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Energy-protein supplementation enhances milk production and nutritional status of lactating goats under sorghum stubble

La suplementación energético-proteica mejora la producción de leche y el estado nutricional de cabras lactantes alimentadas con rastrojo de sorgo

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ABSTRACT. The general objective of this study was to evaluate the effects of four energy-protein supplements on the nutritional status, blood metabolites, milk yield, and milk quality of lactating goats adapted to the Comarca Lagunera region and fed a basal diet of sorghum stover. Sixteen goats with similar initial live weight (41.52 ± 1.8 kg) and body condition (2.1 ± 0.2) were randomly assigned to one of four dietary treatments: alfalfa hay (GA), dried distillers' grains (DDG), corn gluten meal (CG), and wheat milling by-products (WM) (n = 4 per treatment). The animals were managed individually and underwent an 8-day supplement adaptation period, followed by a 30-day experimental phase. Dry matter intake was significantly higher ($p < 0.05$) in goats supplemented with alfalfa hay compared to the other treatments. Daily weight gain was higher ($p < 0.05$) in the GA and WM groups, indicating better energy utilization with these supplementation strategies. No significant differences in blood metabolites were found among treatments ($p > 0.05$), although numerically higher values were observed in the DDG group. Milk yield was significantly affected by supplementation ($p < 0.05$); goats receiving corn gluten meal showed the highest production, differing from the GA group. Conversely, milk composition parameters were not affected by dietary treatment ($p > 0.05$), suggesting that the type of supplement influenced production volume more than milk quality attributes. Overall, energy-protein supplementation improved nutrient intake and enhanced the productive performance of goats consuming low-quality sorghum stover. While all supplements maintained acceptable body condition and metabolic stability, corn gluten meal demonstrated a superior effect on milk production. These findings highlight the potential of strategic supplementation as a viable nutritional management alternative during the dry season in semi-arid grazing systems, where vegetation quantity and quality vary throughout the year.
Keywords: Lactation, metabolites, grazing, milk quality.

RESUMEN. El objetivo general de este estudio fue evaluar los efectos de cuatro suplementos energético-proteicos sobre el estado nutricional, los metabolitos sanguíneos, la producción de leche y la calidad de la leche en cabras lactantes adaptadas a la región de la Comarca Lagunera y alimentadas con una dieta basal de rastrojo de sorgo. Dieciséis cabras con peso vivo inicial (41,52 ± 1,8 kg) y condición corporal (2,1 ± 0,2) similares fueron asignadas aleatoriamente a uno de cuatro tratamientos dietéticos: heno de alfalfa (GA), granos de destilería secos (DDG), harina de gluten de maíz (CG) y subproductos de la molienda de trigo (WM) (n = 4 por tratamiento). Los animales se manejaron de forma individual y pasaron por un periodo de adaptación a la suplementación de 8 días, seguido de una fase experimental de 30 días. El consumo de materia seca fue significativamente mayor ($p < 0,05$) en las cabras suplementadas con heno de alfalfa en comparación con los otros tratamientos. La ganancia de peso diaria fue mayor ($p < 0,05$) en los grupos GA y WM, lo que indica una mejor utilización de la energía con estas estrategias de suplementación. No se encontraron diferencias significativas en los metabolitos sanguíneos entre los tratamientos ($p > 0,05$), aunque se observaron valores numéricamente más altos en el grupo DDG. La producción de leche se vio afectada significativamente por la suplementación ($p < 0,05$); las cabras que recibieron harina de gluten de maíz mostraron la mayor producción, diferenciándose del grupo GA. Por el contrario, los parámetros de composición de la leche no se vieron afectados por el tratamiento dietético ($p > 0,05$), lo que sugiere que el tipo de suplemento influyó más en el volumen de producción que en los atributos de calidad de la leche. En general, la suplementación energético-proteica mejoró la ingesta de nutrientes y potenció el desempeño productivo de las cabras que consumían rastrojo de sorgo de baja calidad. Si bien todos los suplementos mantuvieron una condición corporal y una estabilidad metabólica aceptables, la harina de gluten de maíz demostró un efecto superior en la producción de leche. Estos hallazgos destacan el potencial de la suplementación estratégica como una alternativa viable de manejo nutricional durante la temporada seca en sistemas de pastoreo semiáridos, donde la cantidad y calidad de la vegetación varían a lo largo del año.
Palabras clave: Lactancia, metabolitos, pastoreo, calidad de leche.

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INTRODUCTION

Goat farming, both globally and in Mexico, is a livestock activity that contributes substantially to improving the livelihoods of rural populations and supports household food security (Isidro-Requejo *et al.* 2019). By 2025, Mexico's goat inventory approached 9 million head, with an annual milk production exceeding 168 million liters (SIAP 2025). The Comarca Lagunera region, located in the states of Coahuila and Durango, accounts for over 400 000 head of goats and nearly 60 million liters of milk, positioning it as one of the country's most important goat milk-producing regions (Navarrete-Molina *et al.* 2024, SIAP 2025). In this semi-arid agricultural region, goat farming is primarily carried out by small-scale producers of low socioeconomic status, for whom milk sales represent a primary source of daily income (Anzaldo-Montoya 2020, Arenas-Báez *et al.* 2023). The main production system relies on daily daytime grazing on native vegetation and crop residues, followed by confinement at night (Navarrete-Molina *et al.* 2020). However, during the winter season, forage availability declines, and its nutritional quality deteriorates, limiting voluntary intake and failing to meet animal requirements (Izquierdo *et al.* 2021). Although agricultural residues constitute an accessible feed resource, their low digestibility and limited nutrient content restrict productive performance when offered as the sole diet component (Barrera-Guzmán *et al.* 2022). Energy–protein supplementation has been proposed as an effective strategy to enhance ruminal fermentation and improve the utilization of structural carbohydrates such as cellulose and hemicellulose, particularly under conditions of ruminal nitrogen and energy deficiency (Lei *et al*. 2024). Synchronization of protein and carbohydrate availability in the rumen increases microbial protein synthesis and nutrient flow to the small intestine, thereby improving animal performance (Izquierdo *et al.* 2021), may be the only amino acid source for synthesis of tissues and products (Zurak *et al.* 2023). Therefore, using protein supplements in ruminant feed improves nutrient digestion, serum metabolites, and nitrogen utilization in growing goats (Șonea *et al.* 2024). However, it is important to consider that given the rising costs of protein supplements and the greater need for sustainable livestock practices, optimizing the efficiency of nitrogen use combined with the use of preserved forages is essential (Leon-Tinoco *et al.* 2025). Previous studies have demonstrated that supplementation with agro-industrial byproducts enhances the digestibility of sorghum stubble and corn residues, improves protein retention, and sustains body weight and milk production in goats (Serrato-Corona *et al.* 2016, Maldonado-Jáquez *et al.* 2017, Shah *et al.* 2025). Given the need for cost-effective supplementation alternatives under semi-arid grazing conditions, the present study aimed to evaluate the effectiveness of four feed supplements in lactating goats fed sorghum stubble, focusing on indicators of nutritional status, blood metabolites, milk yield, and milk quality.

MATERIALS AND METHODS

Ethics statement

All experimental procedures complied with international and national guidelines for the ethical use and care of research animals (FASS 2010, NAM 2010). Animal handling practices were implemented to minimize stress and ensure welfare throughout the fieldwork for the experiment.

Location of the experimental area

The research project was conducted in January 2025 at the goat facility of the Faculty of Agriculture and Animal Science (FAZ) of the Juárez University of the State of Durango (UJED), located in Ejido Venecia, Gómez Palacio, Durango, Mexico. This semi-arid area is characterized by a dry climate, with a mean annual temperature of 21°C, ranging from 37°C (May-August) in summer to 0°C (November-February) in winter (INEGI 2024).

Animals and management

From a grazing family herd, 16 crossbred goats (Nubian, Alpine, Saanen, Toggenburgh x Criollo) with two kiddings and 70 days in production were selected, with an average weight of 41.52 ± 1.8 kg (Truper Electronic Hanging Scale, 300 kg capacity) and a body condition score using a scale of 1 (very thin) to 4 (very fat) of 2.1 ± 0.2 units (Walkden-Brown *et al.* 1997). They were dewormed with 1% ivermectin at a dose of 0.5 mL per 25 kg (Baymec, Bayer, Mexico City, Mexico) and given 1 mL of vitamins A, D, and E at the beginning of confinement (Vigantol: ADE + Selenium, 250 mL, Zapopan, Jalisco, Mexico). Water was provided free choice. The goats are confined in shaded cyclone mesh pens measuring 2 x 1.5 m. The main feed was sun-dried forage sorghum stubble (due to its nutritional characteristics being like the feed consumed during the dry season). It was offered twice a day at 07:00 h and 19:00 h. The amount provided was calculated based on 2.2% of live weight and was adjusted according to daily consumption.

Treatments

The goats were individually confined for 38 days: eight days for adaptation and 30 days for the study period. The ingredients used in the four supplements were: ground alfalfa, dried distillers grains, corn gluten, wheat silage, cane molasses, urea, soybean hulls, flaked sorghum, sorghum stubble distributed in different percentages, in order to meet their nutritional needs, as well as the total. Four types of supplements were used to improve the protein and energy content of the goats' diet. These were organized into four treatments with four repetitions each. Each treatment received one type of supplement. The treatments were identified according to one of the main ingredients: ground alfalfa hay with a particle size of 2 cm (GA); dried distiller grain (DDG); corn gluten (CG); and wheat middlings (WM). The number of supplements was provided based on 1% of the animals' live weight. The supplements were offered daily in the mornings along with sorghum stubble with 4.9% CP and 1.2 Mcal of ME (Table 1 and Table 2). In addition, the sorghum stubble showed 40% DM, 65% NDF and 45% ADF.

Variables evaluated

Nutritional status of the goats

Dry matter intake (DMI) was determined daily by weighing the feed rejected over a 24-hour period and subtracting it from the feed offered. For live weight (LW), goats were weighed at the beginning and end of the study. Daily weight gain (DWG) was obtained by dividing the change in weight by the number of days in the study. Both the weighing of rejected feed and the weight of the goats were performed using digital scales.

Table 1. Crude protein (CP) and metabolizable energy (ME) content of the ingredients included in the supplements and of sorghum stubble in percentage for multi-breed goats in production.

Ingredient (%)	Treatment				CP (%)	ME ([b]Mcal)
	[a]GA	DDG	CG	WM		
Ground alfalfa	10				18	2.1
Dried distillers grains		10			23	3.7
Corn gluten			10		25	3.5
Wheat silage				10	19	3.0
Cane molasses	5	5	5	5	6	2.7
Urea	1	1	1	1	287	0
Soybean hulls	9	9	9	9	13	2.8
Rolled sorghum	7	7	7	7	11	3.3
Sorghum stubble	68	68	68	68	4.9	1.2
Total	100	100	100	100		

[a] Treatments: GA = Ground alfalfa hay, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble; DDG = Dried distillers grain, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble; CG = Corn gluten, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble; WM = Wheat middlings, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble. [b] Mcal = Megacalories.

Table 2. Contributions of crude protein (CP) and total metabolizable energy (ME) of each treatment, consumed by multi-breed goats in production (NRC 2007).

[a]Treatments	CP (%)	ME ([b] Mcal)
GA	21.23	2.60
DDG	22.39	3.04
CG	22.44	3.09
WM	21.47	2.89
Sorghum stubble	4.90	1.20

[a]Treatments: GA = Ground alfalfa hay, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble; DDG = Dried distillers grain, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble; CG = Corn gluten, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble; WM = Wheat middlings, cane molasses, urea, soybean hulls, rolled sorghum, sorghum stubble. [b]Mcal = Megacalories.

Blood metabolites

On the last day of the study, blood sampling was performed by puncturing and extracting blood from the jugular vein of each goat after a 12-hour fast. Sampling began at 7:00 am. Each sample was centrifuged at 3 000 rpm for 20 minutes to obtain blood serum. The serum was stored in two 2 ml Eppendorf tubes labeled at -20°C for subsequent analysis. Glucose, cholesterol, nitrogen, and protein determinations were performed using photocolorimetry with a photocolorimeter (DR3900 RFID*, HACH®, Aguascalientes, Mexico).

Milk production and composition:
Milk yield was recorded on days 15 and 30 using a graduated cylinder. Goats were hand-milking once a day. Milk samples (50 mL) were analyzed for density, fat, protein, lactose, and solids-not-fat using a LactiCheck™ LC-01 analyzer (RapiRead, USA) in the nutrition laboratory of the FAZ UJED.

Statistical analysis
The statistical design used to analyze the response variables was a completely randomized design. Data for dry matter intake (DMI), live weight, milk production, and milk composition were analyzed using ANOVA. The Shapiro-Wilk test was used to verify data normality. Blood metabolite levels were analyzed using PROC GLM. Treatment means were compared using the least significant difference (LSD) test. Differences between treatments were considered significant if $p < 0.05$. The statistical software SAS (version 9.4, SAS Institute Inc., Cary, NC, USA) was used for analysis.

RESULTS

Live weight and dry matter intake
Dry matter intake (DMI) was significantly different in the treatments ($p < 0.05$; Table 3). Goats supplemented with ground alfalfa (GA) exhibited the highest intake (1196.8 g day^{-1}), exceeding the other treatments. Animals receiving dried distillers grains (DDG) showed similar DMI to those fed corn gluten (CG) ($p > 0.05$), but greater intake than goats supplemented with wheat middlings (WM) ($p < 0.05$). The lowest DMI was observed in the WM group. Initial and final live weights were not statistically different among treatments ($p > 0.05$). However, daily weight gain (DWG) differed significantly ($p < 0.05$). Goats in the GA and WM groups showed greater weight gains compared to DDG and CG. The lowest ADG was recorded in the CG group (0.0413 kg animal^{-1} day^{-1}).

Table 3. Comparison of dry matter intake (DMI), initial live weight (ILW), final live weight (FLW), and daily weight gain (DWG) of multi-breed goats in production, supplemented and fed with sorghum stubble.

	Treatments					
Variables	**GA**	**DDG**	**CG**	**WM**	**n**	**SE**
DMI (g día^{-1})	1196.8^{a}	1136.5^{b}	1090.3^{ab}	1050.0^{c}	4	15.60
ILW (kg)	42.3^{a}	41.6^{a}	40.9^{a}	42.5^{a}	4	0.06
FLW (kg)	47.4^{a}	43.5^{a}	42.1^{a}	47.0^{a}	4	0.03
DWG (kg animal^{-1})	0.1700^{a}	0.063^{b}	0.0413^{b}	0.1500^{a}	4	0.08

GA = Ground alfalfa, DDG = Dried distiller grain, CG = Corn gluten, WM = Wheat middlings; n = Number of repetitions, SE = Standard error. Values between rows with different letters are statistically different ($p < 0.05$).

Blood metabolites
The serum metabolite concentrations were similar in the treatments ($p > 0.05$, Table 4). Glucose, cholesterol, urea nitrogen, and total protein values remained within physiological ranges across all treatments. Although goats receiving DDG showed numerically higher glucose concentrations

(59.31 mg dL^{-1}) and the GA group the lowest (54.69 mg dL^{-1}), these differences were not statistically significant, indicating comparable metabolic status among treatments.

Table 4. Behavior of blood metabolites in multi-breed production goats supplemented and fed with sorghum stubble.

Variables	Treatments				n	SE
	GA	DDG	CG	WM		
Glucose (mg dL^{-1})	54.688^a	59.305^a	58.425^a	57.530^a	4	0.476
Cholesterol (mg dL^{-1})	63.748^a	66.318^a	65.700^a	64.748^a	4	0.586
Urea nitrogen (mg dL^{-1})	41.940^a	43.990^a	42.290^a	42.740^a	4	0.145
Proteín (mg dL^{-1})	64.038^a	65.488^a	66.738^a	64.738^a	4	0.384

GA = Ground alfalfa, DDG = Dried distiller grain, CG = Corn gluten, WM = Wheat middlings; n = Number of repetitions, SE = Standard error. Values between rows with different letters are statistically different ($p < 0.05$).

Milk Production and Composition

The milk yield was different in the groups of goats ($p < 0.05$; Table 5). Goats supplemented with corn gluten (CG) produced the highest milk volume (524.88 mL day^{-1}), which was statistically similar to DDG and WM but greater than GA. Milk composition variables, including fat, protein, lactose, and density, were not influenced by treatment ($p > 0.05$). However, non-fat solids differed significantly ($p < 0.05$), with the highest values in the CG group compared with GA, while DDG and WM showed intermediate responses.

Table 5. Milk production and composition in multi-breed goats supplemented and fed with sorghum stubble.

Variables	Treatments				n	SE
	GA	DDG	CG	WM		
Production (ml)	477.50^b	523.13^a	524.88^a	503.75^{ab}	4	15.050
Fat (gL^{-1})	3.92^a	3.51^a	3.50^a	3.66^a	4	0.0506
Proteín (gL^{-1})	2.80^a	2.90^a	2.94^a	2.82^a	4	0.0501
Lactose (gL^{-1})	4.11^a	4.25^a	4.28^a	4.14^a	4	0.0508
Non-fatty solids (gL^{-1})	8.40^b	8.65^{ab}	8.74^a	8.63^{ab}	4	0.0987
Density (g cm^3)	30.27^a	29.80^a	29.99^a	30.17^a	4	0.2973

GA = Ground alfalfa, DDG = Dried distiller grain, CG = Corn gluten, WM = Wheat middlings; n = Number of repetitions, SE = Standard error. Values with different letters between rows are statistically different ($p < 0.05$).

DISCUSSION

Live weight and dry matter intake

The GA-treated goats exhibited the highest dry matter intake (DMI), likely due to the uniform 2-cm forage particle size of the alfalfa and sorghum stubble, which facilitated consistent and homogeneous bite formation and ingestion. (Li *et al.* 2014, Chen *et al.* 2022). Recorded DMI (250-1 200 g day^{-1}) aligned with reference ranges for goats on diverse forages (Elizondo-Salazar 2018) and

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exceeded NRC (2007) maintenance requirements for comparable phenotypes. Sorghum stubble exhibits inherently low digestibility due to its fibrous nature (Serrato-Corona *et al.* 2016). Coarse forages reduce passage rate and prolong satiety thereby depressing intake (Hernández and Hernández 2023). Despite this observed DMI remained acceptable (NRC 2007, Elizondo-Salazar 2018) likely due to supplemental enhancement of stubble digestibility. This microbial activity improves fibrous feed digestion, accelerates passage rate and sustains DMI (Moyo *et al.* 2017). Supplementation enabled DMI maintenance or an increase in lambs grazing sorghum residues (Yerradoddi *et al.* 2015). Live weight showed no significant treatment effect ($p>0.05$) CG group exhibited minimal gain (0.041 kg animal^{-1}). The GA and WM groups showed the highest DWG compared to the rest of the treatments ($p < 0.05$). This information coincides with that reported by (Zhao *et al.* 2023) who carried out a study where they evaluated the changes in dietary protein levels and their effect on milk production, body weight gain, blood biochemical parameters and intestinal microbiota in lactating sheep, body weight gain was greater ($p < 0.05$) in sheep fed with the protein dietary treatment than in those fed with protein-free diets respectively. Dietary energy drives propionate production for gluconeogenesis sparing muscle amino acids from catabolism and stabilizing live weight (NRC 2007). Supplemental energy and protein enhance fiber digestibility via microbial stimulation (Obe and Yusuf 2017). This elevates passage rate intake and nutrient availability for maintenance and production (Weimer 2022). Serrato-Corona *et al.* (2016) successfully maintained growing goat weight using agro-industrial byproduct supplements with sorghum stalks. Argüelles-Verdugo *et al.* (2018) maintained lactating goat weight using *Moringa oleifera* supplementation. Slight CG gain advantage may reflect its higher nutrient density (Maldonado-Jaquez *et al.* 2017). In this study, all four supplements effectively maintained the live weight of lactating goats throughout the trial. The statistical equivalence among treatments confirms that the evaluated supplements represent viable strategies for maintaining the body condition of lactating goats consuming crop residues. This finding is particularly relevant for production systems in arid and subtropical regions, where sorghum is a crucial resource. By mitigating the reduction in intake associated with fibrous forages, strategic supplementation emerges as a key tool for enhancing the sustainability of goat production systems. The demonstrated efficacy of these supplements supports their recommendation for small-scale production systems facing seasonal variations in the quality of grazed forage.

Blood metabolites

Glucose concentrations were similar across treatments ($p > 0.05$) with DDG (59.305 mg dL^{-1}) and GA (54.688 mg dL^{-1}) representing extremes. These values exceeded those reported for high-producing Saanen goats (Carta *et al.* 2022) and aligned with Alpine goats producing 1.4-2 L milk^{-1} (Posada *et al.* 2012). All supplements-maintained glucose above 50 mg dL^{-1} minimum physiological threshold (Bermúdez *et al.* 2020). Muscle glycogenic activity likely contributed to glucose homeostasis (Carta *et al.* 2022). Supplemental energy and protein stimulate rumen microbial proliferation. Cholesterol levels were statistically similar across treatments ($p > 0.05$) ranging from 65.70 mg dL^{-1} (DDG) to 63.748 mg dL^{-1} (GA). These values fell below concentrations observed in high-producing goats receiving wheat brand and pistachio shells (Naserian *et al.* 2016) and those supplemented with spent coffee grounds (Carta *et al.* 2022). All goats exhibited cholesterol below the 80 mg dL^{-1} minimum physiological range (Bermúdez *et al.* 2020). Dietary energy did not

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stimulate cholesterol synthesis. Cholesterol levels correlate directly with dietary carbohydrates and lipids (Leduc *et al.* 2021). High-fiber rations lower blood cholesterol (Silva *et al.* 2015). This effect stems from unsaturated and polyunsaturated fatty acids incorporated into protozoal biomass, which are subsequently degraded in the small intestine. Blood urea nitrogen (BUN) concentrations ranged from 41.94 to 43.99 mg dL^{-1}, with no differences among treatments ($p > 0.05$). All supplements resulted in BUN concentrations exceeding suggested physiological ranges (Bermúdez *et al.* 2020). Insufficient energy availability prevents the complete incorporation of ruminal ammonia into microbial protein, thereby raising BUN levels (Abdelsattar *et al.* 2021, Torres-Cavazos *et al.* 2023). Total protein ranged from 66.738 to 64.038 mg dL^{-1}, with no differences among treatments ($p > 0.05$). The CG group showed the highest values, while the GA group showed the lowest. These concentrations were lower than Creole goats on pasture (Mellado *et al.* 2020) but exceeded those of high-producing goats (Naserian *et al.* 2016). Low blood protein reflects inadequate dietary energy and protein availability limiting microbial protein synthesis (Abdelsattar *et al.* 2021). The NRC (2007) recommends 127 g day^{-1} crude protein and 2.25 Mcal $days^{-1}$ metabolizable energy. Despite low treatment concentrations all supplements maintained protein within desired physiological range (64 mg dL^{-1}) for goats (Bermúdez *et al.* 2020).

Milk Production and Composition

CG exhibited highest milk production (524.88 mL) statistically like DDG and WM ($p > 0.05$) and higher than GA ($p < 0.05$). Production aligned with grazing Creole goats during winter forage scarcity in La Comarca Lagunera (Isidro-Requejo *et al.* 2019) but fell below supplemented grazing goats (Maldonado-Jaquez *et al.* 2017, Argüelles-Verdugo *et al.* 2018). Energy and protein are essential for lactogenesis (Castillo 2022). The mammary gland utilizes over 80% of consumed energy for milk synthesis (Ferro *et al.* 2017). Amino acids support mammary tissue regeneration and milk protein formation. Glucose serves as primary energy substrate for lactogenic cells enabling uptake and production of proteins lactose and fat (Silva *et al.* 2022). Nutrient supply derives primarily from diet and secondarily from endogenous mobilization (Kim and Lee 2021). Supplements mitigate nutritional deficiencies though incompletely when basal forages possess low nutritional value like sorghum stubble (Goetsch 2016, Maldonado-Jaquez *et al.* 2017, Ponce *et al.* 2021). Despite fibrous basal diet all four supplements maintained acceptable milk production ranges (Isidro-Requejo *et al.* 2019). This improves nutrient availability through increased volatile fatty acid production for energy and microbial protein synthesis (Wang *et al.* 2020). GA exhibited highest milk fat (3.92 gL^{-1}) though treatments did not differ significantly ($p > 0.05$). CG showed lowest fat (3.25 gL^{-1}). Observed range exceeded housed high-producing Saanen goats (Castillo 2022, Naserian *et al.* 2016) but fell below grazing Creole goats (Maldonado-Jaquez *et al.* 2017). Higher fat in GA and WM may reflect greater fiber content from these supplements. Fiber promotes ruminal acetate production a direct precursor for milk fat synthesis. Milk yield also influences fat concentration. CG showed highest milk protein (2.944 gL^{-1}) though all treatments were statistically equal ($p > 0.05$). GA exhibited lowest protein (2.80 gL^{-1}). Values were below unsupplemented grazing goats (Maldonado-Jaquez *et al.* 2017) and supplemented goats during rainy season (Castillo 2022). Milk protein percentages were low across treatments. Supplements improved nutrient availability from sorghum stubble but insufficiently to achieve optimal milk protein. Blood metabolite concentrations reflect dietary composition (Chikwanda and Muchenje 2017). Milk protein synthesis demands over 80 gL^{-1} of dietary protein and energy; inadequate supply negatively affects milk protein percentages (Pecka-Kielb *et al.* 2018). Lactose concentrations showed no treatment differences ($p > 0.05$). CG exhibited highest lactose (4.275 gL^{-1}) whereas GA the lowest (4.111 gL^{-1}). All treatments were within basal parameters for goat milk (4.1 gL^{-1}, Park 2013) but below supplemented and unsupplemented grazing goats (Maldonado-Jaquez *et al.* 2017, Argüelles-Verdugo *et al.* 2018). Water secretion by lactocytes is directly proportional to lactose synthesis. CG exhibited highest non-fat solids (8.74 gL^{-1}) statistically equal to DDG and WM and higher than GA. Values exceeded high-producing housed supplemented goats (Naserian *et al.* 2016) and supplemented and unsupplemented grazing goats (Argüelles-Verdugo *et al.* 2018) all with higher milk production than present study. High NFS aligned with Creole goats during dry season (Kasapidou *et al.* 2022). NFS content associates with milk volume. Milk production depends on dietary energy and protein availability (Flórez-Delgado *et al.* 2018). Acceptable production in this study reflects supplemental energy and protein enhancing nutrient availability. GA exhibited highest milk density (30.17 g cm^{-3}) although treatments showed no significant differences. All groups exceeded housed supplemented Saanen goats producing more than 1 L of milk (Castillo 2022) and grazing Saanen goats with and without orange silage supplementation (Cruz *et al.* 2019). Overall, the supplementation strategy influenced intake patterns, growth performance, and milk yield, whereas metabolic indicators and most milk compositional traits remained stable across treatments.

CONCLUSIONS

Energy–protein supplementation improved nutrient availability and productive performance in lactating goats fed sorghum stubble. All supplements maintained metabolic indicators within acceptable physiological ranges, supporting daily weight gain and milk production under low-quality forage conditions. Corn gluten enhanced milk yield, whereas ground alfalfa promoted greater dry matter intake and body weight gain, indicating differential nutrient partitioning among supplements. The absence of metabolic disturbances suggests effective buffering of the nutritional limitations imposed by sorghum residues. Energy and protein supplementation during the dry season can prevent productive decline and reduce the risk of nutritional marasmus in grazing systems. The limitations of the present study are based on the fact that a low number of goats per treatment were used, which represents an area of opportunity, and new scientific questions arise. Future studies should evaluate in vivo digestibility, nitrogen utilization efficiency, and the long-term economic sustainability of these supplementation strategies.

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CONFLICT OF INTEREST

The authors declare no conflict of interest in this article.

LITERATURE CITED

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