Original Article

Short-term effect of coconut oil supplementation on meal pattern in crossbred dairy goats fed under tropical environment

Sumpun Thammacharoen[1]* Thiet Nguyen[1]

Somchai Chanpongsang[2] Narongsak Chaiyabutr[1]

Abstract

Eating behavior is influenced by various external stimuli, including food and ambient temperature (Ta). In dairy animals, high ambient temperature (HTa) decreases eating and subsequently reduces milk production. Eight crossbred non-lactating Saanen goats in late pregnancy fed under HTa condition were used to investigate the normal eating behavior by comparing the short-term eating pattern of control with 2% coconut oil supplemented formulations. The goats were fed *ad libitum* twice daily a total mix ration with free access to water. The experiment lasted 17 days, 9 days for adaptation and 8 days for data collection. Meal patterns were determined on the last day of experiment. The short-term 2% coconut oil supplementation (0.91±0.08 kg/day) did not affect daily dry matter intake (DMI) as compared with the control (0.83±0.05 kg/day). However, daytime DMI of the coconut oil supplemented group (0.82±0.05 kg) was higher than that of the control group (0.57±0.06 kg/day). This effect was derived primarily from the longer eating duration and meal duration during daytime and the bigger meal size during spontaneous meals. The present results suggested that, under HTa condition, the spontaneous meal, rather than the scheduled meal, was first deviated by the new diet. Another aspect of the normal eating pattern in crossbred dairy goats was the crepuscular eating pattern which could not be replaced by the scheduled afternoon feeding. This finding suggested that under HTa, the crepuscular eating is the norm, and modification in the afternoon feeding schedule should be considered to avoid the effect of HTa.

Keywords: food intake, ruminant, crossbred dairy goat, fat

[1]*Department of Physiology,* [2]*Department of Animal Husbandry, Faculty of Veterinary Science, Chulalongkorn University, Bangkok 10330, Thailand*

****Correspondence**: sprueksagorn@hotmail.com*

Introduction

High ambient temperature (HTa) is the major negative factor in milk production which dairy ruminants in tropical countries cannot avoid. The effect of HTa on milk yield has been explained by both direct and indirect mechanisms. A decrease in dry matter intake (DMI) in response to HTa influences nutrient balance and indirectly decreases milk yield. Moreover, HTa apparently has a direct effect on the mammary glands by influencing milk synthesis mechanisms (Rhoads et al., 2009). DMI also plays a major role in milk yield. However, most experiments on the eating behavior of ruminants were conducted in the temperate zone (Senn et al., 1990; Rossi and Scharrer, 1992; Abijaoude et al., 2000; Morand-Fehr, 2003). Therefore, the eating pattern of dairy goats fed under HTa condition was of interest to the present experiment.

The eating patterns of goats fed in stalls have been described previously regarding the bout or meal during day and night times (Senn et al., 1990; Rossi and Scharrer, 1992; Abijaoude et al., 2000; Baumont et al., 2000). Specifically, the eating pattern of goats has been classified into main and secondary meals (Abijaoude et al., 2000; Baumont et al., 2000; Morand-Fehr, 2003). This is similar to the eating pattern of laboratory rodents, in which their main meal is scheduled at the beginning of the dark period followed by spontaneous or secondary meals. Thus, the size and duration of each meal are the major determinants of daily DMI (Woods et al., 2000; Strubbe and Van Dijk, 2002). Like other homeothermic animals, daily DMI in goats negatively correlates with ambient temperature (Ta). In Ta ranging from 20 to 40°C, the threshold of Ta which decreases DMI has been demonstrated at 25-30°C in Alpine goats (Lu, 1989). This information is apparently far from the nature of crossbred goats fed under tropical conditions since Ta and acclimatization process are the fundamental factors influencing DMI. A few studies previously showed that eating and grazing behaviors changed under harsh conditions (Sharma et al., 1998; Morand-Fehr, 2005). However, details about the eating patterns of goats fed under HTa of the tropical zone have not been reported.

The aim of the present experiment was to investigate the normal eating pattern of goats fed under HTa in the central area of Thailand (tropical climate). The present experiment used fat supplementation to deviate from the normal eating pattern. This idea was executed based on 2 main reasons. First, by comparison, high fat diets and their effects on eating behavior are well known in laboratory animals in obesity research (Farley et al., 2003; Woods et al., 2003). Second, it has been shown in ruminants that fat supplementation produces 2 opposite effects on DMI based on the level of supplementation and 2% fat supplementation has been shown to increase DMI (Heinrich et al., 1982; Chillard, 1993; Hollman and Beede, 2012). Therefore, the present experiment selected 2% vegetable fat supplementation for the facilitation of eating behavior and comparison of the eating pattern with a normal control diet.

Materials and Methods

Animals and management: The experiment was carried out at Nakhon Pathom training farm, Nakhon Pathom province, Thailand. Ta of the experimental area in the morning (0700) and in the afternoon (1500) were 25.0±0.6°C and 32.6±0.5°C, respectively. Percentages of relative humidity (RH) during both periods in the morning and afternoon were 82.9±2.3% and 65.6±0.9%, respectively. Temperature and humidity indexes (THI) calculated according to NRC (1971)'s formulation were 75.4±1.1 and 84.7±0.8, respectively. The procedures of this experiment were performed according to the guidelines for the use of animals from National Research Council of Thailand and were approved by Animal Care and Use Committee, Faculty of Veterinary Science, Chulalongkorn University (#1531074).

Eight crossbred Saanen goats in late pregnancy, with average body weight (BW) of 32.08±1.47 kg, were used in this experiment. The animals were divided into 2 experimental groups (n=4) based on 2 TMR rations, without coconut oil (control ration) and with 2% coconut oil fed in concentrate (coconut oil ration). The experimental TMR rations were prepared from 44% corn silage and concentrate (56% for control ration and 54% for coconut oil ration) according to the National Research Council's recommendation (NRC, 1981). The corn silage used in the present experiment was chopped to pieces approximately 5 cm long. The ingredients and chemical composition of TMRs are presented in Table 1. The experiment lasted 17 days, 9 days for adaptation (control ration) and 8 days for treatment. During the experiment, the animals were housed individually in 2 x 1 m shaped pens with plastic floors. All goats had *ad libitum* access to water and were fed a total mixed ration (TMR) twice daily at 0700 and 1400 (Thammacharoen et al., 2014) to maintain a moderate body score condition at 2.5 (1-5 scale). For daily food intake, feed and refusal samples were weighed and collected every day throughout the experiment. The feed sample was dried in a microwave, until it reached a constant weight, to determine dry matter and DMI. All feed samples were mixed thoroughly, and subsamples were dried at 65°C overnight (approximately 12 h) and analyzed for dry matter, nitrogen and ash according to AOAC (1990).

Meal pattern measurement: On the last day of experiment, meal pattern was recorded continuously 24 hr from 0700 using a digital balance equipped with data processing software (PBA 665 & Weigh Term 231G, Mettler Toledo, Zürich, Switzerland). The digital balance was fixed under the feed containers and protected by a wood box. The actual weight of feed containers was checked and recorded automatically, in each minute, using a personal computer. Meals were defined as feed removals exceeding 5 g separated by at least 15 minutes of non-feeding (Rossi et al., 1992). By this definition, the calculated total daily intake from the whole day automatic records correlated well (n=6, R^2=0.99) with the manual feed offer and refusal techniques. Moreover, there was no difference in DMI from both methods. The automatic recording system was used to measure meal patterns such as meal size,

meal duration, meal frequency and inter-meal interval. One-hour DMI (1-hr DMI) from 24-hr meal pattern was presented to show the eating pattern from the whole day. In addition, eating duration is the duration that the animal used for eating within a day and was calculated by the sum of all meal duration within 24 hr. In the present experiment, the main meals of morning and afternoon feeding were called scheduled meals and the secondary meals were called spontaneous meals (Abijaoude et al., 2000; Baumont et al., 2000; Morand-Fehr, 2003).

Statistical analysis: All data were reported as mean ± SEM. Daily DMI and 1-hr DMI were analyzed with repeated ANOVA. Mean comparison was done with the Bonferroni's multiple comparison test. Analysis of meal patterns was performed using Student's t test. Differences were considered to be significant when $P<0.05$.

Table 1 Chemical composition (%DM) of the control and 2% coconut oil supplemented diets

	Diets	
	Control	**Coconut oil**
Dry matter (%)	37.7	37.7
Chemical composition (%DM)		
Crude protein	16.4	16.7
Neutral detergent fiber	42.9	42.5
Acid detergent fiber	25.6	25.9
Ether extract	3.0	4.7
Ash	7.4	7.5
Net energy (Mcal/kg DM)	1.7	1.7

Results

Short-term effect of coconut oil supplementation on meal patterns and eating behavior : In the present experiment, the daily DMI from 3 days before the experimental TMRs was first analyzed. Because there were no significant differences in DMI during this period ($P>0.05$), the present experiment used the average DMI from this period as the basal DMI for the control and coconut oil supplementation before treatment (Fig. 1, 887±33 and 830±160 g/animal/day, respectively). During the treatment period, there were no significant differences again in the daily DMI between the groups ($P>0.05$, Fig. 1).

Meal pattern measurement on day 7 during the treatment period revealed that the daytime DMI from the coconut oil supplemented group was higher than that from the control group ($P<0.05$, Table 2). The nighttime and 24-hr DMI of both groups were not significantly different ($P>0.05$, Table 2). The results of DMI corresponded to the eating duration. The daytime eating duration of the coconut oil supplemented group was longer than that of the control group ($P<0.05$, Table 2). The night-time and 24-hr eating duration of both control and coconut oil supplemented groups was not significantly different ($P>0.05$, Table 2). Meal size analysis of the average 24 hr, daytime and nighttime did not show significant differences between the groups ($P>0.05$, Table 2). However, the daytime meal duration of the coconut supplemented group was significantly longer than that of the control group (Table 2). Meal frequencies of the average 24 hr, daytime and nighttime were not significantly different between the groups ($P>0.05$, Table 2). Finally, the average between meal period or inter-meal interval of 24 hr, day and night times was not significantly different between the groups ($P>0.05$, Table 2).

Table 2 Dry matter intake and meal pattern on day 7 of the treatment period

		Diets		
		Control	**Coconut oil**	**P**
DMI (kg/animal)	24 hr	0.78±0.07	0.95±0.03	0.08
	Daytime*	0.57±0.06	0.82±0.05	0.02
	Nighttime	0.22±0.08	0.13±0.04	0.42
Eating duration (hr)	24 hr	6.64±0.59	9.06±1.00	0.08
	Daytime*	4.59±0.61	6.93±0.51	0.03
	Nighttime	2.05±0.55	2.12±0.51	0.93
Meal size (g)	24 hr	63.62±11.17	70.82±9.51	0.64
	Daytime	69.67±16.93	100.10±14.09	0.22
	Nighttime	45.36±11.84	25.92±5.67	0.19
Meal duration (min)	24 hr	33.25±3.42	42.50±4.05	0.13
	Daytime*	34.50±5.04	54.50±6.08	0.04
	Nighttime	31.25±4.75	23.50±2.84	0.21
Meal frequency	24 hr	13±2	14±2	0.87
	Daytime	9±1	8±1	0.77
	Nighttime	4±1	5±1	0.52
Inter-meal interval (min)	24 hr	60.50±5.55	70.00±16.70	0.61
	Daytime	32.25±6.29	38.00±5.70	0.52
	Nighttime	122.75±19.60	124.00±39.64	0.98

* represents the effect of coconut oil supplementation.

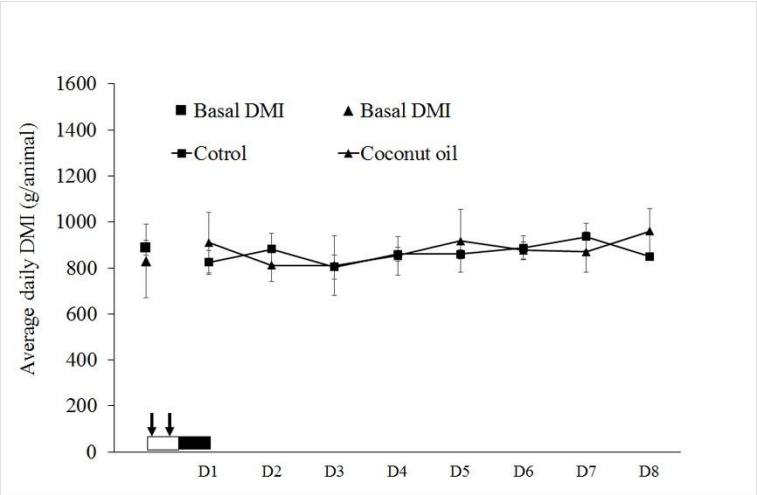
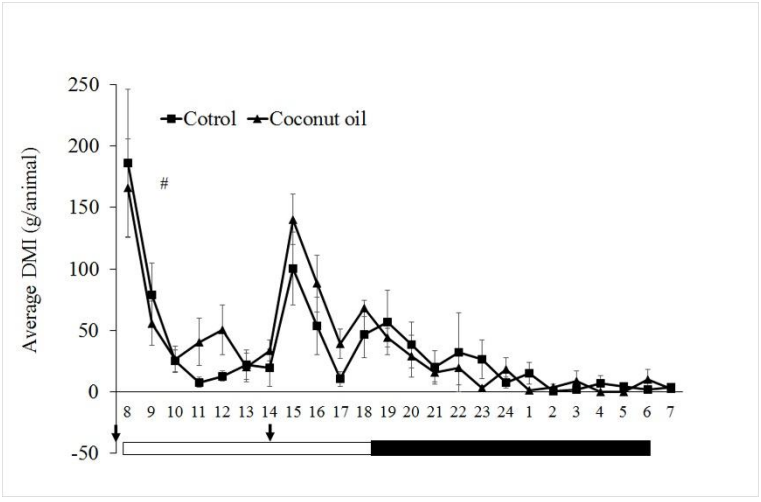


Figure 1 Average daily DMI between the control and coconut oil supplemented groups during the experimental period (day 1-8, D1-D8). The average basal DMI was calculated based on DMI of 3 days before the experimental diet. Food was offered 2 times during the light phase (arrows at the white block). Food intake that was used to calculate DMI was the sum of the light phase and dark phase FI (dark block).

The information from meal pattern recorded on day 7 during the treatment period revealed the effect of the present feeding schedule on eating behavior. First, there was no significant effect of coconut oil supplementation on the average 1-hr DMI ($P>0.05$, Fig. 2a). Second, within 24 hr of recording, there was the effect of time on 1-hr DMI ($P<0.05$, Fig. 2a). The present experiment also analyzed the meal size and duration of the scheduled and spontaneous meals. The average scheduled meal sizes of the 2 feeding programs of the control and coconut oil supplemented groups were 190.2±41.4 and 225.3±52.6 g, respectively. For the spontaneous daytime meals, the average meal sizes of the control and coconut oil supplemented groups were 29.6±5.0 and 59.7±4.4 g, respectively. Although there were no significant differences in the scheduled meal size between the groups ($P>0.05$, Fig. 2b), the spontaneous meal sizes in the coconut oil supplemented group were larger than in the control group ($P<0.05$, Fig. 2b). The analysis of meal duration revealed results, similar to those of meal size, that did not have significant effect on the scheduled meal duration (control: 60±14 min and coconut oil: 100±19 min, Fig. 2c), whereas the spontaneous meal duration was longer in the coconut oil supplemented group (control: 24±3 min and coconut oil: 40±5 min, $P<0.05$, Fig. 2c). Finally, the analysis of eating rate calculated from meal size and duration revealed no significant difference between the control and coconut oil supplemented groups ($P>0.05$, Fig. 2d). The eating rate calculated from the scheduled meals in the control group was 37.8±13.3 g/10 min, whereas it was 24.1±2.0 g/10 min in the coconut oil supplemented group. The eating rate calculated from the spontaneous meals in the control group was 13.7±2.2 g/10 min, whereas it was 14.9±0.6 g/10 min in the coconut oil supplemented group. When comparing the eating rate between the scheduled meal and the spontaneous meals, it was clear that the eating rate of the scheduled meal was faster than that of the spontaneous meals ($P<0.05$).



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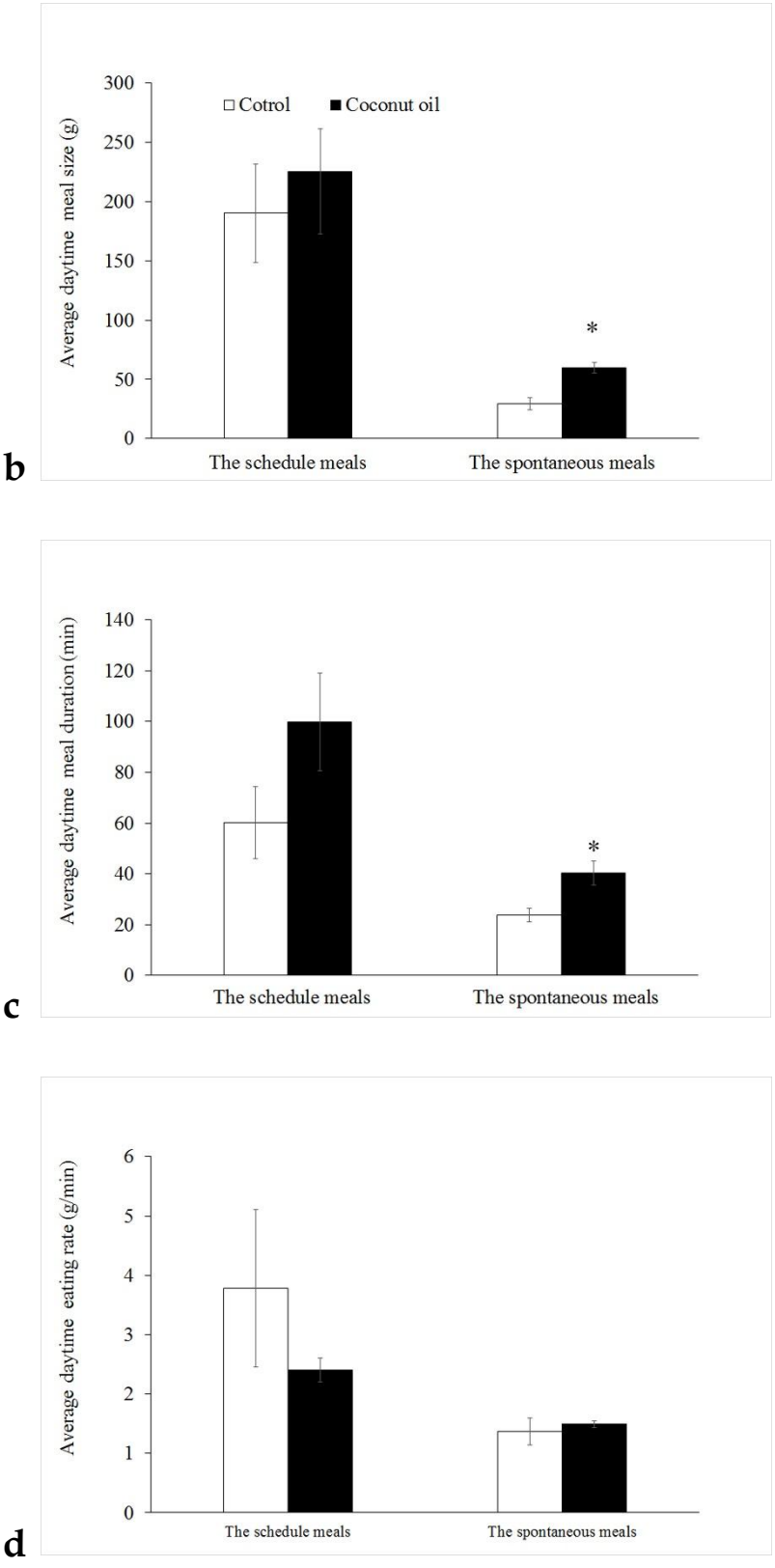

Figure 2 One-hour eating pattern on day 7 of the treatment period from both control and coconut oil supplemented groups. Food was offered 2 times during the light phase at 0700 and 1400 (arrows at the white block). Food intake measurement was started at 0700 until the next 0700 (24 hr). The white and black bars under the x-axis represent light and dark phases, respectively (a). Average meal size (b), duration (c) and eating rate (d) of scheduled meals are presented separately from spontaneous meals. * represents the effect of coconut oil supplementation. # represents the effect of time on 1-hr eating pattern.

Circadian eating behavior, the crepuscular eating and the scheduled eating behavior under high environmental temperature: Because there was prominent circadian eating pattern in both the control and coconut supplemented groups (Fig. 2a), the present experiment averaged 1-hr DMI in both groups

and analyzed the eating pattern according to the present feeding schedule. The average 1-hr DMI was significantly different with respect to time (P<0.05, Fig. 3). The 1-hr DMI from 0800 (the first scheduled meal of daytime) was significantly higher than the 1-hr DMI from 1500 (the second scheduled meal of daytime, P<0.05, Fig. 3). The 1-hr DMI from 1500 was significantly higher than that from 1800 and 1900 (P<0.05, Fig. 3). In addition, the 1-hr DMI from 1700 was significantly lower than that from 1800 (P<0.05, Fig. 3).

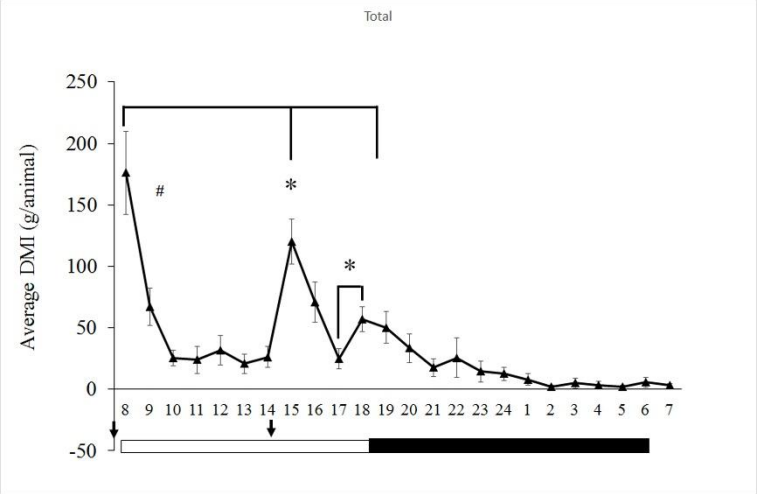

Figure 3 Average 1-hr eating pattern on day 7 of the treatment period from both control and coconut oil supplemented groups. Food was offered 2 times during the light phase at 0700 and 1400 (arrows at the white block). Food intake measurement was started from 0700 until the next 0700 (24 hr). The white and black bars under the x-axis represent light and dark phases, respectively. # represents the effect of time on 1-hr eating pattern. * represents the differences between time points.

Discussion

The present results revealed the pattern of eating behavior in crossbred dairy goats fed under hot and humid conditions of the tropical zone. Although there was no effect on daily DMI as a result of coconut oil supplementation, the higher DMI during daytime in the coconut oil supplemented group was mainly due to the longer eating duration and meal duration during daytime and the bigger meal size during the spontaneous meals. In addition, the second scheduled meals (1400) in the present experiment could not replace the crepuscular eating behavior. Our interpretation of the present information is that the normal eating pattern of crossbred dairy goats fed under HTa could be deviated by short period of 2% coconut oil supplementation. Moreover, the second scheduled feeding (1400) could attenuate the crepuscular eating behavior.

Eating is a fundamental behavior of all organisms. The biological goals of this behavior are to provide energy and nutrients to the body. However, this basic behavior is under complex neural control system and is influenced by multifactorial external stimuli (Berthoud and Morrison, 2008). Under HTa of the tropical areas, eating behavior in dairy animals was depressed and subsequently, in part, influenced milk yield (Rhoads et al., 2009). In the present experiment, the crossbred dairy goats and coconut oil supplemented TMR were used to observe this behavior under HTa condition. It was clear from the present results that coconut oil supplementation had no effect on daily DMI and 24-hr DMI on day 7 during the experimental period. However, the coconut oil supplemented group ate more during daytime. This effect was due to the higher meal size and the duration of the spontaneous meals rather than from the scheduled meals. In dairy cattle, the effect of fat supplementation, including coconut oil, on the reduction of DMI is due to the high level of fat (>3%) used in TMR (Heinrich et al., 1982; Chillard, 1993; Hollman and Beede, 2012). Interestingly, 2% coconut oil supplementation increased DMI on the first day of feeding followed by a gradual decrease in DMI (Hollman & Beede, 2012). The higher daytime DMI from the present experiment was in line with a previous report by Hollaman and Beede (2012). Importantly, the present experiment disclosed directly that the increased DMI effect of coconut oil supplementation was apparently due to the higher meal size and duration. In monogastric animals, including humans, the role of a high fat diet in the hyperphagic effect was partially explained by the palatability and energy density (Warwick et al., 2002; Farley et al., 2003). These results suggested that in ruminants fed under HTa a low level of coconut oil could apparently change the eating patterns. This effect probably came in part from both palatability and energy density effects.

The present experiment revealed another aspect of the eating pattern of crossbred dairy goats fed under HTa conditions and scheduled feeding. Since the analysis of 1-hr DMI revealed the significant effect of time on the eating patterns in both groups (Fig. 2a), this information lets us combine the 1-hr DMI from both groups to show the effect of scheduled feeding program on eating pattern under HTa conditions (Fig. 3). It has been suggested previously in pygmy goats, fed at morning and night times, that the satiation of night feeding schedule is less potent (Langhans et al., 1988; Senn et al., 1990; Rossi and Scharrer, 1992; Rossi et al., 1999; Abijaoude et al., 2000). This is different from

the present results in 2 important aspects. First, the scheduled morning meal from the present experiment was not lower than the scheduled afternoon meal. The lower afternoon meal from the present experiment was probably due to the negative effect of HTa on the eating during afternoon (Fig. 3). Because the feeding schedule used in the present experiment is normally used in Thailand and perhaps also in tropical countries (Thammacharoen et al., 2014), it is interesting to speculate whether the afternoon feeding program should be postponed to match the crepuscular eating pattern to avoid the effect of HTa. Second, despite the afternoon feeding schedule provided in the present experiment, the afternoon meal could not abolish the crepuscular meal. This information apparently suggested that the crepuscular eating behavior was part of the circadian rhythm. In nocturnal laboratory rat, eating behavior at dusk and dawn have been partially explained by maintaining body energy stores and endogenous circadian pacemaker (Strubbe and van Dijk, 2010; Spiteri et al., 1982). It is interesting to note whether the crepuscular meal of the diurnal goat, reported in the current experiment, corresponded to the dawn meal of rats? When the feeding schedule was postponed from afternoon to the beginning of dark to avoid HTa effect and match the crepuscular eating pattern, the motivation of eating during this time is the sum of anticipatory learning and circadian behaviors.

In conclusion, the present experiment revealed the detailed behavioral mechanism that low level fat supplementation diet could enhance the eating behavior in crossbred dairy goats fed under HTa condition. Eating behaviors that deviated from normal behaviors were detected during the spontaneous or secondary daytime meals rather than the scheduled or main meals. This was to our knowledge the first evidence to support the hypothesis that any stimulation from dietary supplementation of DMI should first deviate the spontaneous meals. Only when the stimulation is strong enough, the eating motivation of the new diet will override the anticipatory eating of scheduled meals. Our first conclusion makes the possibility of using eating patterns as the selected method for testing the hedonic effect of diet in ruminants. Moreover, the present experiment revealed that the second scheduled meal which occurred during HTa of daytime could not abolish the crepuscular meal. Under HTa conditions, the present experiment aimed to change the feeding schedule from afternoon to evening to avoid the HTa effect and to match the circadian eating behavior.

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บทคัดย่อ

ผลระยะสั้นของการเสริมน้ำมันมะพร้าวต่อรูปแบบการกินอาหารในแพะนมพันธุ์ผสม ที่เลี้ยงภายใต้สภาวะแวดล้อมร้อนชื้น

สัมพันธ์ ธรรมเจริญ[1*] เทียต เหงียน[1] สมชาย จันทร์ผ่องแสง[2] ณรงค์ศักดิ์ ชัยบุตร[1]

พฤติกรรมการกินอาหารเป็นพฤติกรรมที่ได้รับอิทธิพลจากปัจจัยภายนอกหลายด้านซึ่งรวมถึง อาหาร และอุณหภูมิแวดล้อม สำหรับสัตว์เลี้ยงให้นมอุณหภูมิแวดล้อมสูง (high ambient temperature, HTa) จะลดการกินอาหารและทำให้ผลผลิตน้ำนมลดลง แพะนมตั้งท้องช่วงท้ายและไม่ได้ให้ผลผลิตน้ำนมจำนวน 8 ตัวที่เลี้ยงภายใต้สภาวะ HTa ถูกใช้สำหรับการทดสอบพฤติกรรมการกินอาหารปกติเปรียบเทียบผลระยะสั้นระหว่างอาหารควบคุมและอาหารที่เสริมน้ำมันมะพร้าว 2 เปอร์เซ็นต์ แพะทดลองได้รับอาหารผสมสำเร็จ 2 ครั้งต่อวัน และได้รับน้ำแบบไม่จำกัด รูปแบบการกินอาหาร (meal pattern) จะถูกวัดในวันสุดท้ายของการทดลอง การเสริมน้ำมันมะพร้าว 2 เปอร์เซ็นต์ (0.91±0.08 กิโลกรัมต่อวัน) ไม่ได้ส่งผลต่อปริมาณการกินอาหารแห้ง (dry matter intake, DMI) ในแต่ละวันเมื่อเทียบกับกลุ่มควบคุม (0.83±0.05 กิโลกรัมต่อวัน) อย่างไรก็ตาม DMI ในช่วงกลางวันของกลุ่มที่เสริมน้ำมันมะพร้าว (0.82±0.05 กิโลกรัมต่อวัน) จะมากกว่ากลุ่มควบคุม (0.57±0.06 กิโลกรัมต่อวัน) ผลดังกล่าวนี้เกิดขึ้นจากระยะเวลาการกินอาหารและระยะเวลาของมื้ออาหารที่ยาวนานขึ้นร่วมกับขนาดของมื้ออาหารที่ใหญ่ขึ้นในช่วงมื้ออาหารที่สัตว์กินเองอิสระ ผลการทดลองชี้ให้เห็นว่าภายใต้สภาวะ HTa มื้ออาหารที่สัตว์กินเองอิสระจะได้รับการเบี่ยงเบนก่อนมื้ออาหารที่สัตว์ถูกฝึกให้กิน ผลการทดลองอีกด้านเกี่ยวกับพฤติกรรมการกินอาหารปกติในแพะนมพันธุ์ผสมนั้นจะเกี่ยวกับรูปแบบการกินอาหารช่วงหัวค่ำซึ่งไม่สามารถทดแทนได้ด้วยการกินอาหารที่เกิดจากตารางเวลากินช่วงบ่าย ผลดังกล่าวชี้ให้เห็นว่าภายใต้สภาวะ HTa การกินอาหารในช่วงหัวค่ำเป็นพฤติกรรมการกินอาหารปกติ และการเปลี่ยนแปลงตารางการให้อาหารในช่วงบ่ายของวันอาจต้องมีการพิจารณาอีกครั้งเพื่อหลีกเลี่ยงผลอันเกิดจากสภาวะ HTa

คำสำคัญ: การกินอาหาร สัตว์เคี้ยวเอื้อง แพะนมพันธุ์ผสม ไขมัน

[1]ภาควิชาสรีรวิทยา คณะสัตวแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ปทุมวัน กรุงเทพ 10330 ประเทศไทย

[2]ภาควิชาสัตวบาล คณะสัตวแพทยศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย ปทุมวัน กรุงเทพ 10330 ประเทศไทย

****ผู้รับผิดชอบบทความ** E-mail: sprueksagorn@hotmail.com*