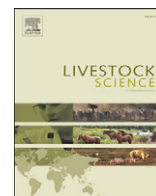


Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

Genetic group × ambient temperature interaction effects on physiological responses and growth performance of rabbits

C.P. Zeferino^a, A.S.A.M.T. Moura^{a,*}, S. Fernandes^a, J.S. Kanayama^b, C. Scapinello^c, J.R. Sartori^b^a Univ. Estadual Paulista, Faculdade de Medicina Veterinária e Zootecnia, Departamento de Produção Animal, 18618-970, Botucatu, SP, Brazil^b Univ. Estadual Paulista, Faculdade de Medicina Veterinária e Zootecnia, Departamento de Melhoramento e Nutrição Animal, 18618-970, Botucatu, SP, Brazil^c Univ. Estadual de Maringá, Departamento de Zootecnia, 87020-900, Maringá, PR, Brazil

ARTICLE INFO

Article history:

Received 14 August 2010

Received in revised form 15 March 2011

Accepted 16 March 2011

Keywords:

Body temperature

Feed consumption

Genetic group

Growth

Respiratory rate

Thermal neutral zone

ABSTRACT

The objective of this study was to evaluate the effects of the interaction between genetic group (Botucatu or crossbred) and ambient temperature (thermoneutral, moderate or intense heat stress) on physiological indicators and performance of growing rabbits. Ninety-six weaned rabbits were used, half from the Botucatu genetic group and half crossbreds (New Zealand White males × Botucatu females). They were assigned to a completely randomized design in a 2 × 3 factorial arrangement (two genetic groups and three ambient temperatures) with repeated measures (weeks). Colonic temperature, skin surface temperature, ear surface temperature, and respiratory rate were recorded from 42 to 67 days of age, whereas body weight and feed intake were recorded from 35 to 70 days of age. Average ambient temperature and relative humidity in the environmental chambers were 18.4 °C and 63.9% (thermoneutral), 24.4 °C and 80.2% (moderate heat stress) and 29.6 °C and 75.9% (intense heat stress). Mean colonic temperatures ranged from 39.4 to 39.7 °C across treatments. Botucatu rabbits showed higher ($P < 0.05$) skin surface temperature under moderate heat stress than the crossbreds (33.0 ± 0.1 vs. 32.6 ± 0.1 °C, respectively) and higher ($P < 0.01$) respiratory rates independently of ambient temperature (161.4 ± 2.8 vs. 148.1 ± 2.8 breaths/min, respectively) than the crossbreds. Skin surface temperature, ear surface temperature and respiratory rate were positively related to ambient temperature. Under intense heat, average daily gain of Botucatu rabbits was higher ($P < 0.05$) than that of the crossbreds (33.72 ± 0.90 vs. 30.66 ± 0.96 g/day, respectively), but there was no difference with thermoneutral or moderate heat conditions. This finding characterizes a genotype × environment interaction. When the age effect was considered, an increase in colonic temperature under intense heat was detected over the last week. Respiratory rate increased in both genetic groups from six to eight weeks of age, but the increase was more pronounced in Botucatu rabbits than in crossbreds, and the difference between groups was consistently amplified over weeks. Intense heat severely depressed average daily gain as age advanced, especially beyond week eight. As expected, feed consumption increased during the experimental period, but the rate was inversely proportional to ambient temperature. Under intense heat stress, feed consumption of Botucatu rabbits was slightly, but consistently, higher than that of the crossbreds as age advanced. Relevant differences in physiological responses and growth performance between rabbit genetic groups under heat stress were detected.

© 2011 Elsevier B.V. Open access under the [Elsevier OA license](http://www.elsevier.com/locate/elsevier).

1. Introduction

The European Food and Safety Authority (2005) pointed out the importance of ambient temperature for rabbit health, and emphasized the need for further studies to investigate the adequate environmental conditions for weaned rabbits.

* Corresponding author. Tel.: +55 14 38117185x220; fax: +55 14 38117180.
E-mail addresses: anamoura@fmvz.unesp.br (A.S.A.M.T. Moura),
cscapinello@uem.br (C. Scapinello), jrsartori@fmvz.unesp.br (J.R. Sartori).

The NRC (1996) recommended that ambient temperature be maintained between 16 and 22 °C for rabbits under laboratory conditions. According to Brody (1964) the thermal neutrality zone for this species is 21 to 25 °C, but it may be different when insulation, posture or basal metabolic rates vary (IUPS, 2001). All these factors are subject to change as the animal grows; therefore heat production and dissipation will change as age advances.

The rabbit is highly susceptible to high ambient temperature because it cannot effectively sweat and panting is not efficient for cooling (Brewer and Cruise, 1994; Marai et al., 2002). The ears are important heat regulating organs in the rabbit because they represent about 12% of the body surface area and are highly vascular. Therefore they have a relevant role for sensible heat loss (Lukefahr and Ruiz-Feria, 2003).

Comparing breeds or strains under the same environment may reveal specific performance levels due to differences in the genotypic values of animals (Lebas et al., 1996). Conversely, a specific environmental difference may not always have the same effect on different genotypes: it could have a greater effect on some genotypes than others or there could be a change in the order of merit of a series of genotypes when measured under different environments, characterizing a genotype \times environment interaction (Falconer and McKay, 1996). When this interaction exists, locally adapted lines should be used in the warm environment, or selection should be conducted in the environment where animals will perform.

In the Southeastern region of Brazil there are two marked seasons: a cool, dry season (from April to September), and a warm, humid season (from October to March) that limits the performance of growing rabbits. In Botucatu, located at 22° 51' south latitude, 786 m above sea level, the warmest month is February. Average temperature and average high during this month were 24.0 and 29.0 °C, respectively, for the five-year period from 2003 to 2007, whereas average temperature and average low in the coolest month (July) were 18.4 and 13.3 °C in the same period (Brunini et al., 2008).

The general effects of environmental temperatures on the performance of growing rabbits have been reported (Amici et al., 1998; Barbosa et al., 1992; Hermes et al., 1999; Pla et al., 1994). However, no differences among genetic groups were detected (Chiericato et al., 1993; Khalil et al., 2002). Moreover, data on physiological responses of growing rabbits to heat stress under controlled conditions are scarce. The identification of genetic groups (or genotypes) having superior performance in warm environments is of extreme importance for the development of rabbit meat production in the tropics. Therefore, this study aimed to investigate the effect of the genetic group \times ambient temperature interaction on physiological indicators of heat stress and performance of growing rabbits.

2. Materials and methods

2.1. Animals and design

A completely randomized design in a 2 \times 3 factorial arrangement (two genetic groups and three ambient temperatures) with repeated measures (weeks) and eight replicates was adopted.

A total of 96 weaned rabbits, males and females, half from the Botucatu genetic group and half from crossbreds were used for performance traits, whereas 48 individuals (24 from each genetic group) were used for the measurements of physiological indicators. The crossbreds were produced by mating 10 New Zealand White bucks to 29 Botucatu does. These New Zealand White males were from the *Universidade Estadual de Maringá* population, whose founders were imported from *Oregon State University* in 1989. The *Botucatu* rabbit is a synthetic strain, originated from Norfolk 2000 rabbits. It has four decades of local adaptation and has been selected for growth rate and litter size since 1992 (Garreau et al., 2004; Moura et al., 2001).

From birth to weaning at 35 days of age, the rabbits were housed in 0.80 \times 0.60 \times 0.45 m wire cages in an open east-west oriented maternity building equipped with plastic curtains. At weaning, they were transferred to smaller cages (0.60 \times 0.50 \times 0.45 m) in the environmental chambers. Three similar chambers (5.0 \times 3.0 \times 2.6 m) were used to house the animals from five to 10 weeks of age: the thermoneutral chamber was maintained at 18 °C; the moderate heat chamber was maintained at 25 °C and the intense heat chamber was kept at 30 °C. No humidity control was available in those chambers. Rabbits from both sexes were randomly assigned to the chambers, two rabbits from the same genetic group per cage, 16 cages per chamber, half from each genetic group. Cages were fitted with nipple drinkers and earthenware feeders. The first week in the chambers was dedicated to acclimation.

Air temperature and relative humidity were recorded daily in the chambers at 9:00 am, 2:00 pm and 9:00 pm, beginning in the second half of the acclimation week. Maximum and minimum daily temperatures were also recorded. Mean air temperature and relative humidity were computed according to Müller (1989) and the temperature-humidity index (THI) according to Kelly and Bond (1971). A 12L:12D photoperiod (from 9:00 am to 9:00 pm) was supplied, according to the recommendation of Verga et al. (2007) for growing rabbits.

Animals had free access to water and to a commercial pelleted diet (Specialties Line—Nutricoelho, Purina®). The composition of the diet, on a dry matter basis, as revealed by the chemical analyses was 17.3% crude protein, 16.7% crude fiber, 21.6% acid detergent fiber, 2.4% ether extract and 12.4% mineral matter.

The procedures involving animals were approved by the Faculdade de Medicina Veterinária e Zootecnia, UNESP, Institutional Animal Ethics and Use Committee (CEUA) under protocol number 01/2007.

2.2. Physiological indicators of heat stress and performance

Length of the right ear was recorded at weaning and at 70 days. Physiological indicators (colonic temperature, body surface temperature, ear surface temperature and respiratory rate) for one rabbit per cage were recorded weekly from 42 to 67 days of age. This rabbit was taken at random the first day and was used during the whole experimental period. Wooden stocks were especially designed to restrain the rabbits, allowing the use of probes for colonic temperature measurement. The restrainer prevented walking and grooming, but not limb moving. Each rabbit was trained in a stock for five

minutes three times during the week before the actual measurements started.

Physiological indicators were recorded three times a week for four weeks on Tuesdays, Wednesdays and Thursdays from 2:00 to 5:00 pm, to eliminate possible influences of circadian rhythms. Colonic temperature was assessed with a three-channel digital thermometer (*Physitemp®*). For that, one of the attached probes was inserted approximately 50 mm beyond the rectal sphincter and allowed to equilibrate for a minute. Fur trimming from three body regions (the back and upper portions of the fore and hind legs) was performed weekly on Mondays to facilitate recording the skin surface temperature with a pistol type laser sighting infrared thermometer (*Icel®*) positioned at approximately 25 cm from the target spot. Mean skin surface temperature was estimated with the equation proposed by [Gonzalez et al. \(1971\)](#), based on the relative contributions of portions to total body surface area:

$$T_{ss} = 0.83T_{bs} + 0.08T_{fs} + 0.09T_{hs}$$

where:

T_{ss}	mean skin surface temperature;
T_{bs}	back surface temperature (mean back surface);
T_{fs}	foreleg surface temperature (above the elbow);
T_{hs}	hind leg surface temperature (above the knee).

Ear surface temperature was recorded with a pistol type laser sighting infrared thermometer from the dorsal surface of the right ear. Respiratory rate per minute was estimated by direct count during 15 s. This value was subsequently multiplied by four. The average of three daily measurements of each physiological indicator (colonic temperature, skin surface temperature, ear surface temperature, and respiratory rate) was used as the weekly value for each individual rabbit.

Body weights were recorded at 35 days and weekly thereafter, up to 70 days of age. Average feed consumption, daily gain and feed conversion were estimated weekly on a cage basis.

2.3. Statistical analyses

The experimental unit was the individual rabbit for the physiological indicators (colonic temperature, body surface temperature, ear temperature and respiratory rate), and the cage for performance traits (body weight, weight gain, feed consumption and feed conversion) because two rabbits were housed per cage.

Estimation and hypothesis testing were performed with the MIXED procedure of SAS (2003), using models with repeated measures (weeks). The fixed effects of the genetic group, ambient temperature, weeks and all interactions were considered in the models. Two random errors were defined: 1) the variance between animals (subjects) within treatments; 2) the variance between measurements within animals. The first random error was used to test the effects of genetic group, ambient temperature and the genetic group \times ambient temperature interaction. The second random error was used to test the remaining effects in the model. The autoregressive covariance structure [AR(1)] was used.

Body weight and initial and final ear lengths were included as covariates in the models for the physiological indicators and were excluded if not significant ($P > 0.05$). Mean contrasts were computed when necessary.

Two rabbits (2.1%) died during the experiment: one with diarrhea in the thermoneutral chamber and another with respiratory problems in the intense heat chamber. Their data were excluded from the analyses.

3. Results

Average daily ambient temperature and relative humidity during the experimental period were 18.4 °C and 63.9% in the thermoneutral chamber, 24.4 °C and 80.2% in the moderate heat chamber and 29.6 °C and 75.9% in the intense heat chamber. Therefore, mean ambient temperatures were maintained within narrow limits from the target values in all chambers (18 °C, 25 °C and 30 °C, respectively). Relative humidity, on the other hand, oscillated due to the lack of resources for its control in the chambers. The THI values ranged from 62 to 66 in the thermoneutral chamber, from 72 to 75 in the moderate heat chamber and from 80 to 83 in the intense heat chamber ([Fig. 1](#)), showing that, despite the variation in relative humidity, heat stress conditions in the chambers were not changed.

3.1. Physiological indicators

Temperature, genetic group and the genetic group \times temperature interaction had no effect on colonic temperature ([Table 1](#)). Average colonic temperatures ranged from 39.4 to 39.7 °C across treatments. The genetic group \times ambient temperature interaction affected skin surface temperature. Whereas no difference between genetic groups was found in the thermoneutral and intense heat chambers, under moderate heat skin surface temperature was higher in the Botucatu rabbits ([Table 1](#)).

Botucatu rabbits had longer ears than the crossbreds: 83.6 ± 0.5 vs. 81.7 ± 0.5 mm at 35 days ($P < 0.01$) and 108.9 ± 1.2 vs. 103.2 ± 1.2 mm at 70 days ($P < 0.01$), but no effect of the genetic group or the genetic group \times temperature interaction was found on ear temperature, although ambient temperature affected this trait ([Table 1](#)).

No effect of the genetic group \times ambient temperature interaction was detected on respiratory rate, but each main factor influenced this trait separately ([Table 1](#)). Botucatu rabbits showed higher respiratory rates than the crossbreds. The covariate final ear length also influenced ($P < 0.01$) respiratory rate: for each additional mm in the ear at 10 weeks of age, a mean reduction of 0.99 ± 0.35 breaths/min was found.

As expected, skin surface temperature, ear surface temperature and respiratory rate increased as ambient temperature increased ([Table 1](#)). Differences between the two extreme treatments (intense heat and thermoneutral) were around 6 °C for skin surface temperature, 10 °C for ear surface temperature and 85 to 95-breaths/min for respiratory rate. The covariate body weight had no effect on the physiological indicators.

A temperature \times week interaction effect ($P < 0.01$) was detected on colonic temperature. No clear trend was

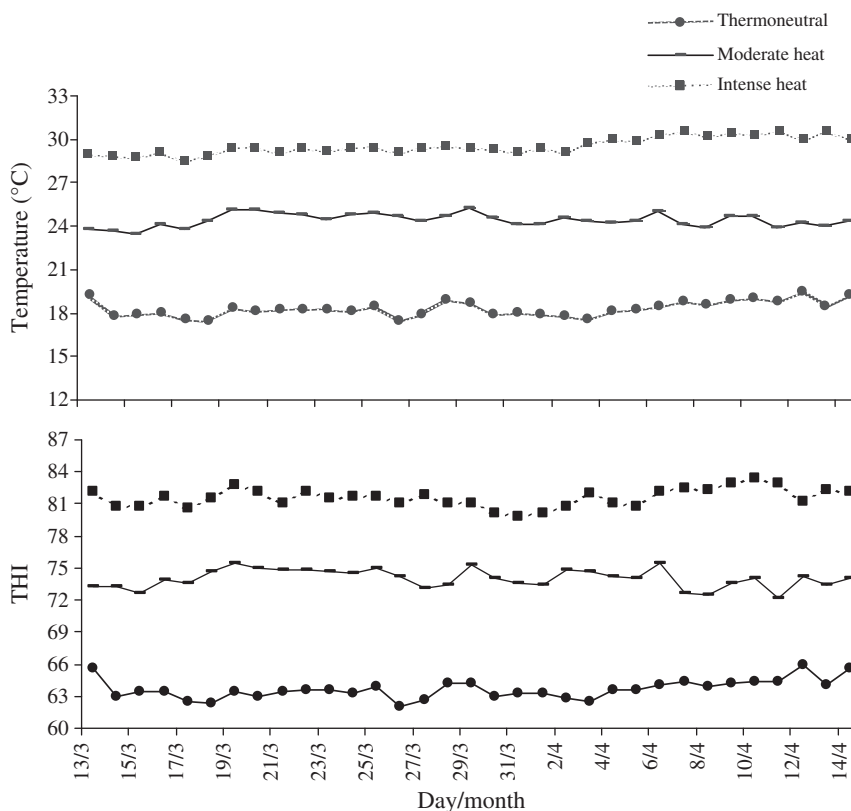


Fig. 1. Average temperature (upper panel) and Temperature and Humidity Index (THI, lower panel) in the thermoneutral, moderate heat and intense heat chambers from March 13 to April 14.

observed in the first three weeks, but in the last week colonic temperature was higher ($P < 0.001$) with intense heat than with moderate heat and thermoneutrality. An ambient temperature \times week interaction effect ($P < 0.001$) was detected on skin surface temperature, but differences among ambient temperatures over weeks were small and unimportant.

Genetic group \times week ($P < 0.05$) and ambient temperature \times week ($P < 0.0001$) interaction effects were both found on ear temperature and on respiratory rate. An evident rise in ear temperature was noticeable between week six and eight in both genetic groups (Fig. 2). Ear surface temperature was higher ($P < 0.05$) in Botucatu rabbits than in the crossbreds at weeks seven (29.0 ± 0.2 vs. 28.4 ± 0.2 °C) and nine (29.8 ± 0.2 vs. 29.1 ± 0.2 °C) (Fig. 2). Respiratory rate increased in both

genetic groups from six to nine weeks of age (Fig. 2), but the increase was more pronounced in Botucatu rabbits (31%) than in crossbreds (18%). On week nine respiratory rates were 181.5 ± 3.7 breaths/min in Botucatu rabbits and 156.1 ± 3.7 breaths/min in the crossbreds ($P < 0.001$) (Fig. 2).

3.2. Growth performance

The genetic group \times ambient temperature interaction effect affected ($P < 0.05$) body weight and average daily gain during the experiment. No differences in mean body weight and average daily gain were found in the thermoneutral or moderate heat chambers, but under intense heat, Botucatu rabbits were heavier than ($P < 0.01$) and gained more weight ($P < 0.05$) than the crossbreds (Table 2). The genetic group

Table 1

Effects of ambient temperatures and genetic group on physiological indicators of growing rabbits.

	Thermoneutral		Moderate heat		Intense heat		Significance level ¹		
	Straightbred	Crossbred	Straightbred	Crossbred	Straightbred	Crossbred	GG	Temp.	GG \times Temp
Colonic temperature (°C)	39.60 ± 0.03	39.53 ± 0.03	39.54 ± 0.03	39.52 ± 0.03	39.59 ± 0.03	39.60 ± 0.03	ns	ns	ns
Skin surface temperature (°C)	28.7 ± 0.1	29.0 ± 0.1	33.0 ± 0.1^a	32.6 ± 0.1^b	34.8 ± 0.1	34.6 ± 0.1	ns	***	*
Ear surface temperature (°C)	23.7 ± 0.2	23.4 ± 0.2	30.0 ± 0.2	29.9 ± 0.2	33.7 ± 0.2	33.1 ± 0.2	ns	***	ns
Respiratory rate (breaths/min.)	113.5 ± 4.9	105.4 ± 4.6	160.5 ± 4.7	146.5 ± 4.5	211.6 ± 5.0	190.6 ± 4.9	**	***	ns

GG = genetic group; Temp = ambient temperature.

¹ ns: $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

^a Differ ($P < 0.05$) for GG \times Temp interaction effect.

^b Differ ($P < 0.05$) for GG \times Temp interaction effect.

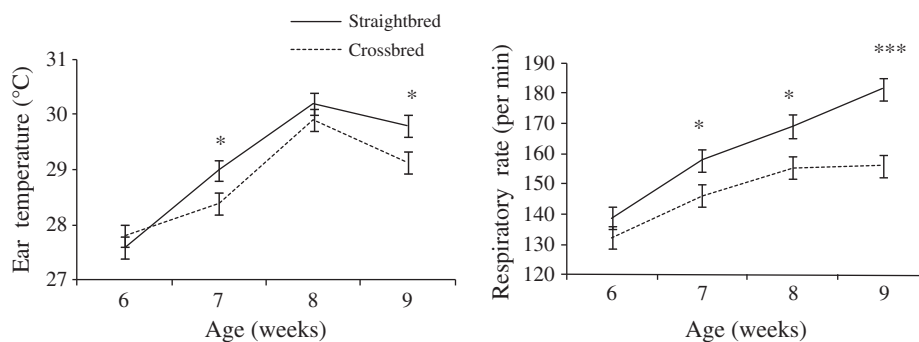


Fig. 2. Effect of the genetic group \times week interaction on ear surface temperature and respiratory rate of rabbits. * $P < 0.05$; *** $P < 0.001$.

affected mean body weight, but not average daily gain, whereas both, mean body weight and average daily gain had negative relationships with ambient temperature (Table 2).

No effect of the genetic group \times ambient temperature interaction was detected on daily feed consumption, but as expected, ambient temperature influenced ($P < 0.001$) this trait (Table 2). No effect of the genetic group \times ambient temperature or of the main factors was detected on feed conversion (Table 2).

When the age effect was considered, a three-way interaction effect ($P < 0.01$) was detected on body weight. In the thermoneutral chamber and under moderate heat stress, no differences were observed between genetic groups. Under intense heat stress, however, the body weight of Botucatu rabbits exceeded that of the crossbreds during the whole experimental period. An ambient temperature \times week interaction was detected on average daily gain ($P < 0.0001$). At week six, rabbits in the moderate heat chamber gained more weight ($P < 0.05$) than those in the thermoneutral chamber (Fig. 3). Intense heat severely depressed average daily gain as age advanced, especially beyond week eight ($P < 0.001$), such that values dropped from 34 ± 1 g/day on week eight to only 26 ± 1 g/day on week 10 (Fig. 3).

The three-way interaction effect was also detected ($P < 0.05$) on feed consumption. As expected, feed consumption increased during the experimental period, but the rate was inversely proportional to ambient temperature. Under intense heat stress, feed consumption of Botucatu rabbits seemed to be slightly, but consistently, higher than that of the crossbreds as age advanced, whereas feed consumption of crossbreds was higher ($P < 0.05$) than that of Botucatu rabbits

in the thermoneutral chamber on week eight (145.8 ± 4.6 vs. 131.2 ± 4.9 g/day). Additionally, feed consumption reached a plateau a week earlier under intense heat stress, whereas an increasing trend persisted in the last week with the other two ambient temperatures.

None of the possible interactions among the three experimental factors affected feed conversion, but, as expected, it increased with the advancement of age from 2.31 ± 0.06 at week six to 4.51 ± 0.06 at week 10.

4. Discussion

Rabbits are very sensitive to heat stress and this fact has been pointed out as one of the major limitations for rabbit meat production in the tropics (Cheeke, 1986; Marai et al., 2002). The two major routes of heat dissipation in these animals are evaporation from the respiratory tract and radiation of heat from the body to the environment. The latter is facilitated by behavioral responses and by the large surface area of the ears. Therefore, longer ears, as observed in Botucatu rabbits, compared to crossbreds, represent a higher potential to dissipate heat.

As ambient temperature did not affect colonic temperature in this study, we assumed that the rabbits were able to regulate body temperature efficiently in all three chambers. The narrow range of colonic temperatures described here (39.4 to 39.7 °C) were in the upper limit of adult New Zealand White rabbits temperatures at resting metabolic rate, reported by Brewer and Cruise (1994) to be between 38.5 and 39.5 °C. Growing animals were involved in the present study and they were not effectively at rest, because they were

Table 2

Effects of ambient temperatures and genetic group and on the performance of growing rabbits from 35 to 70 days.

	Thermoneutral		Moderate heat		Intense heat		Significance level ¹		
	Straightbred	Crossbred	Straightbred	Crossbred	Straightbred	Crossbred	GG	Temp.	GG \times Temp
Mean body weight (g)	1572 \pm 31	1596 \pm 29	1640 \pm 29	1590 \pm 29	1595 \pm 29 ^b	1453 \pm 31 ^a	*	*	*
Weight gain (g/day)	38.04 \pm 0.96	40.63 \pm 0.92	39.07 \pm 0.90	38.28 \pm 0.92	33.72 \pm 0.90 ^d	30.66 \pm 0.96 ^c	ns	***	*
Feed consumption (g/day)	130.6 \pm 3.6	135.1 \pm 3.3	125.7 \pm 3.3	125.7 \pm 3.3	108.6 \pm 3.3	101.6 \pm 3.6	ns	***	ns
Feed conversion (g feed/g gain)	3.41 \pm 0.07	3.31 \pm 0.07	3.32 \pm 0.06	3.36 \pm 0.07	3.35 \pm 0.06	3.45 \pm 0.07	ns	ns	ns

GG = genetic group; Temp = ambient temperature.

¹ ns: $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

^a Differ ($P < 0.01$) for GG \times Temp interaction effect.

^b Differ ($P < 0.01$) for GG \times Temp interaction effect.

^c Differ ($P < 0.05$) for GG \times Temp interaction effect.

^d Differ ($P < 0.05$) for GG \times Temp interaction effect.

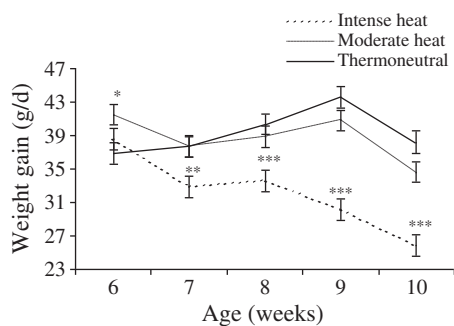


Fig. 3. Effect of the ambient temperature \times week interaction on the combined average daily gains of rabbits from two genetic groups. * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

restrained in stocks and allowed to equilibrate for only one minute after the rectal probe was inserted for colonic temperature assessment. This may partially explain the relatively high values of colonic temperatures, compared to those authors. The increase in colonic temperature observed in the last week of the experiment under intense heat, suggested that the animals were becoming more sensitive to heat stress as they aged. Gonzalez et al. (1971) working with four adult New Zealand White rabbits in a series of assays designed to study heat balance, observed that colonic temperature increased by 1.4 °C when ambient temperature increased from 30 to 35 °C, suggesting that there was some degree of body heat gain when ambient temperature exceeded 30 °C. Marai et al. (2002) reported rectal temperatures ranging from 39.8 to 40.2 °C in a review of three studies conducted in the summer in Egypt, when mean ambient temperature was 30.7 °C. Although the ambient temperature was only 1.1 °C higher than in the intense heat chamber in the present study, rectal temperatures were visibly more elevated than the ones presented here. Several factors may affect body temperature values and make comparisons among studies difficult, such as the environment in which they were conducted (controlled vs. natural) and different rabbit strains and measurement tools used.

Skin surface temperature was higher in Botucatu rabbits under moderate heat stress; this is an indication of increased heat production in this group. Differences in fur thickness and density may exist between these two genetic groups, since relative skin weight of crossbreds was, on average, higher than that of Botucatu rabbits at slaughter (unpublished data). Additionally, skin surface temperature showed a direct relationship with ambient temperature. This was most likely the result of body temperature regulation through vasomotor control. As suggested by Gonzalez et al. (1971), within the 20 to 30 °C range of ambient temperature, the regulation of body temperature in the rabbit appears to be attained mainly through this mechanism.

Ear surface temperature was higher in Botucatu rabbits than in the crossbreds at seven weeks of age, possibly indicating a more pronounced sensible heat loss in this group, which exhibits longer ears. Ear surface temperature showed a wider range of variation than skin surface temperature, within the same ambient temperature range. As indicated by Gonzalez et al. (1971), fluctuations in ear temperature may actually serve as a fine control for vasomotor regulation of

body temperature within the range of 20 to 30 °C ambient temperature. The ears (about 12% of body surface) have the largest arteriovenous anastomotic arrangement in the rabbit body, facilitating heat exchange through a countercurrent system (Brewer and Cruise, 1994). Under intense heat stress, ear surface temperature was high from the beginning and changed little as age advanced, suggesting that maximum vasodilation was taking place from the first week.

Botucatu rabbits showed higher respiratory rate than crossbreds, and the difference between groups grew as age advanced. Although panting is not an efficient mechanism for cooling (Brewer and Cruise, 1994), this result suggests that Botucatu rabbits have a higher capacity for heat dissipation through respiratory evaporative heat loss than the crossbreds, which may be a sign of warm acclimation. Gonzalez et al. (1971) stated that adult New Zealand White rabbits required increased evaporative heat loss in ambient temperatures above 25 °C to achieve thermal balance. Barbosa et al. (1992) described values of respiratory rate in New Zealand White rabbits that were even higher than those presented here (246.8 ± 3.5 breaths/min) in the afternoon during the summer (24 °C average daily temperature and 63.9% relative humidity), in Maringá, Brazil.

As mentioned before, radiation of heat from body surface, especially the ears, and evaporation from the respiratory tract have complementary roles for heat dissipation in the rabbit. Therefore, a possible trade-off between these two mechanisms can be hypothesized to explain the decrease in respiratory rate as ear length (and consequently ear surface) increased.

Botucatu rabbits revealed a greater growth potential than crossbreds under intense heat stress, but with thermoneutral and moderate heat conditions, no differences were detected between genetic groups. This finding characterizes a novel genotype \times environment interaction in rabbits. In warm environments, the use of locally adapted lines or conducting selection in the environment where animals will perform could be recommended because of their increased heat tolerance. Chiericato et al. (1993), working with three genetic groups (New Zealand White, Grimaud and Provisal) in the winter and summer did not find any differences among them in respect to body weight or average daily gain under the two conditions. The superior performance of Botucatu rabbits under intense heat stress could be, at least in part, attributed to the selection program practiced for almost two decades (Bianospino et al., 2006, Moura et al., 2001) and to the four decades acclimation period.

In the first week, rabbits kept under moderate heat gained more weight than those in the thermoneutral chamber, corroborating the hypothesis that 18.4 °C may have been below the optimal temperature for rabbits of this age. Average daily gain was comparable in thermoneutral and moderate heat conditions from week seven to nine, indicating that moderate heat (24.4 °C, on average) was not limiting for performance during this period. Under intense heat, the decrease in average daily gain that occurs with advancement of age was much more marked and a week earlier. Accordingly, Hermes et al. (1999) did not detect differences in average daily gain of eight-to ten-week-old Californian rabbits subjected to either 20 or 26 °C, but found an important decline with ambient temperature above 32 °C.

Increased feed consumption under heat stress is consistent with findings reported earlier, showing that heat dissipation and average daily gain were higher in Botucatu rabbits with intense heat stress. This may have been a positive consequence of warm acclimation. Reduced feed consumption at high temperatures was reported in studies involving different breeds and commercial hybrids in the summer (Chiericato et al., 1993) or under controlled conditions (Hermes et al., 1999).

Similar to what happened in the present study where neither the genetic group, nor ambient temperature affected feed conversion, Chiericato et al. (1996) did not detect differences in feed conversion among three genetic groups (New Zealand White, Grimaud and Provisal) subjected to two ambient temperatures: thermoneutral at 20 °C and heat stress at 28 °C. These results indicate that, although growth rate was reduced, the efficiency of the growth process was not affected by heat stress.

5. Conclusions

Intense and moderate heat stress caused elevations in body and ear surface temperatures and respiratory rates in Botucatu and crossbred rabbits. These changes were accompanied by decreased feed consumption, body weight and average daily gain, especially under intense heat stress and from eight to ten weeks of age.

Botucatu rabbits had longer ears and higher respiratory rates than the crossbreds, which are indicators of increased heat production and, perhaps, higher metabolic rates. This group showed higher body weight and average daily gain than the crossbreds under intense heat, but not under the other two conditions, characterizing a genotype x environment interaction.

Acknowledgments

The authors thank Mrs. Irene F. Arruda for technical assistance. This study was supported by a grant from the Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Brazil. C. P. Zeferino received a scholarship from the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil. A.S.A.M.T. Moura, C. Scapinello and J.R. Sartori are recipients of productivity scholarships from the CNPq, Brazil.

Appendix A. Supplementary data

Supplementary data to this article can be found online at doi:10.1016/j.livsci.2011.03.027.

References

Amici, A., Canganella, F., Bevilacqua, L., 1998. Effects of high ambient temperatures in rabbits: metabolic changes, caecal fermentation and bacterial flora. *World Rabbit Sci.* 6, 319–324.
Barbosa, O.R., Scapinello, C., Martins, E.N., Mendes, L.D.V., Sugohara, A., Saito, E.Y., 1992. Desempenho de coelhos da raça Nova Zelândia Branco, criados em diferentes tipos de instalações, durante as estações de verão e

inverno. 1 Temperatura corporal, frequência respiratória, consumo de ração, ganho de peso e conversão alimentar. *R. Bras. Zootec.* 21, 779–786.
Bianospino, E., Wechsler, F.S., Fernandes, S., Roça, R.O., Moura, A.S.A.M.T., 2006. Growth, carcass and meat quality traits of Botucatu rabbit and crossbred Botucatu rabbits. *World Rabbit Sci.* 14, 237–246.
Brewer, N.R., Cruise, L.J., 1994. Physiology. In: Manning, P.J., Ringler, D.H., Newcomer, C.E. (Eds.), *The Biology of the Laboratory Rabbit*. Academic Press, New York, pp. 63–70.
Brody, S., 1964. *Bioenergetics and Growth*. Hafner, New York.
Brunini, O., Abramides, P.L.G., Pantano, A.P., Rolim, G.S., Blain, G.C., Ribeiro, R.V., Tremocoldi, W.A., Calheiros, R.V., de Camargo, M.B.P., Pedro-Junior, M.J., 2008. Monitoramento ambiental e hidrometeorológico no Estado de São Paulo – uma ação pelo CIIAGRO-SAA. *Tecnol. Inov. Pec.* 1, 90–96.
Cheeke, P.R., 1986. Potentials of rabbit production in tropical and subtropical agricultural systems. *J. Anim. Sci.* 63, 1581–1586.
Chiericato, G.M., Rizzi, C., Rostellato, V., 1993. Effect of genotype and environmental temperature on the performance of the young meat rabbit. *World Rabbit Sci.* 1, 119–125.
Chiericato, G.M., Rizzi, C., Rostellato, V., 1996. Effect of genotype and environmental conditions on the productive and slaughtering performance of growing meat rabbits. In *Proceedings of 6th World Rabbit Congress*, Toulouse, France, July 9–12, pp. 147–151.
EFSA (European Food and Safety Authority), 2005. Scientific opinion of the scientific panel on animal health and welfare on “The impact of the current housing and husbandry systems on the health and welfare of farmed domestic rabbit”, EFSA-Q-2004-023. *EFSA J.* 267, 1–31.
Falconer, D.S., McKay, T.F.C., 1996. *Introduction to Quantitative Genetics*, fourth edition. Pearson Prentice Hall, Harlow.
Garreau, H., Piles, M., Larzul, C., Baselga, M., de Rochambeau, H., 2004. Selection of maternal lines: last results and prospects. In *Proceedings of 8th World Rabbit Congress*, 7–10 September 2004, Puebla, Mexico, pp. 14–25.
Gonzalez, R.R., Kluger, M.J., Hardy, J.D., 1971. Partitional calorimetry of the New Zealand White rabbit at temperatures 5–35 °C. *J. Appl. Physiol.* 31, 728–734.
Hermes, J.H., Ahmed, B.M., Khalil, M.H., Salah, M.S., Al-Homidan, A.A., 1999. Growth performance, nutrients utilization and carcass traits of growing Californian rabbits raised under different ambient temperatures. *Egypt. J. Rabbit Sci.* 9, 117–138.
IUPS, 2001. Glossary of terms for thermal physiology [revised by The Commission for Thermal Physiology of the International Union of Physiological Sciences (IUPS)]. *Jpn. J. Physiol.* 51, 245–280.
Kelly, C.F., Bond, T.E., 1971. Bioclimatic factors and their measurement. In: *National Academy of Sciences (Ed.), A Guide to Environmental Research on Animals*. IAS, Washington.
Khalil, M.H., Al-Sobayel, K., Hermes, J.H., Al-Homidan, A.A., 2002. Cross-breeding effects for post-weaning growth, rectal and year temperatures, and respiratory rates in crossing Saudi Gabali with Spanish V-line rabbits. In *Proceedings of 7th World Congress on Genetics Applied to Livestock Production*, 19–23 August 2002, Montpellier, France.
Lebas, F., Coudert, P., Rochambeau, H., Thebault, R.G., 1996. El conejo: cria y patología. Colección FAO. Producción y sanidad animal. Organización de las Naciones Unidas para la Agricultura y la Alimentación, Roma.
Lukefahr, S.D., Ruiz-Feria, C.A., 2003. Rabbit growth performance in a subtropical and semi-arid environment: effects of fur clipping, ear length, and body temperature. *Livest. Res. Rural Dev.* 15, 1–10.
Marai, I.F.M., Habeeb, A.A.M., Gad, A.E., 2002. Rabbits' productive, reproductive and physiological performance traits as affected by heat stress: a review. *Livest. Prod. Sci.* 78, 71–90.
Moura, A.S.A.M.T., Costa, A.R.C., Polastre, R., 2001. Variance components and response to selection for reproductive, litter and growth traits through a multi-purpose index. *World Rabbit Sci.* 9, 77–86.
Müller, P.B., 1989. *Bioclimatologia aplicada aos animais domésticos*, Third edition. Sulina, Porto Alegre.
NRC (National Research Council), 1996. *Guide for the Care and Use of Laboratory Animals*. National Research Council. National Academy Press, Washington D. C.
Pla, M., Fernandez-Carmona, J., Blas, E., Cervera, C., 1994. Growth and some carcass traits of adult rabbits under high ambient temperature. *World Rabbit Sci.* 2, 147–151.
SAS/STAT, 2003. *User's Guide (Release 9.1.3 Service Pack 2)*. SAS Inst. Inc, Cary.
Verga, M., Luzi, F., Carenzi, C., 2007. Effects of husbandry and management systems on physiology and behaviour of farmed and laboratory rabbits. *Horm. Behav.* 52, 122–129.