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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

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Abstract

The enhancement of protein content in grains is interesting because starch is the main energy component used in beef cattle feeds. Corn malt-sactic is a modified corn grain with increase protein content and improve digestibility through the process of malt germination and microbial fermentation. Therefore, the effects of feeding malt-sactic from corn grain as a high protein energy source in diet were investigated on rumen fermentation, nutrient digestibility, blood metabolites, and growth performance in beef heifers. Sixteen of 1-year-old Brahman crossbred growing beef heifers with an initial weight of 220 ± 24.5 kg were randomly assigned into 4 different rations according to completely randomized design (CRD). Experimental treatments were corn grain or corn malt-sactic mixed concentrates with roughage sources as follow, T1; corn grain mixed concentrate with corn husk, T2; con grain mixed concentrate with rice straw, T3; malt-sactic mixed concentrate with corn husk, and T4; corn malt-sactic mixed concentrate with rice straw. The results showed that total feed intake and digestibility of dry matter, crude protein, NDF and ADF were significantly higher in the heifers fed corn malt-sactic mixed concentrate diet than corn mixed concentrate diet ($p < 0.05$). Ruminal pH post-feeding, blood urea nitrogen, and blood glucose were not different among treatments ($p > 0.05$). Body weight gain and average daily gain were significantly higher ($p < 0.05$), while feed conversion ratio was lower in corn malt-sactic mixed concentrate diet as compared with corn mixed concentrate diet ($p < 0.05$). The source of roughage did not affect rumen fermentation, nutrient digestibility, blood metabolites, or growth performance ($p > 0.05$). Results indicated that using corn malt-sactic as an ingredient in beef heifer diets can improve digestibility and growth performance.

Keywords: Corn malt-sactic, Rice straw, Corn husk, Growth performance, Beef heifers

Introduction

In Thailand, beef cattle are one of the most economically important animals and are expanding rapidly due to the government's various policies (2011 - 2015) to develop a new beef breed for increasing production performance. The indigenous cattle and their crossbred with the Brahman breed distributed more than 60 % of Thailand's total beef cattle population [1]. The crossing breed between indigenous breeds and Brahman breeds showed higher growth performance and mature body size than uncrossing native breeds. The high-performance cattle required a high protein and energy diet to meet the requirements. However, the situation of protein and energy feed ingredients has increased in price, which is reason enough to raise animal feed prices and limit usage.

There are alternative protein and energy sources that are required. The enhancement of protein content in grains is interesting because starch is the main energy component used in beef cattle feeds [2]. Corn grain is one of the starch sources that is typically used in the diet in a high ratio [3]. However, it has low ruminal solubility at 40 - 60 % [4], and limited protein content at approximately 7 - 8 % of dry matter [5]. An excess of corn grain in the diet causes low starch digestibility, and cattle receive less energy and protein than expected. Therefore, enhancement of protein content and digestibility is a primary target for improving grain quality and has attracted the attention of researchers to develop processing methods.

According to Srakaew *et al.* [6], corn malt-sactic is corn grain that has undergone a modified process for malt germination combined with a fermentation process with mixed microbial juice containing yeast juice and lactic acid bacteria juice. Its main objective is to increase protein content and improve the utilization efficiency of corn grain through the process of malt germination and microbial fermentation. Boarapa *et al.* [7]. Reported that corn seed germination transforms starch into sugar and increases protein content, the protein content of corn malt increased from 7.0 - 8.0 to 10.0 - 12.0 % compared with non-germinated corn seed. Ensiling corn malt with yeast and lactic acid bacteria increased crude protein content by approximately 14 - 15 % and increased dry matter digestibility. According to the *in vitr*o study of cattle diet containing 5 - 15 % of corn malt-sactic increased cumulative gas production and dry matter digestibility by *in vitro* gas production technique [8]. Chaiwong *et al.* [9], indicated that adding corn malt-sactic at 5 - 15 % in broiler diet positively affected intake, digestibility and growth performance. These are the satisfied results on *in vitro* digestibility in beef cattle and growth performance in broilers when interlaced corn malt-sactic in the diet. However, an *in vivo* study in growing beef cattle, including rumen fermentation, blood metabolites, and growth performance, is required to elucidate these results further. Therefore, the effects of corn malt-sactic in the diet were determined for production performance in growing beef heifers as the aim of the current study.

Materials and methods

Animal ethics

The experimental procedure was approved by the Animal Ethics Committee of Institutional Animal Care and Use for Animal Research (IACUC) of Science research of Rajamangala University of Technology Lanna (RMUTL) with comply with the standard of animal care and use established under the ethical guidelines and policies of Office of the National Research Council of Thailand (NRCT). Approval No. RMUTL-IACUC 003/2022.

Animal and experimental design

Sixteen head 1-year-old of Thai x Brahman crossbred beef heifers with an average initial body weight (BW) of 220 ± 24.5 kg (mean ± SD) were housed individually in a 2×2.5 m^2 concrete-floor pens with open-air ventilation. Commercial vitamin was injected with a dosage (3 mL/head) of a multiple vitamin (AD_3E), internal and external parasites were dewormed with IVERMECTIN$^{@}$ (2.5 mL/heads) and the Foot-and-mouth disease (FMD) was vaccinated (2.0 mL/head) before entering to a 14 days of adaptation period to experimental pens. The animals received 3 step-up diets containing increasing levels of concentrate, and to a 90-day feeding trial period. The animals were randomly assigned to one of 4 experimental rations according to completely randomized design (CRD). Experimental feeds were offered to all heifers twice daily with drinking water ad libitum.

Preparation of corn malt-sactic

Corn malt-sactic is corn grains that have undergone a modified process to corn malt combine with a process of microbial fermentation with yeast and lactic acid bacteria according to Srakaew *et al.* [7]. The process was started from preparing corn malt by soaking 30 kg of corn grain in water for 5 h as a ratio 3:1 (corn grain: Water by fresh weight). Then pour out all the water before incubated soaked corn grain in a holes ventilation basket in which covered by wet cloth for 3 - 5 days (saw a sprouted corn grains). The sprouted corn grains were fermented with mixed microbial juices including yeast and lactic bacteria juices. The yeast juice was prepared by using yeast powder (*Saccharomyces cerevisiae*) according to the method of Thongnum *et al.* [10]. Lactic acid bacteria juice was prepared by grinding 200 g of fresh Napier grass then mixed with 1 liter of water, after that filter only the water and added 20 g of sugar before incubated in hot air oven at 39 °C for 3 days according to the method of Bureenok *et al.* [11]. The quantitative of yeast and lactic acid bacteria was performed with an average number totally 6.90×10^7 CFU/mL and 2.02×10^8 CFU/mL, respectively. When corn malt-sactic ingredients were obtained, the sprouted corn grains as fresh basis were mixed with 1 % (v/w) of yeast juices and 1 % (v/w) of lactic acid bacteria juice before being fermented in fermentation tanks under anaerobic conditions for 14 days. After that, the fermented sprouted corn grains were spread on a carpet in natural sun conditions until the moisture content of sample was less than 13% then grounded pass through a 4 mm sieve screen before mixing in the concentrate.

Treatment and animal feeding

All the concentrate were formulated with a similar level of nutritive contents approximately 16 % of crude protein and 2.70 Mcal ME/kg DM of metabolizable energy (**Tables 1** and **2**). Experimental feeds were offered to the heifers as a separate feeding twice daily (08.00 AM. and 05.00 PM.). The heifers received the concentrate at 1.5 % of body weight (BW). Rice straw or corn husk as roughage was provided *ad libitum*. The concentrate was formulated using the ingredients as shown in **Table 1**. Experimental treatments were corn grain or corn malt-sactic mixed concentrates with roughage sources as follow, T1; corn grain mixed concentrate with corn husk, T2; con grain mixed concentrate with rice straw, T3; malt-sactic mixed concentrate with corn husk, and T4; corn malt-sactic mixed concentrate with rice straw.

Table 1 Percentage of feed ingredients of experimental concentrates.

Items	Corn mixed concentrate	Malt-sactic mixed concentrate
	kg/100 kg	
Cassava chip	45.0	45.0
Ground corn	15.0	2.00
Ground malt-sactic	0.00	15.0
Rice brand	8.50	8.50
Soybean meal	13.0	11.0
Palm kernel meal	13.0	13.0
Salt	0.40	0.40
Dicalcium phosphate	1.50	1.50
Premixed	0.50	0.50
Sulfur	0.30	0.30
Molasses	1.30	1.50
Urea	1.50	1.30
Total	100.0	100.0

Table 2 Chemical composition of experimental diets.

Items	Corn mixed concentrate	Malt-sactic mixed concentrate	Malt-sactic	Corn husk	Rice straw
Dry matter, %	91.2	91.4	90.4	90.6	89.7
	----------------------------% of dry matter-------------------------------------				
Organic matter	93.4	93.7	96.7	84.8	88.2
Crude protein	16.3	16.4	14.1	3.94	3.30
Ether extract	4.37	4.29	6.56	1.62	0.90
Crude fiber	10.6	10.9	2.41	38.3	45.1
NFE	62.2	62.1	73.6	40.9	38.8
NDF	38.1	37.2	21.3	68.4	81.1
ADF	14.5	12.9	9.52	38.5	57.7
Ash	6.57	6.31	3.34	15.2	11.8
ME[1], Mcal/kgDM	2.66	2.65	2.95	1.90	1.86

NFE = nitrogen free extract, NDF = neutral detergent fiber, ADF = acid detergent fiber

[1]Calculated according to Harris *et al.* [12]

ME in Mcal/kg = DE (Mcal/kg)×0.82

DE is using the factor of 4.41 Mcal/kg TDN

for concentrate TDN (% of DM) = 40.2625+0.1969(%CP)+0.4228(%NFE)+1.1903(%EE)−0.1379(%CF)

for roughage TDN (% of DM) = −7.2649+1.2120(%CP)+0.8352(%NFE)+2.4637(%EE)+0.4475(%CF)

Body weight gain and performance measurement

After 14 days of the adaptation period the animals were weighed in the early morning before first feeding at the beginning date and every 30 days of the experimental period. Body weight (BW) gain and average daily gain (ADG) was calculated by the difference between final weight and initial weight divided by number of days on feeds. Feeding volume was adjusted monthly according to body weight for use as a concentrate feeding guideline for the beef heifers. Feeding volume and feed refusal were recorded at 8:00 AM. daily to calculate individual feed intake during the experimental period. The concentrate and roughage intake were calculated as the difference between the offered amount and the weight of orts left collected before the morning feeding. The roughage and concentrate were offered in different containers.

Sample collection and analysis

Experimental concentrate diets, corn husk and rice straw were sampled every 15 days. Fecal samples were collected by rectal sampling during the last 7 days of the experimental period. Samples of diets, corn husk, rice straw and feces of each collection time were pooled and oven-dried at 60 °C for 72 h before being analyzed for dry matter (DM; methods 967.03), ash (method 942.05), ether extracts (method 920.39), and crude protein (CP; method 984.13) contents [18], Next fiber fractions including neutral detergent fiber (NDF), and acid detergent fiber (ADF) were analyzed following the method described by Van Soest *et al.* [19]. Acid insoluble ash (AIA) was analyzed from ash according to the method proposed by Van Keulen and Young [13], and was used as an indicating marker to calculate the apparent digestibility of nutrients.

On the last day of the experimental period, rumen fluid and jugular blood samples were collected at 0 and 4 h post-morning feeding. Ruminal fluid samples (approximately 500 mL) were collected by a stomach tube according to the method of Klopp *et al.* [14]. The pH of the ruminal fluid was immediately measured using a portable pH meter. Samples of rumen fluid were filtered through 4 layers of cheesecloth and then 100 mL of filtrated rumen fluid was mixed with 10 mL of 50 % sulfuric acid (H_2SO_4) solution and used for ammonia-nitrogen (NH_3-N) and volatile fatty acid (VFA) analyses. The mixed sample was centrifuged at 16,000×g for 15 min and the supernatant was stored at −20 °C prior to NH_3-N measurement according to the method of Bremner and Keeney [15], and VFA analysis using HPLC (model RF-10AXmugiL; Shimadzu; Japan) [16]. Samples of blood were drawn from the jugular vein into 2 tubes (about 10 mL/tube). The first tube was separated by centrifugation at 500×g for 10 min and stored at −20 °C until analysis of blood urea nitrogen (BUN) according to the method of Crocker [17]. The second blood tube measured blood metabolites such as glucose and insulin at Thonburi Lab Center Co., Ltd.

Statistical analysis

All obtained data were subjected to the Analysis of Variance (ANOVA) procedures of SAS [18], according to a CRD design. Data were analyzed using the model; $Y_{ij} = \mu + M_i + \varepsilon_{ij}$, where Yij = observation from animal j, receiving diet i; μ = the overall of mean, Mi = the mean effect of treatment (i = 1,2,3,4), εij = the residual effect. The means of treatments were statistically compared using Duncan's New Multiple Range Test (DMRT) [19], at a significance level of $p < 0.05$.

Results and discussion

Feed intake and nutrient digestibility

The feed intake, apparent digestibility, and nutrient utilization of dietary treatments are presented in **Table 3**. No difference among dietary treatments was observed concerning concentrate, roughage, and feed intake, calculated as percent of body weight ($p > 0.05$). Total feed intake was increased in beef heifers fed a corn malt-sactic mixed concentrate ($p < 0.05$). However, roughage source had no effect on feed intake ($p > 0.05$). Total feed intake averaged 2.37 - 2.39 % BW and related to normal guidelines for feeding beef cattle weighing 250 - 350 kg as recommended average feed intake at 2.5 % BW [20]. Srakaew *et al.* [6], reported that beef cattle with an average body weight of 250 - 450 kg consumed diets at about 2.35 - 2.55 % BW. Apparent digestibility of DM, CP, and NDF was increased when dietary corn malt-sactic-based concentrate diets were fed to beef heifers ($p < 0.05$), while organic matter (OM), CP, EE, and ADF were not significantly different among treatments ($p > 0.05$).

All nutrient digestibility were not influenced by the source of roughage ($p > 0.05$). However, the apparent digestibility of DM, CP, and NDF was influenced by adding corn malt-sactic to diets. The heifers fed corn malt-sactic mixed concentrate diet showed higher digestibility of DM, CP, and NDF than the corn mixed concentrate diet ($p < 0.05$). From a satisfactory result, dietary corn malt-sactic had a tendency to improve the ability of feed digestion in beef heifers. Germination corn grain during the malting process, enhanced the surface softness of the corn kernel, made it available for microbial attachment, and resulted in greater ruminal digestion of corn malt due to its high digestibility [21]. Compared with intact corn grain, corn malt-sactic was more digestible due to changes in the structure of starch granules following exposure to a combination of moisture and microbial activity during the fermentation period. According to Bugoni *et al.* [22], who found that dietary dry malt extract increased the apparent digestibility of DM and CP, decreased ruminal pH, and increased the proportion of butyrate and acetate in lactating dairy cows. During the corn malt-sactic process, adding yeast and lactic acid bacteria with ensiling conditions, starch was released from binding components and extensively degraded by several starch-degrading enzymes into sugars that could be easily fermented [23]. In another way, the term of probiotics was defined as "a live microbial used for animals that incorporates *Lactobacillus*, *Bifidobacterium*, *Lactococcus*, *Bacillus*, *Streptococcus*, and yeast, such as *Candida* and *saccharomyces* [24]. The microbial cells from corn malt-sactic (yeast and lactic acid bacteria) added in feed that may beneficially affect the cattle upon ingestion by improving its intestinal microbial balance" and also beneficially affect a lower gut digestibility [25]. Factors such as strain and feeding duration may affect cattle's response to probiotics [26]. Based on this reason, corn malt-sactic was used as a probiotic and served to the cattle, resulting in an increase in living cell activity in the rumen of microorganisms, leading to a high ability of digestion. Lascano *et al.* [27], report that a diet with yeast culture increased dry matter digestibility in heifers. Haiyan *et al.* [28], found that the inclusion of lactic acid bacteria in ruminant diets has improved nutrients digestibility. The cows supplemented with *B. licheniformis* showed significant higher OM, CP, NDF, and ADF digestibility coefficients [29].

Nevertheless, digestible DM, CP, NDF, and ADF intake were increased ($p < 0.05$) and there was a tendency for high digestible OM intake (P = 0.09) in corn malt-sactic mixed concentrate diets (**Table 3**) ($p < 0.05$), while digestible EE intake was not significantly different among dietary treatments ($p > 0.05$). No influence by roughage source was observed in all digestible nutrient intake ($p > 0.05$). Higher digestible DM, CP, NDF, and ADF intakes were related to higher total feed intake and apparent digestibility of DM, CP, and NDF in beef heifers fed corn malt-sactic mixed concentrate diets. Due to an increase of feed intake, digestibility, and digestible nutrient intake, we discovered a high metabolizable energy intake in beef heifers fed corn malt-sactic mixed concentrate diets compared with corn mixed concentrate diets ($p < 0.05$) as shown in **Table 3**. The growth performance of beef heifers observed in this experiment met energy requirements for gain as reported by Br-Corte [30].

Table 3 Effects of dietary corn malt-sactic on voluntary feed intake and digestibility.

Items	Treatments				SEM	*p*-value	Contrast	
	T1	T2	T3	T4			C vs MS	RS:CH
Feed intake (kg, DM)								
Concentrate	3.85	3.78	4.05	4.02	0.331	0.244	0.142	0.437
Roughage	3.16	3.22	3.29	3.39	0.241	0.228	0.180	0.831
Total	7.01^{a}	7.00^{a}	7.37^{b}	7.41^{b}	0.073	0.036	0.049	0.418
% of BW	2.37	2.34	2.39	2.36	0.107	0.562	0.453	0.746
Apparent digestibility (%)								
DM	60.4^{a}	62.9^{ab}	65.6^{b}	66.6^{b}	1.045	0.049	0.033	0.303
OM	71.6	72.0	72.6	72.9	1.968	0.777	0.481	0.493
CP	68.8^{a}	68.1^{a}	70.8^{b}	70.6^{b}	0.530	0.047	0.049	0.631
EE	84.1	80.1	82.2	82.9	1.883	0.441	0.526	0.281
NDF	59.4^{a}	60.3^{a}	65.5^{b}	66.4^{b}	1.071	0.011	0.069	0.972
ADF	40.6	40.8	40.1	41.6	2.904	0.266	0.511	0.324

Items	Treatments				SEM	*p*-value	Contrast	
	T1	T2	T3	T4			C vs MS	RS:CH
Digestible nutrient intake (kg/day)								
DM	4.23[a]	4.40[a]	4.81[b]	4.93[b]	0.069	0.014	0.013	0.575
OM	4.71	4.72	4.84	4.90	0.123	0.093	0.077	0.641
CP	0.52[a]	0.51[a]	0.55[b]	0.54[b]	0.022	0.048	0.106	0.280
EE	0.17	0.17	0.16	0.17	0.060	0.292	0.093	0.841
NDF	2.17[a]	2.18[a]	2.73[b]	2.82[b]	0.116	0.010	0.065	0.245
ADF	0.72[a]	0.73[a]	0.97[b]	1.02[b]	0.034	0.009	0.581	0.427
Metabolizable energy intake, Mcal/d								
	16.3	16.3	16.9	16.9	0.399	0.084	0.030	0.401

[abc]Values in the same row with different superscripts differ ($p < 0.05$), SEM = standard error of the mean
T1 = corn grain mixed concentrate with corn husk, T2 = corn grain mixed concentrate with rice straw, T3 = corn malt-sactic mixed concentrate with corn husk, T4 = corn malt-sactic mixed concentrate with rice straw
DM = dry matter, OM = organic matter, CP = crude protein, EE = ether extract, NDF = neutral detergent fiber, ADF = acid detergent fiber

Rumen fermentation products

The pH values in the rumen of heifers did not differ ($p > 0.05$) among dietary treatments at 0 - 4 h post-feeding. The difference in roughage source with rice straw or corn husk did not influence on ruminal pH (**Table 4**). It is noteworthy that regardless of treatments, all heifers maintained a mean ruminal pH in the normal range of 6.5 - 7.0 and greater than 6.0, as they did not have a time period with a pH of 5.8, meaning that no acidotic conditions were present in the rumen [31]. Rumen pH ranged from 6.58 to 7.08, and in the normal range of rumen ecology (pH 6.2 - 7.0), it was reported as optimal for microbial fermentation [32].

Rumen fermentation end-products, including total VFAs, acetate (C2), propionate (C3), and butyrate (C4) concentrations, the C2:C3 ratio, rumen NH_3-N, and BUN, were not significantly different among dietary treatments ($p > 0.05$). However, at 4 h after feeding, the total VFAs showed a trend to be high in the corn malt-sactic mixed concentrate diets (P = 0.08). According to our observed data, although the C2:C3 ratio was not significantly different among treatments, the C2:C3 ratio at 4 h post-feeding showed a trend to be higher when beef heifers fed corn malt-sactic mixed concentrate diets (P = 0.09). The NH_3-N values in this experiment ranged in the optimal range (15 - 30 mg %) to support microbial protein synthesis and optimize ruminal feed digestibility [33]. In the same trial, there was no difference in total VFAs, C2, C3, and C4 concentrations, C2:C3 ratio, rumen NH_3-N, or BUN compared to rice straw and corn husk ($p > 0.05$). An increasing trend of total VFAs is related to a higher digestibility observed in heifers fed corn malt-sactic mixed concentrate diets compared with corn mixed concentrate diets.

Table 4 Effects of dietary corn malt-sactic on ruminal production and blood urea nitrogen.

Items	Treatments				SEM	*p*-value	Contrast	
	T1	T2	T3	T4			C vs MS	RS:CH
Ruminal fermentation products, 0 h post-feeding								
Rumen pH	6.78	6.87	6.85	6.80	0.211	0.585	0.740	0.621
Rumen NH_3, mg/dl	16.1	16.5	16.6	16.3	1.044	0.458	0.611	0.853
Ruminal VFA production, % of total								
C2	70.0	69.4	68.2	69.9	1.136	0.711	0.410	0.441
C3	18.4	17.9	19.1	18.5	0.866	0.533	0.625	0.370

Items	Treatments				SEM	*p*-value	Contrast	
	T1	T2	T3	T4			C vs MS	RS:CH
C4	11.6	12.7	12.7	11.7	0.544	0.535	0.451	0.503
C2:C3 ratio	3.79	3.86	3.66	3.78	0.358	0.191	0.180	0.590
Total, mg/100 mL	109.9	108.1	109.0	111.2	18.910	0.281	0.865	0.642
BUN, mg/dl	9.13	9.09	10.2	11.1	1.402	0.411	0.230	0.623
Ruminal fermentation products, 4 h post-feeding								
Rumen pH	6.56	6.61	6.57	6.60	0.064	0.532	0.401	0.375
Rumen NH_3, mg/dl	18.1	17.8	18.6	18.3	1.640	0.659	0.294	0.721
Ruminal VFA production, % of total								
C2	69.7	69.1	70.7	70.2	1.990	0.247	0.103	0.411
C3	19.7	19.0	20.4	20.7	1.203	0.218	0.133	0.574
C4	10.6	11.9	8.99	9.12	0.540	0.185	0.561	0.630
C2:C3 ratio	3.53	3.63	3.46	3.39	0.158	0.090	0.081	0.694
Total, mg/100 mL	120.4	118.5	129.4	131.2	6.777	0.080	0.069	0.542
BUN, mg/dl	11.3	12.0	12.3	12.1	0.795	0.411	0.679	0.662

[abc]Values in the same row with different superscripts differ ($p < 0.05$), SEM = standard error of the mean
T1 = corn grain mixed concentrate with corn husk, T2 = corn grain mixed concentrate with rice straw, T3 = corn malt-sactic mixed concentrate with corn husk, T4 = corn malt-sactic mixed concentrate with rice straw

Blood glucose and insulin

The glucose and insulin concentrations in the blood are shown in **Table 5**. At 0 - 4 h of feeding time, the concentration of blood glucose showed no statistically significant difference among dietary treatments ($p > 0.05$) and was not influenced by roughage source ($p > 0.05$). Monitoring of glucose levels in the blood before feeding showed a slightly lower glucose level than at 4 h post-feeding. According to Wasserman [34], the lowest glucose levels in the blood are found before the first feed in the morning of the day and, after that, rise every hour or 2 by a few millimoles. Glucose values in the blood of all dietary treatments were within the normal range of 45 to 75 mg/dl [35]. No significant difference in blood glucose is reasonable because glucose is regulated by metabolic hormones and stored as glycogen found in skeletal muscle and liver cells [36]. Hormone regulation is most important. There are 2 types of mutually antagonistic metabolic hormones affecting blood glucose levels: Catabolic hormones (such as glucagon, cortisol, and catecholamines), which increase blood glucose [37], and an anabolic hormone (insulin), which decreases blood glucose. Glucose levels in the blood are usually within the normal range. If glucose levels stray out of this range, the amounts of insulin and glucagon produced by the pancreas adjust to bring glucose levels back into normal range [38]. In this experiment, the blood insulin levels at 4 h after first feeding showed a tendency to be high in beef heifers fed corn malt-sactic mixed concentrate diet ($P = 0.09$). Two sources of roughage did not affect blood insulin ($p > 0.05$). Heifers fed corn malt-sactic mixed concentrate diet had trended to have higher insulin levels. In contrast, glucose levels strayed within the normal range, which led to a decrease in the ratio of glucose to insulin when compared to corn-mixed concentrate diet. These results indicated that the concentration of glucose absorbed across gut epithelial cells to the blood may increase in treatments of high blood insulin, but levels of glucose in the blood were not significantly different owing to homeostasis, which decreased blood glucose to bring glucose levels back into normal range by insulin [36]. Thus, increasing the insulin concentration in the blood may result in the heifers fed a corn malt-sactic mixed concentrate diet having more nutrient digestibility and increasing glucose absorbed into the blood [38].

Table 5 Effects of dietary corn malt-sactic on blood glucose and insulin.

Items	Treatments				SEM	*p*-value	Contrast	
	T1	T2	T3	T4			C vs MS	RS:CH
Blood glucose and insulin, 0 h post-feeding								
Glucose, mg/dL	70.2	69.4	70.7	70.5	1.551	0.677	0.390	0.471
Insulin, µIU/mL	10.3	9.91	9.85	10.5	1.442	0.364	0.779	0.822
Glucose-to-insulin ratio, mg/Dl to µIU/mL								
	6.82	6.99	7.00	7.05	0.213	0.611	0.690	0.775
Blood glucose and insulin, 4 h post-feeding								
Glucose, mg/dL	72.4	71.9	73.0	72.5	0.113	0.259	0.212	0.684
Insulin, µIU/mL	14.3	13.9	15.8	15.2	0.731	0.088	0.070	0.441
Glucose-to-insulin ratio, mg/Dl to µIU/mL								
	5.06^{b}	5.17^{b}	4.62^{a}	4.76^{a}	0.099	0.032	0.098	0.511

^{abc}Values in the same row with different superscripts differ ($p < 0.05$)., SEM = standard error of the mean T1 = corn grain mixed concentrate with corn husk, T2 = corn grain mixed concentrate with rice straw, T3 = corn malt-sactic mixed concentrate with corn husk, T4 = corn malt-sactic mixed concentrate with rice straw

Body weight changes and feed conversion ratio

The heifer growth performances during the experimental period are shown in **Table 6**. There were significant differences in growth performance among dietary treatments ($p < 0.05$). Still, they were not influenced by the roughage source found in this experiment ($p > 0.05$). Heifers receiving diets containing the corn malt-sactic mixed concentrate had higher BW gain and ADG than those in the corn-based concentrate ($p < 0.01$). The feed conversion ratio (FCR) exhibited a strong decrease when the heifers received corn malt-sactic mixed concentrate diet compared with corn mixed concentrate diet ($p < 0.05$). However, there was no significant difference in feed efficiency between the heifers fed corn malt-sactic mixed concentrate diet and corn mixed diet ($p > 0.05$). Concerning the nutrient requirements for the maintenance and BW gain of Brahman crossbred cattle based on the equation reported by WTSR [39]. The calculated energy and protein requirements related to BW gain and were significantly higher ($p < 0.01$) in the heifers fed corn malt sactic mixed concentrate diet than corn-mixed concentrate diet. According to energy and protein intake, those trends tend to be high (P = 0.09) and significantly higher ($p < 0.01$) in the heifers fed corn malt-sactic mixed concentrate diet than in the corn mixed concentrate diet, respectively. Heifers in the corn malt-sactic mixed concentrate diet had average energy and protein utilization efficiency of 92 and 108 % of the requirement, respectively. In contrast, the heifers fed with the corn-mixed concentrate diet had average energy and protein utilization efficiency of 88 and 103 % of the requirement, respectively. In this study, dietary corn malt-sactic affected high energy and protein utilization efficiency and related a high BW gain and ADG. Poolthajit *et al.* [40], recently reported that cattle with higher energy utilization efficiency had higher growth performance. According to the above, nutrient digestibility and digestible nutrient intake showed high levels when the heifers were fed corn malt-sactic mixed concentrate diet. As a result, using corn malt-sactic in the diet increased feed utilization efficiency and made more energy and protein available for production for the cattle.

Table 6 Effects of dietary corn malt-sactic on growth performance.

Items	Treatments				SEM	*p*-value	Contrast	
	T1	T2	T3	T4			C vs MS	RS:CH
Initial weight (kg)	228.6	232.8	230.3	230.8	-	-	-	-
Final weight (kg)	332.4	339.6	350.4	355.3	-	-	-	-
Weight gain (kg)	103.8[a]	106.8[a]	120.1[b]	124.5[b]	6.068	0.011	0.009	0.602
ADG (kg/day)	1.15[a]	1.19[a]	1.33[b]	1.38[b]	0.072	0.011	0.009	0.752
Feed conversion ratio, kg feed/kg gain								
	6.08[b]	5.90[b]	5.50[a]	5.36[a]	0.202	0.009	0.007	0.391
Feed efficiency, kg gain/kg feed								
	0.16	0.17	0.18	0.19	0.379	0.111	0.120	0.524
Nutrient utilization efficiency								
ME requirement [1/], Mcal/d								
	14.2[a]	14.5[a]	15.4[b]	15.7[b]	0.612	0.047	0.041	0.833
ME intake, Mcal/d	16.3	16.3	16.8	16.9	0.088	0.082	0.201	0.693
ME utilization efficiency [2/]								
	0.87[a]	0.89[a]	0.92[b]	0.93[b]	0.018	0.046	0.033	0.761
Protein requirement [1/], g/d								
	767.7[a]	782.0[a]	825.6[b]	841.0[b]	20.213	0.012	0.009	0.482
Protein intake, g/d	752.0[a]	746.7[a]	772.7[b]	771.1[b]	8.037	0.009	0.011	0.614
Protein utilization efficiency[2/]								
	1.02	1.04	1.07	1.09	0.082	0.093	0.108	0.782

[abc]Values in the same row with different superscripts differ ($p < 0.05$)., SEM = standard error of the mean
T1 = corn grain mixed concentrate with corn husk, T2 = corn grain mixed concentrate with rice straw, T3 = corn malt-sactic mixed concentrate with corn husk, T4 = corn malt-sactic mixed concentrate with rice straw
[1/] ME requirement (Mcal/d) = $(0.1162\times BW^{0.75})+((0.00039\times BW^{0.75})+(5.379\times ADG))$, where ADG (kg) and protein requirement (g/d) = $0.38\times ADG+5.03\times BW^{0.75}$, where ADG (g/kg $W^{0.75}$) [39].
[2/] Nutrient efficiency = nutrient requirement/nutrient intake

Conclusions

The results from the present study are interpreted to suggest that corn malt-sactic incorporated in concentrate can be used to improve feed utilization, body weight gain, and the average daily gain of growing beef heifers in developing tropical countries. Furthermore, our results indicate that con malt-sactic is a new energy source with high protein that is available for use as a ruminant feed ingredient and will beneficially affect the growth performance of growing beef heifers.

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