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Does early thermal conditioning sometimes fail to improve the resistance of broilers to heat stress?

Vasco De Basilio[a], Fanny Requena[b], Alicia Leon[b], Zoraida Velazco[b], Michel Picard[c*]

[a] Universidad Central De Venezuela Facultad de Agronomia Apdo. 4579, Maracay, Venezuela
[b] Centro Nacional de Investigaciones Agropecuarias, Instituto Nacional de Investigaciones Agropecuarias Apdo. 4653, Maracay, Venezuela
[c] Institut National de la Recherche Agronomique, Station de Recherches Avicoles, 37380 Nouzilly, France

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Abstract — Early age thermal conditioning (TC) by exposing young chicks to 40 °C for 24 hours reduces body temperature (Tb) and improves long-term broiler resistance to heat stress. Three experiments were performed under semi-controlled tropical environmental conditions to evaluate the factors affecting TC efficacy. The addition of infrared bulbs during TC reduced growth and increased water intake compared to gas heaters at similar ambient temperatures (Ta). TC consistently reduced the Tb of chickens at 7 and 40 days of age independently of the heat source (– 0.22 °C on average). During heat stress after 40 days of age, significant reduction in mortality was observed in the TC chickens when only gas heaters were used in the second experiment. The use of infrared bulbs during the first week of age never resulted in reduced mortality. The third experiment demonstrated late acclimatization when chickens were exposed to natural climatic conditions (Ta varying daily from 26 to 36 °C) compared to maximal Ta limited to 31 °C by air-conditioning from 30 to 40 days of age. Chickens exposed to natural climatic conditions had lower Tb (– 0.16 °C) and resisted heat stress at 38 ± 2 °C at 41 days of age, although 12.6% of the air-conditioned chickens died. The TC effects were maintained on Tb in late acclimatized chickens but no differences in mortality due to TC occurred during heat stress. Inconsistencies between TC experiments arise from an imprecise definition of TC and heat stress conditions, and from the environmental conditions perceived by chickens after TC, which can induce late acclimatization. Persistent reductions in Tb after TC have been consistently measured but these might not be directly responsible for resistance to heat stress. Conversely, of the 525 heat stressed chickens studied during the 3 experiments, 64% of those who had a Tb lower than 40.8 °C at 4 days of age (prior to TC exposure) survived heat stress although only 47% of the chicks having a Tb higher than 40.8 °C at 4 days did. Further research is warranted on the Tb of newly hatched chicks.

chicken / temperature / acclimatization / mortality / body temperature

* Correspondence and reprints
Tel.: +33 (0)2 47 4278 40; fax: +33 (0)2 47 42 77 78; e-mail: picard@tours.inra.fr

Résumé — L'acclimatation précoce échoue-t-elle parfois à renforcer la résistance des poulets de chair à un stress thermique chaud ? L'acclimatation précoce (TC) qui consiste à exposer des jeunes poussins à 40 °C pendant 24 heures, fait baisser la température corporelle (Tb) et améliore durablement la résistance des poulets de chair à un coup de chaleur. Trois expériences conduites dans un environnement tropical semi-contrôlé évaluent des facteurs de variation de l'efficacité de TC. Par rapport à une source unique de chaleur au gaz pendant TC, l'adjonction d'ampoules infra rouges a diminué la croissance et augmenté la consommation pour une même température ambiante (Ta). Quelle que soit la source de chaleur, Tb mesurée à 7 et 40 jours d'âge, était toujours diminuée par TC (–0,22 °C en moyenne). TC n'a réduit la mortalité pendant un stress thermique après l'âge de 40 jours que lorsqu'il était appliqué avec des éleveuses à gaz au cours de la seconde expérience. L'utilisation d'ampoules infra rouges pendant la première semaine de vie n'a jamais permis de réduire la mortalité. La troisième expérience démontre l'existence d'une acclimatation tardive lorsque les poulets sont élevés en conditions tropicales naturelles (Ta variant quotidiennement entre 26 et 36 °C) par rapport à des poulets dont la Ta maximale a été limitée à 31 °C par conditionnement d'air entre 30 et 40 jours d'âge. La Tb des poulets élevés en climat tropical naturel était réduite (–0.16 °C) et ils résistaient à un stress thermique à 38 ± 2 °C à l'âge de 41 jours, alors que 12,6 % des poulets dont l'air était conditionné mourraient. L'effet de TC sur Tb était maintenu dans les deux environnements mais aucune différence de mortalité pendant le stress thermique n'était mesurable. Les irrégularités de réponse à TC d'une expérience à l'autre proviennent d'une définition imprécise des conditions d'application de TC et des stress thermiques et des conditions environnementales après TC qui peuvent induire une acclimatation tardive. La Tb était toujours réduite de manière durable après TC mais cette réduction pourrait n'être pas directement la cause de la résistance aux stress thermiques. En revanche, sur les 525 poulets ayant subit un stress thermique pendant les 3 expériences, 64 % de ceux qui avaient à l'âge de 4 jours (avant l'exposition à TC) une Tb inférieure à 40,8 °C ont survécu au coup de chaleur final contre seulement 47 % des poussins qui avaient une Tb supérieure à 40,8 °C à 4 jours. La température corporelle des poussins nouveau-nés mérite des recherches complémentaires.

poulet de chair / température / acclimatation / mortalité / température corporelle

1. INTRODUCTION

Warm climatic conditions reduce feed intake and growth rate of most domestic animals including chickens. Short periods of intense heat during the dry season in tropical countries induce major economic losses by increasing late mortality of fast growing broiler chickens. Heat exposure at warm ambient temperature (Ta = 36–38 °C) for 24 hours at 5 days of age, a technique described as "early age thermal conditioning" (TC), durably increases the broiler's resistance to heat stress without negative effects on growth and feed conversion [2, 3, 26, 28]. Similar results have been obtained under real and simulated tropical conditions [10, 11] in the laboratory and also under practical broiler production in the tropics [9].

Most published results report a reduction in mortality of TC exposed broilers during heat stress after 5 weeks of age compared to control broilers. A non-significant or non-measurable reduction in mortality rate after TC has also been reported in broiler chickens [4, 15, 17, 24]. However, no negative effect of TC has been published and this technique consistently reduces the body temperature (Tb) of broilers [8]. The source of heat used to increase Ta during conditioning is rarely reported in studies of TC. In practical tropical poultry sheds, chicks are heated with gas heaters but some farmers still use infrared bulbs. A combination of gas heater and infrared bulbs is an efficient way to improve homogeneity of Ta over the large area of the shed during TC. In a preliminary unpublished laboratory study, TC failed to reduce mortality when infrared bulbs were used to increase Ta by 8 °C during TC. Lighting conditions change chicken behavior [19] and consequent or simultaneous muscle growth [22], fatness [18] or leg disorders [7]. The Tb of chicks was increased when infrared bulbs were added to gas heaters under our conditions as compared to similar Ta conditions using only gas.

Another factor that may vary the efficacy of TC in real tropical climatic conditions is the Ta in the shed from 6 to 40 days of age, i.e. from TC to final heat stress. Tropical poultry sheds are submitted to open-air Ta fluctuations that may induce a late acclimatization. For example, cyclic Ta from 24 to 35 °C for several days after 4 weeks of age reduces Tb and mortality in broiler chickens during a subsequent heat stress [14, 16, 20]. Chicks acclimatized by TC at an early age may not differ from unexposed controls if the Ta is moderately and progressively increased during the finishing stage of production.

Because TC might become a practical method in the tropics, it is essential to identify factors affecting its efficacy. The purpose of the three experiments presented here was to evaluate the effects of the heat sources of TC and the effects of Ta conditions prior to heat stress on Tb and the resistance of broiler chickens to heat stress applied after 40 days of age.

2. MATERIALS AND METHODS

All experiments were undertaken at the experimental station of INIA (National Institute of Agricultural Research) in Maracay – Venezuela. The first two experiments were identical except that there were twice as many birds in the second experiment than in the first. The effects of the heat source on Tb during TC (G = gas or G+E = a combination of gas and infrared bulbs) and resistance of broilers to heat stress applied after 40 days of age were tested. In the third experiment, the effects of two distinct Ta were tested on the same criteria between 30 and 40 days of age. One experimental treatment consisted in limiting the daily maximal Ta to 31 °C although the control chickens were exposed to natural climatic variations up to a maximum of 36 °C. Feed [10] and water were provided ad libitum and lighting was constant throughout the experiments.

2.1. Animal husbandry

2.1.1. First week of life

An experimental poultry shed (5 × 11 m) was enveloped in glass house type nylon net curtains allowing air circulation but reducing the external sun radiation by 80%. It was split into two identical rooms by the same type of curtain. An air conditioner (8000 BTU) and 2 fans were used to maintain the Ta at 32 °C at the chicks' level in room 1 whereas the Ta was raised to 40 °C in room 2 during the TC.

Male day-old broiler chicks (Cobb) individually identified by a wing tag were raised in independent wire cages (48 × 40 × 30 cm) containing 6 chicks (Exps. 1 and 2) or 4 chicks (Exp. 3). Each cage was equipped with a drinker and two feeders. The cages were located in four Ta-calibrated circles (diameter = 2.5 m) each heated by one thermostatically controlled gas heater (Shenandoah model GB SMHP 4 17.000 BTUH), two circles in room 1 and two in room 2. Constant lighting was provided using 3 electric bulbs (25 W) per circle. Six infrared bulbs (250 W) were added to one circle in each room during the TC in experiments 1 and 2.

2.1.2. From 7 to 40 days of age

At 7 days of age in experiments 1 and 2, the chicks were transferred to another experimental poultry house divided in floor pens of 12 chickens (1.3 × 1.85 m) each equipped with one feeder and one drinker and rice hull as bedding material. The poultry shed contained 48 pens of which 12 pens were used in experiment 1 and 24 pens were used in experiment 2. The experimental pens were organized in three distinct groups each separated by two empty pens and a plastic curtain from one another to avoid heat effects on neighboring pens when heat stress was performed on one group at a time. Experimental treatments were equally represented in each group. In experiment 3, the chicks remained in rooms 1 and 2 after 7 days of age. The circles and cages were replaced by 16 floor pens (0.50 × 1.00 m) per room with one gas heater for 8 pens. Each pen of 4 chickens was equipped with one feeder and one drinker and rice hull as the bedding material. In room 1, Ta was maintained below 31 °C using air-conditioning whatever the external Ta. In room 2, Ta varied with climatic conditions with daily maximal Ta up to 36 °C.

2.2. Experimental designs and procedures

2.2.1. Experimental designs (Fig. 1)

Experiment 1 followed a factorial design (2 thermal conditions, TC and control × 2 sources of heat, G and G+E), with 6 repetitions of 6 chicks from 1 to 7 days of age. A total of 144 chicks were used. On Day 7, one cage of control and one cage of TC exposed chicks were intermingled in one pen of 12 chickens. The 144 chickens were distributed into 12 pens (6 pens of G and 6 pens of G+E heated chicks). After 7 days, TC and control chicks received exactly the same environmental conditions but TC treatment was nested into the heat source.

Experiment 2 duplicated experiment 1 but with twice as many chickens tested (288). There were 12 repetitions of 6 chicks per experimental treatment from 1 to 7 days of age, 24 pens of 12 chickens from 7 days to heat stress, with 6 TC exposed chicks and 6 control chicks per pen.

Experiment 3 followed a factorial design (2 thermal conditions, TC and control during the first week × 2 thermal conditions from 7 days of age to heat stress, Ta < 31 °C and Ta varying up to 36 °C depending on the natural climate). A total of 192 chicks were used with 24 repetitions of 4 chicks per experimental treatment during the first week. On day 7, 16 cages per experimental treatment were randomly selected and transferred to the pens in order to obtain 8 repetitions of 4 TC chickens and 8 repetitions of 4 control chickens in each room. From 7 days of age to the end of the experiment, the 4 treatments were repeated 8 times with 4 chickens per pen.

2.2.2. Early-age thermal conditioning

Ta at the chicks' level was reduced from 34 °C on arrival to 32 °C on the fourth day of life. On day 5 at 09:00 h, Ta was raised up to 40 ± 1 °C at the chicks' level for 24 hours in room 2 and maintained at 32 ±1 °C in room 1. In one circle per room for experiments 1 and 2 and both circles in experiment 3 this was achieved using gas heaters only. In the other circle of each room in experiments 1 and 2 Ta was achieved using a combination of infrared bulbs and gas. After TC, Ta was returned to 32 ± 1 °C in room 2.

2.2.3. Heat stress

One gas heater per pen (Exps. 1 and 2) and one for 8 pens (Exp. 3) were used to increase Ta to 40 °C for 8 hours. Heat stress was applied at 40, 41 and 42 days of age to the groups of 4 pens (Exp. 1) and 8 pens (Exp. 2) per day. Heat stress was applied at 41 days of age in experiment 3 for all pens.

2.3. Measurements

Ta and relative humidity were recorded continuously throughout the experiments using thermo-hygrometers at the chicken levels. Body weight, feed and water intake were obtained by weighing individual animals,

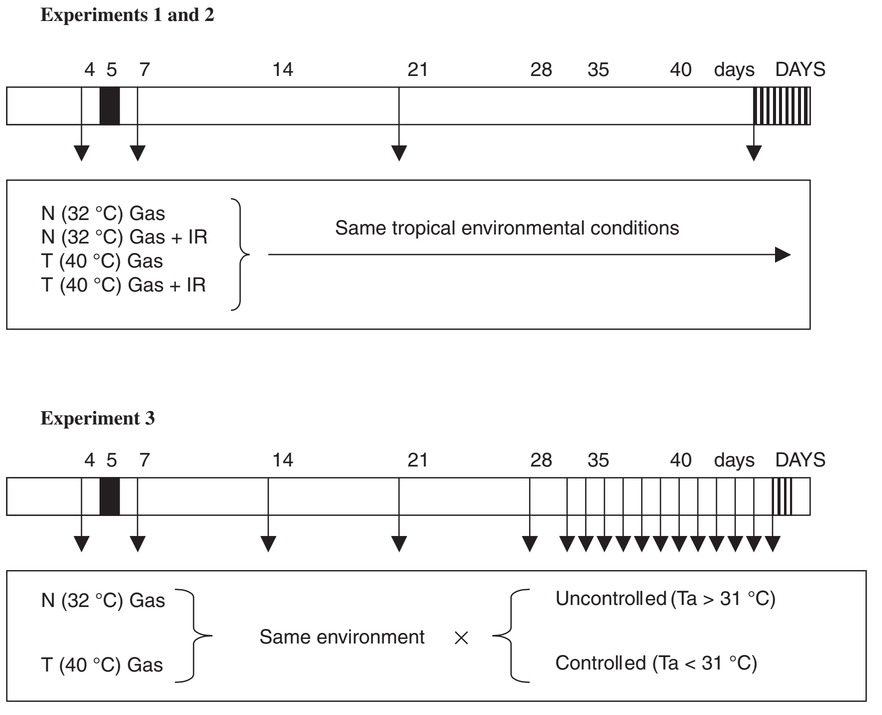

Figure 1. Schematic representation of the experimental designs. Early age thermal conditioning is given at 5 days of age (in black). Arrows correspond to the individual controls of body temperature. The final heat stress is applied after 40 days of age (in hatched). N = control treatments; T = early-age thermal conditioned treatments; IR = infrared bulbs; Ta = ambient temperature.

feeders and drinkers on electronic balances (± 0.1 g). Body temperature (Tb) was measured in the terminal colon using a rapid thermometer (Testo 110) especially calibrated for the range 0–60 °C connected to a probe (CTM, testo Gnbh & CoD 79853 Lenzkirch Germany). Chickens were gently manipulated individually. Optimal penetration according to the size of the chickens and timing were determined by preliminary trials. Simultaneous telemetry recordings confirmed that Tb was not affected by the manipulation of the chickens [12]. Tb was measured in all chicks at 4 and 7 days of age, i.e. one day prior to and one day after TC, and at 21 and 40 days of age. The delay of 24 h prior and after TC was observed to avoid manipulating chicks before TC and let the Tb stabilize after TC. In experiment 3, Tb was measured at 14, 21, 28 days and daily from 30 to 41 days of age (Fig. 1).

2.4. Statistical analyses

All data were averaged per pen prior to analysis. In the case of experiments 1 and 2 after 7 days of age, body weight and Tb of the TC exposed and control chicks were separately averaged per pen but the effect of TC was nested for analysis of variance. The results were expressed as mean and standard errors and the level of significance was 0.05. However, probabilities between 0.05 and 0.10 were given for information. Feed and water intake, body weight and body weight gain, feed conversion and Tb were analyzed by one and two way ANOVA. The Tb recorded daily during the finishing period of experiment 3 were analyzed by repeated measures ANOVA. When interactions were significant, the Newman and Keuls test was used to test the differences between the treatment means. The mortality rate was compared by the χ^2 test. A final repeated measure analysis of variance incorporated 525 Tb records of individual chicks obtained from the three experiments to compare the variations in Tb from 4 to 40 days of age in acclimatized and control chickens that survived or did not survive the final heat stress.

3. RESULTS

3.1. Experiments 1 and 2

3.1.1. Short-term effects of TC and heat source during the first week

During the first week, Ta measured at the chicks' level was consistent with the protocols. For example during TC, Ta was 39.19 ± 0.22 °C (min. = 38.9, max. = 39.7) in the circle where only gas was used (G) and 39.25 ± 0.14 °C (min. 38.9, max. = 39.5) in the circle where gas and infrared bulbs were used (G+E). The respective Ta measured in the control circles were 32.32 ± 0.11 °C for G and 32.41 ± 0.07 °C for G+E. Relative humidity recorded at the level of the chicks varied from 32 to 43% at 32 °C and was decreased to 20–25% during TC in the treated groups. A total of 17 chicks (out of 432) died or were eliminated from both experiments during the first week with no identified relationship with the experimental treatments (i.e., 8 control and 9 TC exposed chicks).

Thermal conditioning (TC) did not significantly reduce the body weight at 7 days of age. However, growth was reduced in the TC-exposed chicks by 30 to 70% during the 24 hours of heat exposure compared to the controls, depending on the heat source (Tab. I). A significant interaction between TC and the source of heat was measured in experiment 1 and a similar but non-significant trend existed in experiment 2. For the same measured Ta, infrared bulbs enhanced the reduction in growth observed during TC with the gas heater. TC reduced feed intake by 25% in both experiments. The effect of energy source was only significant in the first experiment, resulting in a slight but significant increase in feed intake when the infrared bulbs were added to the gas heater. Water intake was stimulated by both factors, but the amount consumed varied between experiment due to the relative imprecision of this measurement.

Body temperature (Tb) prior to TC averaged 40.9 °C at 4 days of age. There were no significant differences between experimental treatments at that age in experiment 2 although a slight (0.1 °C) but significantly higher Tb was measured in the TC chicks in experiment 1. At 7 days of age, i.e. 24 hours after TC, Tb was significantly lower (– 0.2 °C) in the chicks exposed to gas TC in both experiments. Infrared bulbs resulted in increased Tb (+ 0.16 °C) in control and TC chicks during experiment 2. In experiment 1 there was a significant interaction between heat source and TC because the infrared bulbs had a stimulating effect similar to those in experiment 2, but only on TC chicks (Tab. I). TC significantly reduced variations in Tb from 4 to 7 days of age in both experiments.

3.1.2. Effects of TC and heat source during the first week on subsequent performance

The recorded Ta was on average 29 °C from 7 to 40 days of age, varying from 23 to 33 °C with an average relative hygrometry of 65% with wide variations induced by rains. Nine chickens died or were eliminated for reasons independent of the experimental treatments.

Table I. Experiments 1 and 2: mean (SE) feed and water intake, body weight (BW) and body weight gain in g per chick, body temperature (Tb) and Tb variations from 4 to 7 days of age in °C.

Experiment 1

TC	N		T		ANOVA (P <)		
Heat source (S)	G	G+E	G	G+E	TC	S	TC × S
Feed intake during TC	21.3 ± 0.6	23.7 ± 0.9	19.0 ± 0.6	19.7 ± 0.7	0.01	0.05	-
Water intake during TC	51.6 ± 2.0	60.6 ± 3.3	112.8 ± 11.2	125.8 ± 1.4	0.01	*0.08*	-
BW gain during TC	13.1 ± 0.6 a*	13.6 ± 0.4 a	9.4 ± 1.7 b	6.3 ± 0.7 c	0.01	*0.09*	0.02*
BW 7 days of age	125.8 ± 4.0	127.8 ± 3.1	127.4 ± 3.5	129.2 ± 1.8	-	-	-
Tb at 4 days of age	40.94 ± 0.03	40.86 ± 0.05	40.98 ± 0.03	41.01 ± 0.03	0.02	-	-
Tb at 7 days of age	41.26 ± 0.04 a*	41.28 ± 0.04 a	41.02 ± 0.03 b	41.24 ± 0.04 a	0.01	0.01	0.01*
Tb variation 4–7 d	0.32 ± 0.01	0.42 ± 0.08	0.04 ± 0.03	0.23 ± 0.06	0.01	0.01	-

Experiment 2

TC	N		T		ANOVA (P <)		
Heat source (S)	G	G+E	G	G+E	TC	S	TC × S
Feed intake during TC	25.2 ± 1.0	25.2 ± 1.3	20.4 ± 0.6	18.6 ± 0.6	0.01	-	-
Water intake during TC	72.4 ± 7.3	116.0 ± 7.7	85.2 ± 5.1	127.6 ± 2.2	0.05	0.01	-
BW gain during TC	16.9 ± 0.8	16.4 ± 0.9	8.7 ± 1.5	5.5 ± 0.9	0.01	*0.09*	-
BW 7 days of age	160.6 ± 3.6	152.7 ± 2.2	154.2 ± 2.8	150.1 ± 2.5	-	0.04	-
Tb at 4 days of age	40.88 ± 0.02	40.96 ± 0.03	40.87 ± 0.06	40.90 ± 0.03	-	*0.10*	-
Tb at 7 days of age	40.97 ± 0.04	41.19 ± 0.07	40.80 ± 0.05	40.90 ± 0.03	0.01	0.01	-
Tb variation 4–7 d	0.10 ± 0.04	0.23 ± 0.08	-0.07 ± 0.07	0.01 ± 0.04	0.01	*0.10*	-

T: early age thermal conditioned (TC) chicks, N: controls, G: gas as the only heat source at an early age, G+E: mixed gas + electricity heat source at an early age, BW: body weight. There were 6 cages of 6 chickens per treatment in experiment 1 and 12 cages of 6 chickens per treatment in experiment 2. Due to significant interactions between the experiment and effects measured, the results are presented separately.
* A Newman and Keuls test was performed when the TC × S interaction was significant, means with different letters were significantly different (P < 0.05).

Because there was no significant interaction between the experiments and the factors studied, the results after 7 days of age were analyzed jointly (Tab. II). Growth and feed conversion were significantly better in experiment 2 compared to experiment 1 but there was no significant overall effect of the source of heat on these parameters. The nested effect of TC on Tb was significant at 40 days of age. TC-exposed chickens had lower Tb compared to controls (– 0.22 °C on average). This effect was similar to the already mentioned immediate effect measured at 7 days of age. When final body weight was analyzed across experiments, a slight reduction (– 47 g per chicken on average) might be attributable to the use of infrared bulbs during the first week of life (P = 0.06).

Table II. Experiments 1 and 2: mean (SE) feed intake, body weight (BW) and body weight gain in g per chicken, feed conversion and body temperature (Tb) in °C in the finishing period (7–40 days of age).

	Experiment 1				Experiment 2				ANOVA (P <)			
Heat source (S)	G		G+E		G		G+E		S		Exp.	S × Exp.
Feed intake	3905 ± 57		3958 ± 118		4028 ± 58		3941 ± 81		-		0.01	-
BW gain	1938 ± 39		1872 ± 33		2090 ± 25		2068 ± 14		-		0.01	-
Feed conversion	2.02 ± 0.05		2.11 ± 0.05		1.93 ± 0.03		1.91 ± 0.03		-		0.01	-
TC	N	T	N	T	N	T	N	T	S	TC(S)	Exp.	S × Exp.
Tb at 40 days of age	42.15 ± 0.06	42.01 ± 0.08	42.20 ± 0.09	41.87 ± 0.08	41.85 ± 0.04	41.65 ± 0.04	41.94 ± 0.04	41.73 ± 0.04	-	0.03	0.01	-
BW at 40 days of age	2022 ± 54	2104 ± 33	1994 ± 52	2003 ± 24	2247 ± 39	2250 ± 25	2211 ± 23	2226 ± 22	0.06	-	0.01	-

T: early age thermal conditioned (TC) chicks, N: controls, G: gas as the only heat source at an early age, G+E: mixed gas + electricity heat source at an early age, BW: body weight. There were 6 cages of 6 chickens per treatment in experiment 1 and 12 cages of 6 chickens per treatment in experiment 2. The TC effect was nested in the heat source effect due to chicken distribution (cf. Materials and methods).

Maximal Ta measured during heat stress was 40.5 °C with low relative humidity (27%). On average, Ta was maintained between 37 and 40 °C for 8 hours. The resulting mortality rate was high (54% on average). There were no measurable effects of the experimental treatments during experiment 1. However, TC significantly decreased mortality during the second experiment but only when the source of heat was gas (Tab. III). When infrared bulbs were used, no reduction in mortality attributable to TC was measured. A significant overall effect of the heat source was measured in experiment 2; the mortality rate was 47% for gas-heated chicks and 62% when infrared bulbs had been added.

3.2. Experiment 3

3.2.1. Short-term effects of TC during the first week

During the first week, Ta and relative humidity were similar to those of the first two experiments. Two chicks died (1 TC exposed chick (T) and 1 control (N)) for reasons not related to the protocol. Feed intake was on average 144.7 ± 4.0 g per chick from 1 to 7 days of age and feed conversion 1.29 ± 0.05 without significant differences between the T and N chicks. However, body weight at 7 days of age was 5% lower in the T chicks compared to the N chicks ($P = 0.06$). Body temperature was significantly lower ($P < 0.02$) at 7 days of age in the TC-exposed chicks compared to the N chicks (– 0.11 °C on average).

3.2.2. Effects of TC and environmental temperature on subsequent performance

Random selection of 16 pens out of the 24 pens of the first week slightly reduced the difference of Tb at 7 days of age between TC-exposed chicks and controls (– 0.8 °C instead of – 0.11 °C). The reduction was not significant when analyzed with the chickens kept after 7 days of age. The chickens exposed to two different climatic environments from 30 to 40 days of age also had distinct Tb at 7 days of age (Tab. IV). Ta > 31 °C chicks exhibited on average a slightly higher Tb at 7 days of age (+ 0.16 °C) than Ta < 31 °C chicks.

Table III. Experiments 1 and 2: total number of chickens dead/alive after the final heat stress challenge (Ta > 40 °C for 8 hours), after 40 days of age.

Heat source	Experiment 1				Experiment 2				Total
	G		G+E	Total	G		G+E	Total	
N	20/15	-	18/16	38/31	38/30	-	40/24	78/54	116/85
	-		-	-	$\chi^2 = 4.36$ ($P < 0.04$)		-	-	-
T	21/15	-	15/19	36/34	25/41	$\chi^2 = 8.06$ ($P < 0.01$)	43 /26	68/67	104/101
Total	41/30	-	33/35	74/65	63/71	$\chi^2 = 6.38$ ($P < 0.02$)	83/50	146/121	220/186

T: early age thermal conditioned (TC) chicks, N: controls, G: gas as the only heat source at an early age, G+E: mixed gas + electricity heat source at an early age.

From 30 to 40 days of age, environmental temperature (Ta) varied from 26.0 to 36.2 °C in the Ta > 31 °C treatment and from 26.0 to 31.0 in the Ta < 31 °C treatment. The average Ta measured were 32.5 °C and 29.2 °C, respectively. Relative humidity fluctuated from 47 to 81% depending on the rains and Ta. Two chickens died for undetermined reasons.

No significant interaction between TC and climatic conditions was measured after 30 days of age. Mean feed intake, body weight gain and feed conversion from 7 to 41 days of age were not significantly affected by the two factors studied (Tab. IV). Body temperature (Tb) was similar among treatments at 30 days of age. However when measured later (i.e. 38 days of age), average Tb was significantly lower in chickens exposed to Ta > 31 °C compared to chickens exposed to Ta < 31 °C (– 0.16 °C). A significant effect of TC (– 0.15 °C) was also significant at 38 days of age (Tab. IV).

A repeated measures ANOVA was performed on Tb measured from 7 to 41 days of age (Fig. 2). TC significantly reduced Tb ($P < 0.002$) without a significant interaction with the Ta treatment after 30 days of age nor with the age of the chickens. The Ta treatment from 30 to 40 days of age interacted significantly with the age of the chickens ($P < 0.001$). Tb became significantly lower under Ta > 31 °C compared to Ta < 31 °C at 34, 37, 38, 39 and 41 days of age. This effect was the opposite of the differences measured at 7 days of age between the two Ta treatments. As illustrated in Figure 2, Tb was progressively reduced by the natural tropical climate and the reducing effect of TC on Tb was maintained independently.

A heat stress challenge was applied to chickens at 41 days of age. Ta was raised to an average 37.5 °C with peak values at 40.8 °C. However due to the setting of experiment 3 (one gas heater for 8 small pens) Ta was not as consistent as in the previous experiments. A total of eight chickens died (out of 126) all from the Ta < 31 °C treatment (4 TC exposed and 4 control chickens) and none under the Ta > 31 °C ($\chi^2 = 8.8$, $P < 0.01$).

3.3. Body temperature and mortality induced by heat stress

The individual results of Tb at 4, 7, 21 and 40 days of age obtained on 525 chickens from the three experiments were pooled

Table IV. Experiment 3: mean (SE) feed intake, body weight (BW) gain in g per chicken, feed conversion and body temperature (Tb) in °C.

TC	N		T		ANOVA ($P <$)		
Ta max 30–40 d of age	> 31 °C	< 31 °C	> 31 °C	< 31 °C	TC	Ta	TC × Ta
BW 7 days of age	167.7 ± 4.4	162.5 ± 6.2	156.1 ± 2.8	155.2 ± 4.1	0.06	-	-
Feed intake 7–41 d of age	4392 ± 163	4568 ± 73	4280 ± 117	4490 ± 150	-	-	-
BW gain 7–41 d of age	2016 ± 72	2082 ± 59	2012 ± 73	2034 ± 57	-	-	-
Feed conversion	2.19 ± 0.10	2.20 ± 0.06	2.14 ± 0.06	2.23 ± 0.12	-	-	-
Tb at 4 d of age	40.56 ± 0.06	40.50 ± 0.06	40.59 ± 0.04	40.53 ± 0.05	-	-	-
Tb at 7 d of age	40.93 ± 0.06	40.76 ± 0.04	40.84 ± 0.07	40.69 ± 0.05	*	0.01	-
Tb at 30 d of age	41.61 ± 0.04	41.49 ± 0.06	41.54 ± 0.03	41.57 ± 0.07	-	-	-
Tb at 38 d of age	41.56 ± 0.04	41.73 ± 0.09	41.43 ± 0.07	41.57 ± 0.06	0.04	0.04	-

T: early age thermal conditioned (TC) chicks, N: controls. In a natural tropical climate Ta was maintained below 31 °C during the warmest part of the days between 30 and 40 days of age or left unlimited (8 pens of 4 chickens per treatment).
* Tb measured at 7 days of age differed significantly ($P < 0.02$) when the 24 repetitions of the first week were computed (N = 40.86 ± 0.03 and T = 40.75 ± 0.04). However this table presents the results of the 16 pens kept until 41 days of age.

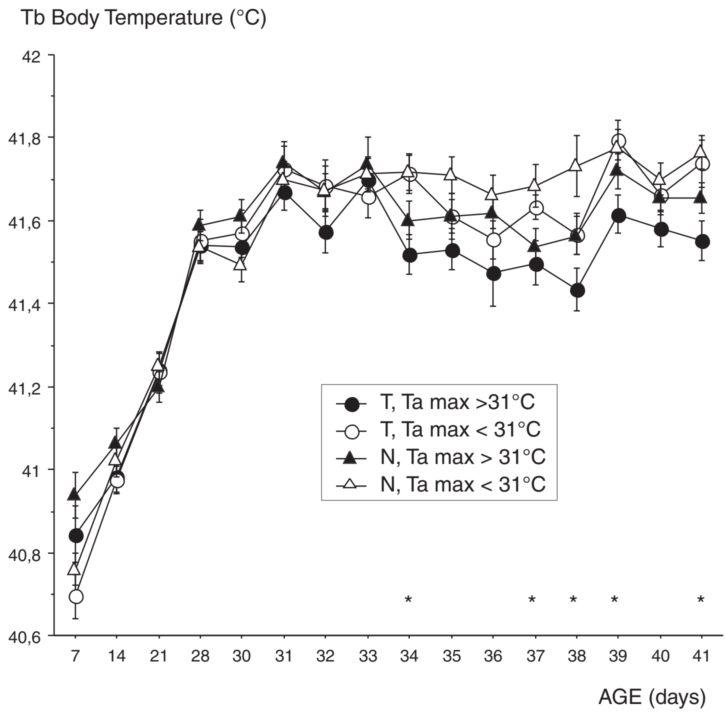

Figure 2. Experiment 3: effects of environmental temperature (Ta) on body temperature (Tb) in early thermal conditioned (T) chicks and controls (N). In a natural tropical climate Ta was maintained below 31 °C during the warmest part of the days between 30 and 40 days of age or left unlimited (8 pens of 4 chickens/condition). * = effect of Ta on Tb ($P < 0.05$).

to assess the Tb variations in relation to TC and heat stress survivorship (Fig. 3). Repeated measures analysis of variance indicated a significant ($P < 0.001$) difference in Tb between survivors after the final heat stress and non-survivors without significant interaction with age or TC. The Tb of the survivors was significantly lower from 4 days of age. TC reduced Tb from 7 days of age ($P < 0.001$) both in the survivors and chickens who died from the heat stress.

Of the chicks having Tb lower than 40.8 °C at 4 days of age (prior to TC), 64% survived heat stress on average, whereas only 47% of the chicks with Tb higher than 40.8 °C at 4 days of age survived ($P < 0.01$).

4. DISCUSSION

A semi-controlled tropical environment may be a valuable paradigm of evaluating techniques at a pre-developmental stage. Early age thermal conditioning (TC) has already been demonstrated to be an effective method to reduce mortality due to heat stress in broilers under experimental and practical conditions [8, for review]. The effects of environmental factors are difficult to evaluate at the production level and completely controlled environments do not exactly reproduce the conditions of a tropical poultry shed. The present results were obtained with a relatively precise control of Ta. However, the need to isolate rooms from one another by nylon curtains reduced solar radiation compared to a regular poultry shed while maintaining ventilation. Chickens restricted to their experimental pens or cages were not allowed to move in the room and this may modify the actual bird density in different parts of a poultry shed [21] and consequently the chickens' perception of their environment. Nevertheless, growth performances were similar to regular production results in tropical countries and Tb, feed and water intake results were reasonably reproducible when an experiment was repeated (Exps. 1 and 2).

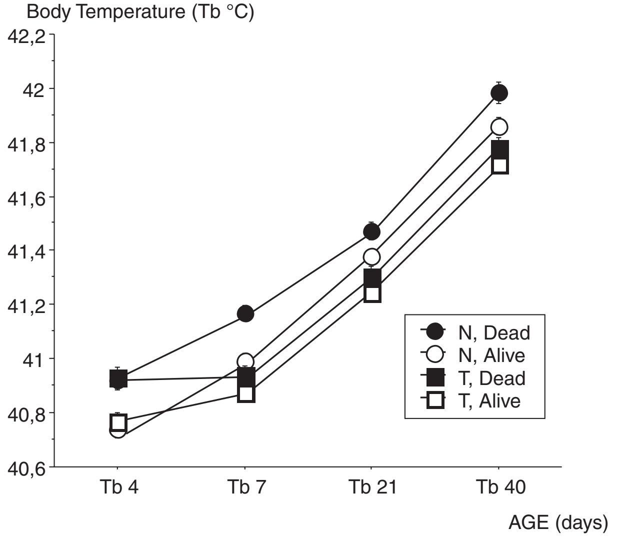

Figure 3. Body temperatures (Tb) from 4 to 40 days of age of early conditioned chickens (T) and control chickens (N) which survived (alive) or died (dead) during the final heat challenge after 40 days of age during the three experiments. In total 120 N chickens died, 108 T died, 141 N survived and 156 T survived after the final heat challenge. Tb of "alive" chickens is lower than the Tb of "dead" chickens from 4 days of age on ($P < 0.001$). TC decreased Tb from 7 days of age on ($P < 0.001$). No significant interaction.

As reported in most studies [8, for review] TC induced immediate effects by increasing water intake and transitorily reducing feed intake and growth without negative consequences on the latter growth. In the three experiments, Tb at 7 days of age was reduced by TC as described earlier [11, 12] and this reduction remained consistent until the end of the production period, in agreement with earlier findings [3, 26, 28]. Recent results showed that TC induces the stimulation of gut development and activity, reduces the circulating level of T3 and increases feed intake during the 48 hours following TC [25]. However, it remains difficult to identify a primary cause among these simultaneous responses to TC.

Using infrared bulbs in addition to gas during the first week and during TC at the same measured Ta, further reduced growth during TC and increased water intake and Tb without a major persistent effect on these parameters. Chicks behaved as if they were in a warmer environment. This was probably due to the radiation emitted by bulbs that are hardly measured by a thermometer and proportional to the surface of the animal. Infrared bulbs produce 80% of heat by radiation and 20% by convection, which is exactly the reverse proportion to gas heaters [5]. The infrared bulbs used in experiments 1 and 2 might have induced light effects on the behavior of the chicks in addition to a greater heat radiation. Light perception by chickens and its influence on growth are still a matter of research [e.g. 6, 22, 23]. Light may affect heat production, however, to a lower level as compared to Ta variation [1]. At a practical level, chickens show different behaviors at different light intensities and this fluctuates with age and light color [19].

Mortality during the final heat stress performed using only gas heaters, was enhanced by the use of infrared bulbs during TC in experiment 2. Although not significant, the effect was almost the opposite in experiment 1 which was performed under similar conditions with fewer chickens. This inconsistency between the two experiments may have been due to a general problem of evaluating mortality rate on relatively small samples of animals. The exact conditions of the application of heat stress are specific to any experiment. However, the reduction of mortality is the actual goal of TC and the initial reason why this technique was developed [2, 3]. A significant reduction of mortality rate has been measured on a large number of broilers at the production level [9]. This difficulty of accurately measuring mortality has led researchers to develop alternative markers of the efficacy of TC such as growth stimulation [13, 25, 27], variations in circulating T3 level [3, 26–28] and body temperature [8, 9, 16, 26, 28].

The use of infrared bulbs increased Tb in experiments 1 and 2, but the variation in Tb from 4 to 7 days of age was similarly decreased by TC with the two heat sources. Tb at 40 days of age was lower in TC-exposed chickens compared to control chicks in both experiments, irrespective of the heat source. Consequently, a distinct effect of TC on Tb depending on heat source cannot explain the variations in mortality. In both experiments the mortality rate might have been too high (compared to real conditions) and the thermal stress excessive to reveal the TC protecting effect. The mortality rate was on average similar in both experiments and, although this cause might have interfered with the results, it does not explain the difference between experiments. The precaution of mixing TC-exposed chickens with controls in the same pens after 7 days of age guaranteed that no major environmental factor might have interfered with the TC factor within an experiment. However, the environmental conditions from 7 to 41 days of age might have differed between experiments 1 and 2.

The environmental conditions applied to chickens after TC is a major issue in all experiments on TC. In tropical countries, climatic conditions vary from one week to another and because broilers approaching the market age are in a critical thermal balance with their environment relatively small Ta variations cause mortality. Late acclimatization [14, 16, 20] might explain the low mortality observed during heat stress in experiment 3. No chickens died from heat stress during experiment 3 when they had previously been exposed to daily peaks of Ta reaching 36 °C and their Tb was significantly reduced compared to counterparts for which the Ta peak was limited at 31 °C by air conditioning (Fig. 2). In this last group, 8 chickens died out of 63 (12.7%), a score closer to the real mortality rate observed in production than those obtained with a more drastic stress in experiments 1 and 2.

The small number of chickens per treatment in experiment 3 (32) preclude a detailed discussion of the lack of effect of TC on mortality rate in Ta > 31 °C chickens. Late acclimatization is only fortuitous in tropical countries because it would be risky and expensive to expose broiler flocks to high environmental Ta at an old age in practice. Interestingly the reduction in Tb induced by late acclimatization seems additive to that of TC, suggesting that both late and early acclimatization act by complementary and distinct ways. However, the actual causal effects of these reductions in Tb on the resistance of broilers to heat stress are called into question by the results given in Figure 3.

When all results from the three experiments were combined, the Tb at 4 days of age (prior to any Ta manipulation) appeared to be a better predictor of mortality at 41 days during heat stress than the subsequent fluctuations in Tb. This unexpected result suggests that in very young chicks Tb might reflect a metabolism rate and/or a thermal set point which predisposes them to resist heat challenges better at an older age. It is consistent with the recent suggestion of Yahav and McMurtry to apply TC to chicks at as early as 3 days of age [27]. Tb in post hatch chicks requires further research because it might have important practical consequences on the management of the starting period and hypothetically on genetic selection.

Several factors account for the apparent failures of the technique of early age thermal conditioning to improve the resistance of broilers to heat stress. The major factor is related to the difficulty of accurately measuring an effect on mortality rate under experimental conditions using limited numbers of animals, which creates inconsistencies from one experiment to another. As demonstrated in one experiment, the heat source may interfere, and should be more precisely controlled and reported. Infrared bulbs under our conditions were less effective than gas heaters in inducing resistance. High environmental temperatures from 30 to 40 days of age induce late acclimatization and result in lower body temperature and this may increase the resistance of broilers to a further heat stress. Body temperature fluctuations of broiler chicks from a very young age are a predictive parameter of resistance to heat that requires further investigation.

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