

THERMAL MANIPULATION IN BROILERS AND LAYERS

B.C. RAKSHIT

Kazi Farms Group, Bangladesh

E-mail: bkvetstust222@yahoo.com

M. OHID ULLAH

Professor, Department of Statistics,
Shahjalal University of Science and Technology, Sylhet-3114, Bangladesh

E-mail: ohidullah@gmail.com

D. MISHRA

Kazi Farms Group, Bangladesh

E-mail: dm117218@yahoo.com

Abstract:

Thermal manipulation during incubation has been shown to have positive effects on performance and mortality of broilers in later life. This only holds when chickens are exposed to temperatures in later life they already experienced during the embryonic phase. Hardly known are the effects of thermal manipulation in layer chickens and furthermore the consequences of a mismatch between incubation temperature and later life ambient temperature. In this study, both cold and warm thermal manipulation was investigated in broilers and layers and the effects in later life during high temperatures. During d 7 to 16 of incubation broiler and layers eggs were exposed to an eggshell temperature (EST) of 37.5°C (C), a high EST of 39.5°C for 12 h per d (H), or a low EST of 36.5°C for 12h per d (L). Hatchability was not affected by breed, but was higher in the H treatment (96.3%) than in both other treatments (92.3% on average). Yolk free body mass was higher in C chickens, followed by H and L chickens in both breeds, whereas the opposite was found for the residual yolk. Body weight till 28d of age was hardly affected by incubation temperature treatment, but body temperature was higher in L chickens than in C and H chickens till 14d of rearing in broilers and till 21d in layers. Mortality during rearing was not affected by breed, but was considerable higher in L chickens (6.7%) than in C (1.8%) and H (1.2%) chickens. Based on this study, we concluded that layers act more or less comparable during and after thermal manipulation than broilers. Secondly, a mismatch between incubation temperature and rearing temperature will not only result in higher body temperatures, but also in considerable higher mortality in later life.

Key words: thermal manipulation, poultry incubation, quantitative methods

Introduction

Extensive progress in genetic selection of fast growing broiler chickens and high yielding laying hens has resulted in high heat production rates and consequently in a reduced ability to cope with high temperatures (Yahav *et al.*, 2004a, b, 2009; Collin *et al.*,

2007). This can lead to poorer post hatch performance, including high mortality (Yahav and Plavnik, 1999), which can have a substantial importance for poultry industry, particularly in (sub)tropical countries (Moraes *et al.*, 2003; Collin *et al.*, 2005).

A way to prepare chickens to the high environmental temperatures in later life is epigenetic temperature adaptation or thermal manipulation (Minne and Decuypere, 1984; Tzschentke *et al.*, 2004; Yahav *et al.*, 2009). Instead of maintaining a constant temperature throughout incubation, which has been shown to result in best hatchability and chickens quality in moderate climates (French, 1997; Lourens *et al.*, 2005), increasing or decreasing the temperature during certain critical periods of embryo development might stimulate the development of different physiological control systems (Yahav *et al.*, 2009). In that way capacity of chickens to cope with heat stress (Yahav *et al.*, 2009) or cold stress (Shinder *et al.*, 2009, 2011) in later life might be improved.

The direction of the thermal manipulation and expected temperature in later life should match to find positive effects of thermal manipulation has been suggested by (Yalçin *et al.*, 2010). In case chickens were programmed to high temperatures in later life, but exposed to normal temperatures (mismatch), body weight gain was lower than in the chickens programmed in the same way, but exposed to high temperatures in later life (match) (Yalçin *et al.*, 2010). However, evidence whether this is also true under practical conditions is lacking. Furthermore, it is not clear whether in laying hens, comparable effects will be found than in broilers, because almost all studies to thermal manipulation are performed in broilers. Thermal manipulation could have comparable effects in layers than in broilers, but both this was not proven under practical circumstances and furthermore, effects of match and mismatch between embryonic and later life temperature are also not known in layers (Walstra *et al.*, 2010).

The aim of this experiment was to investigate the effects of thermal manipulation in both broilers and layers under practical circumstances and furthermore to investigate effects of match or mismatch between temperature during incubation and in later life on growth performance and body temperature of chickens.

Materials and methods

Experimental Design

The experiment was conducted in the central part of Bangladesh during summer 2010, which means that high temperatures were observed during the experimental period. The experiment was carried out at the facilities of Kazi Farms Group, Dhanmondi, Dhaka, Bangladesh. The experiment consisted of two phases; 1) the incubation phase and 2) the rearing phase. During incubation, broiler and layer eggs were incubated at a control egg-shell temperature, a high temperature during 7d to 16d for 12 h per day, or a low temperature during d 7 to 16 for 12 h per day. During rearing, male and female chickens were reared separately till 28d of age.

Eggs, treatments, and incubation

Eggs of a Cobb 500 broiler parent flock, aged 44 wk and a Hyline-Brown layer parent flock, aged 50 wk were used in this experiment. Per parent flock 600 eggs were collected, weighing between 65 and 70 g for the broilers and between 55 and 60 g for the layers. After weighing, eggs were randomly divided over 3 treatments of 200 eggs each.

Treatments were high incubation temperature (H), low incubation temperature (L) and control incubation temperature (C), resulting in six treatment groups (**BH**, **BL**, and **BC** for broilers and **LH**, **LL**, and **LC** for layers). The control treatment consisted of an eggshell temperature (**EST**) of 37.5°C (French, 1997; Lourens et al., 2005) throughout incubation. Eggs in the H treatment were incubated at an EST of 39.5°C for 12 h per d from 7d to 16d (Yahav et al., 2009), whereas eggs in the L treatment were incubated at an EST of 36.5°C for 12 h per day from 7d to 16d. The incubation temperature for the other 12 h per d in the H and L treatment was maintained at 37.5°C. Eggs were incubated in a single stage incubator (Ei Fuzzy Computer Incubator, Qingdao Yingyi Electronic Equipment Co. LTD). Eggs of both broilers and layers of each treatment were incubated in the same incubator, meaning that 3 incubators were used. EST was controlled at each experimental day by using an infra-red digital thermometer just after starting the increase or decrease of the EST and also 6 h later. Eggs were turned hourly from the start of incubation till candling at day 18 of incubation.

After candling at 18d, eggs were transferred to a hatcher (Ei Fuzzy Computer Incubator, Qingdao Yingyi Electronic Equipment Co. LTD). After pull out at 21.5d chickens were manually graded and sexed. Color and feather sexing was applied for layers and broilers, respectively. Chickens were graded as 1 (no defects), 2 (not dry, small size, weakness), or 3 (anomalies, blindness, four legs, unabsorbed yolk, brain exposure). All apparently infertile eggs (18d) and unhatched eggs (hatching) were opened to determine true fertility or moment of death. Moment of death was recorded as early (1d to 7d), mid (8d – 14d) and late (15d -21d) using the breakout analysis manuals of Cobb and Hy-line. Fertility was calculated as number of fertile eggs / number of set eggs, whereas hatchability was calculated as number of hatched chickens / number of fertile eggs.

At pulling, per treatment group 7 male and 7 female chickens were decapitated to determine residual yolk (**RY**) weight and yolk free body mass (**YFBM**), where YFBM was calculated as chicken weight – RY.

Rearing

Only grade 1 chickens were used during the rearing period till 28d of age. A total of 443 broiler chickens and 457 layer chickens were reared in one of two sheds at the same location. Within these chickens, 15 male and 15 female chickens per treatment group were tagged to determine BW during rearing. Male and female chickens were housed separately in floor pens containing litter of rice hulls and calcium oxide. All male or female chickens of each treatment were housed in one pen, meaning that in total 12 pens (6 pens per shed) of approximately 75 chickens per pen were used.

Chickens were reared under normal environmental and management conditions as exists in Bangladesh. Chickens had ad libitum access to commercial available feed and water throughout the rearing period. All chickens were vaccinated against Newcastle disease at 3d and Infectious Bursal Disease at 18d of the rearing period. Additionally, layer female chickens were vaccinated against Marek's disease at hatch day.

Measurements

Body weight of the 30 chickens per treatment (15 males and 15 females) was determined at 0, 7, 14, 21, and 28d of rearing on pen basis. Cloacal temperature (**Tb**) of 7 male and 7 female randomly chosen chickens per treatment was determined at the same days as BW. Mortality was recorded on daily basis per treatment group.

Statistical analyses

All data were analyzed with SAS version 9.2 (SAS Institute Inc., Cary, NC) software. Logistic regression model was used to analyze Fertility, hatchability of fertile eggs, and week of embryo mortality. For fertility the model contained only breed as factor, whereas for hatchability and mortality breed, temperature (treatment) and their interaction were included in the model considering Egg as experimental unit.

BW, YFBM, and RY weight at hatch were analyzed by developing Analysis of Variance (ANOVA) model where breed and temperature were used as factors with their interaction considering Chicken as experimental unit. The Bonferonni correction was applied for adjusting multiple comparisons.

Linear Mixed Model was used to analyze BW and Tb during rearing. The model was developed using Breed and temperature as factor with their interaction considering pen as repeated subject. We found that compound symmetry (CS) structure was the best fit, and was used for within-pen variation.

Mortality during rearing was also analyzed by developing Logistic regression model. In this case we also used Breed and Temperature as factor with their interaction considering Chicken as experimental unit. Data were expressed as LSMeans ± SEM and statistically significant was considered at P≤0.05.

Results

Fertility and hatchability

Average fertility was 83.1% and 90.8% for broiler and layers, respectively (P<0.001; Table 1). Hatchability of fertile eggs was not affected by breed (94.5 and 92.8% for broilers and layers, respectively), but was higher at the High incubation temperature than in both other temperatures (96.3 vs. 92.9 vs. 91.7%, for H, C, and L incubation temperature, respectively). Mortality per week was not affected by week or incubation temperature (Table 1).

Table 1. Effect of breed and incubation temperature profile during d 7 -16 of incubation on fertility, hatchability, and weekly mortality.

1. Breed Temperature ¹	Broilers			Layers			P-value		
	H	C	L	H	C	L	breed	temp.	int.
Fertility, %	83.1			90.8			<0.001	-	-
Mortality wk 1, %	1.2	2.5	1.8	1.6	4.1	4.3	0.20	0.32	0.86
Mortality wk2, %	0.6	0.0	0.6	0.0	0.6	0.5	1.00	1.00	1.00
Mortality wk3, %	1.2	4.3	4.2	2.7	2.9	4.9	0.65	0.16	0.50
Hatchability, %	96.9	93.3	93.3	95.7	92.4	90.2	0.29	0.05	0.88

¹ Low (L): EST=36.5°C for 12 h/d; Control (C): EST=37.8°C for 24 h/d; High (H): EST=39.5°C for 12 h/d.

BW, YFBM, and RY at hatch

BW, YFBM, and RY at hatch showed an interaction between breed and incubation (Table 2). For broilers no differences in BW were observed among incubation, but for layers BW of H chickens were lower than of L chickens with C chickens intermediate. YFBM was higher in broiler chickens than in layer chickens, but within each breed the C chickens had higher YFBM than H chickens with the lowest value for L chickens. The RY was on average

higher in broilers than in layers, but within broilers the C chickens had lowest value, followed by H and L chickens. In layers, H and C chickens had the same RY, with a higher value for the L chickens.

Table 2. Effect of breed and incubation temperature profile during 7d -16d of incubation on body weight at hatch (BW), yolk free body mass (YFBM), and residual yolk (RY) (LSmeans)

Breed Temperature ¹	Broilers			Layers			SEM	P-value		
	H	C	L	H	C	L		breed	temp.	int.
BW, g	47.7 ^a	48.4 ^a	49.2 ^a	40.3 ^c	41.2 ^{bc}	41.6 ^b	0.2	<0.001	<0.001	0.03
YFBM, g	41.6 ^b	42.7 ^a	40.3 ^c	36.1 ^e	37.1 ^d	35.3 ^f	0.1	<0.001	<0.001	<0.001
RY, g	7.1 ^b	5.8 ^c	8.9 ^a	4.2 ^d	4.1 ^d	6.2 ^{bc}	0.2	<0.001	<0.001	0.007

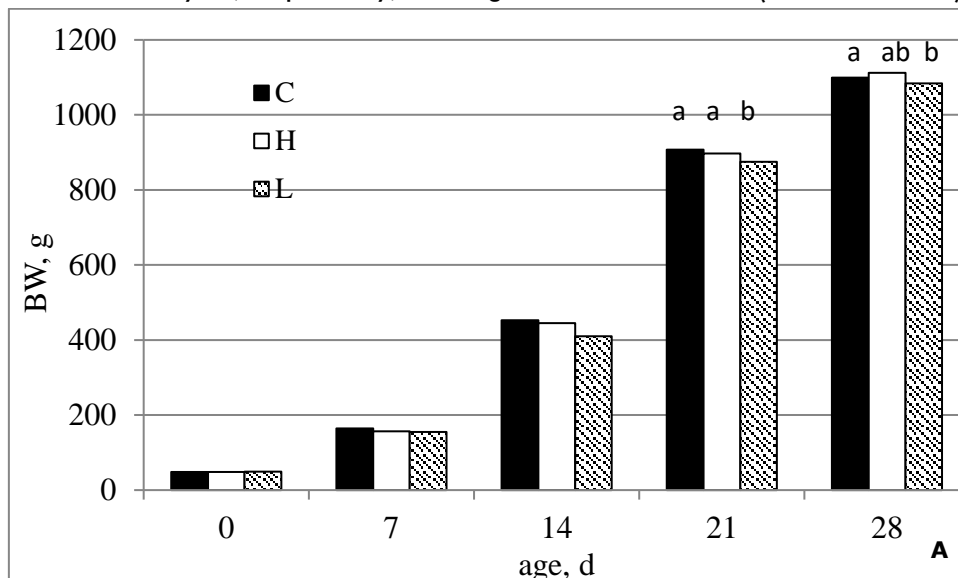
¹Low (L): EST=36.5°C for 12 h/d; Control (C): EST=37.8°C for 24 h/d; High (H): EST=39.5°C for 12 h/d.

^{a-b} Values within a row, lacking a common superscript differed (P≤0.05).

Rearing

Average ambient daytime temperature during the rearing period was 33.4°C (range 32.1-36.5°C). Daytime shed temperature on chicken level in the same period was on average 35.7°C (range 33.3-37.3°C). Nighttime ambient temperature was not recorded, but was in the specific period between 25 and 30°C.

BW during the rearing phase showed a strong breed by day interaction (P<0.001), with diverging higher values for broilers from hatching onward (Figure 1a, b). Within broilers (P=0.007) and layers (P=0.009) an interaction between temperature and day of rearing was found for BW. In broilers no effect of temperature treatment was found at 1, 7, and 28d. At day 14 BW was lower in L chickens compared to C and H chickens, whereas this difference at day 21 was only significant between C and L chickens. In layers, BW did not differ among treatments at day 1, 7, 14, and 21, but at day 28 H chickens had higher BW than both other treatments. Sex differences were found in broilers from day 21 and from d 14 onward in broilers and layers, respectively, with higher values for males (data not shown).



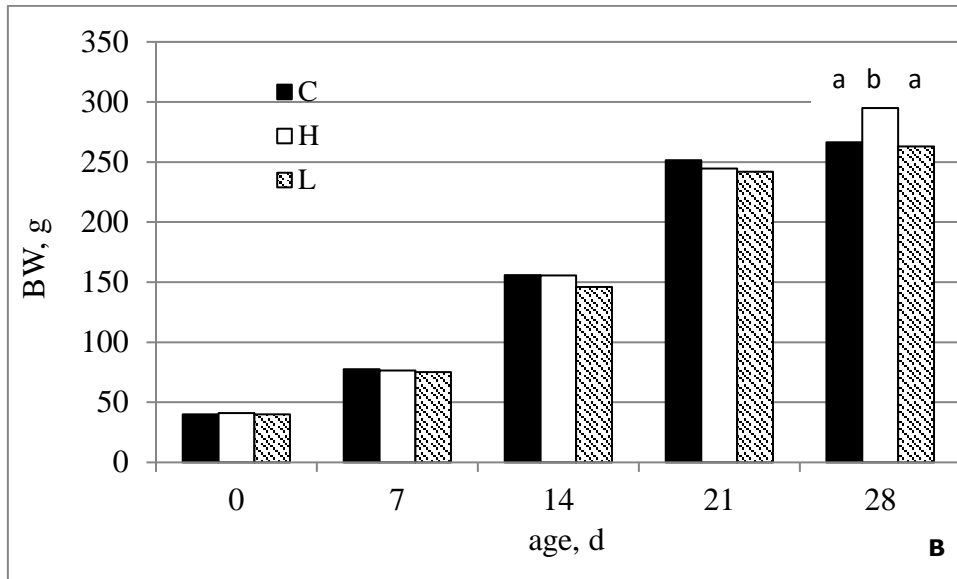
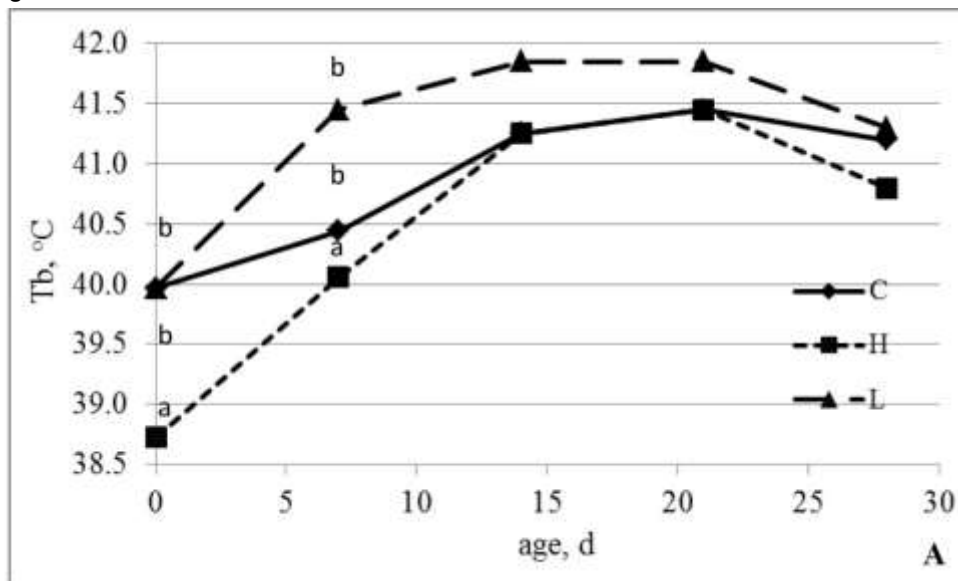


Figure 1. Effects of eggshell temperature (EST) during day 7 to 16 of incubation on BW of broiler (A; overall SEM=4.4) and layer (B; overall SEM=3.5) chickens from 0d – 28d after hatch (LSmeans). Low (L): EST=36.5°C for 12 h/d; Control (C): EST=37.8°C for 24 h/d; High (H): EST=39.5°C for 12 h/d. a,b = values within day and breed lacking a common super-script differ ($P \leq 0.05$).

Rectal temperature (T_b) showed a significant interaction between breed, temperature, and day of rearing ($P=0.005$). No sex effect or interaction with sex was found. Within each breed (broilers: $P=0.01$; layers: $P=0.02$) an interaction between temperature and day was found (Figure 2a, b). In broilers, no effect of temperature treatment was found at day 14, 21, and 28, but T_b was lower in H chickens than in C and L chickens at day 0 and 7. In layers, no effect of incubation temperature was found at d 21 and 28, but T_b was higher in L chickens than in C and H chickens at day 0 and 7, whereas at d 14 this difference was only significant between C and H chickens.



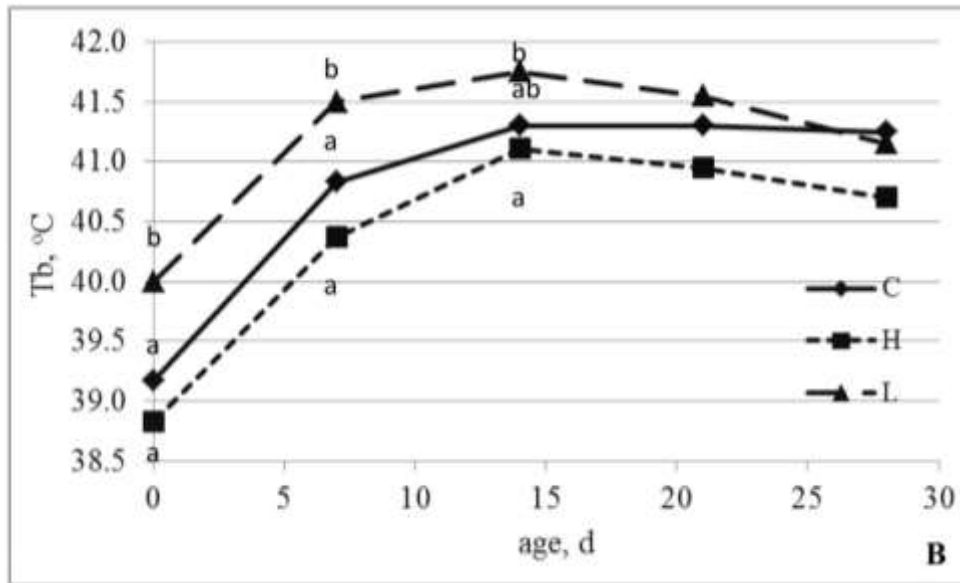


Figure 2. Effects of eggshell temperature (EST) during day 7 to 16 of incubation on body temperature (Tb) of broiler (A; overall SEM=0.22) and layer (B; overall SEM=0.16) chickens from 0d – 28d after hatch (LSmeans). Low (L): EST=36.5°C for 12 h/d; Control (C): EST=37.8°C for 24 h/d; High (H): EST=39.5°C for 12 h/d. a,b = values within day and breed lacking a common superscript differ ($P \leq 0.05$).

Mortality during rearing did not shown an interaction between breed and temperature ($P=0.88$) and was not affected by breed ($P=0.23$), but was higher in the L chickens than in the C and H chickens (Figure 3).

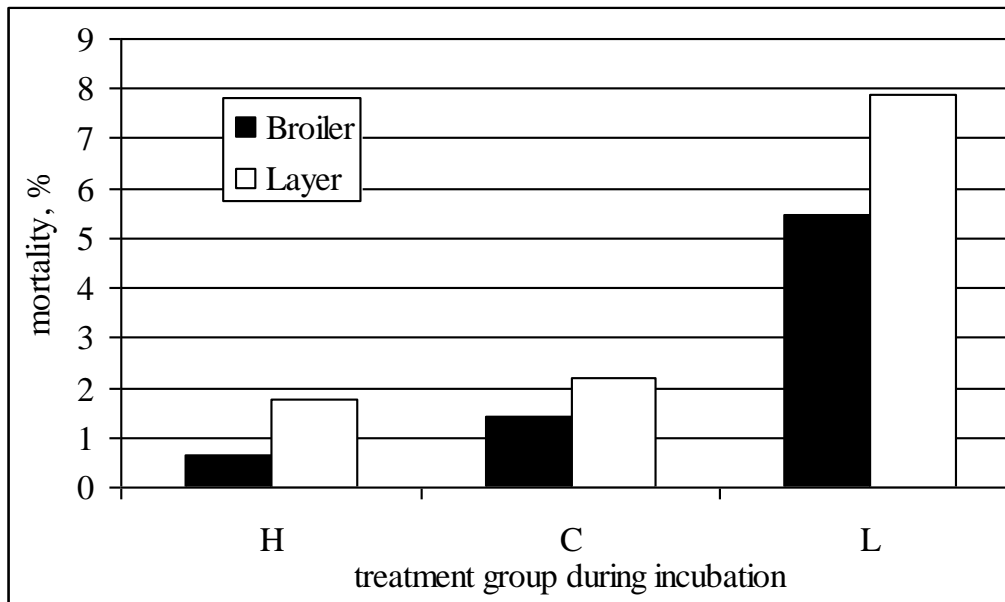


Figure 3. Effects of eggshell temperature (EST) during day 7 to 16 of incubation on mortality of broiler and layer chickens from 0d- 28d after hatch. Low (L): EST=36.5°C for 12 h/d; Control (C): EST=37.8°C for 24 h/d; High (H): EST=39.5°C for 12 h/d.

Discussion

We investigated effects of thermal manipulation during incubation on chicken quality and later life performance. The high incubation temperature treatment was based on the large experiences with thermal manipulation by (Piestun *et al.*, 2008a, b; 2009; 2011) in broilers, whereas the low incubation treatment was not based on literature. Cold thermal manipulation as described in literature (Shinder *et al.*, 2009, 2011) was performed at 18d and 19d of incubation. Because Piestun *et al.* (2008a, b) showed that high thermal manipulation was most effective when provided between incubation 7d and 16d, we have chosen also to lower the incubation temperature in that specific period. A decrease of 2 or 3°C in incubation temperature provided at the end of incubation seems to be no problem (Shinder *et al.*, 2009, 2011; Willemsen *et al.*, 2011), but at day 7, when heat production of embryos is still low (Lourens *et al.*, 2006), a decrease of 2°C might lead to negative effects on hatchability and chicken quality. Therefore, we have chosen to lower the incubation temperature with only 1°C compared to the control treatment.

The significant higher hatchability in the H treatment eggs was in accordance with Yahav *et al.* (2004a) and Collin *et al.* (2007), whereas Yahav *et al.*, (2004b), Collin *et al.* (2005), Piestun *et al.* (2008a, b, 2011), Walstra *et al.* (2010), and Willemsen *et al.* (2011) did not find an effect and Willemsen *et al.* (2010) found a negative effect of high thermal manipulation on hatchability. These ambiguous results might be related to differences in used temperature, moment, and duration of thermal manipulation during incubation. At the other hand, it can be speculated that due to epigenetic effects eggs from breeders in hot climates need higher incubation temperatures to obtain maximal hatchability than breeders from more mild climates. However, this seems to conflict with the results from the current study, which showed that eggs receiving the H treatment delivered chickens with higher RY and lower YFBM. A higher RY and lower YFBM seem to reflect a poorer chicken quality (Lourens *et al.*, 2005; Molenaar *et al.*, 2010; Willemsen *et al.*, 2010). Molenaar *et al.* (2011) speculated that the lower YFBM and higher RY after high incubation temperatures, particularly during late incubation are due to the reduce yolk lipid oxidation, which might be due to a lack of oxygen (Moran, 2007; De Oliveira *et al.*, 2008).

Thermal manipulation has been shown to improve thermo tolerance (Yahav *et al.*, 2004a,b, 2009; Piestun *et al.*, 2008a,b, 2011). Results found in the current study confirm these findings with lower Tb in H treated chickens and higher Tb in L treated chickens. Results also showed that effects of thermal manipulation in Tb were strongly comparable in broilers and in layers; whereas effects on Tb in broilers lasted till d 14, effects in layers were still present at d 21.

Besides effects on Tb, thermal manipulation also can improve chicken performance (Halevy *et al.*, 2001). In the current experiment hardly any effect was found on BW of the H treatment and only the L treatment showed in broilers a small negative effect on BW. In layers the H treatment had a positive effect on BW only at 28d. That the effects on BW in the current study were small is possibly due to the short rearing period we had.

The current study made clear that L treated chickens exposed to high ambient temperature in later life have difficulties to maintain their BW, showing that a mismatch in experienced and expected temperature can give negative effects on BW as shown by Yalçın *et al.* (2010). This confirm studies in which chickens incubated at a high temperature prefer a higher ambient temperature in later life (Tzschentke and Basta, 2002; Yahav, 2009). Moreover, the mismatch in experienced and expected temperature became evident in the current experiment when mortality rate was taken into account. The H and C treatment had both a

low mortality rate, but the L treatment had a considerable mortality rate, both in broilers and layers. The cause of the higher mortality in L incubated chickens might be related to hypothalamic threshold responses (Yahav, 2009), indicating that L incubated chickens were more sensitive to high ambient temperatures.

We conclude from this experiment firstly that layers act more or less comparable during and after thermal manipulation than broilers. Secondly, a mismatch between incubation temperature and rearing temperature (expected and experienced temperature) will not only result in higher body temperatures, but also in considerable higher mortality during rearing. Both in scientific studies and in practice it seems interesting (or may necessary) to take expected seasonal temperature into account, when incubating both broiler and layers eggs.

References

1. Collin, A., Picard, M. & Yahav, S., **The effect of duration of thermal manipulation during broiler chick embryogenesis on body weight and body temperature of post-hatched chicks.** *Animal Research*, 54, 2005, 105-111.
2. Collin, A., Berri, C., Tesserand, S., Requena Rodón, F.E., Skiba-Cassy, S., Crochet, S. Duclos, M.J., Rideau, N., Tona, K., Buyse, J., Bruggeman, V., Decuypere, E., Picard, M. & Yahav, S., **Effects of thermal manipulation during early and late embryogenesis on thermotolerance and breast muscle characteristics in broiler chickens.** *Poultry Science*, 86, 2007, 795-800.
3. De Oliveira, J.E., Uni, Z. & Ferket, P.R., **Important metabolic pathways in poultry embryos prior to hatch.** *World's Poultry Science Journal*, 64, 2008, 488-499.
4. French, N.A., **Modelling incubation temperature: The effects of incubator design on embryonic development, and egg size.** *Poultry Science*, 76, 1997, 124-133.
5. Leksrisompong, N., Romero-Sanchez, H., Plumstead, P.W., Brannan, K.E., & Brake, J., **Broiler incubation. 1. Effect of elevated temperature during late incubation on body weight and organs of chicks.** *Poultry Science*, 86, 2007, 2865-2891.
6. Lourens, A., van den Brand, H., Meijerhof, R. & Kemp, B., **Effect of eggshell temperature during incubation on embryo development, hatchability, and posthatch development.** *Poultry Science*, 84, 2005, 914-920.
7. Lourens, A., Molenaar, R., van den Brand, H., Heetkamp, M.J.W., Meijerhof, R. & Kemp, B., **Effect of egg size on heat production and the transition of energy from egg to hatchling.** *Poultry Science*, 85, 2006, 770-776.
8. Minne, B. & Decuypere, E., **Effect of late prenatal temperatures on some thermoregulatory aspects in young chickens.** *Archive Experimental Veterinary of Medicine*, 38, 1984, 374-383.
9. Molenaar, R., Meijerhof, R., van den Anker, I., Heetkamp, M.J.W., van den Borne, J.J.G.C., Kemp, B. & van den Brand, H., **Effect of eggshell temperature and oxygen concentration on survival rate and nutrient utilization in chicken embryos.** *Poultry Science*, 89, 2010, 2010-2021.
10. Molenaar R., van den Anker, I., Meijerhof, R., Kemp, B. & van den Brand, H., **Effect of eggshell temperature and oxygen concentration during incubation on the developmental and physiological status of broiler hatchlings in the perinatal period.** *Poultry Science*, 90, 2011, 1257-1266.
11. Moraes, V.M.B., Malheiros, R.D., Bruggeman, V., Collin, A., Tona, K., van As, P., Onagbesan, O.M, Buyse, J., Decuypere, E. & Macari, M., **Effect of thermal conditioning during embryonic development on aspects of physiological responses of broilers to heat stress.** *Journal of Thermal Biology*, 28, 2003, 133-140.
12. Moran Jr., E.T., **Nutrition of the developing embryo and hatchling.** *Poultry Science*, 86, 2007, 1043-1049.

13. Piestun, Y., Shinder, D., Ruzal, M., Halevy, O., Brake, J. & Yahav, S., **Thermal manipulations during broiler embryogenesis: Effect on the acquisition of thermotolerance.** *Poultry Scienc*, 87, 2008a, 1516-1525.
14. Piestun, Y., Shinder, D., Ruzal, M., Halevy, O. & Yahav, S., **The effect of thermal manipulations during the development of the thyroid and adrenal axes on in-hatch and post-hatch thermoregulation.** *Journal of Thermal Biology*, 33, 2008b, 413-418.
15. Piestun, Y., Halevy, O. & Yahav, S., **Thermal manipulations of broiler embryos-The effect on thermoregulation and development during embryogenesis.** *Poultry Science*, 88, 2009, 2677-88.
16. Piestun, Y., Halevy, O., Shinder, D., Ruzal, M., Druyan, S. & Yahav, S., **Thermal manipulation during broiler embryogenesis improves post-hatch performance under hot conditions.** *Journal of Thermal Biology*, 36, 2011, 469-474.
17. Shinder, D., Ruzal, M., Giloh, M. & Yahav, S., **Effect of repetitive acute cold exposures during the last phase of broiler embryogenesis on cold resistance through the life span.** *Poultry Science*, 88, 2009 636-646.
18. Shinder, D., Ruzal, M., Giloh, M., Druyan, S., Piestun, Y. & Yahav, S., **Improvement of cold resistance and performance of broilers by acute cold exposure during late embryogenesis.** *Poultry Science*, 90, 2011, 633-641.
19. Tzschentke, B. & Basta, D., **Early development of neuronal hypothalamic thermosensitivity in birds: Influence of epigenetic temperature adaptation.** *Comparative Biochemistry Physiology Part A: Molecular & Integrative. Physiology*, 131, 2002, 825-832.
20. Tzschentke, B., Basta, D., Janke, O. & Maier, I., **Characteristics of early development of body functions and epigenetic adaptation to the environment in poultry: Focused on development of central nervous mechanisms.** *Avian and Poultry Biology Reviews*, 15, 2004, 107-118.
21. Walstra, I., ten Napel, J., Kemp, B. & van den Brand, H. **Temperature manipulation during layer chick embryogenesis.** *Poultry Science*, 89, 2010, 1502-1508.
22. Willemsen, H., Kamers, B., Dahlke, F., Han, H., Son, Z., Ansari Pirsaraei, Z., Tona, K., Decuyper, E., & Everaert, N., **High- and low-temperature manipulation during late incubation: Effects on embryonic development, the hatching process, and metabolism in broilers.** *Poultry Science*, 89, 2010, 2678-2690.
23. Willemsen, H., Li, Y., Willems, E., Franssens, L., Wang, Y., Decuyper, E. & Everaert, N., **Intermittent thermal manipulations of broiler embryos during late incubation and their immediate effect on the embryonic development and hatching process.** *Poultry Science*, 90, 2011, 1302-1312.
24. Yahav, S., **Alleviating heat stress in domestic fowl: different strategies.** *World's Poultry Science Journal*, 65, 2009, 719-732.
25. Yahav, S. & Plavnik, I., **Effect of early-age thermal conditioning and food restriction on performance and thermotolerance of male broiler chickens.** *British Poultry Science*, 40, 1999, 120-126.
26. Yahav, S., Collin, A., Shinder, D. & Picard, M., **Thermal manipulations during broiler chick embryogenesis: Effects of timing and temperature.** *Poultry Science*, 83, 2004a, 1959-1963.
27. Yahav, S., Rath, R.S., & Shinder, D., **The effect of thermal manipulations during embryogenesis of broiler chicks (*Gallus domesticus*) on hatchability, body weight and thermoregulation after hatch.** *Journal of Thermal Biology*, 29, 2004b, 245-250.
28. Yahav, S., Shinder, D., Ruzal, M., Giloh, M. & Piestun, Y., **Controlling Body Temperature. – The Opportunities for Highly Productive Domestic Fowl.** Chapter-3, Nva Science Publishers, Inc., 2009
29. Yalçın, S., Babacanolu, E., Güler, H.C. & Akşit, M., **Effects of incubation temperature on hatching and carcass performance of broilers.** *World's Poultry Science Journal*, 66, 2010, 87-94.