Effects of Milk Replacers with Different Fatty Acid Sources on Growth Performance and Nutrient Digestion and Metabolism in Pre-weaned Calves: Postprint

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Abstract

This experiment investigated the effects of replacing milk fat in milk replacer with coconut oil and palm oil on growth performance and nutrient digestion and metabolism in preweaned calves. Sixty newborn Holstein bull calves were randomly assigned to five groups and fed one of five isonitrogenous and isoenergetic milk replacers differing in fat source: 1) fat in the milk replacer was entirely derived from milk fat; 2) fat in the milk replacer was 50% from coconut oil and 50% from milk fat; 3) fat in the milk replacer was 100% from coconut oil; 4) fat in the milk replacer was 50% from palm oil and 50% from milk fat; and 5) fat in the milk replacer was 100% from palm oil. The experimental period was 56 days. The results showed that: 1) replacement of milk fat with coconut oil or palm oil at 50% and 100% levels had no significant effect on average daily gain, dry matter intake, feed conversion ratio, or diarrhea rate in calves aged 14-56 days ($P>0.05$); 2) replacement of milk fat with coconut oil or palm oil at 50% and 100% levels had no significant effect on serum concentrations of total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, or free fatty acids in preweaned calves ($P>0.05$); 3) replacement of milk fat with coconut oil or palm oil at 50% and 100% levels had no significant effect on apparent digestibility of dry matter, organic matter, crude fat, calcium, and phosphorus, or on energy utilization rate in preweaned calves ($P>0.05$). These results indicate that although replacement of milk fat with coconut oil and palm oil altered the fatty acid composition of the milk replacer, milk replacers with different fatty acid compositions had no significant effect on growth performance or nutrient digestion and metabolism in preweaned calves.

Full Text

Effects of Different Fatty Acid Sources in Milk Replacer on Growth Performance, Digestion and Metabolism of Sucking Calves

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Abstract

This study investigated the effects of replacing butterfat in milk replacer with coconut oil or palm oil on the growth performance and nutrient digestion and metabolism of suckling calves. Sixty newborn Holstein bull calves were randomly assigned to five groups and fed isonitrogenous and isoenergetic milk replacers with different fat sources: 1) butterfat as the sole fat source; 2) 50% butterfat replaced by coconut oil; 3) 100% butterfat replaced by coconut oil; 4) 50% butterfat replaced by palm oil; and 5) 100% butterfat replaced by palm oil. The trial lasted 56 days. The results showed that: 1) replacement of butterfat with coconut oil or palm oil at 50% or 100% levels did not significantly affect average daily gain, dry matter intake, feed conversion ratio, or diarrhea rate in calves aged 14–56 days ($P>0.05$); 2) serum total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and free fatty acid concentrations were not significantly affected by the replacement ($P>0.05$); 3) apparent digestibility of dry matter, organic matter, ether extract, calcium, and phosphorus, as well as energy utilization efficiency, were not significantly affected by the replacement ($P>0.05$). These findings indicate that while coconut oil and palm oil altered the fatty acid composition of milk replacer, milk replacers with different fatty acid compositions had no significant effects on the growth performance or nutrient digestion and metabolism of suckling calves.

Keywords: sucking calf; coconut oil; palm oil; milk replacer; growth performance; digestion and metabolism

Introduction

The digestive and immune systems of suckling calves are not fully developed, and they primarily rely on innate immunity to resist pathogenic infections [1-2]. The National Animal Health Monitoring System (NAHMS) in the United States reported that pre-weaning calf mortality ranges from 6.4% to 10.8%, posing significant challenges to calf rearing. Adequate protein and energy supply is crucial for calf health and growth during the suckling period. As an energy source, fat is essential for calf development, with approximately 35% of digestible energy intake derived from digestible fat in milk replacer [3]. Garcia et al. [4] found that replacing coconut oil with soybean oil improved calf growth performance

and immune status to some extent. Hill et al. [5] reported that adding linseed oil calcium salts to milk replacer or starter feed to provide linolenic acid (C18:3) significantly increased average daily gain (ADG) and feed conversion ratio (FCR) in calves under three months of age. Bowen et al. [6] modified the fatty acid composition of milk replacer and found that medium-chain fatty acids offered potential benefits for calf growth performance and health. These studies suggest that different fat sources or fatty acid compositions can differentially affect calf growth performance and nutrient digestion and metabolism, with medium-chain fatty acids (MCFA) or functional essential fatty acids (EFA) potentially exerting growth-promoting effects. However, research on fat levels and fatty acid composition in calf diets remains limited, and studies on the application of coconut oil and palm oil during the suckling period are particularly scarce.

Coconut oil and palm oil are natural plant oils extracted from fruits of the Arecaceae family. Global annual supply of coconut oil and palm oil ranged from 5.18–6.63 million tons and 77.82–120.09 million tons, respectively, between 2007–2017 [7], accounting for 2.5% and 38% of vegetable oil production. Oil palm plantations occupy 5% of the world' s oil crop cultivation area [8], and palm oil has surpassed soybean oil to become the leading vegetable oil globally.

Coconut oil is rich in C6–C12 fatty acids (MCFA), with lauric acid (C12:0) being the most abundant at 45–53% of total fatty acids. Many studies have attributed the properties of coconut oil to its lauric acid content [9-10]. Palm oil contains abundant saturated fatty acids, primarily palmitic acid (C16:0), and compared to coconut oil, has higher contents of oleic acid (C18:1) and linoleic acid (C18:2) [11]. Whole milk powder, produced by drying breast milk, retains its nutritional composition and has a more diverse fatty acid profile than plant oils. Its myristic acid (C14:0) content is similar to that of coconut oil, while long-chain fatty acids are dominated by C16:0 and stearic acid (C18:0) at lower levels than in palm oil. Unsaturated fatty acids are primarily oleic acid and -linolenic acid (C18:3, ALA), with ALA content higher than in coconut and palm oils. MCFA in coconut oil are digested more rapidly than long-chain fatty acids (LCFA, >14 carbons) in other plant oils [9-10], and medium-chain triglycerides (MCT) undergo higher oxidative metabolism in the liver than long-chain triglycerides (LCT) [12], suggesting potentially superior utilization of MCFA compared to LCFA. Mills et al. [13] found that feeding coconut oil increased fat deposition in calf liver and carcass. Adequate essential nutrient supply benefits normal growth of newborn calves [4]. Linoleic acid and -linolenic acid are essential fatty acids, with appropriate levels promoting pre-weaning calf growth, improving immune function, and enhancing feed efficiency [4-5,14]. China faces shortages of dairy products for feed production and relies heavily on imports; thus, using alternative raw materials represents a promising approach for developing specialized diets for young livestock. This study investigated the effects of replacing butterfat in milk replacer with coconut oil and palm oil, thereby altering fatty acid composition, on the growth performance and nutrient digestion and metabolism of suckling calves, providing a reference for plant oil application in calf diets.

1.1 Experimental Period and Location

The experiment was conducted from September to December 2016 at Wangjia Dairy Farm in Beixiaoying Town, Shunyi District, Beijing.

1.2 Experimental Design

This study employed a single-factor experimental design. Under isonitrogenous and isoenergetic conditions, butterfat from whole milk powder was partially replaced with fat from coconut oil or palm oil to formulate five milk replacers with different fat sources: 1) butterfat as the sole fat source (W100 group); 2) 50% butterfat replaced by coconut oil (C50 group); 3) 100% butterfat replaced by coconut oil (C100 group); 4) 50% butterfat replaced by palm oil (P50 group); and 5) 100% butterfat replaced by palm oil (P100 group). All groups had consistent crude protein (CP), gross energy (GE), and ether extract (EE) levels appropriate for normal growth at this stage (CP 24%, GE 19%, EE 12%) [16]. Milk replacers were provided by Beijing Precision Animal Nutrition Research Center (National Invention Patent CN 02128844.5). Starter feed was a mixed pellet (0.32 cm diameter) suitable for pre-weaning calves, containing 22% CP and 4% EE, provided by Beijing Sanyuan Hefeng Animal Husbandry Co., Ltd. The composition and nutrient levels of milk replacers are shown in Table 1 , starter composition in Table 2 , and fatty acid composition of whole milk powder, coconut oil, palm oil, and milk replacers in Table 3 . Coconut oil and palm oil were spray-dried and coated with maltose syrup and casein (final product contained 14% maltose and 3% casein).

Table 1 Composition and Nutrient Levels of Milk Replacers

Group, Ingredients (air-dry basis), Whole milk powder, Coconut oil powder, Palm oil powder, Skim milk powder, Whey protein concentrate, Others, Total, Nutrient levels (DM basis), Dry matter, Crude protein, Organic matter, Gross energy (MJ/kg), Ether extract

Others contain premix, carrier without butterfat, and protein without vegetable origin. The premix provides per kg of milk replacer powder: VA 15,000 IU, VD3 5,000 IU, VE 50 g, Lysine 22 g, Methionine 5 g, Fe 120 mg, Cu 8 mg, Mn 80 mg, Zn 80 mg, Se 0.3 mg, I 1.0 mg, Co 0.3 mg.

Table 2 Composition and Nutrient Levels of Starter Feed

Item, Content, Ingredients (air-dry basis): Corn, Extruded corn, Flour, Soybean meal, Extruded soybean, Wheat bran, Soybean molasses, DDGS, Glucose, Dried whey powder, Limestone, CaHPO4, NaCl, Premix1), Total, Nutrient levels (DM basis): Dry matter, Crude protein, Organic matter, Gross energy (MJ/kg), Ether extract, Neutral detergent fiber, Acid detergent fiber

1) The premix provided per kg of starter: VA 15,000 IU, VD 5,000 IU, VE 50 mg, Fe 90 mg, Cu 12.5 mg, Mn 60 mg, Zn 100 mg, Se 0.3 mg, Co 0.5 mg.

Table 3 Fatty Acid Composition of Whole Milk Powder, Coconut Oil, Palm Oil, and Milk Replacers

Whole milk powder1), Coconut oil1), Palm oil1), Group2), Total fatty acids TFA3), Percentage of TFA: Caproic acid C6:0, Caprylic acid C8:0, Capric acid C10:0, Lauric acid C12:0, Myristic acid C14:0, Pentadecanoic acid C15:0, Pentadecenoic acid C15:1, Palmitic acid C16:0, Palmitoleic acid C16:1, Margaric acid C17:0, Stearic acid C18:0, Oleic acid C18:1, Linoleic acid C18:2, Linolenic acid C18:3, Arachidic acid C20:0, Eicosenoic acid C20:1, Behenic acid C22:0, Lignoceric acid C24:0, Other, Total, Medium-chain fatty acids MCFA, Saturated fatty acids SFA, Unsaturated fatty acids UFA, UFA/SFA ratio, Monounsaturated fatty acids MUFA, Polyunsaturated fatty acids PUFA, n-6 PUFA, n-3 PUFA, n-6/n-3 ratio

1) Analyzed values. 2) Calculated values. 3) Contents in materials or milk replacers.

1.3 Experimental Animals and Management

Sixty healthy Holstein bull calves of identical parity and breed were selected and randomly divided into five groups of 12 calves each. Calves received adequate colostrum within 2 h of birth and were fed colostrum and whole milk from days 1–5. On day 6, they were transported to the experimental facility and housed by group in pens (6 m × 8 m) with 12 feeding stalls for individual feeding of milk replacer and starter feed. Days 7–14 served as a pre-trial period for milk replacer transition, with days 14–56 as the formal experimental period. Pens were cleaned and disinfected weekly to maintain hygiene. Milk replacer powder was mixed with warm water (50–60 °C) at a ratio of 1:7 (mass:volume) and fed at (39 ± 1) °C. Calves were fed three times daily before day 21 and twice daily from day 21 onward. Milk replacer was provided at 1.2% of body weight (DM basis) and adjusted every two weeks. Starter feed was offered ad libitum from day 14, with free access to water. Daily maximum and minimum temperatures were recorded (Figure 1 [Figure 1: see original paper]).

1.4 Sample Collection and Measurement

Figure 1 Environment temperature

1.4.1 Diet Sample Collection and Measurement During the trial, daily samples of milk replacer and starter feed were collected and stored at -4 °C. After the experiment, samples were pooled and analyzed according to AOAC (2000) [17]. Crude protein was determined using a Kjeltec-8420 FOSS automatic protein analyzer (AOAC Official Method 942.05), ether extract using an ANKOM-XT15i automated fat analyzer (AOAC Official Method 920.39), crude ash using a muffle furnace (AOAC Official Method 942.05), neutral detergent fiber (NDF) and acid detergent fiber (ADF) using a fiber digestion furnace (AOAC Official Method 2002.04 and 973.18), calcium using a TAS-986S atomic

absorption spectrophotometer (AOAC Official Method 927.02), and phosphorus using a MAPADA UV-6100PC UV-Vis spectrophotometer (AOAC Official Method 965.17). Gross energy was measured using a PARR-6400 automatic oxygen bomb calorimeter. Fatty acid content in whole milk powder, coconut oil powder, and palm oil powder was determined by gas chromatography (Agilent 7890N) according to GB/T 21514-2008.

1.4.2 Growth Performance Measurement Daily intake of milk replacer and starter feed was recorded to calculate dry matter intake (DMI) and feed conversion ratio. Body weight was measured before morning feeding on days 14 and 56, with wither height, heart girth, and body length also determined. Fecal consistency was monitored continuously from 07:00 to 18:00 daily and scored based on shape, color, and consistency: 1 = normal, formed or pelleted; 2 = normal, soft but formed; 3 = abnormal, unformed, loose; 4 = abnormal, watery, normal color; 5 = abnormal, watery, abnormal color [15]. Scores 3 were considered diarrhea. Diarrhea rate and fecal index were calculated as follows [18]:

Diarrhea rate (%) = 100 × number of diarrheic calves / total number of calves
Fecal index = sum of fecal scores / total number of calves

1.4.3 Blood Sample Collection and Measurement Six calves per group with body weight close to the group mean were selected. On day 56, jugular blood (10 mL) was collected into vacuum coagulation-promoting tubes before morning feeding, centrifuged at 3,000 r/min for 10 min, and serum stored at -20 °C. Serum total cholesterol (TC), triglycerides (TG), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), and non-esterified fatty acids (NEFA) were measured. TC was determined by oxidase method, TG by glycerol phosphate oxidase method, HDL-C and LDL-C by direct method, and NEFA by double-antibody sandwich ELISA using a KHB-1280 automatic biochemical analyzer with kits from Shanghai Kehua Bioengineering Co., Ltd.

1.4.4 Digestion and Metabolism Measurement At 42 days of age, six calves per group with body weight close to the group mean were selected for a total fecal and urine collection trial lasting 7 days (3-day adaptation, 4-day collection). Daily feed intake, fecal output, and urine volume were recorded. Ten percent of total feces was collected as a composite sample, with 10 mL of 10% H2SO4 added per 100 g fresh feces for nitrogen fixation. One percent of total urine was collected as a composite sample, adjusted to pH 3 with 10% H2SO4. Samples were stored at -20 °C for analysis. Fecal CP, EE, ash, NDF, ADF, Ca, and P were determined by AOAC (2000) [17], and fecal and urine energy by automatic oxygen bomb calorimetry. Energy and nitrogen metabolism indices were calculated as:

Digestible energy [MJ/(kg W^0.75 · d)] = Gross energy intake - Fecal energy

Metabolizable energy [MJ/(kg W^0.75·d)] = Gross energy intake - Fecal energy - Urine energy - Methane energy
Apparent digestibility of gross energy (%) = Digestible energy / Gross energy intake
Metabolic rate of gross energy (%) = Metabolizable energy / Gross energy intake
Metabolic rate of digestible energy (%) = Metabolizable energy / Digestible energy

Methane energy was calculated as 8% of gross energy intake [19].

1.5 Statistical Analysis

Data for ADG, DMI, feed conversion ratio, body measurements, fecal index, diarrhea rate, serum indices, and digestion/metabolism were analyzed using ANOVA in SAS 9.4. When significant differences were detected, Duncan' s multiple range test was applied. $P < 0.05$ indicated significant difference, and $0.05 \quad P < 0.10$ indicated a significant trend.

2.1.1 Growth Performance

As shown in Table 4 , no significant differences were observed among groups in initial weight, final weight, ADG, milk replacer intake, starter intake, total DMI, or feed conversion ratio ($P > 0.05$). However, numerically, ADG and feed conversion ratio in C100 and P100 groups were lower than in W100, C50, and P50 groups. Compared to W100 and C50 groups, ADG in C100 group decreased by 16.4% and 11.7%, respectively, while ADG in P100 group decreased by 21.8% and 11.9% compared to W100 and P50 groups. Feed conversion ratio in C100 group decreased by 17.2% and 12.7% compared to W100 and C50 groups, and in P100 group decreased by 19.0% and 7.8% compared to W100 and P50 groups.

Table 4 Effects of Coconut Oil and Palm Oil on Growth Performance of Sucking Calves

Group, Initial weight (kg), Final weight (kg), ADG (g/d), Milk replacer intake (g/d), Starter intake (g/d), DMI (g/d), Feed conversion ratio, P-value

Values in the same row with different lowercase superscripts differ significantly ($P < 0.05$), while those with the same or no superscripts do not differ significantly ($P > 0.05$). The same applies below.

2.1.2 Body Measurements

As shown in Table 5 , no significant differences were observed among groups in initial values or changes in wither height, body length, or hip width ($P > 0.05$). Initial heart girth in W100 group was significantly lower than in other groups ($P < 0.05$), but no significant differences were found in heart girth at day 56 or in heart girth gain from days 14–56 ($P > 0.05$).

Table 5 Effects of Coconut Oil and Palm Oil on Body Measurements of Sucking Calves

Item, Wither height, Heart girth, Body length, Hip width, Days of 14–56, Group, P-value

2.1.3 Fecal Index and Diarrhea Rate

As shown in Table 6 , no significant differences were observed among groups in fecal index or diarrhea rate ($P > 0.05$). Numerically, compared to W100 group, fecal index and diarrhea rate in C50 group decreased by 5.3% and 26.7%, respectively, and in P50 group decreased by 5.9% and 3.4%, respectively. Diarrhea rates in C100 and P100 groups increased by 26.7% and 10.0% compared to W100 group.

Table 6 Effects of Coconut Oil and Palm Oil on Fecal Index and Diarrhea Rate of Sucking Calves

Item, Fecal index, Diarrhea rate (%), Group, P-value

2.2 Effects of Coconut Oil and Palm Oil on Serum Biochemical Indices

As shown in Table 7 , no significant differences were observed among groups in serum TC, TG, HDL-C, LDL-C, or NEFA concentrations ($P > 0.05$). Numerically, P100 group had lower serum TC, HDL-C, and LDL-C concentrations than other groups.

Table 7 Effects of Coconut Oil and Palm Oil on Serum Biochemical Indices of Sucking Calves

Item, TC (mmol/L), TG (mmol/L), HDL-C (mmol/L), LDL-C (mmol/L), FFA (mol/L), Group, P-value

2.3 Effects of Coconut Oil and Palm Oil on Nutrient Digestion and Metabolism

As shown in Table 8 , no significant differences were observed among groups in DMI or fecal output ($P > 0.05$). Apparent digestibility of DM, CP, OM, Ca, and P also did not differ significantly ($P > 0.05$). However, EE apparent digestibility in P100 group showed a decreasing trend compared to other groups ($P = 0.063$).

Table 8 Effects of Coconut Oil and Palm Oil on Digestion and Metabolism of Sucking Calves

DMI (kg/d), Fecal output (kg/d), Apparent digestibility (%): DM, CP, OM, EE, Group, P-value

2.4 Effects of Coconut Oil and Palm Oil on Energy Utilization

As shown in Table 9 , no significant differences were observed among groups in gross energy intake, fecal energy, urine energy, digestible energy, metabolizable energy, gross energy digestibility, gross energy metabolic rate, or digestible energy metabolic rate (P > 0.05). Fecal energy in P100 group showed an increasing trend (P = 0.084), while gross energy digestibility showed a decreasing trend (P = 0.067).

Table 9 Effects of Coconut Oil and Palm Oil on Energy Utilization Rate of Sucking Calves

GEI [MJ/(kg W^0.75 · d)], FE [MJ/(kg W^0.75 · d)], UE [MJ/(kg W^0.75 · d)], DE [MJ/(kg W^0.75 · d)], ME [MJ/(kg W^0.75 · d)], GE digestibility (%), Metabolic rate of GE (%), Metabolic rate of DE (%), Group, P-value

3.1 Effects of Coconut Oil and Palm Oil on Growth Performance of Sucking Calves

Calves undergo rapid growth and development from birth to weaning, with insufficient body fat stores and high energy demands [20]. Appropriate energy supply is a key factor ensuring normal development. Dietary fat addition is closely related to energy requirements, and further research indicates that calf growth and health status are associated with fat or fatty acid composition. Jenkins et al. [20] and Hill et al. [5,21] found that different dietary fat sources or fatty acids affected growth performance and immune function in suckling calves. Karcher et al. [14] reported that adding 2% flaxseed oil or 2% fish oil to milk replacer, compared to lard, did not significantly affect ADG, feed conversion ratio, fecal scores, or hip width in suckling calves, but flaxseed oil supplementation increased dietary n-3 polyunsaturated fatty acids (PUFA) and reduced gene expression of pro-inflammatory cytokines such as osteopontin and interleukin-8 (IL-8). n-3 PUFA are defined as fatty acids with the first double bond at the third carbon from the methyl end. Based on double bond positions, PUFA include n-6, n-7, and n-9 series, with n-3 and n-6 PUFA being essential fatty acids with important biological functions. n-3 PUFA regulate immune cell proliferation, activation, cytokine production, and immune responses, and studies in humans and animals have confirmed their role in improving atherosclerosis, coronary heart disease, inflammatory diseases, and behavioral disorders [22]. Docosahexaenoic acid (DHA, C22:6) is an important n-3 PUFA derived from -linolenic acid and a major component of membrane phospholipids, with research linking DHA to brain development and retinal function [23]. Studies in suckling calves have shown that increasing dietary -linolenic acid increased ADG and feed conversion ratio [14]. n-6 PUFA have both pro- and anti-inflammatory effects, possibly dose-dependent, with studies showing that linoleic acid and arachidonic acid (AA) can exert both actions [24].

In this study, replacing butterfat with coconut oil and palm oil reduced n-3 PUFA content while increasing n-6 PUFA content and total PUFA in milk

replacer, yet calf growth performance and diarrhea were not improved, possibly due to low PUFA supplementation levels. Garcia et al. [4] reported that optimal supplementation levels for 1–30-day-old Holstein calves were 3–5 g/d linoleic acid and 0.3–0.6 g/d -linolenic acid, which improved growth performance and immune function. In this experiment, supplementation levels were: W100 group (0.6 g/d linoleic acid, 0.6 g/d -linolenic acid), C50 group (0.9 g/d linoleic acid, 0.3 g/d -linolenic acid), C100 group (1.3 g/d linoleic acid, 0.1 g/d -linolenic acid), P50 group (3.2 g/d linoleic acid, 0.3 g/d -linolenic acid), and P100 group (5.6 g/d linoleic acid, 0.1 g/d -linolenic acid), all below the optimal levels. Advanced research on PUFA physiological functions has revealed that not only PUFA content but also the n-6/n-3 balance significantly affects growth and immune performance. This study showed no significant differences in ADG, feed conversion ratio, or diarrhea rate among groups, but numerically lower ADG and feed conversion ratio and higher diarrhea rates in C100 and P100 groups with high n-6/n-3 ratios (19.75 and 49.62) compared to W100, C50, and P50 groups with lower ratios. This aligns with reports by Gao et al. [24] and Pilevar et al. [25]. Leskanich et al. [26] reported the optimal linoleic/ -linolenic acid ratio was 10:1 in pig diets, while Klein et al. [27] reported 6:1 for infants. Although no significant differences were observed among groups in this study, suggesting ruminants may have greater tolerance for n-6/n-3 PUFA balance than monogastrics, numerically superior growth was observed in groups with n-6/n-3 ratios of 1.05–10.89 compared to higher ratios. Hill et al. [5] also found that linoleic/ -linolenic acid ratios of 7.8 and 10.9 produced significantly higher ADG than a ratio of 17.9 in calves.

C50 and C100 groups had higher MCFA content than W100 group. Wang et al. [28] reported that MCFA or MCT promoted growth, improved feed conversion ratio, reduced mortality, and improved gut microbiota structure in suckling piglets. Price et al. [29] found that 12% dietary MCT supplementation reduced growth performance. Wang [30] reported that replacing soybean oil with varying proportions of coconut oil did not significantly affect growth or feed utilization in broilers. Thus, current results on MCFA effects on animal growth performance are inconsistent, possibly related to experimental animals and dietary MCFA levels. In this study, differences in MCFA content from coconut oil and palm oil replacement did not significantly affect calf growth performance. Mills et al. [13] found that replacing 2% butterfat with coconut oil increased liver and carcass fat deposition without affecting growth performance. Wen et al. [31] reported that replacing soybean oil with palm oil did not significantly affect weight gain, feed conversion ratio, or survival rate in juvenile tilapia. Ren [32] found that feeding 6% soybean oil, 6% palm oil, 7.5% powdered palm oil, or 7.5% powdered coconut oil to suckling piglets did not significantly affect weight gain, average daily intake, or feed conversion ratio. These results are consistent with our findings. In summary, replacing butterfat with coconut oil and palm oil altered MCFA and PUFA levels in milk replacer without significantly affecting calf growth performance, possibly due to complementary effects among different fatty acids.

3.2 Effects of Coconut Oil and Palm Oil on Serum Biochemical Indices

Blood lipid concentrations are closely related to dietary fat composition and metabolism, and measuring them can reflect dietary effects on lipid metabolism. Studies have confirmed that blood lipid concentrations are affected by dietary fat levels, with high-fat diets increasing blood lipids [33]. When dietary fat levels are constant, fat source and fatty acid composition also have important effects. Compared to LCFA, MCFA can effectively reduce LDL-C and TG concentrations in hyperlipidemic patients [34]. PUFA have lipid-lowering effects, with n-3 PUFA reported to reduce TG, TC, LDL-C, VLDL-C, and increase HDL-C [35]. Zhang et al. [36] found that n-6 PUFA also significantly reduced serum TG and TC while increasing HDL-C in hyperlipidemic rats. The mechanism may involve PUFA activation of hepatic peroxisome proliferator-activated receptor alpha (PPAR), which stimulates fatty acid -oxidation and glucose metabolism and regulates cholesterol and body fat metabolism [37], thereby reducing blood lipids. Liu et al. [38] reported that feeding 10% coconut oil, 10% fish oil, or 10% lard to weaned piglets significantly reduced serum TG and TC in the PUFA-rich fish oil group. Ren [32] found that adding palm oil powder, coconut oil powder, or soybean oil to piglet diets did not significantly affect serum TG, TC, LDL-C, or HDL-C concentrations on days 22 and 33. This study showed that replacing butterfat with coconut oil or palm oil altered milk replacer fatty acid composition without significantly changing calf serum TC, TG, HDL-C, LDL-C, or NEFA concentrations, consistent with growth performance results. Further studies are needed to clarify the effects of coconut oil or palm oil in calf milk replacer on lipid metabolism.

3.3 Effects of Coconut Oil and Palm Oil on Nutrient Digestion and Metabolism

The digestive system of suckling calves is not fully developed, and nutrient digestion and absorption are similar to monogastric animals, primarily depending on abomasum and intestinal function. This study showed no significant differences among groups in apparent digestibility of DM, CP, OM, Ca, or P, while EE apparent digestibility in P100 group showed a decreasing trend. This may be related to different fat digestibility. Studies have shown that fat digestibility may be related to carbon chain length and degree of unsaturation. Generally, fatty acid chain length is inversely proportional to digestibility, with MCFA-rich oils having higher digestibility than LCFA-rich oils. MCFA and LCFA have different metabolic characteristics: MCFA have low esterification rates, high solubility, and rapid absorption, and can be directly digested and absorbed without lipase action, transported via the portal vein to the liver for rapid oxidative energy provision [39-40]. In contrast, LCFA digestion, absorption, and metabolism are limited by lipase, carnitine palmitoyltransferase I, and oxidative regulatory enzymes. Hong et al. [41] found that adding 0.33% or 0.55% MCT to weaned piglet diets significantly improved whole-tract digestibility of DM, GE, and CP. Unsaturated fatty acids have higher digestibility than saturated fatty acids, possibly

related to differences in water solubility [33]. Coconut oil replacement increased MCFA content, while palm oil replacement increased LCFA and PUFA content, producing different effects on EE apparent digestibility. Based on EE apparent digestibility, coconut oil was superior to palm oil when completely replacing butterfat.

3.4 Effects of Coconut Oil and Palm Oil on Energy Utilization

As important energy sources, the efficiency of fat or fatty acid utilization is a key indicator of oil quality. This study showed no significant differences in energy utilization efficiency among coconut oil, palm oil, and control groups, with gross energy digestibility and metabolic rate around 84% and 76%, respectively. This may be related to the special physiological state and environment of suckling calves. Suckling calves have rapid growth, high metabolic rates, and immature immune systems susceptible to stress, resulting in high energy demands. During the experiment, average ambient temperature remained below 15 °C for extended periods, and chronic low temperature may have caused cold stress [42], increasing fat metabolism for energy. Ren [32] reported no significant differences in energy utilization efficiency among soybean oil, coconut oil powder, and palm oil powder in piglets, consistent with our results. Thus, under our experimental conditions, low ambient temperature increased fat metabolism, but replacing butterfat with coconut oil or palm oil at equal fat levels did not significantly affect energy utilization efficiency in suckling calves.

Conclusion

1. Replacing butterfat with coconut oil or palm oil altered milk replacer fatty acid composition. Compared to the whole butterfat group, coconut oil increased medium-chain fatty acid proportion and decreased PUFA proportion, while palm oil decreased medium-chain fatty acid proportion and increased PUFA proportion.

2. Replacement of butterfat with coconut oil or palm oil at 50% or 100% levels had no significant effects on growth performance, serum biochemical indices, energy utilization, or nutrient apparent digestibility in suckling calves. However, 100% replacement numerically reduced ADG and feed conversion ratio, and 100% palm oil replacement tended to decrease EE apparent digestibility and gross energy digestibility. These results indicate that replacing butterfat with coconut oil or palm oil has no adverse effects on calf growth performance or nutrient metabolism, though 100% replacement was less effective than 50% replacement.

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