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Effect of Rumen-Protected Glucose Supplementation on Feedlot Performance, Carcass Characteristics, and Meat Quality of Kamphaeng Saen Steers

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ABSTRACT

This study aimed to determine the effects of dietary rumen-protected glucose (RPG) supplementation on feedlot steer performance, blood metabolite, carcass characteristics, and meat quality. Twelve Kamphaeng Saen steers were used with mean ± standard deviation for age 27.9 ± 6.9 months and initial body weight of 471 ± 3.03 kg. Steers were randomly assigned to either a control diet (CON) or a diet supplemented with 200 g/head/d of RPG by top-dressing at each feeding daily (RPG). Both groups were fed the concentrate diet, consisting of 14% crude protein and using rice straw as a roughage source in a ratio of 75:25. After being fed for 120 d, the steers were slaughtered. The feedlot performance, ruminal fermentation, blood biochemical parameters, carcass characteristics, and meat quality were evaluated. The results showed that there were no significant differences in the dry matter intake, average daily gain, feed conversion ratio, gain feed ratio (G:F), blood metabolite, and carcass characteristics between the CON and RPG groups. The marbling score, fat and protein contents of the *longissimus dorsi* muscle of the steers fed the RPG diet were significantly ($p<0.05$) greater than those for the steers fed the CON diet. In addition, the cooking loss and shear force of the steers fed the RPG diet were significantly ($p<0.05$) lower than those for the steers fed the CON diet. These results indicated that rumen-protected glucose has the potential to improve the meat quality of Kamphaeng Saen steers.

Keywords: Kamphaeng Saen steers; meat quality; rumen-protected glucose

INTRODUCTION

Recently, beef cattle production for commercial purposes in Thailand has increased due to the increased demand for high-quality meat. However, the production of high-quality beef is still insufficient to meet the needs of domestic consumers (Department of Livestock Development, 2020). Growing urban demand for beef creates more options for high-quality meat from fattening methods. According to Bunmee *et al.* (2018), commercial fattening techniques that produce prime and high-quality beef have a 1% market share. High-concentrate diets fed to beef cattle are commonly based on cereal grains and can improve weight gain and carcass quality, allowing faster fat deposition. These diets, commonly starch-rich, are characterized by rapidly fermented by ruminal microorganisms, providing more energy. However, high-concentrate diets can cause metabolic disorders, such as acidosis. In beef cattle fed high-grain diets, ruminal pH can range from 6.5 to 5.6, but it can drop pH below 5.6 mostly due to an excessive accumulation of volatile fatty acids (VFA), which has significant impact on microbial activity, rumen function, as well as animal productivity and health (Nagaraja & Titgemeger, 2007; Hall *et al.*, 2015; Luo *et al.*, 2017; Ramos *et al.*, 2021).

The strategy of increasing ruminal-resistant starch is beneficial for lowering the risk of metabolic problems and facilitating digestion, also increasing the host's net glucose supply (Deckardt *et al.*, 2013). Harmon (1992) observed that digesting starch in the small intestine rather than fermenting it in the rumen improves the efficiency of starch energy conversion into tissue energy. While Huntington *et al.* (2006) showed that in growing and finishing steers, 700 g/d of starch appeared to be the limit for starch digestion in the small intestine. Therefore, a better method to achieve high digestibility of starch in the small intestine is required to provide high post-absorptive glucose to the host animal. The rumen-protected glucose (RPG) is a good source of glucose for early lactation of dairy cows, encapsulated by hydrogenated fat to escape rumen digestion, can increase milk production (Li *et al.*, 2019), relieve the inflammatory response (Wang *et al.*, 2020a), participate in ileal epithelium metabolism, and regulate genes related to immune homeostasis (Zhang *et al.*, 2019). In the presence of a negative energy balance, RPG supplementation can prevent fat mobilization in dairy cows, as it is completely released after entering the gut. Subsequently, an increased quantity of glucose is transported to the small intestine, which is assimilated

directly by the epithelium and utilized in milk production (Nichols *et al.,* 2016).

Supplementation of rumen-protected sugar (LipoAktiv Glu 60) in transition dairy cows decreased blood β-hydroxy butyric acid concentration, which can associated with reduced subclinical ketosis and improved migration of circulating polymorphonuclear leucocyte (Brock *et al.,* 2023). The predominant substrate for fatty acid synthesis (FA) in ruminants is acetate, which is mainly derived from ruminal fermentation. Glucose can also be used as a substrate for FA *de novo* synthesis in ruminants. Glucose originates from either glucose production via gluconeogenesis from propionate/lactate or glucose absorption via the rumen bypass small intestinal digestion (Nafikov & Beitz, 2007). Subcutaneous (s.c.) adipose tissue preferentially uses acetate as a substrate for FA production, whereas intramuscular (i.m.) adipose tissue preferentially uses glucose (Smith & Crouse, 1984; Rhoades *et al.,* 2007). According to Smith *et al.* (2018), abomasal glucose infusion did not induce more FA production from glucose in i.m. adipose tissue than ruminal glucose infusion. Glucose infusion, on the other hand, resulted in the greatest generation of acetyl units from acetate in i.m. and s.c. adipose tissues.

Based on the associated research, rumen-protected glucose supplementation may provide a safe nutritional strategy for increasing the glucose availability of beef cattle and then improving performance and marbling development during the fattening stage. Therefore, this research aimed to investigate the feedlot performance, ruminal and blood parameters, carcass characteristics, and meat quality of steers fed rumen-protected glucose in tropical conditions.

MATERIALS AND METHODS

The investigation was conducted in the Beef Cattle Farm, Department of Animal Science, Faculty of Agriculture at Kamphaeng Saen, Kasetsart University, Nakhon Pathom, Thailand. The animal study protocol was reviewed and approved by the Institutional Animal Care and Use Committee of Kasetsart University, Thailand, following the Guidelines of Animal Care and Use of the Office of the National Research Council of Thailand (ACKU64-AGK-016).

Animals and Experimental Design

Based on their live weights, 12 Kamphaeng Saen steers (27.9 ± 6.9 months old with an average body weight of 471 ± 13.0 kg) were divided into two equal groups. The animals were reared in individual (2.5 × 4 m) pens. During the adaptation period (14 d) before the experiment, all animals were fed a basal concentrate diet and rice straw in a 75:25 (*ad libitum*) ratio. The treatments were: 1) control (basal diet fed; CON), 2) basal diet fed plus top-dressing with 200 g/head/d of rumen-protected glucose (RPG). The commercial-grade RPG (LipoAktiv Glu 60) contained 60% glucose coated with 40% processed palm oil high in C16:0. The surface fat layer protects the glucose inside the product from rumen fermentation. The fat layer breaks down in the small intestine, allowing the sugar to be absorbed [(Berg+Schmidt (Thailand) Co., Ltd]. The product's rumen-stability level was ≥75% (16 hours). The RPG dosage was based on the manufacturer's recommended dosage for dairy cows (100–500 g/cow/day). The basal diet (14% crude protein) was formulated to meet beef requirements for growth (NRC, 2016). The ingredient and nutrient compositions of the experimental diets are shown in Table 1. Steers were fed twice daily (08:00 and 16:00) and had free access to clean drinking water. Individually, the animals were given a 1.5% basal concentrate diet (dry matter basis; DM) based on their live body weight (BW), with the rice straw *ad libitum*. The initial BW, final BW, and dry matter intake (DMI) were recorded. Body weight gain (BWG), average daily gain (ADG), and the feed conversion ratio (FCR) were calculated to analyze growth performance. The feeding trial lasted for 120 d when the steers had reached market weight (550–600 kg).

Sample Collection and Analysis

Every 14 d samples of the concentrate diet and rice straw were collected for nutrient composition analysis. The diet sample was analyzed for DM, crude protein

Table 1. Ingredients and chemical composition of experimental diet (dry matter basis)

Item	Concentrate	Rice straw
Ingredient (%)		
Corn meal	25.10	
Cassava chip	29.50	
Defatted palm kernel meal	20.40	
Soybean meal	12.70	
Molasses	9.40	
Urea	0.70	
Vitamin and mineral mixture[1/]	0.90	
Sodium bicarbonate	0.30	
Salt	1.00	
Nutrient composition		
Dry matter (DM), %	89.68	90.61
Crude protein, %DM	14.16	5.68
Ether extract, %DM	3.19	1.20
Neutral detergent fiber, %DM	20.51	67.34
Acid detergent fiber, %DM	10.77	43.86
Ash, %DM	5.90	13.71
Non-fiber carbohydrates[2/], %	56.24	12.07
Total digestible nutrient (TDN)[3/], %	80.30	57.14
ME, Mcal/kg DM[4/]	3.43	2.09

Note: [1/]Agromix beef No. 46: vitamin A= 2,160,000 IU, vitamin B3= 100,000 IU, vitamin E= 5,000 IU, Mn= 8.5 g, Zn= 6.4 g, Cu= 1.6 g, Mg= 16 g, Co= 320 mg, I= 800 mg, Se= 32 mg (A.I.P. Co. Ltd, Nakhon Pathom, Thailand).
[2/]Non-fiber carbohydrates were calculated based on 100 – (%Crude protein + %Ether extract + %Ash), according to Sniffen *et al*. (1992).
[3/]Total digestible nutrients (TDN) were calculated using TDN (%DM)= 87.84 – (0.7 × ADF), according to Schmid *et al*. (1976).
[4/]The metabolizable energy (ME) was estimated using ME (Mcal/kg DM)= 1.01× DE (Mcal/kg) – 0.45. and the digestible energy (DE) was estimated using DE (Mcal/kg DM)= 0.04409 × TDN), according to NRC (2001).

(CP), ether extract (EE), neutral detergent fiber (NDF), acid detergent fiber (ADF), and ash (AOAC, 2016). Non-fiber carbohydrate was calculated according to Sniffen *et al.* (1992). Based on Schmid *et al.* (1976), total digestible nutrients (TDN) were calculated as TDN (%DM) = 87.84 - (0.7 × ADF), as shown in Table 1. Based on NRC (2001), the metabolizable energy (ME) was calculated as ME (Mcal/kg DM) = 1.01 × DE (Mcal/kg) - 0.45 and the digestible energy (DE) was calculated as DE (Mcal/kg DM) = 0.04409 × TDN). Jugular blood samples and rumen contents were collected from all steers at 4 hour after morning feeding in the final week of the experimental period. For biochemical analyses, blood serum was separated. The ruminal contents were removed via the esophagus using a stomach tube and a vacuum pump, then mixed well, squeezed through two layers of cheesecloth, placed in a plastic container, and kept at -20 °C for further analysis. A commercial kit (Abbott; USA) was used to analyze the triglyceride, cholesterol, blood urea nitrogen (BUN), and glucose levels (BG) in the blood samples. Electrochemiluminescence (ECL) was used to analyze insulin (Miao *et al.*, 2015). Rumen fluid samples were immediately measured for pH using a handheld portable pH meter (Oakton WD 35634-30; USA) and 50 mL samples were collected from each animal and frozen (-20 °C) prior to subsequent laboratory investigations. VFA concentration determination was performed using gas chromatography (the initial oven temperature was 120 °C, held for 10 min, then to 200 °C at 10 °C/min. Helium was the carrier gas at a flow rate of 150 kPa. The injector was 250 °C and the detector at 280 °C); samples were centrifuged at 10,000×g for 10 min at 4 °C and then 100 μL of supernatant was mixed with 20 μL of 25% metaphosphoric acid and kept at 4 °C (overnight). Then, samples were centrifuged at 10,000×*g* for 10 min at 4 °C. Subsequently, the supernatant (50 μL) was mixed with crotonic acid (50 μL). Next, the samples were transferred into vials for gas chromatography injection (Shimadzu; Japan) equipped with a CHROMPACK; CP9001 fused silica capillary column (0.32 mm internal diameter × 50 m length, 3.0 μm film; Shinwa; Japan). A phenol-hypochlorite assay based on spectrophotometric detection at 660 nm was used to determine ruminal ammonia nitrogen (NH_3-N), according to Khongpradit *et al.* (2020).

At the end of the experiment, the day before slaughter, the steers were transported to the slaughterhouse after 120 days of study and fasted for 16 hours (only water was provided) before being slaughtered humanely according to the halal protocol (OIE, 2014). After slaughtering, carcasses were weighed and chilled at 4 °C. The hot carcass dressing percentage was calculated using (hot carcass weight / slaughter live weight) × 100. After 7 d of chilling, the cold carcass percentage was calculated as cold carcass (%) = (chilled carcass weight / slaughter live weight) × 100. The *longissimus dorsi* muscle (LM) was cut between the 12th and 13th ribs on the right side of the carcass and immediately transported at 4 °C to the laboratory for carcass characteristics analysis, after which the sample was frozen prior to further chemical analysis. The pH of the carcass was measured in the LM using a portable pH meter (Mettler-Toledo AG, Analytical CH-8603 Schwerzenbach; Switzerland) at 1 and 48 hours after slaughtering. The irregular shape of the LM area was measured using a compensating planimeter (Barcellos *et al.*, 2017). Based on Françozo *et al.* (2013), the backfat thickness was measured using calipers between the 12th and 13th ribs on the LM at three-quarters of the length of the loin eye muscle from the chine (backbone). Then, from each rib piece, three 2.5 cm thick steaks were cut and trimmed of all exterior fat to measure drip loss and cooking loss (Kaić *et al.*, 2020). In addition, to determine the shear force value after finished cooking loss sample and take it to cut for size width × length × thickness (1 × 2 × 1 cm) along the muscle fibers (Jaturasitha *et al.*, 2009) was measured using a texture analyzer (Brookfield texture analyzer, model CT3-25kg; Middleboro, MA, USA) and set speed 200 mm/min. Marbling was evaluated by estimating the amount of intramuscular fat visible on the cut surface of the rib eye muscle between the 12th and 13th ribs using a photographic standard scale of five values (1= devoid, 2= slight, 3= small, 4= moderate, and 5= abundant) after chilling for 7 d according to the Thai Agricultural Commodity and Food Standard (National Bureau of Agriculture Commodity and Food Standard, 2004). Meat color was measured at three spots on a freshly cut, transverse surface after 30 min of blooming using a color meter (Hunter Lab Mini Scan EZ; Reston, VA, USA) according to the L* (lightness), a* (redness), and b* (yellowness) standard (Françozo *et al.*, 2013). The moisture, crude protein, and crude fat contents of the LM sample were determined in duplicate (AOAC, 2016).

Statistical Analysis

The statistical analysis was conducted using the SAS on Demand for Academics software (SAS Institute; Cary, NC, USA). The data were analyzed based on an independent-sample t-test to determine the effects of rumen-protected glucose addition on the feedlot performance, ruminal parameters, blood metabolites, and meat quality in the Kamphaeng Saen steers. The nonparametric Kruskal-Wallis test was used to detect aggregate group differences in marbling scores. Significance was declared at p-value of <0.05, with tendencies declared at p-values between 0.05 and 0.10.

RESULTS

Feed Intake and Performance

Table 2 shows the feed intake and feedlot performance of the steers. The dietary treatments did not affect the total DMI, concentrate, or rice straw intake of the Kamphaeng Saen steers. The final BW and BWG of steers did not differ between treatments. In addition, the ADG, FCR, and feed efficiency (G:F) did not differ between regimens.

Rumen pH, NH_3-N, and Volatile Fatty Acids

The rumen fermentation characteristics are shown in Table 3. There were no significant differences between

treatments in ruminal pH, NH_3-N concentrations, acetate or butyrate concentrations. However, compared to the control group, the Kamphaeng Saen steers in the RPG group tended to decrease propionate concentration (p=0.091) and increase the acetate-to-propionate ratio (p=0.079).

Blood Metabolites

In this trial, the serum insulin concentration was similar between treatments (4.18 versus 4.66 uIU/mL for the CON and RPG treatments, respectively). BG did not alter significantly across treatments (Table 4). There were no significant differences in the BUN concentrations across treatments (Table 4). There was no significant difference in the triglyceride levels in the blood serum of the steers fed the control diet or the RPG-supplemented diet; however, RPG supplementation enhanced the availability of cholesterol in the blood serum (p=0.097).

Carcass Characteristics and Meat Quality

There were no significant differences in live weight (LW), hot carcass weight (HCW), or cold carcass percentage (CCP) between the Kamphaeng Saen steers fed the RPG or the control diets. Furthermore, there were no significant differences between the two treatments for back fat thickness and loin eye area (Table 5). In addition, steers fed a diet supplemented with RPG had a higher marbling score (50% of marbling score= 3; based on a 1–5 scoring system) than the control group (p<0.05; 2.5 versus 1.0).

Table 6 shows the meat quality of steers fed the CON and RPG-supplementation diet. The pH at 1 hour and 48 hours, and in the carcass temperature post-mortem were similar between treatments. Steers fed RPG showed lower drip loss (p=0.08), cooking loss p<0.05), and shear force (p<0.05) than the CON group. Meat color values (L*, a*, b*) did not differ significantly across treatments. The average moisture content range was 70.95%–75.33%. Compared to the control group, steers fed the RPG diet had a greater protein, fat (p<0.05) and ash content (p=0.089).

DISCUSSION

Rumen-protected glucose is a source of glucose that has been encapsulated by hydrogenated oil to avoid digestion in the rumen. Based on our results and the small number of animals in the current investigation, RPG supplementation did not negatively affect the DMI of the studied Kamphaeng Saen steers. Beglinger *et al.* (2006) proposed that the presence of carbohydrates in the small intestine reduces feed intake by regulating

Table 2. Effect of rumen-protected glucose on dry matter intake and growth performance of Kamphaeng Saen steers

Variables	Treatments		SEM	p-value
	CON	RPG		
Total intake, kg DM/d	9.04	8.97	0.193	0.734
Concentrate, kg DM/d	6.56	6.38	0.168	0.315
Roughage, kg DM/d	2.48	2.59	0.156	0.502
Total intake, % BW	1.59	1.56	0.051	0.551
Initial BW, kg	471.00	473.00	7.866	0.804
Final BW, kg	568.40	578.20	20.635	0.648
Weight gain, kg	96.80	101.80	15.139	0.750
ADG, kg/d	0.80	0.84	0.129	0.810
FCR	11.34	11.31	1.472	0.988
G:F	0.09	0.10	0.014	0.680

Note: CON= control, RPG= rumen-protected glucose, SEM= standard error of mean, DM= dry matter, BW= body weight, ADG= average daily gain, FCR= feed conversion ratio, G:F= gain feed ratio.

Table 3. Effect of rumen-protected glucose on ruminal fermentation profiles of Kamphaeng Saen steers

Variables	Treatments		SEM	p-value
	CON	RPG		
Ruminal pH	6.70	6.55	0.247	0.541
NH_3-N, mgN/100 mL	9.50	8.55	0.959	0.347
Volatile fatty acids				
Acetate, mol/100 mol	81.27	82.08	2.270	0.729
Propionate, mol/100 mol	12.21	9.78	1.268	0.091
Butyrate, mol/100 mol	8.32	8.14	0.919	0.846
Acetate:Propionate	6.71	8.63	0.954	0.079

Note: CON= control, RPG= rumen-protected glucose, SEM= standard error of mean, NH_3-N= ammonia nitrogen.

Table 4. Effect of rumen-protected glucose on blood metabolites of Kamphaeng Saen steers

Variables	Treatments		SEM	p-value
	CON	RPG		
Insulin, uIU/mL	4.18	4.66	1.586	0.770
BG, mg/dL	79.40	74.60	6.263	0.465
BUN, mg/dL	14.44	12.24	1.918	0.285
Triglyceride, mg/dL	33.60	38.00	9.678	0.661
Cholesterol, mg/dL	125.60	142.2	8.826	0.097

Note: CON= control, RPG= rumen-protected glucose, SEM= standard error of mean, BG= Blood glucose, BUN= Blood urea nitrogen.

Table 5. Effect of rumen-protected glucose on carcass characteristics of Kamphaeng Saen steers

Variables	Treatments		SEM	p-value
	CON	RPG		
LW, kg	549.20	547.50	17.127	0.924
HCW, kg	340.40	344.30	14.641	0.799
CCP, %	60.33	61.42	1.098	0.344
Marbling score (1–5 score)	1.00	2.50	0.579	0.041
Marbling score, %				
Grade 1	66.67	16.67	-	-
Grade 2	33.33	33.33	-	-
Grade 3	-	50.00	-	-
Grade 4	-	-	-	-
Grade 5	-	-	-	-
Back fat thickness, cm	0.84	0.86	0.208	0.926
Loin eye area, cm^2	97.98	86.80	9.265	0.262

Note: CON= control, RPG= rumen-protected glucose, SEM= standard error of mean, LW= Live weight, HCW= hot carcass weight, CCP= chill carcass percentage.

Table 6. Effect of rumen-protected glucose on meat quality of *longissimus dorsi* muscle of Kamphaeng Saen steers

Variables	Treatments		SEM	p-value
	CON	RPG		
pH at 1 h	6.54	6.45	0.149	0.537
Temperature at 1 h, °C	40.31	40.97	1.130	0.586
pH at 48 h	5.86	5.95	0.064	0.194
Drip loss, %	4.83	3.80	0.518	0.081
Cooking loss, %	28.11	19.82	3.133	0.029
Shear force, kg cm^2	4.13	3.30	0.353	0.047
Meat color				
L* (lightness)	40.92	41.99	1.461	0.485
*a** (redness)	22.50	21.13	1.242	0.300
*b** (yellowness)	18.52	18.38	0.826	0.871
Chemical composition				
Moisture, %	75.33	70.95	2.921	0.184
Crude Protein, %	20.37	22.24	0.627	0.025
Ether extract, %	2.16	4.71	0.832	0.015
Ash, %	1.02	1.13	0.051	0.089

Note: CON= control, RPG= rumen-protected glucose, SEM= standard error of mean.

glucagon-like peptide-1, an intestinal hormone with profound effects on glycemic regulation, including stimulating glucose-dependent insulin secretion and inhibiting feed intake. In this case, if we consider that RPG increases glucose reaching the small intestine, this condition should have reduced the feed intake. The DMI results are consistent with several other studies that provided glucose, either invennously (Malacco *et al.,* 2020) or with rumen-protected glucose products (McCarthy *et al.,* 2020; Sauls-Hiesterman *et al.,* 2020). ADG, FCR, and feed efficiency (G:F) did not differ significantly between regimens in this study. A study by Russi *et al.* (2019) reported that steers fed 180 g/d of protected dextrose tended to have an excellent ADG in the final stage of their study.

The plasma insulin concentration was comparable between treatments (4.18 versus 4.66 uIU/mL). In contrast, Li *et al.* (2019) found that dietary RPG (200 g/d) supplementation in transition dairy cows increased their plasma insulin concentration, with the highest plasma insulin concentration occurring on day 14. McCarthy *et al.* (2020) reported that the plasma insulin concentration of transition dairy cows fed a diet containing RPG (pre-fresh 5.3% of DM and postpartum 6.0% of DM) tended to be higher than that of their control cows. Russi *et al.* (2019) found that the plasma insulin concentrations of steers fed different diets on days 0, 15, and 39 were comparable, but on day 62, the plasma insulin concentration of steers fed 360 g/d rumen-protected dextrose was the highest. Blood glucose concentration is one of the biochemical indicators that can be used to determine the body's energy supply. There was no significant variation in plasma BG between the RPG-fed steers and the control group (74.60 versus 79.40 mg/dL), which is unsurprising, considering that glucose is homeostatically controlled (Baumgrad *et al.,* 2017). Dietary RPG supplementation (200 g/d) tended to decrease the plasma glucose concentration in transition dairy cows (Li *et al.,* 2019). In Russi *et al.* (2019) experiment found that when steers were fed a control diet, their blood glucose content was highest compared to steers given 180 and 360 g/d of rumen-protected dextrose (88 mg/dl, 83 mg/dl, and 83 mg/dl, respectively; $p<0.05$). The serum glucose concentration increased following RPG treatments and then declined over time, reaching a maximum of 21 days with the 250 g/d RPG group, which could be related to the dose of RPG supplementation and its metabolism adaptation (Wang *et al.,* 2020b). The differences in the blood glucose response to exogenous glucose between our investigation and previous studies could be attributed to differences in the amount of glucose supplied, the mode of administration, and the content of basal diet.

The ruminal pH and NH3-N, acetate, and butyrate concentrations did not differ significantly between regimens. However, compared to the control group, RPG-supplemented diets tended to decrease the propionate concentration and increase the acetate-to-propionate ratio in the steers. Because the rumen-stability level of the RPG product was 75% (at 16 hours), it was necessary to investigate RPG degradation in the rumen. Wang *et al.* (2020a) reported that the percentage of RPG released in the rumen was 45.97% in experiments and that different doses of RPG (0 g/h/d, 200 g/h/d, 350 g/h/d, and 500 g/h/d) supplementation affected rumen fermentation parameters, such as the pH and propionate, indicating that RPG supplementation affected the rumen environment. Li *et al.* (2019) observed that the 200 g/head/d RPG supply did not affect the apparent digestibility of CP, EE, ADF, and NDF in dairy cows throughout the transition period. Different results could be attributed to the RPG dose, the content of the basal diet, and the physiological status of the test animals in the experiment. There is currently very little published research on the rumen fermentation of feedlot steers following various dosages of RPG during the finishing stage.

The level of urea-N in blood serum is a measure of nitrogen sufficiency or deficiency in an animal's diet. There were no significant differences in the blood urea nitrogen concentrations between treatments in the present study, nor in the triglyceride levels in the blood serum of steers fed a control diet or the RPG-supplemented diet. Cholesterol is synthesized in the body of animals from fatty acids, and its concentration in the serum indicates body fat metabolism. Insufficient nutrient intake can reduce circulatory glucose and cholesterol levels (Reynolds *et al.,* 2003). RPG supplementation improved the availability of cholesterol in blood serum in the current study. This could be attributed to RPG (which contains 60% glucose and 40% palm oil) supplementation increasing energy intake. Previous research has demonstrated an increase in blood total cholesterol levels but no differences in LDL or triglyceride levels between Kamphaeng Saen steers fed concentrate with palm oil supplementation to the feed (Matsuba *et al.,* 2019).

In the present study, there were no significant differences in LW, HCW, and CCP of the Kamphaeng Saen steers fed RPG or the control diets. Furthermore,

there were no significant differences between treatments for back fat, the 12th rib, and the loin eye area. This was consistent with Boonsaen *et al.* (2017), who reported that backfat thickness and the loin eye area of Kampaeng Saen steers fed different energy sources were not significantly different, nor were the crude protein levels. Furthermore, they reported that both meat tenderness and marbling association genes were discovered in a few individual animals, indicating that Kamphaeng Saen beef cattle had low levels of meat tenderness and marbling association genes. In a study conducted by Chanjula *et al.* (2016), it was shown that substituting crude glycerin (glucogenic substrates) for corn in the diet of Kampaeng Saen steers did not affect the marbling score of meat.

In the present study, steers given RPG supplementation diet had a greater marbling score (50% of marbling score= 3; based on a 1-5 score system) than the control group (2.5 versus 1.0, respectively), indicating that RPG feeding would affect meat quality. Rhoades *et al.* (2007) used an in vitro system of adipose tissue from Angus and Wagyu steers to show that intramuscular adipose tissue uses glucose as a carbon source for de novo fatty acid biosynthesis more than subcutaneous adipose tissue, even though glucose use is the same in both types of fat. The same researchers reported that feeding a corn-based diet increased glucose absorption in intramuscular fat (IMF), while providing a hay-based diet may cause subcutaneous fat to build up by adding acetate to FA. So, if the IMF prefers glucose as a building block for FA production, RPG feeding may lead to more IMF deposition. A previous study also found that steers that were weaned early and given a high-energy diet from 100 days to 250 days of age before being managed normally had higher marbling scores than steers that were weaned normally (Nayananjalie *et al.*, 2015; Scheffler *et al.*, 2014). Consumer tend to believe that heavily-marbled beef is more palatable than lightly-marble beef (Lee *et al.*, 2018; Motoyama *et al.*, 2016).

One of the essential meat properties is the pH value. The readings in a live animal's muscle are in the neutral zone (7.2). A normal rate corresponds to a pH of 5.8-6.0 measured 45-60 min after death. A rapid fall in pH is caused by rapid glycogen degradation due to acute (short-term) stress before slaughter or by genetic predisposition. The pH levels at 1 h and 48 h, and in the carcass temperature post-mortem were identical in steers fed CON and RPG supplementation. The RPG-fed steers experienced lower drip loss, cooking loss, and shear force than the CON-fed steers. According to these findings, RPG supplementation affects the water retention capacity and softness of steer carcasses. Su *et al.* (2022) found that diets containing corn and barley starch as a carbohydrate source can increase the water-holding capacity of Xiangxi yellow steer meat. However, no differences in drip loss or cooking loss of Kamphaeng Saen meat were observed between the control and crude glycerin (7%, 14%, or 21%) groups, as reported by Chanjula *et al.* (2016). Other research on various energy sources found no significant effects on the shear force and carcass quality of Kamphaeng Saen steers (Boonsaen *et al.*, 2017). In support of the current finding, Hunt *et al.* (2014) reported steaks from carcass with higher marbling scores had lower shear force values than steaks with low marbling scores. The color of fresh meat can vary depending on IMF content (Lee *et al.*, 2018). The meat color values (L*, a*, b*) did not differ significantly across treatments in the current study, which was consistent with the findings of Boonsaen *et al.* (2017), who found no significant differences in meat color values between Kamphaeng Saen steers fed two distinct total mixed rations despite the different energy sources. Fresh beef quality varies depending on many reasons animal variables, including age, sex, breed, growth rate, and diet (Corrigan *et al.*, 2009; Devlin *et al.*, 2017; Liu *et al.*, 2022).

The average moisture level of the LD muscle ranges from 70.95% to 75.33%, indicating normal water content because it does not surpass the standard water content threshold for fresh meat. This is consistent with the findings of a study conducted by Khasrad *et al.* (2017), where the water content of beef from different breeds ranged between 67% and 74%. According to Lawrie & Ledward (2006), young animals have more water than older animals; increasing age results in increased intramuscular fat deposition in meat, followed by a decrease in water content. The average crude protein and total fat contents in the longissimus muscle of a crossbred (*Bos Taurus* × *Bos indicus*) bull or Hereford and Braford steers in a feedlot ranged from 21.1%–24.4% and 2.21%–3.81%, respectively (Ducatti *et al.*, 2009; Freitas *et al.*, 2014). The protein, fat, and ash contents of the LD muscle were higher in the RPG-fed steers than in the control group. In the current investigation, changes in fat or moisture content could alter muscle protein content. According to Paddon-Jones & Leidy (2014), red meat is a source of high-quality protein and highly bioavailable iron that can help boost vitality. However, research evaluating total protein or amino acid content in red meats and how these components might be modified to improve nutritional value utilizing nutritional methods are lacking (Huang *et al.*, 2018). The fat content of meat positively influences sensory quality traits as the steaks with high IMF were profiled as tender, juicy, and flavourful (Shahrai *et al.*, 2021; Frank *et al.*, 2016; Jung *et al.*, 2016; Lee & Choi *et al.*, 2019). The amount of each fat deposit changes depending on the species, age, and calorie intake of the animal (Lawrie & Ledward, 2006).

CONCLUSION

The current study discovered supplementing finishing steer with rumen-protected glucose can result in higher-quality beef by improving marbling, fat, and protein contents in the longissimus dorsi muscle, as well as lowering shear force and water loss, but did not affect the dry matter intake, growth performance, rumen fermentation characteristics, blood metabolites, or carcass characteristics of Kamphaeng Saen steers. Further research is needed to determine the effect of RPG supplementation at various doses on beef's rumen microbes and fatty acid composition.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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