BREEDING AND GENETICS

Feeding Regimen by Sire Family Interactions on Growth, Immunocompetence, and Disease Resistance in Chickens

N. K. PRAHARAJ, W. B. GROSS, E. A. DUNNINGTON, and P. B. SIEGEL

Department of Animal and Poultry Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0306

ABSTRACT

Progeny from matings of 12 sires from a White Plymouth Rock line selected for high juvenile BW and 96 dams from a White Leghorn line selected for low antibody production to SRBC were reared under alternate-day (AD) or ad libitum (AL) feeding regimens. Within a feeding regimen males were heavier than females, and within a sex, chicks fed AL were heavier than those fed AD. Feeding regimen by sire family interactions were significant for BW at 21 d of age for both male and female progeny. The interaction was due to differences among sires in the magnitude of the AD:AL relationship. Product moment correlation coefficients between feeding regimens for male and female progeny of sire families for 21-d BW were essentially zero, which was consistent with the sire family by feeding regimen interactions observed at this age. At 41 d of age, relative to BW, weights of empty esophagus plus crop and of crop contents were greater for AD than AL chicks. There were differences among sire families for crop content and breast weights relative to BW. Lesion scores to Escherichia coli challenge were lower and antibody titers to SRBC antigen were higher in AD than in AL chicks. Sire families differed in antibody titers to SRBC antigen. Feeding regimen by sire family interactions were significant for percentage change in BW 144 h after E. coli challenge and lesion scores were greater for AL than AD chicks.

(Key words: feeding regimen, growth, sheep red blood cell antibody, Escherichia coli, organ weights)

INTRODUCTION

Genotype by environment interactions can occur when animals of dissimilar genotypes respond differently in a variety of environments (McBride, 1958; Mathur and Horst, 1994). There are two ways such interactions may occur. First, if animals of one genotype are superior to those of another genotype in Environment A but inferior in Environment B, the interaction is the result of different rankings of the two genotypes in Environments A and B. Second, an interaction may be significant in a statistical sense even if the rankings of genotypes in the environments are consistent. That is, animals of one genotype are superior to those of another genotype in both environments, but the magnitude of that superiority is greater in Environment A than B. Marks (1993, 1995) has provided excellent examples of this with his lines of Japanese quail. Similar situations can occur when evaluating performance of sire families (Sorensen, 1977; Muir, 1985). The varying performance of offspring of specific sire families in different environments is, therefore, of interest in designing breeding programs. Estimation of the magnitude of interactions and correlations between the rankings of sire families in different environments provides insights into this phenomenon.

Although it is well documented that immunocompetence and growth are influenced by genetic and nongenetic factors, only recently has evidence appeared showing a negative relationship between body weight and immunocompetence in Leghorns (Siegel et al., 1982; Martin et al., 1990), broilers (Qureshi and Havenstein, 1994), and brown egg layers (Kreukniet et al., 1994). In broiler breeding there is a further complication because although broilers are reared under ad libitum feeding, the management of broiler breeders involves restriction in feed intake to control overconsumption and its deleterious effects on health and reproduction (Katanbaf et al., 1989; O'Sullivan et al., 1991a). As a result of this husbandry, research results have accumulated on effects of various feeding regimens on body weight (e.g., Nitsan et al., 1983; Nir et al., 1987; Robinson et al., 1993; Zuidhof et al., 1995) and feed intake and diet selection (Forbes, 1995). The experiment reported here was designed to compare growth, immunocompetence, and disease resistance of progeny from different sire families reared under alternate-day or ad libitum feeding regimens.

Received for publication September 29, 1995.
Accepted for publication March 7, 1996.

To whom correspondence should be addressed.
MATERIALS AND METHODS

Stock and Husbandry

Twelve roosters from a White Plymouth Rock population that had undergone 37 generations of selection for high 8-wk BW (Liu et al., 1994) and 96 hens from a White Leghorn population that had been selected for 21 generations for low antibody production to SRBC (Martin et al., 1990) were mated to produce the chicks used in this experiment. Each sire was mated to eight dams. Eggs were identified by sire and incubated in one machine to produce chicks in a single hatch. At hatch, chicks from each sire were wing-banded, vaccinated for Marek's disease, weighed, and randomly distributed into 8 pens for a total of 96 pens. The number of chicks per sire ranged from 35 to 61. Continuous lighting and a room temperature of 21 ± 1 C were maintained throughout the experiment. Brooder temperature was 34 ± 1 C to 7 d of age and was gradually decreased to room temperature by Day 21 when the chicks were moved to grower batteries.

Diet and Feeding Regimens

To Day 7, feed was provided for ad libitum consumption to all chicks. On Day 7, the eight pens of chicks from each sire were randomly assigned to one of the two feeding regimens with four pens per sire per regimen. Feed was continuously available to chicks on the AL regimen and on alternate days for those on the AD regimen. Feeder space was adequate for all chicks to eat at one time. Chicks were fed a mash diet that contained 24% protein and 3,146 kcal ME/kg.

Traits Measured

Chicks were weighed individually before feeding (0800 h) on Days 0, 7, 21, 35, and 41. Feed consumption was measured on a pen basis from 7 to 21 d of age and feed efficiency was calculated as the ratio of BW:feed consumed. Prior to moving at 21 d of age, 6 chicks from each of 6 of the 12 sires in each feeding regimen (total of 72 chicks) were chosen at random and blood samples were obtained from the brachial vein using EDTA as the anticoagulant. After bleeding, chicks were returned to their respective pens. The procedure was repeated 24 h after moving for six different chicks from the same sire-feeding regimen subclasses. Blood samples were prepared using May-Grunwald-Giemsa stain and heterophils (H) and lymphocytes (L) were counted to a total of 60 cells (Gross and Siegel, 1983). Counts of H and L were converted to a ratio of H:L.

On Day 36, all chicks from four pens of each sire (two pens per feeding regimen) were given a 0.1 mL i.v. injection of 0.5% SRBC or 10^-4 dilution of E. coli (serotype 01:K1 incubated for 24 h in tryptose broth) in the posterior thoracic air sac. On the day of injection, all E. coli-injected chicks were weighed individually and feed was made continuously available until the end of experiment. Alternate-day feeding was continued for SRBC-injected chicks that had been on the AD regimen. Individual BW and feed consumption by pen were recorded 96 and 144 h after challenge. On Day 42, (144 h after challenge) all the E. coli-inoculated chicks were killed by cervical dislocation and scored for pericardial and air sac lesions. Scores were as follows: 1, none; 2, mild air sac; 3, moderate air sac; 4, mild to moderate heart; 5, extensive heart; and 6, dead (O'Sullivan et al., 1991a).

Antibody production in response to SRBC antigen was measured 5 d postinoculation (Day 41) by the microtiter hemagglutination procedure (Wegmann and Smithies, 1966). Also on that day, cockerels inoculated with SRBC were weighed, killed by cervical dislocation, and weights obtained for esophagus plus crop with feed, esophagus plus crop without feed, abdominal fat pad, and breast weight including bone.

Statistical Analysis

Data were subjected to analysis of variance (General Linear Models procedures, SAS® Institute, 1985) with sire, sex and their interactions as main effects and sex as a factor in a factorial arrangement in a fixed effect model. An additional main effect included in the analysis was a fixed effect for H:L ratios was time (before and after moving to different cages). Sex was not included as a main effect for the analysis because the outcome of organs and crop content weights because data were obtained for males only or for feed efficiency, which was on a pen basis. When interactions were significant, separate analyses were conducted within each main effect. Comparisons of multiple means were made by Duncan's multiple range test. Significance was considered as P ≤ 0.05. Prior to analyses, BW was transformed to the common logarithms and feed efficiency to arc sine square roots. Product moment correlations were calculated [General Linear Models procedure, SAS® (1985)] for all the traits between the two feeding regimens for all the progeny of 12 sires except for H:L ratios, for which data were obtained on only 6 of the sires. Significance for correlations was considered as P ≤ 0.10. Analyses after 35 d of age were conducted separately for cockerels inoculated with SRBC and those given E. coli. Throughout this paper variation is shown as SEM.

RESULTS

Growth and Feed Efficiency

Because sexual dimorphism for BW was significant at 7 d of age and thereafter, BW data are presented separately for each sex. As expected, within a feeding regimen males were heavier than females, and within a sex, chicks fed AL were heavier than those fed AD (Figure 1).

Although feeding regimen by sire interactions were not significant for BW on Days 0, 7, 35, and 41, they were significant at 21 d of age for both males and females. This
interaction is illustrated (Figure 2) for males and for females as the deviation of each sire family from the mean relative BW [(AD:AL) x 100] of all sire families. Not only was the interaction caused by different responses of sire families to the two feeding regimens, but there were inconsistencies for male and female progeny within a sire. To quantify interactions further, correlations were calculated between sire families fed AD and AL (Table 1). Correlations at 21 d were essentially zero, which was consistent with the significant sire by feeding regimen interactions. At 35 d of age, all correlations were positive with that for females being significant. At 41 d of age the correlation for males was similar to those at 35 d but that for females was negative and not significant.

At 21 d of age, the correlation between male and female progeny of sire families fed AD was positive and approached significance (Table 1). For chicks fed AL, the correlation coefficient was much lower. At 35 d of age, correlations were positive but not significant. At 41 d of age, the correlation for males and females from sire families fed AD was essentially zero, whereas that for those fed AL was moderate and significant.

There were no feeding regimen by sire interactions for feed efficiency from 7 to 21 d of age. Feed efficiency was superior for AL as compared to AD chicks (0.82 ± 0.01 vs 0.63 ± 0.01). Feed efficiencies for sire families ranged from 0.68 ± 0.11 to 0.76 ± 0.11 with differences among sire families not significant. The correlation of 0.42 between feeding regimens for the sire families was not significant.

**Heterophil to Lymphocyte Ratios**

There were no significant interactions among feeding regimens, sires, sexes, or times (before and after movement to new cages) for H:L ratios. Also, H:L ratios were similar for chicks fed AD and AL (0.39 ± 0.03 vs 0.39 ± 0.02), males and females (0.42 ± 0.03 vs 0.35 ± 0.02), and before and 24 h after movement from starter to developer batteries (0.35 ± 0.02 vs 0.43 ± 0.03). There were differences among sire families for H:L ratios with the range from the lowest to the highest sire family being 0.33 ± 0.03 to 0.47 ± 0.06.

**Weights of Organ and Crop Contents**

Feeding regimen by sire interactions were not significant for percentage of relative weight of empty esophagus plus crop, crop contents, abdominal fat pad, and breast. Relative to BW, empty esophagus plus crop, and contents of the crop were greater for AD than AL chicks (Table 2). This pattern was reversed for abdominal fat pad and breast. Differences among sire families were evident for crop content and breast weights but not for esophagus plus crop and abdominal fat pad weights. Correlation coefficients between AD and AL feeding regimens for sire families were -0.20, 0.34, 0.17, and 0.46, respectively, for esophagus plus crop weight, crop contents, abdominal fat pad, and breast weights. None were significant.

**Responses to E. coli Challenge and SRBC Antigen**

Interactions among feeding regimens, sires, and sexes for percentage change in BW 96 h after E. coli challenge were not significant (Table 3). Sexual dimorphism was evident as males gained and females lost BW during the 96 h after challenge. The percentage change in BW was greater in AD than AL chicks, with the former gaining and the latter losing BW. Differences among sire families were also evident with change in BW being negative for some
TABLE 2. Means and SEM for percentage relative weights of organ and crop contents \[(weight/BW) \times 100\] at 41 d of age for male progeny by feeding regimen and sire

<table>
<thead>
<tr>
<th>Group</th>
<th>Empty esophagus plus crop</th>
<th>Crop contents</th>
<th>Abdominal fat</th>
<th>Breast muscle with bone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding regimen1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>0.88 ± 0.02a</td>
<td>5.49 ± 0.17a</td>
<td>0.25 ± 0.02b</td>
<td>12.7 ± 0.20b</td>
</tr>
<tr>
<td>AL</td>
<td>0.46 ± 0.01b</td>
<td>0.40 ± 0.08b</td>
<td>0.57 ± 0.03a</td>
<td>14.8 ± 0.16a</td>
</tr>
<tr>
<td>Sire2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to</td>
<td>0.57 ± 0.06</td>
<td>1.98 ± 0.73*</td>
<td>0.27 ± 0.05</td>
<td>11.9 ± 0.75*</td>
</tr>
<tr>
<td>to</td>
<td>0.80 ± 0.12</td>
<td>4.29 ± 1.12</td>
<td>0.57 ± 0.13</td>
<td>14.7 ± 0.31</td>
</tr>
</tbody>
</table>

a,b Means for a feeding regimen with no common superscript differ significantly (P < 0.05).

1AD = alternate day feeding, AL = ad libitum feeding.
2The range for the lowest to highest sire value with * denoting that the effect of sire was significant (P < 0.05).

sire families and positive for others. The correlation of 0.27 for male progeny of sire families fed AD and AL for percentage change in BW was not significant.

Percentage change in BW, 144 h after E. coli challenge was greater for male than female chicks (Table 3). There were significant feeding regimen by sire interactions for percentage change in BW. The interactions are presented in Figure 3 for AD and AL feeding regimens. The interactions show that the deviation of each sire family from the mean percentage BW change of all sires families within each regimen was not consistent between feeding regimens. Correlations for males and for females from sire families fed AD and AL for percentage change in BW were the same (-0.11) and not significant.

Interactions among feeding regimens, sires, and sexes for scores of E. coli lesions were not significant. Lesion scores were greater for AL than AD chicks although sexes and sire families responded similarly (Table 3). The correlation of 0.16 for lesion scores for males from sire families fed AD and AL was not significant.

There were no significant interactions among feeding regimens, sires, and sexes for antibody titers to SRBC. Antibody titers were similar for males and females (Table 3). Chicks fed AD had higher SRBC titers than those fed AL. There were differences in titers among sire families, with means ranging from 3.67 ± 0.25 to 4.83 ± 0.41. Correlation coefficients for antibody titers to SRBC for male and female progeny from sire families fed AD and AL were 0.01 and -0.42, respectively, and not significant.

**DISCUSSION**

Both of the lines used to produce the F1 chicks used in this experiment are relatively low producers of antibody to SRBC (Miller et al., 1992). The dam line has slower growth and greater resistance to E. coli than the sire line (Dunnington and Siegel, 1985). As in commercial poultry breeding, within-line performance may or may not reflect F1 performance, with heterosis complicating generalizations.

The significant feeding regimen by sire family interaction for BW at 21, but not at 7, 35, or 41 d of age observed in this experiment may be attributed to

TABLE 3. Means and SEM for percentage change in BW [(BW after hours of challenge/BW before challenge) \times 100], Escherichia coli lesion scores, and antibody titers to SRBC by sex, feeding regimen, and sire

<table>
<thead>
<tr>
<th>Group</th>
<th>Percentage change in BW after challenge (%)</th>
<th>Lesion scores</th>
<th>Antibody titers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>96 h</td>
<td>144 h</td>
<td></td>
</tr>
<tr>
<td>Sex1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>2.79 ± 0.74a</td>
<td>13.03 ± 0.97a</td>
<td>2.70 ± 0.14</td>
</tr>
<tr>
<td>F</td>
<td>-1.73 ± 0.88b</td>
<td>4.72 ± 1.28b</td>
<td>2.98 ± 0.16</td>
</tr>
<tr>
<td>Feeding regimen1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AD</td>
<td>2.86 ± 0.73a</td>
<td>...</td>
<td>2.56 ± 0.14b</td>
</tr>
<tr>
<td>AL</td>
<td>-1.23 ± 0.88b</td>
<td>...</td>
<td>3.07 ± 0.16a</td>
</tr>
<tr>
<td>Sire3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>to</td>
<td>-3.15 ± 2.26*</td>
<td>...</td>
<td>2.13 ± 0.29</td>
</tr>
<tr>
<td>to</td>
<td>7.32 ± 1.31</td>
<td>...</td>
<td>3.46 ± 0.34</td>
</tr>
</tbody>
</table>

a,b Means within a column subgroup with no common superscript differ significantly (P < 0.05).

1M = male, F = female, AD = alternate day feeding, AL = ad libitum feeding.
2Feeding regimen by sire interaction was significant (P < 0.05) for BW change 144 h after E. coli challenge.
3The range for the lowest to highest sire value with * denoting that the effect of sire was significant (P < 0.05).
FIGURE 2. Percentage deviation of 21-d BW by sire family from mean relative BW [(AD:AL) x 100] for males (73.0%) and females (75.2%) of all sire families. AD = alternate-day feeding; AL = ad libitum feeding.

FIGURE 3. Percentage deviation in BW change, from time of challenge to 144 h after *Escherichia coli* challenge by sire family from the mean BW change of all sire families for AD (13.2%) and AL (5.9%). AD = alternate-day feeding; AL = ad libitum feeding.
and the thermoregulatory system (Whittow, 1974). This dynamic situation may result in sire family by feeding regimen interactions being significant at some ages and not others.

Higher correlation coefficients at 35 d of age between the two feeding regimens suggest that genes responsible for BW responded in more similar fashion to these regimens. As the chicks became older, at 41 d of age, however, genes in males and females responsible for BW interacted differently with the feeding regimens, as evidenced by the negative correlation for females and positive for males. This inconsistency between sexes across ages may be partially due to hormonal differences contributing to sexual dimorphism for BW.

The lack of increase in H:L ratios 24 h following transfer of chicks from starter to developer batteries was contrary to results of Zulkifli et al. (1993) with dwarf and normal White Plymouth Rock populations. The inconsistency between experiments may be partially due to differences in the background genomes of stocks. The differences in magnitude of H:L ratios among sire families (as evidenced from the differences in crop content weights) demonstrate variability in ability to increase intake capacity.

Greater relative weights of empty esophagus plus crop and of crop contents of AD chicks than AL chicks is consistent with a functional adaptation by the former to AD feeding (Nir et al., 1987; Katanbaf et al., 1988a; O'Sullivan et al., 1991b; Zulkifli et al., 1993). Although there were no differences between feeding regimens for empty esophagus plus crop weight, differences in crop storage capacity among sire families (as evidenced from the differences in crop content weights) demonstrate variability in ability to increase intake capacity.

Greater changes in BW of AD chicks 96 h after E. coli challenge may be partly due to a synergistic effect of two factors. First, because of preferential allocation of resources to defense (Katanbaf et al., 1988a; Praharaj et al., 1995), AD chicks should more effectively defend against E. coli challenge than AL chicks. Evidence for this thesis was higher lesion scores to E. coli challenge and lower antibody titers to SRBC in AL than AD chicks. Second, the greater change in BW of AD than AL chicks might partially be due to the amount of crop contents because AD chicks were released to ad libitum feeding after challenge. Praharaj et al. (1996) found that, on the day of feeding, crop contents can be 30 to 40% of BW. This result is because storage capacity of the upper gastrointestinal tract increases as a functional adaptation to AD feeding.

ACKNOWLEDGMENTS

The authors are thankful to I. Nir, S. Price, and M.H.A. Willemsen for their assistance in data collection and to S. I. Jackson for help in preparation of the manuscript. This research was supported, in part, by a grant from The Virginia Agricultural Council.

REFERENCES


Miller, L. L., P. B. Siegel, and E. A. Dunnington, 1992. Inheritance of antibody response to sheep erythrocytes in
lines of chickens divergently selected for fifty-six day body weights and their crosses. Poultry Sci. 71:47-52.


