



Research article

Effects of corn malt on rumen fermentation, blood metabolites and growth performance in fattening goats

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Abstract

Importance of the work: Corn malt (CM), derived from fermented corn grain, has the potential to improve ruminant feed quality and enhance growth.

Objectives: To evaluate the effects of different CM and fermented corn husk (CH) ratios on rumen fermentation, blood metabolites and growth performance in fattening goats.

Materials and Methods: In total, 20 male crossbred Native × Boer goats (13.0 ± 4.0 kg initial body weight) aged 3 mth were randomly assigned to five total mixed ratio (TMR) diets: T1 = 50% corn grain (CG) + 50% CH; T2 = 50% CM + 50% CH; T3 = 60% CM + 40% CH; T4 = 70% CM + 30% CH; and T5 = 80% CM + 20% CH. A completely randomized design was applied for the 90 d trial. The parameters measured were: rumen pH, volatile fatty acids (VFA), ammonia-nitrogen ($\text{NH}_3\text{-N}$), blood urea nitrogen (BUN), blood glucose, insulin, body weight gain (BWG), average daily gain (ADG), feed conversion ratio (FCR) and feed intake (FI).

Results: The rumen pH, VFA, $\text{NH}_3\text{-N}$ and BUN levels were within their optimal ranges across treatments. The CM-based diets (T2–T5) produced higher blood glucose levels ($p < 0.01$) than T1. Goats fed T5 produced the highest BWG (12.97 kg), ADF (0.21 kg/day) and FI (1.38 kg/day), representing a 75% increase in ADG over T1. FCR was similar across treatments; however, higher CM inclusion enhanced nutrient utilization and feed palatability.

Main finding: The TMR diet with 80% CM and 20% CH (T5) significantly improved growth performance and feed efficiency, suggesting its potential as a cost-effective strategy for fattening goats. Further studies are needed to validate its use in other ruminant species and diverse environments.

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Introduction

Corn grain (CG) is a widely used energy source in ruminant diets due to its high starch content, which supports energy demands in production systems (Marcela and Granodos-Chinchilla, 2018). However, its utilization efficiency is hindered by low rumen solubility of 40–60% (Pilachai et al., 2012) and a limited protein content of approximately 7–8% of dry matter (Sommart et al., 2021). Excessive inclusion of corn grain in rations can reduce starch digestibility, leading to inefficient energy and protein intake, which ultimately limits animal growth and productivity (Srakaew et al., 2021). This challenge has prompted research into methods for improving the nutritional value of CG and expanding the range of viable alternative feed ingredients for ruminants.

More recent trends in feed science have involved using microbial additives, such as lactic acid bacteria and yeast, to enhance the digestibility of fibrous feedstuffs, as these additives improve roughage quality by breaking down complex components, such as cellulose, hemicellulose and lignin, thereby increasing nutrient availability (Bourapa et al., 2021). Corn husk (CH), a by-product of corn processing, has potential as a sustainable feed ingredient but is characterized by its low crude protein (2.8%) and high crude fiber (36.52%) contents (Van Soest et al., 1991). Fermentation processes have been explored as a strategy to enhance the quality of CH; however, there are still major challenges such as the low protein content and poor digestibility (Foiklang et al., 2016).

A promising solution involves modifying CG through malt germination and fermentation with mixed microbial juice containing yeast and lactic acid bacteria to produce corn malt (CM). This process greatly enhances the protein content and nutrient digestibility of CG. For example, Srakaew et al. (2021) reported that CM production increased the protein content to 10.0–12.0%, compared to 7.0–8.0% in ungerminated corn seeds. Additionally, ensiling CM with microbial additives further improved crude protein levels to 14–15% and enhanced dry matter digestibility (Bourapa et al., 2021). In addition, the fermentation process converts starch into simpler sugars, increasing energy availability (Srakaew et al., 2021). These improvements position CM as a high-quality feed ingredient with potential for broad applications in ruminant nutrition.

Studies have demonstrated the benefits of incorporating CM into concentrates for inclusion in the diets of ruminants. For example, Bourapa et al. (2021) observed significant improvements in feed efficiency, body weight gain (BWG) and average daily gain (ADG) in beef heifers fed CM in tropical environments. Similarly, Chaiwong et al. (2023) found that CM-sactic supplementation in broiler diets at levels of 5–15% positively influenced feed intake, nutrient digestibility and growth performance. Furthermore, *in vitro* studies on beef cattle (Srakaew et al., 2021) reported enhanced cumulative gas production and dry matter digestibility with CM inclusion. Nonetheless, there remains a lack of *in vivo* research on the use of CM in small ruminants such as goats.

Goats play a vital role in tropical livestock production systems, where improving feed efficiency is critical for sustainability (Koluman, 2023). The potential of CM to increase protein content, enhance digestibility and improve nutrient utilization in goats warrants further investigation. Therefore, the present study aimed to evaluate the effects of total mixed ration (TMR) diets containing CM and CH fermented with yeast and lactic acid bacteria on rumen fermentation, blood metabolites and growth performance in fattening goats. The findings should provide valuable insights into the practical application of CM as a cost-effective and nutritionally efficient feed ingredient for small ruminants.

Materials and Methods

Animal ethics

The experimental protocol was approved by the Animal Ethics Committee of Institutional Animal Care and Use for Animal Research (IACUC) at Rajamangala University of Technology Lanna (RMUTL), adhering to ethical guidelines and policies of the Office of the National Research Council of Thailand (NRCT). The approval number for the study was RMUTL-IACUC 002/2022.

Animal and experimental design

A sample of 20 male crossbred goats (Native × Boer) 3 mth, with an initial mean body weight of 13.0 ± 4.0 kg was selected for the study. The goats were randomly assigned to one of five dietary treatments, with four animals per treatment. The five treatments comprised total mixed ratio (TMR)

diets with varying combinations of corn grain (CG), corn malt (CM) and fermented corn husk (CH): T1: 50% CG + 50% CH; T2: 50% CM + 50% CH; T3: 60% CM + 40% CH; T4: 70% CM + 30% CH; and T5: 80% CM + 20% CH.

The goats were housed individually in 3 m × 3 m pens with concrete floors and open-air ventilation. During the adaption period (14 d), the animals were allowed to acclimate to the experimental environment, feeding arrangements and diets. Each goat received a commercial multivitamin (AD₃E, 1 mL), internal and external parasite treatment (IVERMECTIN, 1 mL) and Foot-and-Mouth Disease (FMD) vaccination (1.0 mL).

The adaptation program include step-up feeding of the experimental concentrate *ad libitum*: Week 1, 70% commercial feed and 30% experimental concentrate; days 8–11, 30% commercial feed and 70% experimental concentrate; and final 3 days, 10% commercial feed and 90% experimental concentrate.

The subsequent 90 d feeding trail involved twice-daily feeding at 0700 hours and 1600 hours, with *ad libitum* access to drinking water. Feed palatability and animal health were monitored daily, with the environmental conditions maintained at 20–25°C with 70–75% relative humidity. Body weight (BW) was recorded at the beginning of the trial (day 0) and subsequently every 30 days until day 90. Body weight gain (BWG) was calculated as the difference between the initial and final body weights and average daily gain (ADG) was determined by dividing the BWG by the number of feeding days. Feed intake (FI) was measured daily and the feed conversion ratio (FCR) was calculated as the FI divided by the BWG, following Zhao et al. (2010).

Preparation of corn malt and fermented corn husk

The CM was prepared using hard corn seeds that underwent germination and microbial fermentation (Srakaew et al., 2021). Seeds were soaked in water (1:1 ratio) for 5 hr, drained and then incubated in hole-ventilated baskets covered with wet cloths for 3–5 d to allow germination. The germinated seeds were fermented with mixed microbial juice, including *Saccharomyces cerevisiae* yeast juice (Thongnum et al., 2018) and lactic acid bacterial juice, prepared by incubating Napier grass extract with sugar in a hot-air oven at 39°C for 3 d (Bureenok et al., 2007). Fermentation involved 1% yeast juice and 1% lactic acid bacterial juice under anaerobic conditions for 14 d. The fermented CM was dried to <13% moisture content and ground to pass through a 4 mm sieve.

The fermented CH was prepared by mixing CH with water (1:1 ratio) and adding 1% yeast and lactic acid bacterial juices. The mixture was subjected to anaerobic fermentation for 14 d, dried and ground for inclusion in the TMR diets, following the method of Thongnum et al. (2018).

Sample collection and analysis

Samples from the five treatments ($n = 3$ replicates per treatment) were dried at 60°C for 72 hr before analysis. The dry matter (DM), ash, ether extract and crude protein (CP) contents were measured using standard methods (Nocek and Tamminga, 1991). The neutral detergent fiber (NDF) and acid detergent fiber (ADF) contents were analyzed according to Van Soest et al. (1991).

On day 90, rumen fluid and blood samples were collected at 0 hr and 4 hr post-feeding. Approximately 500 mL of rumen fluid was collected via stomach tubing, with the pH measured immediately using a portable pH meter. The fluid was filtered through cheesecloth and a 100 mL aliquot was mixed with 10 mL of 50% sulfuric acid (H₂SO₄) for analysis of the ammonia-nitrogen (NH₃-N) and volatile fatty acid (VFA) contents. Each sample was centrifuged at 16,000×g for 15 min and the supernatant was stored at -20°C. VFA was analyzed using high-performance liquid chromatography (model RF-10AXmugIL; Shimadzu corporation; Kyoto, Japan) according to Mathew et al. (1997), while the NH₃-N was determined following Bremner and Keeney (1965).

Blood samples (10 mL) were collected from the jugular vein of each goat into two tubes. Serum from the first tube was used for blood urea nitrogen (BUN) analysis (Crocker, 1967). Glucose and insulin levels were measured from the second tube at Nan Lab Center Co., Ltd, Nan, Thailand.

Statistical analysis

The experimental data were analyzed using a completely randomized design. Before analysis, normality tests were conducted on all variables using the PROC UNIVARIATE procedure in SAS® OnDemand for Academics software (SAS Institute Inc.; Cary, NC, USA) to confirm that the assumptions of normality were met.

One-way analysis of variance was applied to evaluate the effects of the five dietary treatments (T1–T5) on all measured parameters of rumen fermentation, blood metabolites and growth performance. Differences among treatments means were assessed using Duncan's new multiple range test (Steel and Torrie, 1980), with statistical significance set at $p < 0.05$.

To further investigate the effects of CM inclusion levels, orthogonal polynomial contrasts were performed to identify trends and specific comparisons between treatments. Two main comparisons were conducted: 1) comparison between CG and CM treatments, involving a comparison of T1 (50% corn grain + 50% fermented corn husk) with T2 (50% corn malt + 50% fermented corn husk) to determine the effect of replacing corn grain with corn malt; and 2) linear effects of increasing CM levels, where treatments T2, T3, T4 and T5 were analyzed to evaluate the linear effect of increasing CM levels in the TMR diets on measured parameters.

The statistical model used for analysis was $y_{ij} = \mu + M_i + e_{ij}$, where y_{ij} is observation from goat j receiving diet I , μ is the overall mean, M_i is the fixed effect of treatment i ($i = 1, 2, 3, 4$ and 5) and e_{ij} is the residual effect $NID \sim (0, \sigma_e^2)$.

All results were presented as mean ($\bar{x}$) values $\pm$ their standard error of the mean (SEM) to indicate the precision and variability within treatment groups. Statistical significance was determined at $p < 0.05$, while trends were noted and discussed for p values approaching significance.

Results and Discussion

Treatment and animal feeding

The ingredients and chemical composition of the experimental concentrate diets, including their CG

and CM bases, are detailed in Table 1. Both CG and CM were nutritionally adjusted to achieve a CP content of 15% and GE of 3,000 kcal/kg of DM. Then, these concentrate bases were incorporated into TMR diets with fermented CH at varying ratios, as outlined in Table 2. The chemical compositions of the resulting TMR diets indicated CP values in the range 13.50–15.70% and ME values in the range 2,400–2,700 kcal/kg of DM, demonstrating the nutritional adequacy of all treatment diets for fattening goats.

Table 1 Ingredients and chemical composition of experimental concentrate diets (% dry matter basis).

Ingredient	Concentrate (kg/100 kg)	
	Corn-grain based	Corn-malt based
Cassava chips	40.00	40.00
Molasses	1.50	1.50
Soybean meal	10.00	10.00
Rice bran	15.00	15.00
Corn meal	30.00	20.00
Corn malt with yeast	-	10.00
Premix	0.50	0.50
Urea	1.50	1.50
Sulfur	0.20	0.20
Salt	0.30	0.30
Dicalcium phosphate (14% P)	1.00	1.00
Total	100.00	100.00
Chemical composition		
Protein (% of DM)	15.00	15.00
Gross energy (Kcal/kg DM)	3,000.00	3,000.00

DM = dry matter

Table 2 Chemical composition of experimental diets for fattening goats.

Item	Treatment (kg/100 kg)				
	T1	T2	T3	T4	T5
Concentrate					
CG	50.00	-	-	-	-
CM	-	50.00	60.00	70.00	80.00
Fermented CH	50.00	50.00	40.00	30.00	20.00
Dry matter (%)	64.99	53.55	51.49	50.99	50.15
-----% of DM-----					
Crude protein	13.50	14.20	14.50	15.20	15.70
NDF	54.93	59.33	59.08	59.87	54.93
ADF	43.16	37.36	36.98	36.19	43.16
Ash	5.80	4.07	3.51	3.09	2.80
ME (Kcal/kg DM)	2,400.00	2,400.00	2,500.00	2,600.00	2,700.00

CG = corn grain; CM = corn malt; CH = corn husk; NDF = neutral detergent fiber; ADF = acid detergent fiber; ME = metabolizable energy.

T1 = 50% corn grain concentrate diet 50% fermented corn husk (50% CG + 50% CH).

T2 = 50% corn malt concentrate diet 50% fermented corn husk (50% CM + 50% CH).

T3 = 60% corn malt concentrate diet 40% fermented corn husk (60% CM + 40% CH).

T4 = 70% corn malt concentrate diet 30% fermented corn husk (70% CM + 30% CH).

T5 = 80% corn malt concentrate diet 20% fermented corn husk (80% CM + 20% CH).

Fermentation of CH with yeast and lactic acid bacteria significantly improved the nutritional quality of the CH. Srakaew et al. (2021) reported that CH harvested 100 d after fermentation contained approximately 90% DM and 4% CP, with fermentation not only enhancing the CP content but also stimulating the growth of lactic acid bacteria, preserving feed quality during storage and ensuring high-quality fermentation.

In the present study, the CH used had a DM content of approximately 28% and a baseline protein content of 1.18%. After fermentation, the protein content increased to 4–5%, indicating the efficacy of yeast and lactic acid bacteria in enriching the feed's protein level. Similarly, transforming corn seeds into malted corn seeds through microbial fermentation resulted in a substantial increase in the protein content. Wanapat and Pimpa (1999) reported a rise in protein levels from 8–9% in unfermented maize seeds to 10.85% in malted corn, aligning with the current findings. Boarapa et al. (2023) investigated the effects of feeding malt-sactic from corn grain as a high protein energy source in the diet on rumen fermentation, nutrient digestibility, blood metabolites and growth performance in beef heifers, where consistent with the research of Nocek and Tamminga (1991), dietary corn malt saccharification tended to improve the ability of feed digestion in beef heifers. They reported that germination of the corn grain during the malting process enhanced the surface softness of the corn kernel, making it more available for microbial attachment. This resulted in greater ruminal digestion of the corn malt due to its high digestibility.

These improvements in nutritional composition highlighted the potential of fermented CH and CM as effective feed components. The enhanced CP levels and energy density of the TMT diets likely contributed to the improved growth performance observed in the fattening goats fed diets with higher proportions of CM. This supported fermentation technology as a valuable tool for upgrading agricultural by-products into nutritionally viable feedstuffs for ruminants.

Body weight gain and performance measurement

The growth performance of goats under the five dietary treatments is summarized in Table 3. There were significant differences among the treatments for BWG, ADG and FI. Goats fed the TMR diets containing the CM-based concentrate (T2–T5) had higher values of BWG, ADG and FI than those fed the CG-based diet (T1). Notably, the TMR diet with the highest CM inclusion (T5) resulted in the greatest values for BWG (12.97 kg), ADG (0.21 kg/day) and FI (1.38 kg/day).

No significant differences were observed in the FCR values among the treatments. However, the improved values for BWG and ADG observed in the TMR diets containing CM suggested that the CM enhanced feed palatability and nutrient utilization. The results indicated a linear improvement in growth performance with increasing CM inclusion, particularly in the T4 and T5 diets, underscoring the effectiveness of CM in enhancing feed intake and growth efficiency.

Table 3 Effects of treatments on growth performance of fattening goats

Item	Treatment					SEM	p value		
	T1	T2	T3	T4	T5		A	B	C
BW initial (kg)	14.49	15.42	12.47	12.85	16.03	0.61	0.49	0.69	0.40
BW final (kg)	20.67	23.33	21.33	22.33	29.00	1.29	0.20	0.25	0.63
BW gain (kg)	6.18 ^d	7.91 ^c	8.86 ^{bc}	9.48 ^b	12.97 ^a	0.16	<0.01	0.01	<0.01
ADG (kg/d/head)	0.12 ^c	0.16 ^d	0.19 ^c	0.20 ^b	0.21 ^a	0.01	0.07	<0.01	<0.01
FCR	1.74	1.85	1.91	1.50	1.46	0.29	0.25	0.33	0.33
FI (kg/d)	0.91 ^c	1.12 ^{bc}	1.18 ^{ab}	1.31 ^a	1.38 ^a	0.30	<0.01	0.06	0.07

BW initial = body weight at start of the study; BW final = body weight at end of study; BW gain = BW final – BW initial; ADG = average daily gain; FCR = feed conversion ratio; FI = feed intake; SEM = standard error of mean.

Values within same row with different lowercase superscripts indicate significant ($p < 0.01$) differences.

Statistical contrast: A = T1, T2, T3, T4, T5; B = T1 versus T2; C = T2, T3, T4, T5.

T1 = 50% corn grain concentrate diet 50% fermented corn husk (50% CG + 50% CH);

T2 = 50% corn malt concentrate diet 50% fermented corn husk (50% CM + 50% CH);

T3 = 60% corn malt concentrate diet 40% fermented corn husk (60% CM + 40% CH);

T4 = 70% corn malt concentrate diet 30% fermented corn husk (70% CM + 30% CH);

T5 = 80% corn malt concentrate diet 20% fermented corn husk (80% CM + 20% CH).

The superior performance of the CM-based diets could be attributed to the improved digestibility and nutrient availability of the CM. The malting process modifies the corn's nutritional profile by forming a thick protein coating, which slows digestion and improves rumen fermentation (Srakaew et al., 2021). Additionally, fermentation with microorganisms enhances feed palatability, making it more attractive to goats (Irwansyah and Junaedi, 2023). During malting, starch is converted into sugars and the addition of enzymes, such as amylase, facilitates faster feed digestion, encouraging higher intake and nutrient absorption (Wanapat and Pimpa, 1999)

Adding ensiled corn malt to the diet tended to improve feed digestibility in beef heifers, possibly because the germination and softening of the kernel's surface of the corn during the process of malting made it more accessible for microbial attachment, leading to greater ruminal digestion (Nocek and Tamminga, 1991). Compared to intact corn grain, corn malt-sactic is more digestible because the structure of the starch granules and of the seed surface are changed when the grains are exposed to moisture and microbial activity during the ensiled

time (Srakaew et al., 2021). According to Bugoni et al. (2022), dietary dry malt extract increased the apparent digestibility of dry matter and crude protein in lactating dairy cows.

These findings suggested that the CM-based TMR diets were a viable strategy for improving growth performance in fattening goats, particularly in tropical farming systems. However, further research is recommended to validate these results in other ruminant species and under varying environmental and management conditions. The development of CM-based feeds represents a promising approach to enhancing livestock production by transforming hard corn into a nutritionally superior and palatable feed ingredient.

Rumen fermentation products

There were no significant differences in the rumen pH values measured from 0 hr to 4 hr post-feeding among the five dietary treatments (Table 4). Both the CG- and CM-based TMR diets with fermented CH maintained the rumen pH within the optimal range (6.5–7.0), as reported by McNiven et al. (1995).

Table 4 Effects of treatment diets on ruminal production and blood metabolites in fattening goats

Item	Treatment					SEM	p value		
	T1	T2	T3	T4	T5		A	B	C
Ruminal pH									
0 hr post-feeding	6.68	6.77	6.75	6.70	6.72	0.11	0.49	0.64	0.52
4 hr post-feeding	6.56	6.61	6.57	6.60	6.59	0.06	0.53	0.40	0.38
NH ₃ -N (mg/dL)									
0 hr post-feeding	15.10	15.50	15.60	15.30	16.10	0.29	0.61	0.15	0.53
4 hr post-feeding	18.10	17.80	18.60	18.30	18.20	1.64	0.66	0.29	0.72
Ruminal VFA (mol/100 mol)									
Acetate (C2)									
0 hr post-feeding	70.00	69.40	68.20	69.90	68.0	1.14	0.71	0.41	0.44
4 hr post-feeding	69.60	69.00	70.60	70.10	71.70	1.89	0.15	0.10	0.41
Propionate (C3)									
0 hr post-feeding	18.41	17.92	19.11	18.51	18.91	0.87	0.53	0.63	0.37
4 hr post-feeding	19.60	18.90	20.30	20.60	20.5	1.10	0.12	0.13	0.57
Butyrate (C4)									
0 hr post-feeding	11.62	12.71	12.73	11.71	12.61	0.54	0.54	0.45	0.50
4 hr post-feeding	10.50	11.80	8.89	9.02	8.99	0.44	0.09	0.56	0.63
C2:C3									
0 hr post-feeding	3.79	3.86	3.66	3.78	3.65	0.36	0.19	0.18	0.59
4 hr post-feeding	3.52	3.62	3.36	3.29	3.45	0.06	0.09	0.08	0.69

C2 = acetate; C3 = propionate; C4 = butyrate; BUN = blood urea nitrogen; SEM = standard error of the mean.

Statistical contrast: A = T1, T2, T3, T4, T5; B = T1 versus T2; C = T2, T3, T4, T5.

T1 = 50% corn grain concentrate diet 50% fermented corn husk (50% CG + 50% CH).

T2 = 50% corn malt concentrate diet 50% fermented corn husk (50% CM + 50% CH).

T3 = 60% corn malt concentrate diet 40% fermented corn husk (60% CM + 40% CH).

T4 = 70% corn malt concentrate diet 30% fermented corn husk (70% CM + 30% CH).

T5 = 80% corn malt concentrate diet 20% fermented corn husk (80% CM + 20% CH).

None of the treatments caused the pH to drop below 5.8, indicating an absence of an acidic condition. The observed pH range was considered suitable for microbial fermentation, as it provided an environment conducive to optimal microbial activity and digestion (Huntington, 1997). High-roughage diets, such as those in the current study, are known to stimulate chewing activity and saliva secretion, which help regulate rumen pH (Jiang et al., 2017).

No significant differences were observed in the total VFA concentrations or in the individual proportions of acetate (C2), propionate (C3) and butyrate (C4) across treatments (Table 4). Additionally, the C2-to-C3 ratio remained consistent among the groups, aligning with the typical ratio of 70:20:10 reported by Wanapat (2000). The uniformity in the VFA profiles could be attributed to the consistent source of roughage (CH) across all diets. While the total VFA showed a tendency to be higher in the CM-based diets 4 hr post-feeding, this trend was not statistically significant.

The ammonia-nitrogen ($\text{NH}_3\text{-N}$) concentrations across treatments remained within the optimal range of 15–30 mg/dL, which is sufficient for supporting microbial protein synthesis and enhancing forage digestibility (Wanapat and Pimpa, 1999). Similarly, the BUN levels were within the standard range (11.2–27.7 mg/dL), as reported by Wanapat (2000). Although no significant differences in $\text{NH}_3\text{-N}$ and BUN were observed among treatments, a trend toward higher levels was noted in

the CM-based diets, particularly in T5. This increase may reflect the improved protein quality and digestibility of CM. Wanapat (2000) reported that BUN levels are known to correlate with the dietary protein content and $\text{NH}_3\text{-N}$ concentrations.

These findings indicated that the inclusion of CM in the TMR diets did not adversely affect the measured rumen fermentation parameters or blood metabolite profiles. The stability of the rumen pH, VFA, $\text{NH}_3\text{-N}$ and BUN levels across treatments highlighted the suitability of CM-based diets for fattening goats. Furthermore, these results suggested that CM supported microbial fermentation and nutrient utilization without compromising rumen health. While there have only been limited published reports on *in vitro* research regarding CM's effects on rumen fermentation, the current study provided valuable *in vivo* evidence supporting its use in goat diets. Future studies should explore CM's effects on other ruminant species to further validate its potential as a sustainable feed ingredient.

Blood glucose and insulin

During the 0–4 hr feeding interval, no significant differences were observed in the blood glucose and insulin concentrations among the dietary treatments, except for blood glucose at 4 hours post-feeding ($p < 0.01$), as shown in Table 5.

Table 5 Effects of dietary corn malt with fermented corn husk, yeast and lactic acid on blood metabolites in fattening goats

Item	Treatment					SEM	<i>p</i> value		
	T1	T2	T3	T4	T5		A	B	C
BUN (mg/dL)									
0 hr post-feeding	10.70	11.70	12.00	12.30	12.70	0.30	0.90	0.60	0.70
4 hr post-feeding	10.75	12.33	13.33	14.00	14.07	0.54	0.08	0.20	0.15
Glucose (mg%)									
0 hr post-feeding	54.30	55.30	58.00	60.80	72.10	1.50	0.05	0.90	0.10
4 hr post-feeding	66.33 ^c	68.00 ^b	70.67 ^b	72.33 ^{ab}	77.00 ^a	0.62	0.01	0.48	0.01
Insulin (μIU/mL)									
0 hr post-feeding	10.30	11.70	12.10	12.30	12.70	0.35	0.90	0.60	0.70
4 hr post-feeding	14.50	15.33	15.40	15.70	15.85	0.09	0.07	0.25	0.19

BUN = blood urea nitrogen; SEM = standard error of the mean.

Mean values within same row with different lowercase superscripts (^{a,b,c}) are significantly ($p < 0.01$) different.

Statistical contrast: A = T1, T2, T3, T4, T5; B = T1 versus T2; C = T2, T3, T4, T5.

T1 = 50% corn grain concentrate diet 50% fermented corn husk (50% CG + 50% CH).

T2 = 50% corn malt concentrate diet 50% fermented corn husk (50% CM + 50% CH).

T3 = 60% corn malt concentrate diet 40% fermented corn husk (60% CM + 40% CH).

T4 = 70% corn malt concentrate diet 30% fermented corn husk (70% CM + 30% CH).

T5 = 80% corn malt concentrate diet 20% fermented corn husk (80% CM + 20% CH).

The blood glucose levels before feeding were significantly lower than those measured 4 hr post-feeding across all treatments. At 4 hr post-feeding, the highest blood glucose level was in the goats fed T5 (80% CM + 20% CH), while the lowest was observed in T1 (50% CG + 50% CH). Diets containing CM concentrate (T2–T5) consistently had higher blood glucose levels than the CG-based diet (T1).

The observed increase in blood glucose in the CM-fed goats suggested improved nutrient digestibility and glucose absorption, as CM undergoes enzymatic modification during malting, converting starch into simpler sugars (Srakaew et al., 2021). Enhanced glucose uptake was likely responsible for the superior growth performance (BWG and ADG) observed in the goats fed the CM-based diets. Lehninger et al. (2017) proposed that increased glucose absorption by intestinal epithelial cells contributed to improved nutrient utilization, which aligned with these findings from the current study. Furthermore, Wasserman (2009) noted that blood glucose levels are typically lowest before morning feeding and increase incrementally over the next 1–2 hr, a pattern consistent with the current results. Notably, all the blood glucose levels remained within the normal range for goats (45–75 mg/dL), as reported by Kaneko (1980), indicating that the diets were metabolically safe.

Despite the rise in blood glucose, there were no significant differences in the insulin levels among treatments (Table 5). Although there was a slight increase in the insulin levels in the CM-fed goats, these differences were not statistically significant. The regulatory mechanisms of metabolic hormones may explain this stability, as insulin is responsible for managing glucose storage in skeletal muscle and liver cells in the form of glycogen (Lehninger et al., 2017). This suggested that while glucose utilization was enhanced in the CM-fed goats, insulin homeostasis was maintained across all diets.

The CM-based TMR diets, particularly T5 (80% CM + 20% CH), showed potential to enhance glucose availability and growth performance in fattening goats. The increased blood glucose levels observed in the CM-fed goats reflected the improved digestibility and energy availability provided by the CM, which likely contributed to the superior BWG and ADG results. Additionally, the malting process used to produce CM not only to enhance starch digestibility but also to improve feed palatability, further supporting increased feed intake and growth performance.

While the current results underscored the potential benefits of CM in goat diets, there were some limitations in the current study, such as the small sample size, variability in environmental conditions and differences in feed sources, which should be considered when interpreting these findings. Further research is warranted to validate these results in larger populations and under diverse management systems. In addition, the utility of CM in sustainable livestock production could be broadened through the application of CM-based diets in other ruminant species.

Conclusions

TMR diets with CM-based concentrates and fermented CH were effective and nutritionally suitable for fattening goats. All the investigated treatments maintained the measured rumen fermentation parameters (pH, VFA, $\text{NH}_3\text{-N}$ and BUN) within normal ranges. At the same time, the CM-based diets significantly improved blood glucose, BUN, feed intake, BWG and ADG compared to the CG-based diets. The T5 diet (80% CM + 20% CH) was identified as the optimal formula, delivering the best growth performance. These results highlighted the potential of CM as a cost-effective and sustainable feed ingredient for small ruminants. However, further research is needed to validate its application in other ruminant species and varying conditions.

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Conflict of Interest

The authors declare that there are no conflicts of interest.

References

- Bourapa, R., Kuha, K., Sintala, K., Srakaew, W., Supphakitchanon, T. 2021. Effect of modified grain corn using different processing as energy source in total mixed ratio on rumen fluid degradability and metabolizable energy using *in vitro* gas production technique. *Khon Kaen Agr. J.* 49: 1080–1091. [in Thai]
- Boarapa, R., Chaiwong, S., Kuha, K., Sintala, K., Wachirapakorn, C., Wongnen, C., Srakaew, W. 2023. Effects of dietary corn malt-sactic mixed concentrate with rice straw and corn husk on rumen fermentation, nutrient digestibility, blood metabolites and growth performance in growing beef heifers. *Trends Sci.* 21: 7060. doi.org/10.48048/tis.2023.7060
- Bremner, J.M., Keeney, D.R. 1965. Steam distillation methods of determination of ammonium, nitrate and nitrite. *Anal. Chem. Acta.* 32: 218–225. doi.org/10.1016/S0003-2670(00)88973-4
- Bugoni, M., Takiya, C.S., Nathalia, S.G., Nunes, A.T., Júnior, PCV., Chesini, RG., Silva, GGD., Alcantara, LVBD., Rennó, LN., Rennó, FP. 2022. Dry malt extract from barley partially replacing ground corn in diets of dairy cows: Nutrient digestibility, ruminal fermentation, and milk composition. *J. Dairy Sci.* 105: 5714–22. doi.org/10.3168/jds.2021-21682
- Bureenok, S., Tamaki, M., Kawamoto, Y., Nakada, T. 2007. Additive effects of green tea on fermented juice of the epiphytic lactic acid bacteria (FJLB) and the fermentative quality of Rhodes grass fermented. *Asian-Aust. J. of Anim. Sci.* 20: 920–924. doi.org/10.5713/ajas.2007.920
- Chaiwong, S., Yakab, M., Kanthiya, N., Nopparatmaitree, M., Sintala, K., Kullama, P., Boarapa, R., Srakaew, W. 2023. Effects of dietary corn malt-sactic on growth performance, nutrient digestibility and microbial population in posterior gut of broilers. *Khon Kaen Agr. J.* 51: 547–560. doi.org/10.14456/kaj.2023.42. [in Thai]
- Crocker, C.L. 1967. Rapid determination of urea nitrogen in serum or plasma without deproteinization. *Am. J. Med. Technol.* 33: 361–365.
- Foiklang, S., Wanapat, M., Opatpatanakit, Y., Paserakung, A. 2016. Effect of yeast fermented and physical forms of corn husk on digestibility and fermentation by using *in vitro* gas techniques. In: *Proceedings of the 17th Asian-Australasian Association of Animal Production Societies Animal Science Congress*. Fukuoka, Japan, pp. 555–558.
- Huntington, G.B. 1997. Starch utilization by ruminants: From basics to the bunk. *J. Anim. Sci.* 75: 852–867. doi.org/10.2527/1997.753852x
- Irwansyah, I.P., Junaedi, I. 2023. Effect of Adding Feed Fermentation of Sago Pulp on The Palatability of The Peranakan Etawa. *Chalaza J. of Animal Husbandry.* 4: 24–29. doi.org/10.31327/chalaza.v4i1.934
- Jiang, F.G., Lin, X.Y., Yan, Z.G., Hu, Z.Y., Liu, G.M., Sun, Y.D., Liu, X.W., Wang, Z.H. 2017. Effect of dietary roughage level on chewing activity, ruminal pH, and saliva secretion in lactating Holstein cows. *Dairy Sci.* 100: 2660–2671. doi.org/10.3168/jds.2016-11559
- Kaneko, J.J. 1980. *Carbohydrate Metabolism and Its Disorders: Clinical Biochemistry of Domestic Animals*, 3rd ed. Academic Press, New York, NY, USA.
- Koluman, N. 2023. Goats and their role in climate change. *Small Ruminant Research.* 4: 1–5. doi.org/10.1016/j.smallrumres.2023.107094
- Lehninger, A., Nelson, D., Cox, M. 2017. *Lehninger Principles of Biochemistry*, 7th ed. Macmillan Higher Education. New York, NY, USA.
- Murillo, M.M.S., Chinchilla, F.G. 2018. Total starch in animal feeds and fermented based on the chromatographic determination of glucose. *MethodsX.* 5: 83–89. doi.org/10.1016/j.mex.2018.01.009
- Mathew, S., Sagathevan, S., Thomas, J., Mathen, G. 1997. An HPLC method for estimation of volatile fatty acids of ruminal fluid. *Indian J. Anim. Sci.* 67: 805–807.
- McNiven, M.A., Weisbjerg, M.R., Hvelplund, T. 1995. Influence of roasting or sodium hydroxide treatment of barley on digestion in lactating cows. *J. Dairy Sci.* 78: 1106–1115. doi.org/10.3168/jds.s0022-0302(95)76727-3
- Nocek, J.E., Tamminga, S. 1991. Site and digestion of starch in the gastrointestinal tract of dairy cows and its effect on milk yield and composition. *J. Dairy Sci.* 74: 3598–3629. doi.org/10.3168/jds.S0022-0302(91)78552-4
- Pilachai, R., Schonewille, J.Th., Thamrongyoswittayakul, C., Aiumlamai, S., Wachirapakorn, C., Everts, H., Hendriks, W.H. 2012. The effects of high levels of rumen degradable protein on rumen pH and histamine concentrations in dairy cows. *J. Anim. Physiol. Anim. Nutr.* 96: 206–213. doi.org/10.1111/j.1439-0396.2011.01139.x
- Sommart, K., Wanapat, M., Parke, D.S., Rowlinson, P. 2021. Cassava chip as an energy source for lactating dairy cows fed rice straw. In: *Proceedings of the British Society of Animal Science*. Cambridge University Press. Cambridge, UK, pp. 98–98.
- Srakaew, W., Wachirapakorn, C., Wongnen, C. 2021. Dietary modified cassava chip and corn seed: Effect on growth performance, rumen production, and blood glucose and insulin in early fattening beef bulls. *Walailak J. Sci. Technol.* 18: 9217–9229. doi.org/10.48048/wjst.2021.9217
- Srakaew, W., Leepradit, P., Chaiwong, S., Boarapa R., Sintala, K., Kuha, K. 2021. Ensiling corn malt on chemical composition and gas production kinetic by using *in vitro* gas production technique. *Khon Kaen Agr. J.* 48: 496–501. [in Thai]
- Steel, R.G., Torrie, J. 1980. *Principles and Procedures of Statistics: A Biometrical Approach*. McGraw-Hill Book Company. New York, NY, USA.
- Thongnum, A., Khongphetsak, P., Sarkaew, W., Poojit, S., Potirahong, S., Wachirapakorn, C. 2018. Effects of fiber feed improvement with urea on chemical composition and kinetic ruminal gas production of both rice straw and sugar cane top. *J. Agr. Res. Ext.* 35: 126–134.
- Van Soest, P.J., Robertson, J.B., Lewis, B.A. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.* 74: 3583–3597. doi.org/10.3168/jds.S0022-0302(91)78551-2

- Wanapat, M., Pimpa, O., Sommart, K., Uriyapongson, S., Toburan, W., Parker, D., Rowlinson, P. 1995. Effects of energy sources on rumen fermentation, degradability and rice straw intake in swamp buffaloes. In: Proceedings of International Workshop on Draft Animal Power to Increase Farming Efficiency and Sustainability. Khon Kaen, Thailand.
- Wanapat, M., Pimpa, O. 1999. Effect of ruminal $\text{NH}_3\text{-N}$ levels on ruminal fermentation, purine derivatives, digestibility and rice straw intake in swamp buffaloes. *Asian-Aust J. Anim. Sci.* 12: 904–907. doi.org/10.5713/ajas.1999.904
- Wanapat, M. 2000. Rumen manipulation to increase the efficient use of local feed resources and productivity of ruminants in the tropics. *Asian-Aus. J. Anim. Sci.* 13: 59–67.
- Wasserman, D.H. 2009. Four grams of glucose. *Am. J. Physiol. Endocrinol. Metab.* 296: E11–E21. doi.org/10.1152/ajpendo.90563.2008
- Zhao, X., Wang, Y. Gu, Q., Li, W. 2010. Effect of dietary probiotic, *Bacillus coagulans*, on growth performance, chemical composition, and meat quality of Guangxi Yellow chicken. *J. Poult. Sci.* 89: 588–593. doi.org/10.3382/ps.2009-00319