The Association Between Broiler Potential Growth Rate and Sensitivity to Heat Stress

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Broiler performance is significantly reduced by heat stress. This phenomenon is becoming more marked as the genetic potential of commercial stocks improves. The problem cannot be completely eliminated by management practices, particularly in developing countries, because they are too costly. Better genetic adaptation to heat stress can facilitate efficient broiler production in hot climates. Improved adaptation to heat stress can be achieved by selection under the stress conditions, or by introducing stress-resistance genes into commercial stocks. Several examples are described, such as selecting for weight gain during hot vs. temperate seasons, or using the naked-neck (Na) gene to reduce feather coverage and alleviate heat stress.

Introduction

Heat stress can be either acute or chronic. Acute stress occurs when ambient temperature increases drastically for a short time (no more than a few days). Due to the sporadic and short-term nature of acute heat stress, chicken survival should rely on management practices, such as cooling or feed deprivation. The present paper deals with chronic heat stress, which depresses broiler growth, especially when it comes with extremely low or high relative humidity.

The strong negative effect of heat stress on broiler growth, feed efficiency and meat yield is well documented (Adams and Rogler, 1968; Washburn and Eberhart, 1988; Chwalibog and Eggum, 1989; Howlider and Rose, 1989; Osman et al., 1989; Cahaner and Leenstra, 1992; Leenstra and Cahaner, 1992b). Deeb (unpublished data) calculated that a 1-degree centigrade (°C) increase in ambient temperature reduces 4-wk to 6-wk weight gain (WG) and 6-wk body weight (BW) by about 4% of the performance at 24°C, i.e. BW of broilers at 32°C is only 2/3 of that exhibited by their counterparts at 24°C. Resistance (or tolerance) to chronic heat stress is therefore expressed by lower heat-induced depression of broiler performance.

With the rapid development of the poultry industry worldwide, importation of high-performance broiler stocks to hot regions is on the rise. However, primary breeding programs of the international poultry breeding companies are located in North America and Western Europe, in temperate climates and optimally controlled facilities, without any selection for adaptation to extreme climates. To date, none of the large companies has developed a broiler
stock with improved adaptation to hot climates. Farmers are advised to use expensive management practices to control ambient temperature in their facilities. However, the depression of broiler growth due to high temperature cannot be completely eliminated by such management practices. Moreover, practices aimed at alleviating heat stress are for the most part quite expensive and hence not economically feasible, especially in developing countries.

Breeding chickens for stress resistance, once successful, is a more cost-effective approach to mitigating the stress. Breeding for improved adaptation to a particular stressful environment should be the strategy of choice when genotype X environment (GxE) interaction significantly affects economically important traits (Cahaner, 1990; Hartmann, 1990). Such a breeding may take place in a particular stressful location ("localized breeding") or under artificially induced stress. Localized breeding of heat-tolerant chickens has been suggested for the Tropics (Horst, 1982; Horst and Mathur, 1990; Mukherjee, 1992; Singh, 1992). In theory, whatever stress affects the individuals in the primary breeding populations, selection during the course of localized breeding will improve, or at least maintain resistance to that stress. The major poultry breeding companies have been doing just the opposite, by applying optimal environmental conditions for their selection flocks. This approach goes against the concept of selection for adaptation and may lead to a further increase in sensitivity to stresses, including heat stress. Localized breeding is not necessary once genes which provide stress resistance are bred into commercial stocks.

The effect of reduced feathering on sensitivity to heat stress

Heat stress negatively affects chickens because their feather coverage hinders the dissipation of internal heat, leading to elevated body temperatures. To avoid a dangerous increase in body temperature, broilers minimize endogenous heat production by reducing feed intake, and consequently exhibit decreased growth and meat yield. Decreasing the feather coverage should enhance heat dissipation and consequently alleviate the heat stress on chickens reared in hot climates. In addition, reduced feathering saves valuable protein which is turned instead into meat tissues (Cahaner et al., 1987; Ajang et al., 1993).

The naked-neck (Na) gene reduces feather coverage in chickens by 20 and 40% in the heterozygous (Na/na) and homozygous (Na/Na) states, respectively. The effects of this gene on growth rate and egg production have been reviewed by Merat (1986, 1990). The potential usefulness of heterozygous naked-neck broilers under heat stress was studied in the early '80s (Hanzl and Somes, 1983), but this genotype's effect has been larger in the fast-growing broilers of the '90s (Lou et al., 1992; Cahaner et al., 1993; Eberhart and Washburn, 1993a,b; Deeb and Cahaner, 1994). These studies, all conducted in controlled-environment facilities and mostly under constant ambient temperature, showed that naked-neck broilers are superior to their normally feathered counterparts when reared at ambient temperatures above 25°C, more so above 30°C. This advantage was associated with the naked-neck broilers' higher rate of heat
dissipation, as measured by infrared thermal imaging radiometer (Yahav et al., 1996). The increase in body temperature under high ambient temperature was higher in normally feathered broilers than in their naked-neck counterparts (Eberhart and Washburn, 1993a; Deeb and Cahaner, 1994). In the natural climates of Israel and Turkey (Cahaner et al., 1994a), as well as Egypt (Saleh, Horst and Cahaner, unpublished results), heterozygous naked-neck broilers were superior to normal ones in the summer, but inferior during the cold winter, mainly because brooding conditions were not adjusted accordingly. Naked-neck broilers are expected to exhibit a larger, year-round advantage in tropical climates.

A higher reduction in feathering, up to 40%, is obtained in homozygous naked-neck broilers, which exhibit higher performance than their heterozygous counterparts at a constant 32°C (Cahaner et al., 1993). Reduced feather coverage may result from selection for polygenes affecting the rate of feather development (Ajang et al., 1993). The frizzle gene (F) reduces the density of feather coverage and provides some heat tolerance to egg-type layers (Merat, 1990; van Haaren-Kiso et al., 1992) and broilers (Yunis and Cahaner, 1994). Feather reduction accumulates in combinations of naked neck with slow feathering (Lou et al., 1992) or with frizzled feathers (Yunis and Cahaner, 1994). The concept of relieving heat stress via reduced feather coverage was reviewed by Cahaner et al. (1994b), who suggested that even the sc gene for complete nakedness (Somes and Johnson, 1982) may be useful for extremely fast-growing future broilers under severe heat stress.

Potential Growth Rate and Sensitivity to Heat

Rural breeds in hot regions, which exhibit resistance to heat stress, are characterized by very low BW and productivity (e.g. Sinai Bedouin fowl, Arad and Marder, 1982). The heat-stress effect is more pronounced in fast-growing commercial broilers than in non-selected meat-type lines (Adams and Rogler, 1968; Washburn et al., 1992; Eberhart and Washburn, 1993b), or in broiler lines with somewhat higher growth rates (Cahaner and Leenstra, 1992; Leenstra and Cahaner, 1992b; Washburn et al., 1992; Cahaner et al., 1995b). The association between heat-stress effect and growth potential was more evident when birds were fed high-protein diets (Cahaner et al., 1995b), and more evident in males than in females (Cahaner and Leenstra, 1992). In the latter study, males and females of two fast-growing lines exhibited an advantage of about 15% in potential growth over their counterparts from three other lines, when reared at low or normal ambient temperatures. At high ambient temperature (constant 32°C), means of 6- to 8-wk WG and 8-wk BW of the five lines were similar for females, whereas for males, line means ranked in reverse order relative to their genetic potential. However, the higher heat-induced growth depression of the high-potential lines, found in that study (Cahaner and Leenstra, 1992) could have resulted from other genetic differences between those two lines and the three others.
To isolate the genetic effect of growth potential on heat tolerance from other genetic factors, a study was initiated within a commercial sire line. One group of breeders was selected from the heaviest males and females, and another group was taken from those near the line's average (Figure 1). Pedigree matings were conducted among three males and 15 females within each of the two groups. Offspring of each dam were equally divided into heat-stressed and temperate environments and their BW was determined weekly. In the temperate environment, offspring of the "Fast" parents reached an average BW of 2365 g at 6 wk of age, 238 g more than the offspring of the "Average" parents, whereas at high ambient temperature, the difference in 6-wk BW between the two groups was only 127 g (Figure 2). The interaction between the potential growth rate and ambient temperature was more pronounced when weekly WGs were compared (Figure 3). In the temperate environment, the expected advantage of the "Fast" offspring was similar from 14 to 42 d of age (about 7 g/d). In the hot environment, the advantage of "Fast" offspring was exhibited only up to 21 d of age, i.e. before the chicks were actually stressed by the heat. During the 4th week, the advantage of the "Fast" broilers was reduced to about 3g/d, and during the last 2 weeks, the two groups had similar growth rates (Figure 3). These results indicate that the genetic advantage of the "Fast" group, obtained by a within-line selection similar to the breeding procedure used by commercial breeders, could not be expressed under heat-stress conditions. In other words, the experimental selection on BW was very successful for temperate environments, but less effective for hot environments.

Figure 1. Construction of experimental groups
Figure 2. The effect of ambient temperature and potential growth rate on body weight

Figure 3. The effect of ambient temperature and potential growth rate on weight gain
A more detailed experiment was conducted with a commercial broiler parent stock at the experimental station "Erneyli" in Turkey, in 1995. In this study, temperate and heat-stressed environments were established by the natural climatic differences between spring and summer (Figure 4). The full-pedigree, randomly-assigned mating scheme consisted of 29 sires and about five dams per sire. Their offspring were produced in two hatches. The spring broilers hatched in April, the summer broilers in July. All the chicks were weighed at hatch (BW 0), 4-wk and 7-wk, and their WG from 4- to 7-wk was calculated.

The climatic differences between the seasons had a substantial effect on the growth of the broilers, indicating that they indeed represented two different environments (Table 1). Hatch weight was lower in summer by 8% (possibly due to a heat-induced decrease in egg weight), and BW was lower by about 30% at 7 wk of age. In agreement with previous findings, the heat-induced depression of broiler growth was larger in males than in females, but only after 4 wk of age. Summer WG 4-7wk was lower than in the spring, by 29% (20.3 g/d) in males and only 22% (12.6 g/d) in females (Table 1).

Table 1. Means (and SD) of body weight (BW) and body weight gain (WG) by sex and season (Erneyli, Turkey, 1995)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Season</th>
<th>n</th>
<th>BW 0</th>
<th>BW 4wk</th>
<th>BW 7wk</th>
<th>WG 4-7wk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>g</td>
<td></td>
<td></td>
<td>g</td>
</tr>
<tr>
<td>Male (M)</td>
<td>Spring</td>
<td>316</td>
<td>52.5 (3.7)</td>
<td>895 (117)</td>
<td>2381 (248)</td>
<td>70.9 (9.6)</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>225</td>
<td>48.1 (3.5)</td>
<td>568 (103)</td>
<td>1623 (222)</td>
<td>50.6 (7.7)</td>
</tr>
<tr>
<td>Female (F)</td>
<td>Spring</td>
<td>296</td>
<td>51.9 (4.0)</td>
<td>851 (106)</td>
<td>2074 (237)</td>
<td>57.6 (9.5)</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>289</td>
<td>47.9 (3.3)</td>
<td>542 (37)</td>
<td>1493 (189)</td>
<td>45.0 (7.2)</td>
</tr>
<tr>
<td>M + F</td>
<td>Spring</td>
<td>612</td>
<td>52.3</td>
<td>873</td>
<td>2228</td>
<td>64.3</td>
</tr>
<tr>
<td></td>
<td>Summer</td>
<td>514</td>
<td>47.9</td>
<td>555</td>
<td>1558</td>
<td>47.8</td>
</tr>
</tbody>
</table>

The data of the four traits were subjected to a mixed-model ANOVA, in which the GxE interaction was expressed by the Season*Sire factor. This factor was significant for all growth traits (Table 2), indicating a substantial interaction between the genotypes in the tested population and the seasonal differences in ambient temperature. The GxE interaction resulted from a variation in the magnitude of heat-induced growth depression among sire families, i.e. in the sensitivity to heat stress. The GxE interaction completely masked the genetic differences between sires, as apparent from the non-significant Sire effect in the ANOVA of their offspring's performance data from both seasons (Table 2). Therefore, breeding values of each sire were estimated from data of each season separately.
Table 2. ANOVA of body weight (BW) and body weight gain (WG) in the spring and summer (Erbeyli, Turkey, 1995)

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>BW 0</th>
<th>BW 4wk</th>
<th>BW 7wk</th>
<th>WG 4-7wk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P(F)</td>
<td></td>
<td>.62</td>
<td>.78</td>
<td>.78</td>
<td>.66</td>
</tr>
<tr>
<td>Season</td>
<td>1</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sex</td>
<td>1</td>
<td>.125</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Season*Sex</td>
<td>1</td>
<td>.326</td>
<td>.203</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sire</td>
<td>28</td>
<td>.922</td>
<td>.569</td>
<td>.859</td>
<td>.504</td>
</tr>
<tr>
<td>Dam:Sire</td>
<td>104</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>.158</td>
<td>.215</td>
</tr>
<tr>
<td>Sire*Sex</td>
<td>28</td>
<td>.430</td>
<td>.794</td>
<td>.618</td>
<td>.783</td>
</tr>
<tr>
<td>Season*Sire</td>
<td>28</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>.028</td>
</tr>
</tbody>
</table>

The nature of the genotype by climate interaction was evaluated by regressing sires' breeding values under heat stress vs. the breeding values estimated from their spring offspring. The latter values are indicators of the genetic potential growth rate of each sire. The regression for BW at 4 wk is presented in Figure 5. The slope (b) of the regression calculated from all 29 sires is 0.48, significantly lower than β=1, an additional indication of GxE interaction, and not different from β=0. When three sires (marked with *) were removed from the calculation, the regression coefficient (b=.69) was significantly higher than 0 but lower than 1. The b estimates indicate that only about 50% of the genetic differences in spring BW 4wk, were expressed under the summer conditions. The heritability of BW 4wk in the summer was twice as high as that found in the spring (Figure 5), indicating that the low b values resulted from a genetic variation in growth under heat. A similar interaction between sires and tropical vs. temperate climates was found for egg-production traits (Mukherjee et al., 1980; Mathur and Horst, 1994).

Similar regressions for BW at 7 wk are given in Figure 6. The b calculated from all 29 sires is negative (-0.21) and when four sires (marked with *) were excluded, b=-0.15 was calculated, significantly lower than β=0. The negative regression estimates indicate that on average, sires with higher potential (spring breeding value) tend to have lower breeding values under heat stress. This negative association was more evident for WG 4-7wk (Figure 7). A slope of b=-0.21 was calculated from all 29 sires, and when only three of them were removed, a b=-0.45 was obtained, significantly lower than β=0. The results in Figures 6 and 7 clearly indicate that selection for BW 7wk or WG 4-7wk under optimal conditions will reduce the stock's performance under hot conditions.
Figure 4. Broiler-house ambient temperature in two seasons (Erbeyli, Turkey, 1995)

Figure 5. Body Weight 4wk - Erbeyli, Turkey, 1995

<table>
<thead>
<tr>
<th></th>
<th>b</th>
<th>P(β=0)</th>
<th>P(β=1)</th>
<th>r</th>
<th>Heritability</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>0.48</td>
<td>0.15</td>
<td>0.01</td>
<td>0.27</td>
<td>Spring</td>
<td>11</td>
</tr>
<tr>
<td>*Excluded</td>
<td>0.69</td>
<td>0.01</td>
<td>0.01</td>
<td>0.46</td>
<td>Summer</td>
<td>17</td>
</tr>
</tbody>
</table>
Figure 6. Body Weight 7wk - Erbeyli, Turkey, 1995

![Graph showing the relationship between sire breeding value in SPRING and SUMMER.](image)

<table>
<thead>
<tr>
<th></th>
<th>b</th>
<th>P(b=0)</th>
<th>P(b=1)</th>
<th>r</th>
<th>Heritability</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>-0.08</td>
<td>0.46</td>
<td>&lt;.001</td>
<td>0.14</td>
<td>Spring</td>
<td>11</td>
</tr>
<tr>
<td>Excluded</td>
<td>-0.15</td>
<td>0.03</td>
<td>&lt;.001</td>
<td>0.43</td>
<td>Summer</td>
<td>13</td>
</tr>
</tbody>
</table>

Figure 7. Body Weight Gain 4-7wk - Erbeyli, Turkey, 1995

![Graph showing the relationship between sire breeding value in SPRING and SUMMER.](image)

<table>
<thead>
<tr>
<th></th>
<th>b</th>
<th>P(b=0)</th>
<th>P(b=1)</th>
<th>r</th>
<th>Heritability</th>
<th>CV%</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>-0.21</td>
<td>0.22</td>
<td>&lt;.001</td>
<td>0.23</td>
<td>Spring</td>
<td>14</td>
</tr>
<tr>
<td>Excluded</td>
<td>-0.45</td>
<td>&lt;.001</td>
<td>&lt;.001</td>
<td>0.50</td>
<td>Summer</td>
<td>15</td>
</tr>
</tbody>
</table>
Summary

The results presented here clearly indicate the negative association between potential growth rate of broilers and their tolerance to heat stress. This higher sensitivity results from the higher basal metabolic rate of broilers with more rapid growth rates (Mitchell and Sandercock, 1995; Sandercock et al., 1995). Already today, the increase in genetic potential of the advanced meat-type stocks is hardly expressed under heat stress. Future broilers will grow even faster, due to continuous selection for rapid growth, hence they will generate more heat which will need to be dissipated at a higher rate. Therefore the losses due to heat stress in broiler operations in hot climates are expected to increase, unless breeding for heat-stress tolerance is incorporated into their selection programs.

One approach would be to introduce genes which may alleviate heat stress, possibly through reduced feather coverage, such as the naked-neck gene (Cahaner, 1994). In the future, further reduction in feather coverage is expected to be advantageous, even at temperate ambient temperatures. Incorporation of other genes, for frizzled feathers, slow feathering, or even the sc gene for complete nakedness (Somes and Johnson, 1982), should be tested as potential broiler growth increases.

Breeding for nonspecific heat tolerance should be feasible if a significant GxE interaction is identified, with E being temperate vs. high ambient temperature, and G the relevant genotypes (families or individuals within a primary breeding population). Such a selection may take place under simulated climatic stress, if the stress is of a simple, mono-factorial nature. This approach would allow the breeding companies to keep their standard selection programs, and run a segment of them (usually sib- or offspring-testing) in facilities where heat stress is artificially created. However, superimposing artificial heat stress is complicated because hot climates may differ in diurnal temperature cycle and relative humidity, as well as in their interaction with other specific environmental factors (housing, feed, sanitation, etc.). The other alternative is “localized breeding”, i.e. selection under natural climatic stress, which solves the problem of simulating a complex environment. Such a selection has already proved successful: as compared to a US-bred broiler stock, its counterpart which had been selected in India for 10 generations exhibited better adaptation to the local environment (Singh, 1992). Primary broiler breeders should consider a methodological application of this approach, in order to maintain, or even improve, the heat tolerance of their fast-growing broiler stocks.
REFERENCES


Questions and Answers

G.L. Jain: Did you measure feed efficiency? If so, was there any difference in this trait between naked-neck and normal broilers, in spring and in summer?

Answer: The reduction in feather coverage clearly improves feed efficiency of broilers reared at high ambient temperature. This advantage, which increases with temperature, is evident when the two genotypes are kept to the same age, and more so to the same BW. It is only at ambient temperatures below 20°C that naked-neck broilers may have somewhat inferior feed efficiency.

G.L. Jain: Was there any difference in mortality between normal and naked neck birds in different seasons?

Answer: The heat stress in our experiments is chronic in nature and hardly causes heat-related mortality. Therefore no consistent differences in such mortality, nor for any other reason, where observed in either season. However, in a few cases involved in an accidental acute heat wave, we observed better survival of naked-neck broilers and breeders.

A. Emsley: Feed conversion and protein need: Na vs. na?

Answer: Indeed the better feed conversion of naked-neck vs. normal broiler may also result from the lower feather mass, which may have a special effect on protein needs. This topic was recently studied by Pesti et al. (Poultry Science 75:375-380), under temperate ambient temperature (constant 22°C). In our experiments we found that high-protein diets increase the advantage of naked-neck broilers at high ambient temperatures.

A. Emsley: Asymmetry of response, whether selected in optimal or chronic heat conditions?

Answer: Since the best genotypes for optimal conditions are inferior under heat stress, I assume that genotypes selected as best under heat won’t have the same ranking at optimal conditions.

B. Gowe: Would you comment on the K gene in reducing feather mass and in increasing heat tolerance. Is there any interaction with the Na gene or the F gene?

Answer: A couple of studies have indicated a positive effect of the slow-feathering K gene on broiler performance, which could result from their reduced feathering, although these studies weren’t conducted at high ambient temperature. In our studies, all birds were fast-feathering and hence I can’t comment on the effect of the K gene on heat-stressed broilers, nor on its interaction with the Na and F genes.

M. Sadjadi: What was the effect of naked-neck gene on breast blister and processing quality?

Answer: Although not determined methodologically, processing quality of naked neck broilers appear to be superior to that of normal ones. Being leaner and without feather follicles, the naked skin is more resistant to blisters, infections and tears. However, if some broilers step on others during live haul, their naked skin may get scratched.

R.P. Reddy: Are there any pleiotropic effects on Na and F genes, especially on reproduction?

Answer: We observed the well-documented reduction in hatchability of Na/Na embryos, and therefore the production of homozygous naked-neck broilers is not feasible. However, our results indicate normal reproductivity of Na/Na or Na/na male and female breeders, and normal hatchability of heterozygous naked-neck chicks, and we therefore expect that the production of Na/na broilers will be as feasible as that of normal ones. As for the F gene, frizzle breeders tend to have poor feather coverage due to feather breakage, and hence they suffer at temperate or low ambient temperature. Consequently, they may exhibit poor reproduction.