Original Article

Impact of colostrum lactose concentration in relation to metabolomic profiles on kid growth performance of Black Bengal goats

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Abstract

Colostrum composition, including lactose concentration in relation to metabolomic profiles on kids' growth performance of Black Bengal goats, has not yet been elucidated. Macronutrients, including lactose and metabolomic profiles, were determined in 37 colostrum samples using MilkoScan and ^{1}H-nuclear magnetic resonance technique, respectively. Kids' growth performance, including birth weight, average daily gain at 0–4 weeks (ADG0-4W), 4–8 weeks (ADG4–8W), and wean weight were determined. A total of 51 metabolites were detected in the colostrum. From the general linear model for univariate analysis, kids born from multiple litter sizes showed lower ADG during the first month postpartum (P = 0.004). The ADG0-4W was correlated positively with lactose (r = 0.434, $P < 0.001$), betaine (r = 0.263, $P < 0.05$), glycine (r = 0.303, $P < 0.05$), and trimethylamine N-oxide (r = 0.372, $P < 0.01$) but negatively with most metabolites. By using a generalized linear mixed model procedure when kid growth performances were regarded as dependent variables, and the damID was considered as a random effect with birth weight, parity number, and litter size as covariates, kids consumed colostrum with high lactose ($P < 0.001$) but lower protein, fumarate, malonate, glucose, myo-inositol, vitamin B2, and vitamin B7 ($P < 0.05$) had higher ADG0-4W. Therefore, growth performance 1 month postpartum was enhanced in kids consuming high lactose with low metabolite contents, which reflects not only the lactose is the main source of energy but also its possible role on the osmotic water-pulling effect on colostrum yield.

Keywords: caprine, foremilk, metabolome, preweaning weight

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Introduction

The Black Bengal (BB) goats have been raised in tropical regions for meat production as they are well tolerant of harsh environment and contribute to sustainable agricultural development of Asian countries (Hossain, 2021). The prominent characteristics are small body size but large sized litter. Therefore, the increased survival rate of kids from high litter size dams is the key goal for farm success. Nowadays, colostrum, the first mammary gland secretion, is the focus of intensive research. Colostrum contains high concentrations of many substances including growth factors, immunoglobulin (Ig), vitamins, and nutrients which are essential for kid development and growth. Analysis of BB mammary secretion for the first 7 days after parturition found that the concentrations of insulin-like growth factor 1 (IGF-1) and IgG in colostrum were high and dramatically reduced during the transition stage at approximately day 4 until the secretion became milk on day 7 after parturition (Buranakarl *et al*., 2021). Moreover, the levels of IGF-1, IgG, and vitamin A in colostrum were also related to kid growth during the first month after parturition (Buranakarl *et al*., 2022). A previous study in kids from Lentivirus-positive dams showed that the body weights within 2 months postpartum of kids that immediately weaned and received bovine colostrum for 5 days until they started to receive a whey-based milk replacer was lower than those who stayed with their mother and received dam colostrum (Nalbert *et al*., 2019). Although the weight could be caught up later, the risk of low immunity and preweaning death may be high especially when kids are born from high litter size. Although many factors in colostrum related to kids' growth were extensively reviewed, data of macronutrients and metabolites on kid growth in Black Bengal goats is still lacking.

For the macronutrients, lactose, protein, and fat in the colostrum are essential since they are primary sources of energy for neonate. Lactose in colostrum is the main precursor of glucose for kids immediately after parturition until the first few days when glucose production was still not functioning well (Hammon *et al*., 2013). Protein in colostrum is crucial for muscle development of kids while fat plays a key role in neurological development.

Other than macronutrients, the metabolites in colostrum have been extensively studied. The small molecular weight metabolites in biological fluid could be measured using many techniques such as mass spectrometry (MS-based) (LC/MS, GC/MS and CE/MS) and nuclear magnetic resonance (NMR)-based analysis. NMR spectroscopy could be applied for detecting the inborn errors of metabolism in humans (Moolenaar *et al*., 2003). In ruminants, metabolomic profiles in milk were altered, and they can be used as biomarkers for diseases such as ketosis (Klein *et al*., 2012; Eom *et al*., 2021), subclinical mastitis (Luangwilai *et al*., 2021), and lameness (Zwierzchowski *et al*., 2020). Metabolomic analysis was also introduced to investigate the biomolecular profiles of various dairy products with different objectives such as accessing and predicting the quality of products (Settachaimongkon *et al*., 2017; Sanchez *et al*., 2021; Suh, 2022). It can be used to test the impact of processing on the molecular authenticity and traceability of fluid milk products (Cui *et al*., 2019).

The metabolomic profiles of colostrum were reported in many species such as sheep and goats (Caboni *et al*., 2019), sow (Picone *et al*., 2018), and cow (O'Callaghan *et al*., 2020; Settachaimongkon *et al*., 2021). The metabolomic profiles of mammary secretions were recently reported in BB goats (Vo *et al*., 2024) regardless of kids' growth performance. The objective of this study was to determine whether the growth performance of BB goats during the preweaning period was affected by macronutrients and metabolites in colostrum.

Materials and Methods

***Ethical approval*:** The present study was conducted according to the Animal Care and Use Protocol approved by the Animal Care and Use Committee, Faculty of Veterinary Science, Chulalongkorn University, Protocol number 2231025.

***Study location, period, and protocol*:** This study was performed at the Chaipattana Foundation's Bengal Goat Domestication Project's Farm located in Chiang Rai Province, Thailand. The retrospective study for kid weight and routine colostrum collection was performed in dams delivered from March to July 2022. The meteorological data were obtained from the official provincial meteorological stations near (< 100 km) the herd. The average temperature in March, April, May, June and July were 27.5 ± 0.2, 26.9 ± 0.4, 27.5 ± 0.2, 28.0 ± 0.1 and 27.5 ± 0.3°C, respectively. The humidity average for the whole study was 79.1 ± 0.5%. Thirty-seven Purebred BB female goats and 65 neonates born from these purebred BB goats were included in this study. Metabolomic profiles were measured in the colostrum of dams while the data on litter size and parity number were recorded. Some samples of colostrum metabolomic profiles were shared from a previous study (Vo *et al*., 2024). Kids' growth performance, including birth weight, wean weight, and average daily gain (ADG) calculated from birth until 4 weeks (ADG0–4W) and from 4 weeks until 8 weeks (ADG4–8W) were determined.

***Housing and management*:** All goats were reared in a conventional open-housing system. The commercial concentrate was served to adult goats at approximately 2% of body weight per day (91.2% dry matter (DM) and chemical composition of 17.2% crude protein, 2.9% fat, 12.6% crude fiber, 14.3% ash, 34.1% neutral detergent fiber (NDF), and 16.4% acid detergent fiber (ADF) per DM basis). Meanwhile roughage sources that came from the experimental station were given with 2 kg/goat/day Napier grass (16.2% DM with 15.0% crude protein, 1.9% fat, 30.8% crude fiber, 11.3% ash, 61.2% NDF, and 39.3% ADF per DM basis) and 1 kg/goat/day Pangola hay (92.8% DM with 3.5% crude protein, 1.2% fat, 30.6% crude fiber, 5.4 ash, 66.2% NDF and 37.6% ADF per DM basis) daily. All goats were fed twice a day at 7:00 and 18:00 h, according to the standard management, with free water access. All dams were allowed to walk in the field for approximately three to four hours per day, depending on the weather conditions. During the rainy season, goats were limited to being inside.

All dams were naturally mated with selected BB bucks following the breeding plan. Neonatal kids were delivered naturally. After parturition, colostrum was collected once, approximately 20 ml, and fed to newborn kids. The kids were allowed to consume and stay with the dams thereafter. Neonates stayed with their mother until weaning at approximately the 12th week. Kids might start nipping roughage and licking their mother's concentrate, which was given in about 25% more amount after 1 month postpartum until weaning.

Routine recording related to buck and dam characteristics, vaccination program, health status, current litter size, parity number, kidding date, and body weight of newborn kids were conducted for individual goats. Health management and disease monitoring were performed by veterinarians. Anthelmintic medication and dipping or spraying pesticides were regularly performed to control endoparasitic and ectoparasitic infestation. All goats were vaccinated against the foot-and-mouth disease virus twice a year. The results of Caprine arthritis encephalitis (CAE) virus and brucellosis were routinely checked yearly to ensure negative results in the Department of Livestock Department, Thailand. The CAE was checked using a competitive Enzyme-Linked Immunosorbent Assay (ELISA), while brucellosis was screened by the Rose Bengal test (RBT) and confirmed by complement fixation test (CFT) and indirect ELISA.

Sample collections: Laboratory analysis was performed at the Department of Physiology, Faculty of Veterinary Science, Chulalongkorn University. Approximately 50 mL of colostrum was collected per dam by hand milking following the farm's routine procedures. Colostrum samples were collected on the parturition day, mainly within 3 h after parturition, put into disposable plastic tubes, and stored at -20°C. All samples were analyzed for major chemical composition and non-volatile polar metabolite components within 3 months after collection.

***Measurement of kids' growth* performance:** The newborn kids' birth weight was measured within 3 h after parturition by putting them into a basket over the balance (CRD 30, CST Instruments, Taiwan). The body weight was measured weekly until weaning. The ADG of neonates was calculated as ADG0-4W (body weight at day 28 - birth weight/28*1000) and ADG4-8W (body weight at day 56 - body weight at day 28/28*1000). The weaning weight was measured at approximately 12 weeks of age.

Determination of lactose and other chemical composition: Before analysis, all colostrum samples were thawed and filtered by using gauze. On the day of analysis, colostrum samples were incubated in a water bath at 40°C for 20 min. Approximately 20 mL of samples were processed, and chemical compositions, including fat, protein, lactose, solid not fat (SNF), and total solids (TS), were determined using the MilkoScan FT2 analyzer (Foss MilkoScan, Hillerøed, Denmark).

Determination of metabolomic profiles: Non-volatile polar metabolite components in colostrum samples were analyzed using a non-targeted ^{1}H-NMR metabolomics approach as previously described (Vo *et al*., 2024). In brief, the samples were thawed, and the pH was adjusted to 6.0 with 1.0 N HCl. Colostrum was diluted with ultra-pure water and was centrifuged at 3,000 × g at 10°C for 50 min. The dichloromethane was added, vortexed, and centrifuged at 5,000 × g at 4°C for 40 min. The supernatant was subjected to ultracentrifugation at 74,500 × g at 4°C for 60 min while the clear supernatant was collected, filtered through a 3 kDa molecular weight cut-off filter, and recentrifuged at 13,800 × g at 25°C for 20 min. The flow-through was collected, and phosphate buffer was added to serve as an internal standard. The metabolites in the mixture were analyzed by ^{1}H-NMR analysis using a 500 MHz NMR spectrometer (NOESY-GPPR-1D-1H-NMR, Bruker, Rheinstetten, Germany).

***Spectra processing and data acquisition for metabolomic profiles*:** The internal standard (3-[Trimethylsilyl] propionic-2, 2, 3, 3-d4 acid sodium salt; TSP) peak was used to normalize the ^{1}H-NMR spectra. The chemical shift from 0 to 10 ppm was divided by the binning technique, with a 0.02 ppm interval, in Bruker TopSpin 4.2.0 (www.bruker.com). Chenomx NMR suite 8.6 library (Chenomx Inc., Edmonton, Alberta, Canada), Milk Composition Database (www.mcdb.ca), Livestock Metabolome database (www.lmdb.ca), and literature from previous studies were used for metabolite identification. Identified metabolites were classified into six chemical classes: amino acids and derivatives, organic acids and derivatives, carbohydrates and derivatives, lipids and derivatives, vitamins, and others. In each bin, the peak area was quantified and expressed in arbitrary units.

***Statistical analysis*:** The statistical analysis was performed using SAS 9.4 (SAS Institute, Inc., Cary, NC, USA). Data are presented as least square mean ± standard error. Factors for BB kid growth performances were investigated using a general linear model for univariate analysis and were tested for significance. The effects of macronutrients and metabolites on kids' growth in the preweaning period were analyzed using a generalized linear mixed model procedure. The frequency distribution procedure (PROC FREQ) was used to classify all colostrum metabolite contents. All metabolites were classified into low and high concentrations based on average means. The final models included the fixed effects of metabolite concentrations (high and low metabolite concentration). Kid growth performances (ADG0–4W, ADG4–8W, and weaned weight) were regarded as dependent variables. The damID was considered as a random effect with birth weight, parity number, and litter size as covariates. Correlation matrices with Pearson's correlation-based hierarchical clustering and correlation coefficient plots among chemical variables were constructed in the MetaboAnalyst 6.0 online platform (www.metaboanalyst.ca). Observed values were considered statistically significant when $P < 0.05$, while $0.10 > P > 0.05$ was considered a tendency.

Result

Characteristics of dams and kids: The average age of 37 dams was 28.1 ± 2.4 months old, while the parity number and litter size were 2.5 ± 0.3 and 1.8 ± 0.1, respectively. There were 13, 20, and 4 dams that produced single, twin, and triplet kids in one litter size, respectively. Among the 65 kids born from these dams, 13, 40, and 12 kids were born from single, twin, and triplet litter sizes, respectively. The average birth weight was 1.34 ± 0.04 kg. The ADG0–4W and ADG 4–8W were 78.41 ± 2.73 and 66.76 ± 2.56 g/day, respectively. The wean weight was 7.07 ± 0.20 kg.

Composition of macronutrients in colostrum: In a total of 37 samples, colostrum contained fat, protein, and lactose of 9.10 ± 0.52%, 15.96 ± 4.49%, and 2.97 ± 0.71%, respectively. The TS was 29.38 ± 5.38%, while SNF was 21.03 ± 4.04%.

Metabolomic profiles in colostrum of BB goat: The total of 51 metabolites, including their chemical shift measured by NOESY- 1D-^{1}H-NMR technique, were shown in Table 1. The list of metabolites consisted of 14 amino acids and derivatives, 12 organic acids and derivatives, 10 carbohydrates and derivatives, 6 lipids and derivatives, 4 vitamins, and 5 others. The highest metabolite concentration in colostrum was lactose, while the lowest was sarcosine.

Factor affecting kids' growth performances: Significant effects of litter size, parity, and sex on the growth performance of kids are shown in Table 2. Multiple litter sizes had significantly lower ADG0–4W than single litter size (P = 0.004). Kids born from multiparous dams tended to have higher birth weight (P = 0.062) and wean weight (P = 0.062). Male and female kids had no differences in growth performances.

Relationships between macronutrients, metabolites in colostrum, and kids' growth performance: The correlation coefficients between kids' growth performance and both macronutrients and metabolites in colostrum are shown in Table 3 while the correlation matrices were created (Fig. 1). ADG0-4W had significant positive relationships with lactose, betaine, glycine, and Trimethylamine N-oxide (TMAO) but showed negative relationships with most amino acids and fatty acids (Table 3). Similar correlation patterns were found for ADG4-8W and wean weight. Since lactose contributes to a major ingredient in colostrum, the relationships with other constituents were determined. Lactose negatively correlated with protein (r = -0.862, P < 0.001). For metabolites, lactose correlated positively with TMAO (r = 0.479, P<0.001) but negatively with proline (r = -0.239, P = 0.055), valine (r = -0.207, P = 0.098), citrate (r = -0.388, P = 0.001), fumarate (r = -0.270, P = 0.029), myo-inositol (r = 0.340, P=0.006), acetyl-carnitine (r = -0.302, P=0.015), GPC (r = -0.548, P<0.001), PC (r = -0.266, P = 0.032), vitamin B2 (r = -0.281, P = 0.024), vitamin B7 (r = -0.234, P = 0.060), and uridine (r = -0.450, P < 0.001).

Effects of macronutrients and metabolite concentrations on kids' growth performances when using birth weight, parity, and litter size as covariates: When the nutrients and metabolites were divided into two groups (high and low) based upon average means using birth weight, parity, and litter size as covariates, kids that consumed high protein in colostrum had lower ADG0-4W (P = 0.019). However, kids who consumed colostrum with high lactose concentrations had higher ADG0-4W (P < 0.001) and wean weight (P = 0.018) compared with kids in the low lactose group (Table 4). When considering the metabolites that showed the differences between low and high groups, there were negative effects on ADG0-4W for fumarate (P = 0.009), malonate (P = 0.028), glucose (P = 0.034), myo-inositol (P = 0.029), vitamin B2 (P = 0.026), and vitamin B7 (P = 0.044).

Discussion

The macronutrients in the colostrum of BB dams showed slightly higher fat, protein, and TS, while lactose was lower than in the previous study (Buranakarl *et al.*, 2021). This study showed that 51 metabolites in BB goats were found in colostrum using NMR spectroscopy, as demonstrated earlier in colostrum of BB goats (Vo *et al.*, 2024). The 45 non-volatile polar metabolites were found in bovine colostrum using the ^{1}H-NMR technique, wherein the sample was subjected to ultracentrifugation before NMR measurement (Settachaimongkon *et al.*, 2021). Forty-four metabolites were found in goat milk powder using the ^{1}H-NMR technique (Sanchez *et al.*, 2021). Alteration of the detectable metabolites in milk powder may be due to heat during high-temperature processing (Li *et al.*, 2022).

The assignment of metabolites in colostrum showed a chemical shift similar to that found in a previous paper on goat powder milk (Sanchez *et al.*, 2021). They could be divided into amino acids and derivatives, organic acids and derivatives, carbohydrates and derivatives, lipids and derivatives, vitamins, and others. Among all, lactose had the highest concentration, followed by mannitol, glycine, glycerophosphocholine, and myo-inositol. However, other metabolites are also essential for a kid's development and growth.

Kids' growth performance can be affected by many factors, including litter size, parity number, sex of kids, genetic factors, birth type, birth weight, nutrition, stage of growth, rearing system, dam weight, and dam body condition score during kidding (Faruque *et al.*, 2010; Hossain, 2021). This study showed that litter size and parity, but not kids' sex, affected kid growth. Litter size had a significantly negative effect on ADG0-4W, with a slight effect on wean weight. However, higher parity numbers tended to increase birth weight and wean weight. A previous study showed the same effect of litter size in which kids born from high numbers per litter had low body weight and ADG until 9 weeks compared to those born singly (Nuntapaitoon *et al.*, 2021). Moreover, male kids were bigger than females.

Table 1 Assignment table of 51 identified metabolites from 37 colostrum samples.

Metabolites	Concentration(mM)	Chemical shift in ^{1}H-NMR spectra*
Amino acids and derivatives		
Alanine	0.274 ± 0.035	1.48 (d), 3.79 (m)
Betaine	0.606 ± 0.038	3.28 (s), 3.91 (s)
Creatine	0.362 ± 0.026	3.04 (s), 3.92 (s)
Creatine phosphate	0.419 ± 0.029	3.04 (s), 3.97 (s)
Creatinine	0.362 ± 0.023	3.04 (s), 4.06 (s)
Glycine	4.113 ± 0.277	3.57 (s)
Isoleucine	0.340 ± 0.047	0.93 (d), 1.01 (d), 3.69 (d)
Leucine	0.516 ± 0.072	0.95 (d), 0.97 (d), 3.73 (m)
Methionine	0.189 ± 0.024	2.14 (s), 3.86 (m)
Proline	0.698 ± 0.095	2.06 (m), 3.43 (m)
Sarcosine	0.045 ± 0.006	2.73 (s), 3.61 (s)
Threonine	0.366 ± 0.049	1.33 (d), 3.62 (d)
Tyrosine	0.050 ± 0.006	3.21 (m), 3.96 (m)
Valine	0.248 ± 0.031	0.99 (d), 1.05 (d), 3.63 (d)
Organic acids and derivatives		
β-hydroxybutyrate	0.308 ± 0.044	1.23 (d)
Acetate	0.218 ± 0.026	1.93 (s)
Butyrate	0.309 ± 0.046	0.90 (t), 1.56 (m), 2.17 (t)
Citrate	0.870 ± 0.151	2.56 (d), 2.70 (d)
Fumarate	0.096 ± 0.054	6.52 (s)
Hippurate	0.174 ±0.011	7.56 (t), 7.84 (d)
Lactate	0.345 ±0.048	1.33 (d), 4.12 (m)
Malonate	0.121 ± 0.011	3.15 (s)
Pyruvate	0.148 ± 0.021	2.38 (s)
Succinate	0.076 ± 0.009	2.41 (s)
Threonate	0.931 ± 0.091	4.03 (d)
Valerate	0.294 ± 0.041	0.90 (t), 2.16 (t)
Carbohydrates and derivatives		
Levoglucosan	1.175 ± 0.109	3.54 (s), 4.08 (d), 5.47 (s)
Galactose	1.124 ± 0.099	3.50 (m), 3.81 (m), 5.27 (d)
Glucose	0.671 ± 0.054	3.40 (t), 3.49 (t), 3.90(m), 5.24 (d)
Lactose	41.37 ± 2.61	3.30 (t), 3.55 (m), 3.73(m), 3.95 (m), 4.45 (d), 5.24 (d)
Mannitol	6.027 ± 0.369	3.68 (m), 3.81 (d), 3.86 (m)
Myo-inositol	2.063 ± 0.131	3.54 (m), 3.61 (t), 4.05 (t)
N-Acetylglucosamine	0.153 ± 0.017	2.04 (s), 2.06 (s), 3.46 (m)
UDP-galactose	0.772 ± 0.061	4.04 (d), 5.64 (m), 5.97 (d), 7.96 (d)
UDP-glucose	0.734 ± 0.060	3.55 (m), 4.30 (s), 5.97 (d), 7.96 (d)
UDP-Acetylglucosamine	0.469 ± 0.052	5.52 (m), 5.97 (d), 7.96 (d)
Lipids and derivatives		
Acetyl-carnitine	0.136 ± 0.009	2.14 (s), 3.2 (s), 5.59 (m)
Carnitine	0.273 ± 0.025	3.21 (s), 3.40 (d), 3.41 (t)
Choline	0.798 ± 0.049	3.20 (s), 3.52 (m)
Glycerophosphocholine	2.470 ± 0.185	3.23 (s), 4.33 (m)
Phosphocholine	1.521 ± 0.098	3.23 (s), 3.62 (m), 4.20 (m)
Trimethylamine N-oxide	0.691 ± 0.053	3.28 (s)
Vitamins		
Vitamin B2 (Riboflavin)	0.083 ± 0.010	2.58 (s)
Vitamin B5 (Pantothenate)	0.278 ± 0.034	0.91 (s), 0.95 (s), 3.99 (s)
Vitamin B7 (Biotin)	0.266 ± 0.039	1.74 (m), 3.30 (m)
Vitamin C (Ascorbate)	1.477 ± 0.134	3.74 (m), 4.52 (d)
Others		
Acetone	0.064 ± 0.009	2.23 (s)
Adenine	0.152 ± 0.018	8.20 (s), 8.24 (s)
Ethanol	0.470 ±0.058	1.20 (t), 3.67 (m)
Hypoxanthine	0.116 ± 0.014	8.20 (s), 8.22 (s)
Uridine	0.361 ± 0.026	4.23 (t), 5.90 (d), 7.88 (d)

*: Metabolite signal was recorded with 3-(Trimethylsilyl) propionic-2, 2, 3, 3-d4 acid sodium salt (TSP) signal as internal standard at 0.00 ppm; (s): singlet, (d): doublet, (t): triplet, (m): multiplet peak.

Table 2 Univariate analysis shows the *P*-values between parameters and kid performance.

	Birth weight	*P*	ADG0-4W	*P*	ADG4-8W	*P*	Wean weight	*P*
Litter size								
Single	1.24 ± 0.06	0.519	93.96 ± 5.74	0.004	75.55 ± 5.63	0.086	7.78 ± 0.43	0.066
Multiple	1.38 ± 0.04		74.52 ± 2.87		64.56 ± 2.82		6.89 ± 0.21	
Parity number								
Primiparous	1.24 ± 0.06	0.062	76.19 ± 4.32	0.578	62.93 ± 4.50	0.305	6.54 ± 0.34	0.062
Multiparous	1.38 ± 0.04		79.46 ± 3.33		68.59 ± 3.11		7.32 ± 0.23	
Kid sex								
Male	1.33 ± 0.05	0.736	79.03 ± 3.98	0.829	68.78 ±3.72	0.455	7.15 ±0.28	0.678
Female	1.35 ± 0.05		77.84 ± 3.80		64.92 ± 3.55		6.99 ± 0.27	

Data are presented as least square mean ± standard error. ADG0–4W, Average daily gain between birth and 4 weeks; ADG4–8W, Average daily gain between 4 and 8 weeks.

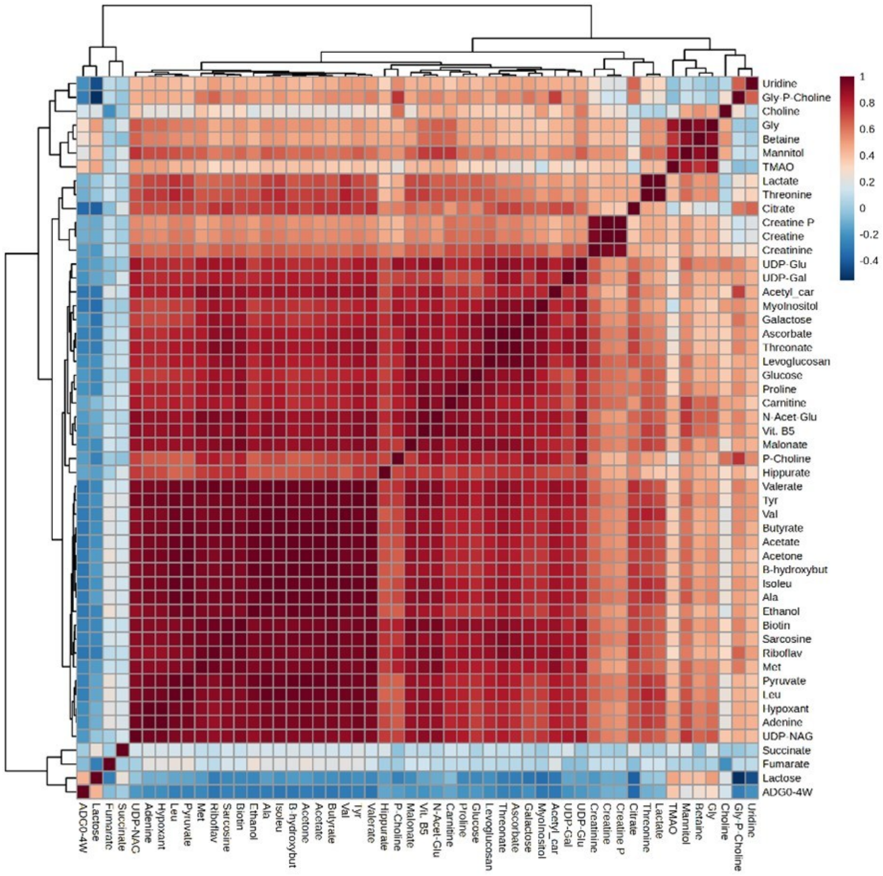

Figure 1 Correlogram of metabolite components in colostrum and kid growth performance at ADG0-4W with Pearson's correlation-based hierarchical clustering. Correlation coefficients are indicated in each colored cell on the map. The red and blue colors shown in the scale code on the top indicate positive and negative correlations, respectively. Gly-P-Choline = Glycerophosphocholine; Gly = Glycine; TMAO = Trimethylamine N-oxide; UDP-glu = UDP-glucose; UDP-gal = UDP-galactose; Acetyl_car = Acetylcarnitine; N-Acet-Glu = N-Acetylglucosamine; P-Choline = Phosphocholine; Tyr = Tyrosine; Val = Valine; B-hydroxybut = β-hydroxybutyrate; Isoleu = Isoleucine; Ala = Alanine; Riboflav = Riboflavin; Met = Methionine; Leu = Leucine; Hypoxant = Hypoxanthine; UDP-NAG = UDP-Acetylglucosamine; ADG0-4W = Average daily gain between birth and 4 weeks.

Table 3 Correlation coefficient (r) and *P*-values between macromolecule/metabolites in colostrum and kid growth performance (n = 65).

	ADG0-4W		ADG4-8W		Wean weight	
	r	*P*	r	*P*	r	*P*
Macronutrients						
Fat	-0.231	0.064	-0.252	0.043	-0.266	0.033
Protein	-0.400	< 0.001	-0.262	0.035	-0.358	0.003
Lactose	0.434	< 0.001	0.149	0.236	0.308	0.013
Metabolomic profiles						
Alanine	-0.287	0.021	-0.214	0.086	-0.305	0.014
Betaine	0.263	0.035	0.136	0.281	0.176	0.162
Glycine	0.303	0.014	0.081	0.520	0.164	0.192
Isoleucine	-0.304	0.014	-0.236	0.058	-0.326	0.008
Leucine	-0.272	0.028	-0.186	0.139	-0.279	0.025
Methionine	-0.242	0.052	-0.189	0.131	-0.276	0.026
Proline	-0.198	0.114	-0.173	0.168	-0.251	0.044
Sarcosine	-0.264	0.034	-0.183	0.145	-0.256	0.040
Tyrosine	-0.273	0.028	-0.226	0.070	-0.304	0.014
Valine	-0.293	0.018	-0.233	0.062	-0.307	0.013
β -hydroxybutyrate	-0.303	0.014	-0.207	0.099	-0.299	0.016
Acetate	-0.299	0.015	-0.217	0.082	-0.307	0.013
Butyrate	-0.303	0.014	-0.219	0.080	-0.312	0.011
Citrate	-0.356	0.004	-0.335	0.006	-0.335	0.006
Fumarate	-0.056	0.660	0.248	0.047	0.071	0.572
Pyruvate	-0.258	0.038	-0.155	0.217	-0.248	0.046
Threonate	-0.265	0.033	-0.238	0.056	-0.289	0.020
Valerate	-0.307	0.013	-0.250	0.045	-0.334	0.007
Galactose	-0.208	0.010	-0.218	0.081	-0.244	0.049
Myo-inositol	-0.302	0.015	-0.160	0.203	-0.226	0.071
UDP-galactose	-0.202	0.106	-0.250	0.045	-0.231	0.064
Acetyl-carnitine	-0.302	0.014	-0.286	0.021	-0.366	0.003
Glycerophosphocholine	-0.276	0.026	-0.362	0.003	-0.402	0.001
Trimethylamine N-oxide	0.372	0.002	0.070	0.582	0.169	0.178
Vitamin B2 (Riboflavin)	-0.309	0.012	-0.270	0.030	-0.347	0.005
Vitamin B5 (Pantothenate)	-0.201	0.108	-0.166	0.188	-0.265	0.033
Vitamin B7 (Biotin)	-0.273	0.028	-0.170	0.177	-0.281	0.023
Vitamin C (Ascorbate)	-0.269	0.030	-0.244	0.050	-0.288	0.020
Acetone	-0.278	0.025	-0.166	0.187	-0.269	0.030
Ethanol	-0.294	0.017	-0.200	0.111	-0.312	0.011
Uridine	-0.204	0.103	-0.304	0.014	-0.253	0.042

Table 4 Effect of metabolite concentrations on kid growth performances using a generalized linear mixed model procedure (only significant metabolites with *P* < 0.05 are shown).

	ADG0-4W	ADG4-8W	Wean weight
Macromolecular nutrients			
Protein			
High (> 16.34 %)	78.15 ± 4.10	67.05 ± 4.41	6.94 ± 0.31
Low (≤ 16.34 %)	91.32 ± 4.18*	70.10 ± 4.49	7.72 ± 0.31
Lactose			
High (> 2.89 %)	92.27 ± 3.47	69.69 ± 4.27	7.73 ± 0.28
Low (≤ 2.89 %)	72.70 ± 4.12***	66.80 ± 4.94	6.72 ± 0.34*
Metabolomic profiles			
Fumarate			
High (> 0.073 mM)	67.76 ± 6.74	62.81 ± 7.04	6.44 ± 0.50
Low (≤ 0.073 mM)	87.77 ± 3.38**	69.69 ± 3.64	7.50 ± 0.25
Malonate			
High (> 0.118 mM)	76.96 ± 4.65	65.48 ± 4.78	6.87 ± 0.34
Low (≤ 0.118 mM)	90.40 ± 4.16*	70.92 ± 4.32	7.67 ± 0.30
Glucose			
High (> 0.666 mM)	78.41 ± 4.35	69.18 ± 4.46	7.07 ± 0.32
Low (≤ 0.666 mM)	90.57 ± 4.30*	67.86 ± 4.40	7.55 ± 0.31
Myo-inositol			
High (> 2.155 mM)	75.35 ± 5.18	63.83 ± 5.32	6.86 ± 0.38
Low (≤ 2.155 mM)	88.34 ± 3.70*	70.47 ± 3.80	7.51 ± 0.27
Vitamin B2			
High (> 0.083 mM)	77.49 ± 4.45	66.19 ± 4.63	6.90 ± 0.32
Low (≤ 0.083 mM)	90.77 ± 4.20*	70.63 ± 4.32	7.69 ± 0.31
Vitamin B7			
High (> 0.265 mM)	78.38 ± 4.46	68.45 ± 4.58	7.10 ± 0.33
Low (≤ 0.265 mM)	89.92 ± 4.21*	68.57 ± 4.33	7.54 ± 0.31

Data are presented as least square mean ± standard error. * = *P* < 0.05; ** = *P* < 0.01; *** = *P* < 0.001 compared with high concentrations using MIXED GLM procedure.

The aforementioned differences may have been due to a previous study that investigated goats of three different genotypes (Saanen, BB, and their crossbred), and the sample size was larger compared to the present study.

The ADG0-4W correlated positively with lactose but negatively with protein. Kids consumed high lactose, but low protein also had high ADG0-4W. Glucose was converted from lactose and fat in colostrum to be a main source of energy after birth (Hammon *et al*., 2013). The energy source in neonatal kids is shifted from glucose that is supplied via the placenta to glucose received from suckling colostrum while glycogenolysis and gluconeogenesis start to be developed (Steinhoff-Wagner *et al*., 2011a). An increase in plasma glucose in kids occurred after the first colostrum consumption (Steinhoff-Wagner *et al*., 2011b).

Rather than the role of lactose in providing glucose for kids, it was also the substrate that determines the colostrum yield by osmotic effect. It has been reported that lactose is one of the most important osmolytes. Low lactose results in low water component, high viscosity, and low yield (McGrath *et al*., 2016). When colostrum was transitioned to milk, lactose increased, as shown previously in BB goats (Buranakarl *et al*., 2021). It is proposed that higher lactose in milk will pull water inside the udder, thereby making a higher yield than colostrum. The association between colostrum yield and lactose was previously demonstrated in Holstein cattle (Soufleri *et al*., 2021). Increased colostrum lactose concentration has been observed with greater colostrum yield after nutrient supplementation in late gestation in sheep (Banchero *et al*., 2004a; Banchero *et al*., 2004b; Olivera-Muzante *et al*., 2022) and cow (Hare *et al*., 2021). Nevertheless, no effect of lactose on yield was found in cows (Zarei *et al*., 2017) and sow (Szyndler-Nedza *et al*., 2020).

Not only lactose but also other metabolites such as betaine, glycine, and TMAO showed positive relationships with ADG0-4W. These metabolites are the osmolyte molecules (Liao *et al*., 2017). Betaine was the highest on the first day postpartum and decreased to its lowest level on day 5 (O'Callaghan *et al*., 2020). Betaine not only provides three methyl groups for the synthesis of many substances, such as creatine and carnitine, but also acts as an organic osmolyte in the cell (de Velt *et al*., 2016).

Negative relationships were found between lactose and protein. Similar results were previously shown in goats (Zhou *et al*., 2023). It is suggested that colostrum yield may dilute the protein component. Although the positive effect of IgG on kids' growth 1 month postpartum was previously reported (Buranakarl *et al*., 2021), the negative association for total protein in the present study may be due to other protein components besides IgG, such as casein, which was diluted when colostrum yield was high. For fat, no relationships with lactose or kid's growth were found, although the roles of fat in colostrum on nutrient absorption, carrier of vitamins, and source of fatty acid to maintain body temperature, growth, and immunity were reported (Zhou *et al*., 2023). However, the controversy was found in sows wherein piglets fed colostrum of low lactose with increased fat and protein contents had higher body weight during the first 3 weeks of age (Szyndler-Nedza *et al*., 2020). Thus, the differences may be due to species of animals or protein and fat in colostrum, which may be dominant in the sow.

Lactose had negative relationships with most metabolites. When growth rate was analyzed using litter size, parity number, and birth weight as covariates, kids in the low metabolites (fumarate, malonate, glucose, myoinositol, vitamin B2, and vitamin B7) group had higher ADG0–4W than those of high metabolite group. The reason was proposed to be due to a higher intake of colostrum in the low metabolite group. These metabolites, however, contribute significantly to the energy source for kids' growth, while fatty acid and ketone bodies may be considered a minority. Fumarate is an organic compound that is involved in the TCA cycle, but the information on its role in newborn child development is still limited. Malonate is an intermediate product of malonyl CoA and is a potent inhibitor of carnitine palmitoyl transferase I in fatty acid β-oxidation (Sun *et al*., 2017). In maternal plasma, it varies at different time points and may be related to amino acid and lipid metabolism (Honda *et al*., 2009). Whether malonate was leaked during colostrogenesis and its role in newborns was obscured. The glucose homeostasis in neonates can be partly regulated by some bioactive agents in colostrum (Savino *et al*., 2011). Moreover, it is suggested that increased glucose in colostrum is important to accelerate the somatotrophic axis and maturation (Hammon *et al*., 2012). Myo-inositol is a precursor of phosphatidylinositol, which is a lipotrophic nutrient, and it promotes brain development in humans (Paquette *et al*., 2023). Vitamin B cannot be synthesized in newborn ruminants, but it is received from colostrum (Duplessis and Girard, 2019). For water-soluble vitamins, orotic acid (vitamin B13) was reported to be the lowest in colostrum and increased to the highest on day 5 postpartum (O'Callaghan *et al*., 2020), while its role in the regulation of genes important for growth and development was found (Loffler *et al*., 2016). However, the role of vitamin B2 and B7 on growth needs to be studied further.

Unlike in ruminants, acetate and taurine in the colostrum of a sow were positively related to litter weight gain and piglet survival, respectively (Picone *et al*., 2018). These amino acids may play some role as substrates for the biosynthesis of cholesterol or long-chain fatty acids and for fat digestion and absorption of piglets.

It should be mentioned that this study had some limitations. Some samples of colostrum were collected a few hours after delivery, which may have influenced the birth weight due to consumption by the kids. Since kids were staying with their mothers, the colostrum yield and the feed intake of kids were not recorded. Although this study was conducted during the summer and the early rainy season, no significant hourly temperature differences were observed between the months. Therefore, the temperature should have minimal effects on our results.

It is concluded that kids who consumed colostrum containing high lactose content with a low concentration of metabolites had high growth performance during one month after parturition. It is hypothesized that lactose in colostrum may reflect the yield and adequacy of colostrum consumption, which determines the growth rate at the first month postpartum.

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