ENVIRONMENT, WELL-BEING, AND BEHAVIOR

Effects of Thermal Manipulation During Early and Late Embryogenesis on Thermotolerance and Breast Muscle Characteristics in Broiler Chickens

A. Collin,*1 C. Berri,* S. Tesseraud,* F. E. Requena Rodón,† S. Skiba-Cassy,* S. Crochet,* M. J. Duclos,* N. Rideau,* K. Tona,‡ J. Buyse,‡ V. Bruggeman,‡ E. Decuypere,‡ M. Picard,* and S. Yahav§

*UR83 Recherches Avicoles, Institut National de la Recherche Agronomique, F-37380 Nouzilly, France; †Producción Animal, Centro Nacional de Investigaciones Agropecuarias-Instituto Nacional de Investigaciones Agrícolas, 2101 Maracay Aragua, Venezuela; ‡Division of Livestock-Nutrition-Quality, Department of Biosystems, Katholieke Universiteit Leuven, 3001 Leuven (Heverlee), Belgium; and §Department of Poultry Sciences, Institute of Animal Science, Agricultural Research Organization, Volcani Center, Bet Dagan 50250, Israel

ABSTRACT Genetic selection has significantly improved the muscle development of fast-growing broiler chickens in the last 50 yr. However, improvement in muscle growth has coincided with relatively poor development of visceral systems, resulting in impaired ability to cope with high environmental temperatures. The aim of this study was to elucidate the effects of thermal manipulation (TM) during different periods of embryogenesis on chick hatchability, BW and thermoregulation upon hatching, on their ability to cope with thermal challenge at 42 d of age, and on carcass and breast meat traits. Control embryos were incubated at 37.8°C. The TM embryos were incubated at 37.8°C and treated for 3 h at 39.5°C on the following days of embryogenesis: E8 to E10 [early (EA)], E16 to E18 [late (LA)], and both E8 to E10 and E16 to E18 (EA-LA). Body weight and body temperature (Tb) were measured at hatching and throughout the growth period as well as during exposure of 42-d-old chickens to a thermal challenge at 35°C for 6 h. The LA and EA chicks exhibited significantly lower Tb than control chicks (37.9 vs. 38.2°C) at hatching, but during the growth period, differences in Tb between treated and control chicks decreased with age. Significant hyperthermia (over 44°C) was monitored in all groups during the thermal challenge, but mortality was higher in treated than in control chickens. No effect of treatments on BW was found during the entire growth period. However, breast yield was higher in LA chickens than in controls at slaughter. The EA and EA-LA treatments slightly decreased the ultimate pH of breast meat, whereas the LA treatment had no effect. In conclusion, none of the TM conditions tested in the present study were able to improve long-term thermotolerance in chickens. Late treatment favored breast muscle growth without affecting ultimate pH and drip loss of breast meat.

Key words: embryo thermal manipulation, body temperature, chicken growth, thermotolerance, breast meat quality

2007 Poultry Science 86:795–800

INTRODUCTION

The significant improvement in body and muscle growth achieved by genetic selection of fast-growing meat-type chickens has not been associated with improved growth of specific visceral organs (Havenstein et al., 2003), the consequence being a reduced ability to cope with extreme environmental temperatures. Recent studies have suggested that it is possible to improve acquisition of thermotolerance in poultry species by exposing them to high ambient temperatures during the early posthatch period. These studies have demonstrated that heat conditioning of chickens during the first week posthatch can induce reduction in body temperature (Tb) and mortality rate during subsequent thermal challenge (Yahav and Hurwitz, 1996; De Basilio et al., 2001, Yahav and McMurtry, 2001). However, such treatments are difficult to use in practice, and using such a procedure during embryogenesis might achieve better results and be easier to perform. Thermal manipulation (TM) of chick embryos has recently been addressed by Yahav et al. (2004a,b), and they reported a reduction in Tb, plasma triiodothyronine and corticosterone concentrations in 3-d-old chicks thermally manipulated during different phases of embryogenesis and exposed to several incubating temperatures. The mechanisms favoring better thermotolerance in heat-conditioned chicks might involve both an increase in their capacity for thermolysis or a decrease in their thermogenic potential (Yahav et al., 2005). However, the effects of TM on improvements in the acquisition of ther-
motolerance and growth performance during the broiler life span have not been examined. The aim of the present study was therefore to determine the effects of TM during early or late embryogenesis on growth performance, body temperature, acquisition of thermotolerance, and on certain quality traits of the pectoralis major breast muscle.

**MATERIALS AND METHODS**

**Experimental Design and Analyses**

**Incubation Conditions.** Fertile Ross PM3 eggs (1,494) from 1 breeder flock at the optimal period of egg production (laying hens of 43 wk of age) were used. The eggs were weighed and divided into 4 groups of similar weight. Control eggs were maintained at 37.8°C and 56% RH during the whole incubation period (Bruzual et al., 2000). Thermal manipulation at 39.5°C and 65% RH was applied for 3 h/d on d 8, 9, and 10 of embryogenesis (treatment EA = early), at d 16, 17, and 18 of embryogenesis (treatment LA = late), or during both periods (EA-LA).

All eggs were incubated in a semicommercial incubator (type B 36I, La-Nationale, Bretagne, France). Eggs from each thermally treated group were divided into 2 subgroups, each being transferred for TM into 1 of 2 experimental incubators (type 540 E, SMA Coudelou, Rochecorbon, France) for 3 h (1200 to 1500 h). The 2 incubators were kept at 39.5°C ± 0.1°C and 65 ± 2.0% RH. Eggs were transferred back to the semicommercial incubator immediately after the end of the TM. All eggs were turned through 90° every hour.

At d 7 of incubation, infertile eggs and dead embryos were identified by candling and removed from the experiment. At d 19 of incubation, the eggs were transferred to a hatching incubator kept at 37.8°C and 70% RH.

The number of chicks hatched was recorded every hour during hatching. After hatching and full feather drying (approximately 2 h posthatch), each chick was taken out of the incubator for immediate measurements of T_{b}, and BW. Body temperature was measured by a digital thermometer (DM 852, Ellab A/S, Compiègne, France; accuracy of 0.1°C) inserted into the distal colon at a constant depth immediately after gently handling the chicks.

**Measurement of Growth and Thermotolerance Parameters.** Thirty-two hours after the beginning of hatching, 960 chicks were brought to a single poultry house. They were divided into 24 pens of 40 chicks (6 pens per treatment equally distributed within the poultry house) and raised under regular conditions (32 ± 1°C). The ambient temperature was then progressively decreased to reach the temperature of 22°C at 24 d of age, and this was maintained until 41 d of age. Animals were fed ad libitum until d 43 of age. Six chicks from each of the 24 pens were randomly chosen and marked to be measured for T_b on a weekly basis (d 14, 21, 28, 35, and 41) and for BW on d 14 and 21. Body weight of all birds was measured on d 28 and 41. Sex was determined on d 35. A quarter of the chickens per treatment (“naive” chickens) were chosen at d 41 according to the average BW of their pen and transferred to another poultry house kept at 22°C. The remaining birds (“challenged” chickens) were exposed to a heat challenge of 35°C for 6 h on d 42, and mortality was recorded every hour during the challenge. Body temperature was measured in 6 to 8 naive and challenged birds per breeding pen during the last 2 h of heat challenge.

**Breast Muscle Traits.** On d 43 after 8 h of feed withdrawal, 20 males and 20 females per treatment from both the challenged and the naive groups were weighed and slaughtered at the experimental processing plant of the INRA Avian Research Center. Birds were stunned in a water bath (125 Hz AC, 80 mA/bird, 5 s) and killed by ventral neck incision. The carcasses were then processed as described by Berri et al. (2001). After 16 h in cold chambers, carcasses were weighed, and the right breast pectoralis major and minor muscles and abdominal fat were excised and weighed. The ultimate pH (pHu) of the

**Table 1. Effects of incubation treatments on zootechnical parameters**

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>EA</th>
<th>LA</th>
<th>EA-LA</th>
<th>SEM</th>
<th>Incubation treatment effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of eggs</td>
<td>373</td>
<td>374</td>
<td>373</td>
<td>374</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Infertile eggs (%)</td>
<td>12.6</td>
<td>13.6</td>
<td>15.5</td>
<td>12.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hatchability (% fertile eggs)</td>
<td>88.2c</td>
<td>96.3a</td>
<td>92.0b</td>
<td>75.5d</td>
<td>0.22</td>
<td>P &lt; 0.0001</td>
</tr>
<tr>
<td>Hatching BW (g)</td>
<td>47.20</td>
<td>47.36</td>
<td>47.15</td>
<td>47.64</td>
<td>0.08</td>
<td></td>
</tr>
<tr>
<td>Hatching T_{b} (°C)</td>
<td>38.21a</td>
<td>37.88b</td>
<td>37.90b</td>
<td>38.04ab</td>
<td>0.08</td>
<td>P = 0.41</td>
</tr>
<tr>
<td>BW (g)</td>
<td>1,405</td>
<td>1,419</td>
<td>1,433</td>
<td>1,413</td>
<td>13</td>
<td>0.48</td>
</tr>
<tr>
<td>BW d 28 (g)</td>
<td>2,578</td>
<td>2,582</td>
<td>2,608</td>
<td>2,584</td>
<td>17</td>
<td>0.60</td>
</tr>
<tr>
<td>Feed conversion ratio (ggg)</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.01</td>
<td>0.48</td>
</tr>
<tr>
<td>BW d 41 (g)</td>
<td>1.97</td>
<td>1.98</td>
<td>1.97</td>
<td>1.95</td>
<td>0.01</td>
<td>0.48</td>
</tr>
</tbody>
</table>

*4-5Means within a row with no common superscripts are significantly different (P < 0.05).  
1All parameters were recorded and analyzed as described in the “Materials and Methods” section. Embryos were incubated either under regular conditions (controls) or heat-conditioned during early (EA) or late (LA) embryogenesis or during both periods (EA-LA).  
2T_{b} = body temperature.  
3Results per pen.
Effects of thermal challenge at 42 d of age on body temperature (Tb42)

<table>
<thead>
<tr>
<th>Thermal exposure at 42 d</th>
<th>Pooled SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naive</td>
<td>Challenge</td>
</tr>
<tr>
<td>Male</td>
<td>41.36b</td>
</tr>
<tr>
<td>Female</td>
<td>41.40b</td>
</tr>
</tbody>
</table>

*Means within a row with no common superscripts are significantly different (P < 0.05).

The body temperature data at d 14, 21, 28, 35, and 41 were subjected to analysis of variance for the effect of incubation treatment (Statview software program, version 5, Abacus Concepts Inc., Berkeley, CA), followed by a Student-Newman-Keuls test for multiple mean comparison. Individual Tb data at d 14, 21, 28, 35, and 41 were subjected to ANOVA including repeated measures, and the effects of the incubation treatments were compared by ANOVA and Student-Newman-Keuls test for each date of measurement. Body weight and feed conversion ratio data per pen were analyzed by ANOVA, considering the incubation treatment as main effect. Body temperature data per pen obtained during the thermal challenge and BW, breast and fat yields, meat pHu, and drip loss were analyzed by ANOVA, with sex, incubation treatment, and thermal challenge (naive or challenge) as main effects and their interactions, followed by a Student-Newman-Keuls test. No mortality was recorded in the naive group during the thermal challenge, so only the percentage of mortality for the challenged chickens was analyzed, considering the incubation treatment and sex as main effects and their interaction in the ANOVA. Linear regression relating drip loss and pHu was calculated. Means were considered significantly different when P < 0.05.

RESULTS

Effects of TM During Embryogenesis on Hatching Parameters, BW, and Tb During Growth Period

Infertile eggs and dead embryos occurred at rates of between 12.6% (control and EA-LA groups) and 15.5% (LA group; Table 1). The highest hatchability occurred in the EA group (96.3%) and the lowest in the EA-LA group (75.5%). No significant difference in BW was observed between treatments at hatching, whereas Tb of the EA- and LA-treated chicks were significantly lower than those of the controls (P < 0.01; Table 1). Body weight and feed conversion ratios were not significantly different between treatments at d 28 and 41 of age (Table 1). Body temperature was significantly affected by treatments during the growth period (P < 0.01), with significant interaction between broiler age and treatments (P < 0.01) and differences in Tb between treated and control chicks decreasing with age (Figure 1). At d 14 and 21, the Tb of all treated chickens were significantly lower than those of the control chickens, but from d 28, the Tb of EA-LA chickens no longer differed from those of control birds. At 35 d, only the Tb of EA chickens were significantly lower than those of control, EA-LA and LA chickens. There was no difference between groups at 41 d of age.

Effects of Embryo TM on Chicken Response to Thermal Challenge at Slaughter Age

There was no effect of the TM treatment on Tb in either challenged or naive chickens at 42 d of age. Hyperthermia (average Tb > 44.3°C; Table 2) developed in challenged chickens of all groups during the thermal challenge, with higher amplitudes in males. Significant differences in mortality were recorded between incubation treatments (P < 0.05) and sex (P < 0.001) during the thermal challenge (Table 3). The highest mortality was recorded in the LA group (49.4%) and the lowest in the control group (28.5%). Mortality was significantly lower in females than in males (P < 0.001). Our results showed that mortality began during the third hour of thermal challenge in the control and EA groups and during the fourth hour of thermal challenge in the LA group.
### Table 3. Effects of incubation treatment, thermal challenge, and sex on mortality, BW at slaughter, abdominal fat yield, and breast meat quality parameters 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Incubation treatment</th>
<th>Thermal challenge</th>
<th>Sex</th>
<th>Significance</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortality2 (%)</td>
<td>Control</td>
<td>EA</td>
<td>EA-LA</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td></td>
<td>28.5 b</td>
<td>42.7 a</td>
<td>49.4 a</td>
<td>45.6 a</td>
<td>52.1 a</td>
</tr>
<tr>
<td>Slaughter BW (g)</td>
<td>2,591</td>
<td>2,620</td>
<td>2,617</td>
<td>2,616 NS</td>
<td>2,641 a</td>
</tr>
<tr>
<td>Abdominal fat yield (% BW)</td>
<td>2.66</td>
<td>2.67</td>
<td>2.66</td>
<td>2.65 NS</td>
<td>2.67</td>
</tr>
<tr>
<td>Ultimate pH</td>
<td>5.92 b</td>
<td>5.92 a</td>
<td>5.92 a</td>
<td>5.90 NS</td>
<td>5.92 b</td>
</tr>
<tr>
<td>Drip loss (% pectoralis major)</td>
<td>1.11 b</td>
<td>1.25ab</td>
<td>1.29ab</td>
<td>1.42 **</td>
<td>1.13 b</td>
</tr>
</tbody>
</table>

*p* < 0.05; **p** < 0.01; ***p*** < 0.001.

1Means of data per pen for BW at slaughter, ultimate pH of breast meat (24 h after slaughter), abdominal fat yield (% BW), and drip loss (% of pectoralis major muscle) were analyzed by ANOVA using sex, thermal challenge (naive or challenge), and incubation treatment [control, heat conditioning during early (EA) or late (LA) embryogenesis or during both periods (EA-LA)] as main effects and their interactions.

2No mortality was recorded in the naive group, so only data per pen for the challenged chickens were analyzed by ANOVA, considering the incubation treatment and sex as main effects and their interactions.

---

**Figure 2.** Incidence of mortality in chickens [control or heat conditioned during early (EA) or late (LA) embryogenesis or during both periods (EA-LA)] exposed to a 6-h heat challenge (TC) at 42 d of age. No dead chickens were found before 2 h of TC. Numbers of dead chickens were recorded successively during the third, fourth, fifth, and sixth hours of TC and between the seventh and 20th hours after beginning the TC.

Body weight at slaughter (Table 3) was not affected by incubation treatment but was significantly decreased in challenged chickens (*p* < 0.01). Abdominal fatness did not differ between incubation treatments. There was a sex effect on BW and abdominal fatness, males being heavier (*p* < 0.01) and leaner (*p* < 0.001) than females. The pHu of the breast pectoralis major muscle was affected by incubation treatment but not by thermal challenge (Table 3). The EA and EA-LA chickens exhibited lower pHu values than control chickens. Sex also affected the breast meat pHu, with males exhibiting higher pHu than females (*p* < 0.05). Finally, incubation treatment (*p* < 0.05), sex (*p* < 0.001), and thermal challenge (*p* < 0.001) affected breast meat drip loss, which was greater in the EA-LA-treated group than in the control group, in the naive than in the challenged chickens, and in females than in males (Table 3). Drip loss was negatively and significantly correlated with the pHu of breast meat (R² = 0.34; *p* < 0.0001).

Breast yield did not differ between challenge and naive birds (not shown) but was significantly affected by incubation treatment in females (*p* < 0.05). LA chickens having higher breast yield than others (Table 4). Control females also exhibited greater breast yield than control males.

---

**DISCUSSION**

Interest is currently increasing in methods to improve acquisition of thermotolerance in the chicken. Thermal
manipulation during the early life of the chick, when $T_b$ regulation and feedback mechanisms are still immature, causes changes in the thermoregulatory threshold response (Yahav, 2000; Nichelmann and Tzschentke, 2002). Exposing embryos to high or low temperatures during incubation improves their capacity to adapt to hot or cold environments, respectively, in the posthatch phase (Decuypere, 1984; Minne and Decuypere, 1984; Janke et al., 2002). Yahav et al. (2004a,b) recently demonstrated that mild TM from d 16 to 18 of incubation induced a reduction in $T_b$ at 3 d posthatch. Such TM was shown to improve chick thermotolerance by limiting the increase in its $T_b$ during heat challenge at 3 d of age (Yahav et al., 2004a,b; Collin et al., 2005). In the present experiment, the hypothesis was tested that TM of embryos could induce long-lasting acquisition of thermotolerance without affecting growth and breast meat quality traits.

The EA and LA treatments applied in our study improved hatchability and did not negatively affect growth of birds, representing important economic criteria. Although Thompson et al. (1976) and Lay and Wilson (2002) found no major effect on hatching rate from increasing incubating temperature to 40.6°C for 24 h at d 16 of embryogenesis, in the present study, TM of 39.5°C from 8 to 10 d (EA) or from 16 to 18 d (LA) in ovo significantly improved hatchability compared with the control group. The double embryo exposure (EA-LA) was the only disadvantageous treatment in terms of hatchability; the repeated exposure might have been too drastic for EA-LA embryo development and survival. Thermal manipulation during embryogenesis was not disadvantageous for the treated chickens, because $B_W$ at hatching and growth performance of chicks reared under thermoneutral conditions were not affected by the different patterns of TM of the embryos.

Although TM was undertaken during embryonic life to improve chicken thermotolerance, this goal was not reached in the present study. Indeed, thermal treatments did not result in long-lasting improvement in thermotolerance. All the thermally treated chickens exhibited lower to significantly lower $T_b$ than controls immediately posthatch. However, the $T_b$ of EA-LA-, LA-, and EA-treated chickens were not different from those of controls after 28, 35, and 41 d of age, respectively. The fact that TM during embryogenesis caused a short-term (but not a long lasting) effect may disprove the hypothesis of long-term thermal adaptation. It may in fact be linked to transient modification of gene and protein expression or enzyme activities. For instance, in the present study, mRNA expression of the avian uncoupling protein, a gene potentially involved in thermogenesis (Taouis et al., 2002; Collin et al., 2003), tended to be lower in LA-treated chicks than in control chicks at 3 d of age ($P = 0.08$, data not shown). However, it is also possible that TM was not applied during the optimal sensitive period in this study. This remains to be determined in future experiments.

The effect of TM during embryogenesis on long-term thermotolerance was tested by exposing chickens to a 6-h heat challenge at 42 d of age. The TM-treated chickens exhibited higher rates of mortality than the controls. The mortality of over 28.5% obtained in this study was probably related to feed allowance during the heat challenge. Whether differences in feeding behaviors might explain differences in mortality between groups was not investigated and remains to be determined in further experiments. The main reason for mortality was probably hyperthermia, with $T_b$ in all groups of chickens reaching over 44°C during the heat challenge. The development of severe hyperthermia was not lower in the TM-treated chickens, which contradicts the thermoregulatory response of chicks similarly treated during embryogenesis but thermally challenged at the age of 3 d (Yahav et al., 2004a; Collin et al., 2005). Furthermore, it has been shown that chickens that were thermally conditioned at 3 or 5 d of age and thermal challenged at the age of 6 wk exhibited lower mortality during the heat challenge than nonthermally conditioned chickens (De Basilio et al., 2001; Yahav and McMurtry, 2001). The lack of long-term response of $T_b$ and the high mortality in the treated groups in the present experiment may have resulted from the timing, level and duration of the manipulation applied during embryogenesis, meaning that further research is needed to reach optimal conditions for thermal manipulation. Another hypothesis is that an additional stimulation is required to obtain long-term thermotolerance. This posthatch heat boost could both decrease $T_b$ and induce compensatory growth, as already suggested in the study of Yahav et al. (2004a), in which chicks were heat-manipulated during both late embryogenesis and soon after hatching (d 3).

A long-lasting effect of TM during embryogenesis was obtained on the breast muscle yield that was higher in the LA-treated chickens than in all the other treatments, especially in females. One possible explanation is that increasing temperature from 16 to 18 d in ovo when the fetal myoblasts are still proliferating (Stockdale, 1992) could affect the cell proliferation and differentiation process and therefore the total number of fibers in the breast muscle.

Two parameters associated with meat quality ($pH_u$ and drip loss) were also considered in this study. Breast muscle $pH_u$, a common acidification parameter of the

---

**Table 4. Effects of incubation treatment and sex on breast yield**

<table>
<thead>
<tr>
<th>Sex</th>
<th>Incubation treatment</th>
<th>Control</th>
<th>EA</th>
<th>LA</th>
<th>EA-LA</th>
<th>Pooled SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>18.9</td>
<td>19.3</td>
<td>19.5</td>
<td>19.1</td>
<td></td>
<td>0.3</td>
</tr>
<tr>
<td>Female</td>
<td>19.6&lt;sup&gt;ab,y&lt;/sup&gt;</td>
<td>18.9&lt;sup&gt;b&lt;/sup&gt;</td>
<td>19.9&lt;sup&gt;a&lt;/sup&gt;</td>
<td>19.1&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<sup>a</sup>Means within a row with no common superscripts were significantly different ($P < 0.05$).

<sup>b</sup>Means within a column with no common superscripts were significantly different ($P < 0.05$).

<sup>c</sup>Data per pen were analyzed by ANOVA considering the incubation treatment [control, heat conditioning during early (EA) or late (LA) embryogenesis or during both periods (EA-LA)], thermal challenge, and sex as main effects and their interactions. Thermal challenge (naive or challenge) did not significantly affect breast yield.

---

**References**

Yahav et al. (2004a, b) recently demonstrated that mild TM from d 16 to 18 of incubation induced a reduction in $T_b$ at 3 d posthatch. Such TM was shown to improve chick thermotolerance by limiting the increase in $T_b$ during heat challenge at 3 d of age (Yahav et al., 2004a, b; Collin et al., 2005). In the present experiment, the hypothesis was tested that TM of embryos could induce long-lasting acquisition of thermotolerance without affecting growth and breast meat quality traits.
meat measured 24 h postslaughter, partly determines the water-holding ability of fresh meat. The negative relationship between pHu and drip loss observed in the present study is consistent with previous results from Le Bihan-Duval et al. (2001) and Berri et al. (2005). The breast meat of control chickens was characterized by the highest pHu and the lowest drip loss, whereas that of EA-LA chickens exhibited the lowest pHu and the highest drip loss, suggesting a lower processing ability of meat in the latter group. Similarly, males differed from females by a higher pHu and reduced drip loss and possibly better processing quality. Probably because of greater body water loss during the heat challenge, breast muscles from heat-challenged chickens showed a lower drip loss during postmortem storage than naive chickens at a similar pHu. In the present experiment, the heat challenge exerted a fairly low (if any) effect on the parameters of breast muscle quality, which is consistent with recent reports that acute, short heat stress before slaughter does not affect breast meat quality (Debut et al., 2003).

Thermal manipulation of chick embryos applied during early or late embryogenesis, or during both periods, did not improve acquisition of thermotolerance tested at 6 wk of age. Late thermal manipulation, however, significantly improved breast muscle yield compared with control chickens, without affecting breast muscle quality. Further research is required to elucidate whether different types of manipulation may lead to a longer-lasting thermoregulatory response and improve the acquisition of thermotolerance.

ACKNOWLEDGMENTS

We thank M. Abbas, E. Baéza, T. Bordeau, F. Breton, C. Bouchot, O. Callot, A. M. Chagneau, P. Chartrin, M. Derouet, S. Duchêne, F. Favreau, M. Gibelin, E. Godet, B. Guillerm, J. M. Hervouet, F. Mercerand, J. M. Meslier, R. Peresson, H. Rigoreau, and M. Tanzi for their skilled technical assistance. We also wish to thank C. Leterrier for helpful advice.

REFERENCES


