Original Article

Yield, composition, fatty acid profile and CLA content of milk from goats fed with different levels of OPF

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Abstract

The objective of this study was to evaluate the effect of different inclusion levels of OPF in total mixed ration (TMR)-based diet on yield, composition, FA profile and CLA content of milk in dairy goats. Six nulliparous female dairy goats (Saanen x Thai native, 19-21 months old, first lactation) were randomly set according to a 3x3 Latin square design with 2 replications for receiving diets consisted of 0% OPF (OPF0), 20% OPF (OPF20) and 40% OPF (OPF40). The average weight of the goats was 32.48±1.30 kg (mean±s.d.). The findings of this study showed that dry matter intake (DMI) and all nutrient intake of the goats increased significantly as OPF inclusion was increased (p<0.05), excluding crude protein intake (CPI) (p>0.05). Goats from OPF40 group had the highest CPI, however, there was no significant difference (p>0.05) in CPI of OPF20 and OPF0 groups. Feeding OPF altered the composition of protein and lactose, density and freezing point (p<0.05). However, it did not influence (p>0.05) the composition of fat, solid non-fat and minerals in the milk. There were no significant differences in oleic acid, dihomo-γ-linoleic acid, and eicosapentaenoic acid in milk fat of goats (p>0.05). 40% OPF inclusion increased the production of LnA, DHA, CLA and the ratio of PUFA:SFA; and lowered AA production and n-6:n-3 ratio of goat milk (p>0.05). It can be concluded that 40% OPF inclusion in TMR-based diet can be used as an alternative to producing goat's milk with enriched potential health benefits.

Keywords: oil palm fronds, TMR-based diet, dairy goats, milk fatty acids profile, CLA

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Introduction

In several countries, goat's milk has become one of the economic interests and an alternative for those who have allergies to dairy cow products (Schettino *et al*., 2017). Goat's milk can be categorized as a functional food due to the large number of bioactive components and the easiness of digestion (Savoini *et al*., 2019). Nutritional quality in food products has become important because there is an increase in consumer awareness of the link between health and diet (Hilali *et al*., 2018). In the human diet, milk and dairy products are the major sources of saturated fatty acids (SFAs) (Bayat *et al*., 2018). It is well documented that humans with high SFA consumption tend to have a higher risk of cardiovascular disease (CVD). Conversely, dietary polyunsaturated fatty acids (PUFAs) from dairy products has been associated with many health benefits (Yurchenko *et al*., 2018; Markey *et al*., 2017; Hilali *et al*., 2018). PUFAs, in particular conjugated linoleic acid (CLA), has physiological effects as an anti-mutagenic, anti-tumor, anti-diabetic (type II), an agent of body fat reduction (anti-obesity), anti-carcinogenic (fight against cancer), an agent of atherosclerosis prevention, an immune function enhancer, an anti-hypertensive, a hyperglycemia reduction agent and bone mineralization improvement agent in human body (Koba and Yanagita, 2013; Bouattour *et al*., 2008; Gomez-Cortes *et al*., 2018; Tudisco *et al*., 2015; Castro *et al*., 2009; Jacobs *et al*., 2011).

Although the composition of fatty acid (FA) in milk is affected by biohydrogenation of rumen and conversion of Δ9-desaturase enzyme, modifying animals diet can make large changes to the milk FA profile (Liu *et al*., 2016; Yurchenko *et al*., 2018; Bayat *et al*., 2018; Hilali *et al*., 2018). Basal diet composition together with source and type of lipid supplementation can affect milk FA composition (Bayat *et al*., 2018). Animals fed with fresh pasture tend to have a better CLA and vaccenic acid (VA) contents in milk compared to animals fed with dried forages. The possible reason is either fresh pasture may improve the growth of rumen's specific bacteria that is liable to CLA production or inhibit the VA to stearic acid final reduction (Nudda *et al*., 2005). Moreover, dietary PUFA sources decreased medium-chain SFA and n-6:n-3 ratio and increased milk CLA concentration, which are favorable as milk with a better nutritional quality for human consumption (Morsy *et al*., 2015; Marin *et al*., 2011; Castro *et al*., 2009).

Oil palm frond (OPF) is a fibrous crop residue that is abundantly available (Dalton *et al*., 2017). OPF has been utilized as a long-term ruminant feed with no toxic effect (Hassan *et al*., 1991). OPF contains PUFAs, especially linolenic acid (LnA; C18:3n-3) and linoleic acid (LA; C18:2n-6) (Hassim *et al*., 2010). The inclusion of OPF in a ruminant diet can increase the proportion of unsaturated fatty acid (UFA) in sheep plasma and rumen contents via regulation of rumen biohydrogenation or restriction of microbial access to facilitate the continuous availability of dietary UFA (Ghani *et al*., 2017). Nevertheless, information regarding dietary different levels of OPF to improve yield, composition, FA profile and CLA content of milk in dairy goats is limited. Therefore, the objective of this study was to provide a report on different OPF inclusion levels in TMR-based diet to produce goat's milk with an improved FA profile and CLA content.

Materials and Methods

Animals, Housing and Experimental Diets: Six lactating dairy goats (Saanen x Thai native, 19-21 months old, first lactation) were blocked by parity and balanced for milking days and body weight. The animals were then randomly arranged in a 3x3 Latin square design with 2 replications. The average weight of the goats was 32.48±1.30 kg (mean±s.d.). All animal handling procedures and experimental protocols were based on the Institutional Animal Care and Use Committee, Prince of Songkla University (U1-01633-2558), based on the Ethical Principles and Guidelines for the Use of Animals, National Research Council of Thailand. Each goat was kept in a stainless steel individual pen in the goat section of the Animal Innovation Production and Management Division, Faculty of Natural Resources, Prince of Songkla University, Hat Yai Campus. Ivermectin injection (Ivomec) was administered to provide efficacy against parasitic infestations.

The goats were provided free access to water and mineral blocks. Three treatment diets consisting of a basal diet (OPF0; 40% rice straw + 60% concentrate), the basal diet with 50% rice straw replacement with OPF (OPF20; 20% rice straw + 20% OPF + 60% concentrate) and the basal diet with 100% rice straw replacement with OPF (OPF40; 40% OPF + 60% rice straw). All treatment diets were set up as iso-nitrogenous and iso-caloric total mixed rations (TMR). The diets were provided *ad libitum*. A *Tenera* hybrid breed (*Dura* x *Pisifera*) more than 5 years old from the Faculty of Natural Resources, Prince of Songkla University was used and was harvested daily. Rice straw and OPF were chopped into 0.5-2 cm length and then mixed with grains on a daily basis to comply with the treatment diets.

The experiment was carried out in three periods. Each period was divided into 14 days for adaptation time and 30 days for data collection. Body weights (BW) of the goats were recorded weekly before morning feeding. Feed intake and milk production were recorded daily throughout the data collection.

Data Collection and Laboratory Analysis Procedures:
Feed Sampling Procedures: The samples of diets were collected once every 5 days to analyze feed composition. Additional feed samples were taken to determine the FA composition. The standard methods of AOAC (1998) were used to analyse the dry matter (DM), organic matter (OM), crude protein (CP), ether extract (EE) and ash of the feed and residual feed. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to the method described by Van Soest *et al*. (1991) with adaptation for Fiber Analyzer. The amount of EE was obtained by extracting the samples with dichloromethane using a Soxtec System based on AOAC (1998). All nutrient compositions were expressed based on the final DM. A calorimeter (LECO AC500) was used to determine the gross energy (GE) of the diets.

Milk Yield, Milk Composition and Milk FA Profile: Milk samples were collected twice a day (120 ml each), in the morning and afternoon milking during the data collection time. An additional milk sample from each goat (120 ml) was collected for milk FA profile analysis. Milk samples were stored at -20°C until milk composition and milk FA analysis. The samples of milk were sent to a laboratory for fat, protein, total solid, solid non-fat and lactose analysis (AOAC, 1990) by mid-infrared spectrophotometry (Lactostar).

Lipid in milk samples was extracted following the method of Zhang *et al*. (2015). The samples of milk from each goat were pooled and then extracted in 4 mL of isopropanol and hexane (ratio 2/3, v/v), then followed by the solution of 2 mL sodium sulfate and centrifuged at 2,500 x g at 20°C for 20 mins. The supernatant was moved into a hydrolysis tube and dried with a nitrogen flow. A 2 mL of $NaOCH_3$-methanol was then pipetted to the dry sample. The mixture was entirely blended using a vortex mixer and heated for 15 mins at 50°C. After the period of cooling, 2 mL of methanol was added to the mixture and provide a time of 15 mins at 80°C for the mixture to react. After cooling down, 3 mL of deionized water and 6 mL of hexane were added to the mixture. The mixture was completely homogenized utilizing a vortex mixture and was centrifuged at 2,500 x g at 20°C for 20 mins. The supernatant was poured into a graduated tube with hexane and fitted to 10 mL. Approximately 1 g of anhydrous sodium sulfate was added.

Fatty acid methyl esters (FAMEs) of feed and milk samples were analyzed using gas chromatography (GC) fitted with an HP-88 fused-silica capillary column (100 m x 0.25 mm with a film thickness of 0.2 µm). The temperature of the column was initially held at 120°C for 10 mins. Afterward, it was heated up to 230°C at 3.2°C/mins and held for 35 mins. The injector temperature was kept at 250°C and the detector temperature was maintained at 300°C. The volume of injection was 1 µL. Each peak was identified by utilizing the pure methyl ester standards.

Statistical Analysis: Analysis of variance (ANOVA) for 3x3 Latin Square using SPSS Statistics version 16 was performed on the DM, nutrient intake, milk yield, milk composition and milk FA profile to study the influence of the treatment diets. The parametric model was denoted as $X_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + \epsilon_{ijk}$, where X_{ijk} is the examination from animal j with diet i, in period k. Whereas, μ stands for the overall mean, α_i is the OPF levels effect (i = 0%, 20%, 40%), β_j is the animal effect (j = 1, 2, 3, 4, 5, 6), γk is the period effect (k = 1, 2, 3) and ϵ_{ijk} is the residual effect. Duncan's new multiple range tests were further performed to determine differences between treatment means (Steel and Torrie, 1980.

Results

Chemical Compositions and Fatty Acids Profile of Treatment Diets: The chemical compositions and fatty acids (FA) profile of the treatment diets are presented in Table 1 and Table 2. The inclusion of OPF increased the moisture content and lowered the ash content of TMR-based diets. All treatment diets had similar CP and gross energy (GE) contents. The treatment diet with the highest percentages of EE and fiber was OPF40, followed by OPF20 and OPF0. OPF40 and OPF20 had a similar amount of LnA, whereas OPF0 was the lowest. Compared to the diet without OPF inclusion, OPF20 and OPF40 contained a higher FA from the n-3 family. A similar PUFA:SFA ratio was indicated in all treatment diets. OPF inclusion in TMR-based diet lowered n-6:n-3 ratio. The ratio of n-6:n-3 in OPF0, OPF20, and OPF40 were 8.7:1, 5.1:1, and 4.8:1, respectively.

Table 1 Chemical compositions of experimental diets

Items	Treatment[1]		
	OPF0	OPF20	OPF40
Ingredients (%)			
OPF	0.00	20.00	40.00
Rice straw	40.00	20.00	0.00
Soybean meal	25.15	23.01	21.66
Corn	28.86	30.99	32.34
Molasses	3.00	3.00	3.00
Premix	3.00	3.00	3.00
Chemical compositions			
DM (%)	87.82	67.04	55.62
CP %)DM(	17.86	17.43	17.07
EE %)DM(	1.80	2.42	2.84
Ash %)DM(	10.44	8.65	7.57
NDF %)DM(	31.61	38.07	48.80
ADF %)DM(	19.31	20.26	22.04
Gross energy)Cal/kg DM(	3984.93	4021.32	4087.62

DM :dry matter; CP :crude protein; EE :ether extract; NDF :neutral digestible fiber; ADF :acid detergent fiber.
[1)] OPF0: 60% concentrate + 40% rice straw; OPF20: 60% concentrate + 20% rice straw + 20% oil palm fronds; OPF40: 60% concentrate + 40% oil palm fronds.

Table 2 Fatty acids profile of experimental diets

Items	Treatment[1]		
	OPF0	OPF20	OPF40
Fatty acids profile)g/100 g FA([2]			
C18:0, Stearic acid	1.61	2.48	1.81
C18:1n9c, Oleic acid	8.21	10.22	9.82
C18:1n9t, Elaidic acid	0.20	0.22	0.30
C18:2n6c, Linoleic acid (LA)	16.67	20.78	16.59
C18:2n6t, Linolelaidic acid	1.85	1.09	1.35
C18:3n3, α-Linolenic acid (LnA)	2.08	5.10	5.06
C18:3n6, γ-Linolenic acid	7.99	6.68	8.54
C20:0, Eicosanoic acid	0.41	0.46	0.22
C20:2, Eicosadienoic acid	0.32	0.11	0.11
C20:3n3, Eicosatrienoic acid	0.44	0.11	0.09
C20:4n6, Arachidonic acid) AA(	0.18	0.09	0.09
C22:0, Docosanoic acid	0.33	0.36	0.23
C22:2, Cetoleic acid	0.56	0.12	0.12
C24:0, Tetracosanoic acid	0.73	0.47	0.44
SFA	58.29	54.35	56.07
MUFA	10.55	11.08	11.52
PUFA	31.16	34.56	32.41
Total n-3[3]	3.43	5.65	5.62
Total n-6[4]	26.84	28.68	26.56
PUFA:SFA	0.54	0.64	0.58
n-6:n-3	8.67	5.12	4.78

[1] (OPF0 :60 %concentrate +40 %rice straw; OPF20 :60 %concentrate +20 %rice straw +20 %oil palm fronds; OPF40 :60 %concentrate +40 %oil palm fronds.

[2] (FA :fatty acids; SFA :sum of saturated fatty acids; MUFA :sum of monounsaturated fatty acids; PUFA :sum of polyunsaturated fatty acids.

[3] (Sum of n-6 fatty acids.

[4]) Sum of n-3 fatty acids.

Dry Matter and Nutrient Intake: The dry matter and nutrient intake of dairy goats fed with different inclusion levels of OPF are shown in Table 3. The findings of this study showed that dry matter intake (DMI) and all nutrients intake of the goats increased significantly as OPF inclusion increased (p<0.05), except for crude protein intake (CPI). Goats from the OPF40 group showed the highest CPI, however, there was no significant difference (p>0.050 in CPI of OPF20 and OPF0 groups. Based on percent body weight (%BW), the DMI of goats fed with OPF40 was 1.14 and 1.06 fold higher than those fed with OPF0 and OPF20, respectively. Fat, fiber and OM intake of the goats increased as the inclusion of OPF was increased. The intakes of EE, OM, NDF, and ADF of the OPF40 group were the highest.

Milk Yield and Milk Composition: Milk yield and milk composition of dairy goats fed with OPF in TMR based diet are shown in Table 4. The highest milk yield was reported in the OPF40 group. However, there was no significant difference in the milk yield of OPF0 and OPF20 groups. Although OPF0 and OPF20 had similar milk yield, goats from OPF20 group produced higher nutrient due to its higher milk density. Goats with higher inclusion of OPF produced higher fat, solid non-fat (SNF), protein, lactose and minerals per day. The highest production of those nutrients was on the OPF40 group, while the lowest was on the OPF0 group. The inclusion of OPF in TMR-based diet of dairy goats altered the composition of milk protein, lactose, density and freezing point but did not alter the composition of milk fat, solid non-fat, and minerals.

Table 3 Dry matter and nutrients intake of lactating dairy goats fed with different levels of oil palm fronds

Item	Treatment[1)]			SEM	*P*-value
	OPF0	OPF20	OPF40		
DM Intake					
Total (g/d)	1113.3[c]	1170.1[b]	1292.6[a]	13.5	<0.001
%BW	3.40[c]	3.63[b]	3.86[a]	0.06	<0.001
g/kg $BW^{0.75}$	80.9[c]	86.5[b]	92.3[a]	1.46	<0.001
Nutrient intake (g/d)					
OMI	996.8[c]	1068.9[b]	1194.7[a]	12.4	<0.001
CPI	198.8[b]	203.9[b]	220.6[a]	2.32	<0.001
EEI	20.0[c]	28.3[b]	36.7[a]	0.36	<0.001
NDFI	351.8[c]	445.4[b]	630.8[a]	6.12	<0.001
ADFI	214.9[c]	237.1[b]	284.9[a]	2.89	<0.001

SEM :standard error of the means) n =3(; DMI :dry matter intake; BW :body weight; CPI :crude protein intake; EEI :ether extract intake; NDFI :neutral digestible fiber intake; ADFI :acid detergent fiber intake; OMI :organic matter intake.

[1)] OPF0: 60% concentrate + 40% rice straw; OPF20: 60% concentrate + 20% rice straw + 20% oil palm fronds; OPF40: 60% concentrate + 40% oil palm fronds.

[a,b,c] Means in the same row with different superscript are statistically different (p<0.05).

Table 4 Milk yield and milk composition of dairy goats fed with oil palm frond in TMR based diet.

Items	Treatment[1)]			SEM	*P*-value
	OPF0	OPF20	OPF40		
Yield					
Milk (kg/d)	1.08[b]	1.09[b]	1.40[a]	17.2	<0.01
Fat (g/d)	30.90[c]	34.20[b]	41.80[a]	0.54	<0.01
Solid non-fat (g/d)	88.15[c]	93.71[b]	116.89[a]	1.41	<0.01
Protein (g/d)	31.81[c]	33.86[b]	42.03[a]	0.51	<0.01
Lactose (g/d)	46.82[c]	48.99[b]	62.10[a]	0.76	<0.01
Minerals (g/d)	10.41[c]	10.93[b]	13.57[a]	0.18	<0.05
Composition					
Fat (%)	2.87	3.03	3.00	0.05	2.62
Solid non-fat (%)	8.18	8.65	8.33	0.15	0.12
Protein (%)	2.95[b]	3.14[a]	3.00[b]	0.02	<0.01
Lactose (%)	4.35[c]	4.62[a]	4.43[b]	0.02	<0.01
Minerals (%)	0.97	0.98	0.97	0.01	0.09
Density	1.0244[c]	1.0259[a]	1.0248[b]	0.01	<0.01
Freezing point (°C)	-0.5541[b]	-0.5761[a]	-0.5557[a]	0.003	<0.01

SEM :standard error of the means) n =6(; OPF0 :60 %concentrate +40 %rice straw; OPF20 :60 %concentrate +20 %rice straw +20 % oil palm fronds; OPF40 :60 %concentrate +40 %oil palm fronds.

[a,b,c] Means in the same row with different superscript are statistically different (p<0.05).

Milk Fatty Acid Profile: Table 5 presents the milk fatty acid profile of dairy goats fed with different inclusion levels of OPF. OPF inclusion up to 40% in the treatment diets significantly increased (p<0.05) the concentrations of elaidic acid (C18:1n9t), linolelaidic acid (C18:2n6t) and α-linolenic acid (ALA; C18:3n3). Similar concentrations of stearic acid (C18:0), eicosatrienoic acid (C20:3n3), and docosahexaenoic acid (DHA; C22:6n3) concentrations were indicated in OPF20 and OPF40 groups (p>0.05). Meanwhile, OPF0 had lower concentrations of those FAs (p<0.05). There was no significant difference in linoleic acid (LA; C18:2n6c) of OPF20 and OPF40 groups. However, the values were lower than the OPF0 group. The lowest concentration of arachidonic acid (AA; C20:4n6) was in the diet with 40% OPF inclusion. Dietary OPF did not alter oleic acid (C18:1n9c), dihomo-γ-linoleic acid (DGLA; C20:3n6), and eicosapentaenoic acid (EPA; C20:5n3) in milk fat of goats (p>0.05). OPF40 contained the highest PUFA and CLA contents and the highest UFA:SFA ratio compared to OPF20 and OPF0 (p<0.05). There was no significant difference in SFA concentration and n-6:n-3 ratio of OPF40 and OPF20, however, the values were significantly lowered than OPF 0. The ratio between n-6 and n-3 in OPF40 and OPF20 was 3.66 and 4.11, respectively.

Discussion

Chemical Compositions and Fatty Acid Profile of Treatment Diets: All treatment diets were formulated as iso-nitrogen and iso-caloric diets, so they were similar in CP and GE contents. Similar values for CP and EE of diets with OPF inclusion were previously reported by Ebrahimi *et al*. (2015), and Hamchara *et al*. (2018), respectively. The higher moisture content of OPF20 and OPF40 could be attributed to the form of OPF used in this study that was fresh and was chopped daily. NDF and ADF contents of OPF20 and OPF40 were also close to the value reported by Ebrahimi *et al*. (2015). Previous studies also reported that linolenic acid (C18:3 n-3) in OPF (24.97%) is higher than in rice straw (1.72%) (Ebrahimi et al., 2015; Taira, 1983). Therefore, the higher the inclusion of OPF in the diet of the present study, the lower the ratio of n-6:n-3 FA.

Dry Matter and Nutrient Intake: The DMI of OPF0, OPF20, and OPF40 were 3.40%, 3.63%, and 3.86% BW, respectively. Exotic breeds raised in tropical areas have typical DMI values of about 3.6% BW (Stares *et al*., 1992). It means that OPF0 had DMI lower than the suggested DMI for Saanen in tropical areas. The findings of this study also indicate that higher moisture content, low palatability of rice straw and lower n-6:n-3 ratio due to OPF inclusion significantly increased DMI and nutrient intake of lactating dairy goats, although diets with higher OPF inclusion contained higher levels of NDF. The treatment diets with OPF inclusion had 60-70% DM, while the diet without OPF contained 90% DM. Adequate moisture content in complete feed can increase palatability and DMI by improving texture and diluting undesirable flavors (Lahr *et al*., 1983). Similar to the findings of this study, Meiske and Goodrich (1971) also reported that feeding feedlot steers with a diet containing roughly 66% DM resulted in the maximum DMI. Moreover, high silica content in rice straw also contributes to its lower palatability and thus feed intake (Nguyen et al., 2020; Oladosu et al., 2016).

We did not observe the effect of n-6:n-3 ratios on fermentation patterns, however, lowered n-6:n-3 ratios in the diet with OPF inclusion may have changed rumen microbial population, thus it could overcome the effect of NDF on DMI. Decreased level of n-6:n-3 PUFA ratios in the diet increases the proportion of cellulolytic bacteria namely *R. albus* and *R. flavefaciens* (Ebrahimi et al., 2017). Additionally, Greco et al. (2015), showed a consistent result with this study that feeding a 3.9:1 ratio of n-6 and n-3 FA resulted in lactating Holstein cows with better DMI. PUFAs potentially affect hepatic oxidation and have the ability to stimulate the release of gut peptides to alter DMI. Opposite results have been reported where dietary different n-6:n-3 ratio did not influence the DMI of lactating goats and growing lambs (Bouattour *et al*., 2008; Kim *et al*., 2007).

Milk Yield and Milk Composition: Higher milk production of OPF40 compared to OPF0 and OPF20 was the result of greater nutrient intake, especially CPI. Protein is an essential limiting nutrient for producing milk and achieving high yields in ruminants (Salo, 2018). Based on Looper (1994), feed provides the nutrients that are the precursors, either directly or indirectly, of the principal milk solids. Thus, an increase in feed intake usually results in the production of a greater volume of milk.

There was no significant difference in milk fat percentage amongst the treatment diets. However, the maintains the rumen pH (Banakar *et al*., 2018).

milk fat percentages of OPF20 and OPOF40 were between the range of Saneen goats during early lactation to late lactation (2.99 to 3.66) as reported by Kljajevic *et al*. (2018), while the OPF0 group was lower than the suggested range. This could be due to higher fiber intake (NDF and ADF) of goats fed with OPF. One of the factors that may affect fat production of dairy animals is the fiber content of the feed. Increasing fiber content and physically effective NDF enhances saliva flow, acetate to propionate ratio, milk fat levels and

Table 5 Milk fatty acids profile of lactating dairy goats fed with oil palm frond in TMR based diet.

Items	Treatment[1)]			SEM	*P*-value
	OPF0	OPF20	OPF40		
Fatty acids profile (g/100 g FA)[2)]					
C4:0, Butyric acid	1.52^{c}	1.97^{b}	2.42^{a}	0.135	0.003
C6:0, Caproic acid	1.47	1.60	1.62	0.089	0.445
C8:0. Caprylic acid	0.71^{c}	0.98^{b}	1.15^{a}	0.034	0.000
C10:0, Capric acid	1.49	1.49	1.39	0.052	0.296
C12:0, Lauric acid	1.83^{a}	1.64^{b}	1.37^{c}	0.035	0.000
C14:0, Myristic acid	7.85^{a}	7.43^{b}	6.81^{c}	0.102	0.000
C14:1, Myristoleic acid	0.74^{a}	0.67^{b}	0.67^{b}	0.01	0.001
C15:0, Pentadecanoic acid	0.97^{a}	0.86^{b}	0.82^{b}	0.02	0.001
C16:0, Palmitic acid	27.72^{a}	25.79^{b}	23.79^{c}	0.308	0.000
C16:1, Palmitoleic acid	1.45	1.45	1.39	0.03	0.209
C17:0, Heptadecanoic acid	0.62^{a}	0.60^{a}	0.46^{b}	0.02	0.000
C18:0, Stearic acid	12.08^{b}	12.29^{a}	12.26^{a}	0.049	0.025
C18:1n9t, Elaidic acid	6.20^{c}	7.49^{b}	9.20^{a}	0.244	0.000
C18:1n9c, Oleic acid	29.54	29.12	29.47	0.203	0.306
C18:2n6t, Linolelaidic acid	0.54^{c}	0.71^{b}	1.01^{a}	0.031	0.000
C18:2n6c, Linoleic acid (LA)	2.25^{a}	2.06^{b}	2.00^{b}	0.051	0.016
C18:3n3, α-Linolenic acid (LnA)	0.58^{c}	0.91^{b}	1.18^{a}	0.044	0.000
C18:3n6, γ-Linolenic acid	0.01	0.01	0.01	0.003	0.927
C20:0, Eicosanoic acid	0.21^{a}	0.19^{a}	0.14^{b}	0.009	0.001
C20:1, Gadoleic acid	0.06^{a}	0.03^{b}	0.02^{b}	0.005	0.001
C20:2, Eicosadienoic acid	0.10^{a}	0.09^{a}	0.05^{b}	0.01	0.025
C20:3n3, Eicosatrienoic acid	0.01^{b}	0.02^{a}	0.02^{a}	0.002	0.004
C20:3n6, Dihomo-γ-linoleic acid (DGLA)	0.02	0.02	0.03	0.004	0.513
C20:4n6, Arachidonic acid (AA)	0.16^{a}	0.15^{a}	0.13^{b}	0.007	0.014
C20:5n3, Eicosapentaenoic acid (EPA)	0.04	0.04	0.05	0.005	0.669
C22:0, Docosanoic acid	0.11	0.45	0.23	0.136	0.260
C22:1n9, Erucic acid	0.02	0.02	0.02	0.004	0.784
C22:2, Cetoleic acid	0.02	0.01	0.01	0.004	0.955
C22:6n3, Docosahexaenoic acid (DHA)	0.03^{b}	0.12^{a}	0.13^{a}	0.012	0.000
C23:0, Tricosanoic acid	0.03^{a}	0.02^{ab}	0.01^{b}	0.006	0.095
C24:0, Tetracosanoic acid	0.03	0.02	0.03	0.006	0.452
C9,T11	1.17^{b}	1.27^{b}	1.63^{a}	0.056	0.000
C9,C11	0.02	0.02	0.02	0.003	0.919
T9,T11	0.12^{c}	0.15^{b}	0.18^{a}	0.006	0.000
SFA	56.90^{a}	55.65^{a}	52.80^{b}	0.417	0.000
MUFA	38.05^{b}	38.78^{b}	40.76^{a}	0.323	0.000
PUFA	5.06^{c}	5.58^{b}	6.44^{a}	0.108	0.000
n-6[3)]	4.30^{b}	4.39^{b}	5.01^{a}	0.079	0.000
n-3[4)]	0.65^{c}	1.08^{b}	1.37^{a}	0.044	0.000
n6:n3	7.16^{a}	4.11^{b}	3.66^{b}	0.233	0.000
PUFA:SFA	0.09^{b}	0.10^{b}	0.12^{a}	0.003	0.000

[1] (OPF0 :60 %concentrate +40 %rice straw; OPF20 :60 %concentrate +20 %rice straw +20 %oil palm fronds; OPF40 :60 %concentrate +40 %oil palm fronds.

[2] (FA :fatty acids; SFA :sum of saturated fatty acids; MUFA :sum of monounsaturated fatty acids; PUFA :sum of polyunsaturated fatty acids.

[3] (Sum of n-6 fatty acids.

[4)] Sum of n-3 fatty acids.

In the present study, there were divergences in the milk protein and lactose compositions among dairy goats fed with different levels of OPF inclusion. One explanation for these results may be related to the

relative amounts of energy and protein available in the rumen. Previous studies have addressed the fact that milk protein content may respond to energy-protein interaction, although the results have been varied

(Brun-Lafleur et al., 2010). Furthermore, a tangible candidate for the relationship between protein supply and lactose output is glucose, in which the whole body (WB) rate of appearance (Ra) of glucose (total of real gluconeogenesis, glycogenolysis and portal absorption) increases with increasing protein supply via casein infusion (Lapierre et al., 2010).

Milk Fatty Acid Profile: The milk FA profile of goats in this study was dominated by oleic acid, palmitic acid, stearic acid, elaidic acid and myristic acid. The findings were in agreement with studies by Ferrand-Calmels *et al*. (2014), Cossignani *et al*. (2014), and Lopez *et al*. (2019). However, the presence of caproic acid (C6:0), caprylic acid (C8:0) and capric acid (C10:0) in the present study were lower than the reported values of those previous studies. Caproic, caprylic and capric acids are medium-chain FAs that have been named after goats because of their prevalence in goat's milk. They makeup to 15% of total FA in goat's milk is responsible for its flavor (Kompan and Komprej, 2012). Dietary high-level pasture tends to lower the production omf capric acid in goat's milk (LeDoux *et al*., 2002). Goats fed with OPF40 contained the highest caprylic acid which can give beneficial effects. Caprylic acid is one of the alternatives as intra-mammary infusion against bovine mastitis (Nair at al., 2005) and is effective in inactivating infant pathogens such as respiratory syncytial virus and herpes simplex virus (Isaacs *et al*., 1995).

Feeding OPF40 to lactating dairy goats resulted in milk with lower AA and higher DHA contents, compared to OPF0. AA is categorized as a PUFA essential for normal health. However, it also contributes to the inflammation process and leads to the promotion of mediators responsible for wound healing and resolving inflammation (Tallima and Ridi, 2017). On the other side, DHA has been known for playing an important role in inflammation, immunity and the functional development and growth of the infant's brain (Lee and Jenkins, 2011; Horrocks and Yeo, 1999). DHA is a biohydrogenation product of LnA. LnA turns into stearidonic acid (18:4n3) and eicosatetraenoic acid (20:4 n-3) to create eicosapentaenoic acid (EPA; 20:5n3). In its later stage, EPA is metabolized to be eicosanoids or DHA (Schmitz and Ecker, 2008). Goats fed with OPF20 and OPF40 yielded similar DHA in milk fat due to similar amounts of LnA in those diets. Both diets also contained LnA higher than OPF0, therefore, a significantly higher amount of DHA was indicated in milk fat of OPF20 and OPF40 groups.

The lower amount of SFA in OPF40 was the consequence of a higher intake of fiber. A linear result was reported by Hassim *et al*. (2010), that higher OPF inclusion rates decreased SFA production in the fermentation pattern of in vitro incubations due to the increasing amount of fiber. In the present study, goats fed with OPF40 received the highest amount of fresh forage. Therefore, it may have led to the highest CLA production. Several factors can affect the variation of CLA contained in milk, such as forage types, forage conservation methods, breeds and lactation stage (Halmemies-Beauchet-Filleau *et al*., 2016; Bouattour *et al*., 2008). Previous studies mentioned that modifying an animal's diet could increase the amount of CLA in milk (Hur *et al*., 2007). Nudda *et al*. (2005), reported that animals fed with fresh pasture tended to have better CLA content in milk compared to animals fed with dried forages. The possible reason is either fresh pasture may improve the growth of rumen's specific bacteria that is liable on CLA production or inhibit the VA to stearic acid final reduction. Additionally, dietary fresh grass speeded up CLA synthesis via stearoyl-CoA desaturase activation (Hur *et al*., 2017).

The n-6:n-3 ratios of OPF20 and OPF40 were 4.11 and 3.66, respectively. Those values were within the range of recommendation (1:1 to 4:1) for human consumption to achieve normal development and homeostasis (Simopoulos, 2008). Finally, milk from the OPF40 group is likely to be preferable due to its higher PUFA:SFA ratio. Recently, consumers have been advised to limit their SFA intake and replace SFA with unsaturated fat (Kris-Etherthon and Krauss, 2020).

The inclusion of OPF enhances the DMI and milk yield of lactating dairy goats. Feeding OPF to lactating dairy goats alters the composition of protein and lactose, density and the freezing point of milk. However, it did not affect the percentage of fat, solid non-fat and minerals in milk. The inclusion of 40% OPF in TMR-based diet increased the production of LnA, DHA, CLA, and PUFA:SFA ratio. It also decreased AA production and n-6:n-3 ratio of goat milk. Feeding 40% OPF in TMR-based diet can be used as an alternative to producing goat milk with enriched potential health benefits.

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