg of BW^{0.75}, respectively),

Table 8. Methane emission of Murciano-Granadina goats ($n = 12$) during midlactation according to the type of diet

Item ¹	Diet ²			Period ³		SEM	<i>P</i> -value		
	CRG	CTP	SYH	A	B		Diet	Period	Diet $\times$ period
CH ₄ , g/d	24.68 ^b	35.09 ^a	34.42 ^a	30.41	32.38	1.334	0.0001	0.23	0.39
Ym, %	5.06 ^b	7.28 ^a	7.09 ^a	6.34	6.61	0.282	0.0001	0.41	0.50
CH ₄ /MEI, %	7.02 ^b	10.33 ^a	10.90 ^a	9.36	9.48	0.462	0.0001	0.79	0.52
CH ₄ , g/kg of DMI	16.37 ^b	22.96 ^a	21.92 ^a	19.97	20.86	0.836	0.0001	0.41	0.49
CH ₄ , g/kg of OM digested	22.00 ^b	30.93 ^a	33.20 ^a	28.42	29.01	1.298	0.0001	0.66	0.59
MEI, MJ/g of metabolizable N	1.03	1.05	1.17	1.12	1.04	0.035	0.23	0.25	0.83
CH ₄ , g/kg of milk	15.46 ^b	18.47 ^{ab}	23.46 ^a	17.26	21.00	1.174	0.0078	0.052	0.26

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Ym = methane energy/gross energy intake; MEI = metabolizable energy intake.

²CRG = corn grain diet; CTP = citrus pulp diet; SYH = soy hulls diet.

³A = first period; B = second period.

and CTP showed an intermediate value (1,147 kJ/kg of BW^{0.75}). The HP was higher for the more-fibrous diet than the more-starchy diet (908 vs. 843 kJ/kg of BW^{0.75} for SYH and CRG, respectively). The efficiency of use of ME for milk production obtained by regression was 0.59. Replacement with fibrous by-products increased methane emissions. Greater CH₄ was produced with dry citrus pulp and soybean hulls diets (34.8 g/d on average) than the corn diet (24.7 g/d). The higher-starch diet resulted in more energy to be partitioned into the body, whereas the fibrous diet split more energy into milk fat. Hence, lactating goats could use dry citrus pulp and soybean hulls diets without detrimental effect on milk performance, although attention should be paid to the quality of forage and level of feeding.

ACKNOWLEDGMENTS

This study was supported by the Instituto INIA Project (Madrid, Spain; ref. RTA2011-00107-C02-02).

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