

Temperature effect on energy partitioning and fast heat production of Anglo Nubian and Saanen goats

Marcia Helena Machado da Rocha Fernandes¹, Ana Rebeca de Castro Lima², Carolina Isabel Soriano Oporto³, Raiza Felismino Silveira⁴, Kleber Tomas de Resende⁵, Bruno Biagioli⁶, Izabelle Auxiliadora Molina de Almeida Teixeira⁷

¹Pesquisadora, Univ. Estadual Paulista, UNESP/FCAV. E-mail: mhmrochaf@fcav.unesp.br

²Doutoranda, Univ. Estadual Paulista, UNESP/FCAV. E-mail: anarebecalimaa@gmail.com

³Graduanda em Medicina Veterinária, Univ. Estadual Paulista, UNESP/FCAV. E-mail: carol_isa16@hotmail.com

⁴Mestranda, Univ. Estadual Paulista, UNESP/FCAV. E-mail: raizazoo@gmail.com

⁵Professor, Univ. Estadual Paulista, UNESP/FCAV. E-mail: kresende@fcav.unesp.br

⁶Pesquisador, Univ. Estadual Paulista, UNESP/FCAV. E-mail: brunobiagioli@fcav.unesp.br

⁷Professora, Univ. Estadual Paulista, UNESP/FCAV. E-mail: izabelle@fcav.unesp.br

Abstract: The objective of this work was to determine the effect of temperature on energy balance and basal metabolism of Saanen and Anglo Nubian goats, using indirect calorimetry system. Six dry and non-pregnant Saanen (53.7 ± 7.7 kg BW) and six dry and non-pregnant Anglo Nubian (56.4 ± 8.0 kg BW) goats, which were on average 5 years old, were used in a factorial design 2×3 (2 breeds and 3 temperatures). The experimental period consisted of three stages corresponding to the temperature of $10.0 \pm 0.23^\circ\text{C}$, $20.0 \pm 0.41^\circ\text{C}$ and $35.0 \pm 1.05^\circ\text{C}$. The adaptation period in each temperature lasted 21 days. Goats were allocated to individual metabolism cages to perform the metabolism assay and gas exchange measurements concomitantly. During feeding period, gas measurement was performed using an open-circuit facemask respirometry in groups of four animals (two of each breed). After that, goats were subjected to 60-h fasting (no feed) to estimate fasting heat production (FHP) or basal metabolism. Irrespective of breed, DM intake (DMI) and organic matter intake (OMI) decreased linearly as ambient temperature increased. During feeding period, rectal temperature was not affected by ambient temperature, but respiratory rate (BPM) and evaporative water loss (EWL) increased linearly with temperature elevation. Saanen's rectal temperature and BPM were higher than Anglo Nubian's. Irrespective of breed ($P = 0.59$), heat production (HP) showed a quadratic effect with the lowest values at 20°C . Conversely, FHP showed a quadratic effect with a tendency of decreasing at increasing rate in temperature above 20° up to 35°C . Consequently heat increment (HI) showed quadratic effect with a sharp increase when the ambient temperature rose from 20 to 35°C . In conclusion, Saanen and Anglo Nubian goats are able to maintain homeostasis in environments between 10 and 35°C . On the other hand, the increase in ambient temperature leads to lower intake, resulting in negative energy balances. Above 20°C , goats tend to decrease fasting heat production, as an attempt to spare heat load in hot environments.

Keywords: basal metabolism, energy balance, facemask respirometry, respiratory rate.

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Introduction

Total energy expenditure for maintenance makes up the most important part of the animal's total energy expenditure. In cattle, 60-70% of the total energy expenditure concerns to maintenance throughout their productive life. One of the factors that directly influence this energy expenditure is the maintenance of homeostasis, so that when exposed to temperature changes, ruminants are able to maintain homeostasis and sustain productive functions by changing their metabolic rate (Silanikove 2000). However, studies indicate that goats exposed to these environmental changes are more efficient at adjusting energy metabolism than other species (Al-Dawood 2016; Al-Dawood 2017; Silanikove 2000). In addition, different breeds differ in their ability to react to climatic conditions (Al-Dawood 2017).

Even though goats are described to be well adapted under different environmental conditions, including extreme and harsh ones (Al-Dawood 2017), the productivity of these animals might be impaired due to environmental stressors such as temperature, so that the understanding of the energy balance of goats at different temperatures becomes necessary for the development of more efficient feeding and production systems. Therefore, the objective of this work was to determine the effect of temperature on energy balance and basal metabolism of Saanen and Anglo Nubian goats, using indirect calorimetry system.

Material and Methods

The experiment was conducted at the Universidade Estadual Paulista/Jaboticabal (UNESP, São Paulo, Brazil). Humane care and handling procedures were conducted in accordance with the University's Animal Care Committee (Comissão de Ética e Bem Estar Animal – CEBEA) under protocol number 9502/13.

Six dry and non-lactating Saanen (53.7 ± 7.7 kg BW) and six dry and non-lactating Anglo Nubian (56.4 ± 8.0 kg BW) goats, which were on average 5 years old, were used in a factorial design 2×3 (2 breeds and 3 temperatures). The experimental period consisted of three stages corresponding to the temperature of $10.0 \pm 0.23^\circ\text{C}$, $20.0 \pm 0.41^\circ\text{C}$ and $35.0 \pm 1.05^\circ\text{C}$. The adaptation period in each temperature lasted 21 days.

The goats were fed the same total mixed ration, which comprised, on a dry matter (DM) basis, 90% corn silage, 6.0% cracked corn, 1.6% soybean meal, 0.4% wheat bran, 1.1% cottonseed meal, 0.2% limestone and 0.5% mineral supplement. The chemical composition of the ration, on a DM basis, was 4.6% ash, 9.0% crude protein, 43.2% neutral detergent fiber, 16.0 MJ per kg DM of gross energy. The mixed ration was formulated for a dairy goat at maintenance. The goats were fed *ad libitum* and the diet was provided once daily at 8:00.

After adaptation period, goats were allocated to individual metabolism cages to perform the metabolism assay and gas exchange measurements concomitantly. After that, goats were subjected to 60-h fasting (no feed) and then, gas exchange measurement was performed. Body weights were recorded immediately before the metabolism assay and after fasting.

Metabolism assay. Goats were housed in metabolic cages. Feed intake, orts and total fecal and urinary output were recorded daily over a collection period of six days. The urine was acidified daily with 100 mL of 10% H_2SO_4 . Composites of feed, orts, and feces were dried at 60 to 65 °C for 72 h and ground through a 1 mm screen using a Wiley mill for further analysis. Samples of feed, orts, and feces were analyzed for analytical DM, ash, total N and C content by Dumas principle, ether extract according to AOAC (1990), neutral detergent fiber (NDF) according to Van Soest et al. (1991), and gross energy (GE) using a bomb calorimeter (Parr Instrument Co., Moline, Urine was analyzed for N and GE as previously described.

Gas measurement. Gas measurement was performed using an open-circuit facemask respirometry, as described by Fernandes et al. (2016). Gas measurements were performed in groups of four animals (two of each breed). During 4-d feeding period, gas exchange were measured during 40 min per goat three times a day: once in the morning within the time of day: 7:00 – 8:00; 8:00 – 9:00; 9:00 – 10:00; 10:00 – 11:00, once within the time of day: 11:00 – 12:00; 12:00 – 13:00; 13:00 – 14:00; 14:00 – 15:00 and once in the afternoon within the time of day: 15:00 – 16:00; 16:00 – 17:00; 17:00 – 18:00; 18:00 – 19:00. Within each 1-h window, masks remained on the goats for 40 min, during which gas exchange of expired air was measured. By the end of the fourth day, there was a representative sample of 12 h of measurements for each goat that were extrapolated to 24 h. After the 4-d feeding period, animals were subjected to 60-h fasting (no feed) and gas exchange was measured during 30 min in each goat, randomly, to estimate fasting heat production.

Heat production was calculated according to Brouwer equation (Brouwer 1965). The evaporative water loss (EWL) was calculated according to Maia et al. (2005).

Statistical analyses. Data were analyzed as a factorial design 2×3 using a MIXED procedure of SAS (SAS Inst. Inc., Cary, NC. version 9.4); with the fixed effects of breed, temperature and their interactions and the random effects of animal and residual. The model used for the analysis of each breed was the following: $Y_{jkm} = \mu + B_j + T_k + A_m + (B \times T)_{jk} + e_{jkm}$, where Y = the observation, B_j = fixed effect of the breed, T_k =

fixed effect of the temperature, Am = random effect of animal, ϵ = the residual as a random effect assumed iid $N(0, \sigma^2_{ij})$. When significant, the effect of temperature was decomposed into two orthogonal polynomial contrasts (linear and quadratic). Because levels were not equally spaced, coefficients were generated using the IML procedure of SAS. When significant, the effect of breed were compared using Fisher's protected LSD (i.e. the DIFF option of the LSMEANS statement). When the breed \times temperature was significant, we compared breed in each temperature by the SLICE option of LSMEANS using Fisher's protected LSD. Significance was declared at $P \leq 0.10$.

Results and Discussion

Goats are distributed worldwide in different ecological conditions, whose ambient temperature variation, mainly heat stress, could affect their bioenergetics and, consequently, negatively influence performance and well-being. Therefore, this study investigated the effect of ambient temperature on

Irrespective of breed, DM intake (DMI) and organic matter intake (OMI) decreased linearly as ambient temperature increased (Table 1). The relationship between DMI and temperature is expressed in Equation 1 ($P = 0.0168$; root mean square of error (RMSE) = 10.45), suggesting a decrease of 0.44 g/kg^{0.75} BW for each 1°C increase. This decrease in feed consumption due to the elevation of ambient temperature is the primary response of the animal in attempting to decrease heat load (Al-Dawood 2017, Marai et al. 2007). In fact, exposure of animals to heat stress activates the hypothalamus-pituitary-adrenal axis and secretion of different hormones regulates stress in animals, such as the increase of leptin concentration (Al-Dawood 2016, Rout et al. 2017), which regulates appetite and energy balance (Al-Dawood 2016).

$$\text{DMI (g/kg}^{0.75} \text{ BW)} = 55.18 \pm 4.18 - 0.44 \pm 4.18 \times T \text{ (}^\circ\text{C)} \quad (1)$$

Where DMI = dry matter intake, BW = body weight and T = ambient temperature

Table 1. Temperature effect on daily intake and digestibility of Saanen and Anglo Nubian goats.

Intake ¹ , g/kg ^{0.75} BW	Saanen			Anglo			SEM	P		
	10°C	20°C	35°C	10°C	20°C	35°C		B	T	B×T
DMI	47.6	53.1	42.5	52.0	43.3	37.2	4.92	0.39	L*	0.27
OMI	46.1	50.0	39.9	50.2	40.5	35.0	4.67	0.37	L*	0.27
CPI	4.7	5.1	4.4	4.8	4.7	3.8	0.51	0.82	0.11	0.50
NDFI	21.1	24.8	20.8	22.7	21.5	17.9	2.12	0.42	0.12	0.34

L = linear, Q = quadratic; SEM = standard error of mean; * $P < 0.10$; ** $P < 0.01$.

¹DMI = dry matter intake; OMI = organic matter intake; CPI = crude protein intake; NDFI = neutral detergent fiber (NDF) intake; BW = body weight.

Ruminants are homeothermic animals and can maintain a constant body temperature within a certain range of ambient temperature (Al-Dawood 2017). Therefore, goats generally utilizes their thermoregulatory mechanisms to relieve from stress, but a previous study showed that they did not exhibit wide variation in rectal temperature during heat stressed period (Rout et al. 2017). In this study, during feeding period, rectal temperature was not affect by ambient temperature (Table 2), indicating that the mechanisms of dissipation or heat generation were effective in maintaining homeothermia. On the other hand, respiratory rate (BPM) and evaporative water loss (EWL) increased linearly with temperature elevation (Table 2), presumably demonstrating an effort of the goats to maintain their normal body temperature by increasing their heat dissipation through increasing respiratory evaporation (Al-Dawood 2017).

Table 2. Temperature effect on physiological parameters of Anglo Nubian and Saanen goats, during feeding period.

Variables	Saanen			Anglo			SEM	P		
	10°C	20°C	35°C	10°C	20°C	35°C		B	T	B×T
T rectal, °C	39.1	38.9	39.1	38.9	38.9	38.9	0.09	0.07	0.38	0.50
TExpAir, °C	24.0	26.3	34.2	23.6	25.4	33.3	0.96	0.51	Q**	0.85
BPM	16.5	28.9	84.3	18.1	18.0	24.1	7.33	0.00	L**	<.0001
VE, L _{BTPS} /min	16.3	19.7	57.6	16.2	13.8	28.9	7.65	0.13	L**	0.05
VO ₂ , L _{STPD} /d	251.8	217.6	347.8	319.6	208.5	349.6	48.2	0.63	Q*	0.61
VCO ₂ , L _{STPD} /d	232.5	203.8	329.1	294.8	191.1	292.1	46.3	0.83	Q*	0.50

VCH ₄ , L _{STPD} /d	26.3	23.2	31.5	32.7	15.9	20.4	3.63	0.22	Q*	0.02
EWL, g/d	101.8	160.3	469.3	86.0	97.2	421.5	79.85	0.56	L**	0.93
RQ	0.92	0.93	0.96	0.92	0.91	0.83	0.038	0.21	0.13	0.53

L = linear, Q = quadratic; SEM = standard error of mean; * P < 0.10; ** P < 0.01.

BPM = respiratory rate, breaths per minute; T_{rectal} = rectal temperature, °C; T_{ExpAir} = temperature of expired air; EWL = evaporative water loss; VCH₄ = methane production; VO₂ = oxygen consumption; VCO₂ = carbon dioxide production; RQ = respiratory quotient, VCO₂/VO₂; VE = ventilation. BTPS = body temperature pressure, saturated air, STPD = standard temperature and pressure

Worldwide, there are more than 600 goat breed and they differ in their capacity to overcome climatic conditions (Al-Dawood 2017). In this study, Saanen's rectal temperature and BPM were higher than Anglo Nubian's (Table 2). In general, goats with loose skin and floppy ears are more heat tolerant than other goats (Al-Dawood 2017), suggesting that Anglo Nubian goats are less sensitive to thermic stress than Saanen goats (Medeiros et al. 2008).

Similarly to DMI, metabolizable energy intake (MEI) decreased linearly as ambient temperature increased (Figure 1), irrespective of breed (P = 0.63), whose relationship is expressed in Equation 2 (P = 0.023, RMSE = 78.73).

$$\text{MEI (kJ/kg}^{0.75} \text{ BW)} = 560.8 \pm 56.6 - 5.74 \pm 2.35 \times T \text{ (}^\circ\text{C)} \quad (2)$$

Where MEI = metabolizable energy intake, BW = body weight and T = ambient temperature.

Clearly, a reduction in energy consumption (Figure 1), which would not be enough to supply daily needs, combined with the increase in energy expenditure for maintenance, due to thermal stress, reduced the energy balance and, consequently, retained energy decreased linearly with increase of ambient temperature (Figure 1), irrespective of breed (P = 0.29).

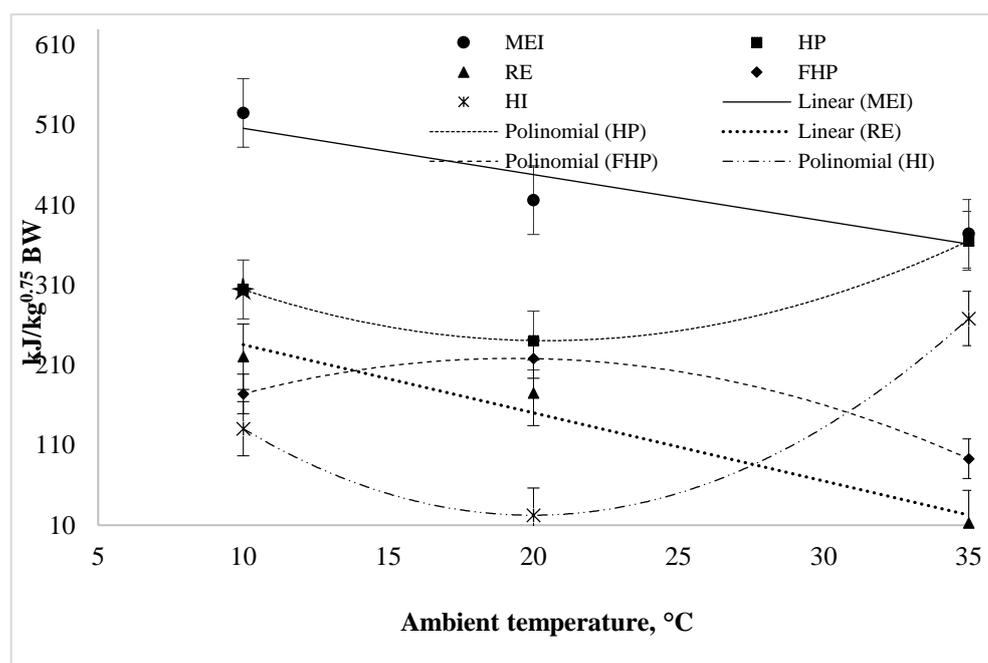


Figure 1. Temperature effect on daily energy balance of goats. MEI = metabolizable energy intake, linear effect, P = 0.05; HP = heat production, quadratic effect, P = 0.06; RE = retained energy, linear effect, P = <0.004; FHP = fast heat production, quadratic effect, P = <0.001; HI = heat increment, quadratic effect, P = <0.001.

Thermoneutral zone is the range of temperature within the animal needs no additional energy to maintain its body temperature. Animals function most efficiently within their thermoneutral zone, however, when exposing to ambient temperature above the upper critical temperature, goats will use the energy to dissipate heat so that to maintain thermal equilibrium. The thermoneutral zone is about 12 and 24°C for goats in the hot regions of the world (Al-Dawood 2017) and the suggested upper limit of heat tolerance for goats is above 40°C (Rout et al. 2017). Irrespective of breed (P = 0.59), heat production (HP) showed a quadratic effect with the lowest values at 20°C (Figure 1). Because HP is directly dependent on MEI, the MEI was included in the equation regarding the relationship between HP and ambient temperature, and expressed in Equation 3 (P

= 0.02, RMSE = 57.14). Conversely, fast heat production (FHP) showed a quadratic effect with a tendency of decreasing at increasing rate in temperature above 20° up to 35°C (Figure 1). Equation 4 (P = 0.03, RMSE = 42.08) expressed the relationship between FHP and temperature. Consequently, in this study, heat increment (HI) showed quadratic effect with a sharp increase when the ambient temperature rose from 20 to 35°C (Figure 1).

$$\text{HP (kJ/kg}^{0.75} \text{ BW)} = 226.8 \pm 145.4 - 15.32 \pm 11.71 \times T \text{ (}^\circ\text{C)} + 0.43 \pm 0.25 \times T^2 \text{ (}^\circ\text{C)} + 0.36 \pm 0.13 \times \text{MEI (kJ/kg}^{0.75} \text{ BW)} \quad (3)$$

Where HP = heat production, MEI = metabolizable energy intake, BW = body weight and T = ambient temperature.

$$\text{FHP (kJ/kg}^{0.75} \text{ BW)} = 22.63 \pm 2.27 \times T \text{ (}^\circ\text{C)} - 0.57 \pm 0.068 \times T^2 \text{ (}^\circ\text{C)} \quad (4)$$

Where FHP = fast heat production, MEI = metabolizable energy intake, BW = body weight and T = ambient temperature.

When environmental temperature rises up to the upper critical temperature, feed consumption and thermogenic hormone secretion decrease to lower the basal metabolism, resulting in a reduction of internal load (Silanikov 2000). Therefore, the observed decrease in FHP when ambient temperature rose from 20 to 35°C might suggest the 35°C to be the temperature approaching the upper critical limit, for both breed, although the combined effects of reduced FHP (Figure 1) and increased EWL enabled the maintenance of homeothermy (Table 2).

Conclusions

Saanen and Anglo Nubian goats are able to maintain homeostasis in environments between 10 and 35°C. On the other hand, the increase in ambient temperature leads to lower intake, resulting negative energy balances. Above 20°C, goats tend to decrease fasting heat production, as an attempt to spare heat load in hot environments.

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