Analysis of Disease Resistance-Associated Parameters in Broiler Chickens Challenged with *Eimeria Maxima*¹

J. J. Zhu,* H. S. Lillehoj,* P. C. Allen,* C.-H. Yun,* D. Pollock,† M. Sadjadi,† and M. G. Emara‡

*USDA, Agricultural Research Service, Livestock and Poultry Science Institute, Immunology and Disease Resistance Laboratory, Beltsville, Maryland 20705; †Perdue Farms, Inc., Salisbury, Maryland 21802; and ‡Department of Animal and Food Sciences, University of Delaware, Newark, Delaware 19717

Abstract To determine an optimal dose for coccidial inoculation and to evaluate genetic resistance or susceptibility in individual chickens, broilers were inoculated with four different doses of *Eimeria maxima* oocysts. Body weight gain, fecal oocyst shedding, concentrations of plasma NO₂⁻ + NO₃⁻, carotenoid, and interferon-γ were measured at two different time periods postinfection. The results showed significant dose and sex effects on most parameters and interaction between dose and sex in some parameters. The dose effects were generally linear; however, some significant quadratic effects were also observed. The measurements from chickens inoculated with 10⁴ oocysts displayed the highest correlation coefficients among oocyst shedding, body weight gain, and concentrations of carotenoid and NO₂⁻ + NO₃⁻. An infection index, calculated from the correlated parameters, displayed high correlation coefficients with the parameters. The infection index may be a better parameter for evaluating individual genetic resistance against coccidial infection.

(Key words: avian coccidiosis, sex effect, dose effect, correlation, infection index)

INTRODUCTION

Coccidiosis continues to impose a significant economic impact on the poultry industry. Chemotherapy and vaccination are the current strategies of disease control. Because DNA markers are available for genotyping and quantitative trait locus (QTL) mapping in the chicken (Cheng and Crittenden, 1994), disease control based on host genetic resistance becomes an attractive alternative approach. Disease resistance to coccidiosis can be considered as a quantitative trait. In contrast to other quantitative traits, such as growth and egg production, disease resistance is usually difficult to measure. In avian coccidiosis, it is almost impossible to measure genetic resistance directly in a feasible way, especially when dealing with individuals. Instead, BW gain, lesion score, feed conversion, and oocyst shedding are measured after chickens are inoculated with an equal amount of oocysts to reflect the resistant or susceptible status of the individuals (Martin et al., 1986; Lillehoj and Ruff, 1987; Lillehoj, 1988; Lillehoj et al., 1989; Bumstead and Millard, 1992; Nakai et al., 1993; Bumstead et al., 1995; Caron et al., 1997; Pinard-Van Der Laan et al., 1998). Some indirect measurements are often complicated by other genetic factors that may not affect genetic resistance or susceptibility. These indirect measurements are usually weakly correlated to each other (Bumstead and Millard, 1987; Caron et al., 1997; Idris et al., 1997). Disease indices have been used to include more information in a QTL mapping study of Marek’s Disease to overcome this disadvantage (Vallejo et al., 1998).

Different resistance to coccidiosis has been observed in inbred and outbred chicken lines (Martin et al., 1986; Lillehoj and Ruff, 1987; Lillehoj, 1988; Lillehoj et al., 1989; Nakai et al., 1993; Bumstead et al., 1995; Caron et al., 1997; Pinard-Van Der Laan et al., 1998). In these studies, fecal oocyst shedding, intestinal lesion scores, and BW gain are the most commonly measured parameters for the evaluation of genetic resistance. Plasma constituents, such as carotenoid and NO₂⁻ + NO₃⁻ concentrations, have been included in some studies of chickens with coccidiosis (Conway et al., 1993; Allen, 1997a,b; Allen and Lillehoj, 1997).

**Abbreviation Key:** BW₀ = BW before inoculation, BWG₀–₆ = BW gain between inoculation and 6 d PI; BWG₀–₉ = BW gain between inoculation and 9 d PI; BWG₆–₉ = BW gain between Days 6 and 9 PI; CRTN₆ = plasma carotenoid concentration at Day 6; CRTN₉ = plasma carotenoid concentration at Day 9; IFN = interferon-γ; IFN₉ = IFN-γ ELISA OD reading of plasma collected at Day 9 PI; II = infection indexes; NO₆ = NO₂⁻ + NO₃⁻ concentrations in plasma collected at Day 6; NO₉ = NO₂⁻ + NO₃⁻ concentrations in plasma collected at Day 9 PI = postinoculation; QTL = quantitative trait locus.

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²To whom correspondence should be addressed: hlilleho@lpsi.barc.usda.gov.
1998). Additionally, interferon-γ was found to be produced in higher quantities by in vitro-cultured lymphocytes from coccidial chickens as compared with those from noninfected chickens (Byrnes et al., 1993; Martin et al., 1994; Breed et al., 1997). These parameters may be useful in measuring host immunity during avian coccidiosis. Limited studies have demonstrated which parameters better reflect the nature of genetic resistance to coccidiosis. No extensive analysis of correlation between these parameters has been reported. To determine which parameters are more useful for mapping loci involved in genetic resistance against coccidiosis in studies using microsatellite DNA markers, we challenged commercial broiler chickens with different doses of Eimeria maxima oocysts. The data collected from individual chickens were statistically analyzed to determine the relationships between the measurements.

**MATERIALS AND METHODS**

**Animals**

One hundred broiler chicks (50 males and 50 females) were obtained from a commercial hatchery at the day of hatch. The chickens, F1, were produced from a cross between a commercial sire and a commercial dam line selected for growth and egg production, respectively. The chickens were raised in a specific pathogen-free housing facility to 4 wk of age. Birds were then transferred to a disease-challenging facility and were raised in individual battery cages. Chickens were provided with SSC-244050 24% Broiler Starter Chicken Feed by Southern States Cooperative, Inc.,3 and were allowed access to feed and water ad libitum. Continuous lighting was provided.

**Coccidiosis Challenge**

A field strain of E. maxima that was isolated from the Eastern Shore was used for challenge. Fifty males and 50 females (4 wk old) were randomly and evenly assigned to five treatment groups for each sex with 10 birds per group. Each chicken in the four female and four male groups was orally inoculated with 1 mL oocyst suspension containing \(10^5\), \(5 \times 10^5\), \(10^6\), or \(2 \times 10^6\) sporulated oocysts. The chickens in remaining groups were orally inoculated with 1 mL water as controls.

**Body Weight Gain**

All chickens were weighed at Days 0, 6, and 9 postinoculation (PI); these weights were designated as BW0, BW6, and BW9, respectively. Three BW gains, BWG0-6, BWG6-9, and BWG0-9 were calculated for the weight gain from Days 0 to 6, 6 to 9, and 0 to 9 PI, respectively.

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3Distributed by Upper Marlboro Service, Upper Marlboro, MD 20772.
4Millipore Corp., Bedford, MA 01730.
5Costar, Cambridge, MA 02139.
6Sigma, St. Louis, MO 63178.
photometer. The plates were washed three times between each step with PBS containing 0.05% Tween 20. Plasma samples collected at Day 9 PI were used for IFN-γ measurements. The IFN-γ concentration was indirectly expressed as the OD reading of ELISA (IFN9).

**Statistical Analysis**

Data were analyzed with SAS software (SAS Institute, 1996). The statistical model of the experiment was $Y_{ijk} = \mu + d_i + s_j + X_{ij} + \varepsilon_{ijk}$, where $Y_{ijk}$ is observation $k$ for sex $j$ and treated with dose $i$, $d_i$ is the effect of inoculation dose $i$, $s_j$ is the effect of sex $j$, $X_{ij}$ is the interaction between doses and sexes, and $\varepsilon_{ijk}$ is the residual of observation $k$ for sex $j$ and treated with dose $i$. The general linear model procedure was used to test the significance of this statistical model. Duncan’s multiple-range test was applied to determine the differences between groups (Zar, 1984). Significance was accepted at $P \leq 0.05$. Stepwise polynomial regression (Zar, 1984) was used to test dose effect using the following model: $Y_{ijk} = \mu + d_i + d_i^2 + \cdots + d_i^k + \varepsilon_{ijk}$. If sex effects or the interaction between sex and dose were significant, the differences between the groups and the regression were tested within sex groups. Because 10 birds per group may be too small to detect weak correlations, each measurement was standardized using $(X_{ijk} - X_{ij})/\text{standard deviation}$, where $X_{ijk}$ is observation $k$ in sex $j$ and treated with dose $i$, and $X_{ij}$ is the mean of sex $j$ treated with dose $i$. Next, the data were pooled for correlation analysis, regardless of inoculation dose and sex.

**Infection Index**

Infection indices (II) were calculated from correlated parameters. Body weight gain was considered as the primary parameter for II calculation. Parameters correlated with BW gain were included stepwise to determine whether the parameters affected the correlation of II with the parameters. An individual II is equal to the sum of difference between an individual parameter value and the mean of the group divided by the SD and multiplied with a factor. The factor, $C$, is +1 and –1 for the parameters negatively and positively correlated to BW gain, respectively. The calculation can be expressed as following formula: $II = \sum \{ C \times \text{(individual value of a parameter - mean of the parameter in the group)/SD} \}$. For the calculation of infection indices, the formula was determined based on how well the indices correlated to the parameters.

**RESULTS**

**Dosage and Sex Effects on Parameters**

In the statistical model, there were no significant sex effects on oocyst shedding, CRTN6, and CRTN9 in the infected or noninfected chickens (Table 1). The relationship between oocyst shedding and inoculation doses was linear $(P < 0.001)$; however, both linear $(P < 0.001)$ and quadratic $(P < 0.03)$ terms were significant in the polynomial regression between dose and CRTN6 and between dose and CRTN9. Higher inoculation doses resulted in higher oocyst shedding, whereas lower values for CRTN6 and CRTN9 were found in chickens inoculated with higher doses.

Sex effects on BWG0–6, BWG0–9, BWG6–9, and IFN9 measurements in the statistical model were significant, and there were significant interactions between dose and sex on NO6, NO9, and IFN9 (Table 2). Therefore, differences among the groups and the regression of dose effect were tested within sex. The differences in NO6 of the female chickens and IFN9 of males and females among the groups were significant. No significant differences were found between the groups in other measurements. There were linear relationships between dose and the measurements of NO9 $(P < 0.05)$, BWG0–6 $(P < 0.01)$, and BWG0–9 $(P < 0.05)$ for females and INF9 $(P < 0.01)$ and BWG0–9 $(P < 0.01)$ for males. The relationships between NO6 and dose were quadratic $(P < 0.001)$ for females. Both linear and quadratic terms were significant in the regression between dose and IFN9 in the females (linear and quadratic, $(P < 0.001)$ and between dose and BWG0–6 in the males (linear and quadratic, $(P < 0.02)$). There were no relationships with doses for NO6 $(P = 0.7)$ and NO9 $(P = 0.19)$ for males and for BWG6–9 in males $(P = 0.08)$ and females $(P = 0.06)$.

**Correlation Among Parameters**

When data from each treatment group was analyzed independently, correlation coefficients were not significant except those among oocyst shedding, NO6, CRTN6, CRTN9, and IFN9 ($r > 0.60$) for the males infected with $10^4$ oocysts. When the data of infected chickens were

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3Bio-Rad Laboratories, Hercules, CA 94547.
standardized and pooled, oocyst shedding showed significant correlation coefficients ($r = 0.35$ and $0.25$, respectively) with NO6 and CRTN9 (Table 3). The correlation coefficients of oocyst shedding with BWG6–9 and IFN9 were not significant ($r = 0.2; P = 0.1$). Among the parameters, except oocyst shedding, BWG6–9 was significantly correlated to CRTN6, CRTN9, and NO6 but not to IFN9 ($r$ ranging from 0.22 to 0.29). All BW gain parameters were significantly correlated with BW0. The CRTN6, CRTN9, and NO6 concentrations were correlated to each other ($r$ ranging from 0.37 to 0.66). The NO6 concentrations were also significantly correlated to NO9 and IFN9 ($r = 0.36$ and 0.31, respectively).

When the standardized data were analyzed by sexes, the correlation coefficients among the parameters appeared to be smaller for females than for males. When the standardized data were analyzed by inoculation doses, the birds inoculated with $10^4$ oocysts displayed a greater number of significant correlations, with much higher correlation coefficients, than those inoculated with other doses. The results were similar to these regardless of doses, but a greater number of significant correlations, with higher correlation coefficients (from 0.77 to 0.45), were found in the groups inoculated with $10^4$ oocysts than other concentrations, regardless of dose (Table 3). The groups inoculated with $10^4$ oocysts also showed a significant correlation between oocyst shedding and BWG6–9. Stepwise regression analysis showed that only the NO6 variable was significant in the model: BWG6–9 = NO6 + CRTN9 + oocyst shedding + IFN9.

### Infection Indexes

Individual II were calculated from the groups inoculated with $10^8$ oocysts because this challenge dose showed the most and largest significant correlation coefficients between the parameters. Although IFN9 was not significantly correlated to other parameters in this experiment, it was also included in the stepwise calculation of II. When BWG6–9 and one other parameter were included in the II calculation, the II showed significant correlation to all correlated parameters (Table 4) with $r$ ranging from 0.51 to 0.96. As more parameters were included in II calculation, the correlation coefficients between the II and the parameter became stable. When all correlated parameters and IFN9 were used in the II calculation, II significantly correlated to all parameters with all correlation coefficients at least 0.82, except for IFN9, where $r = 0.64$.

### DISCUSSION

In this experiment, we observed significant sex effects and an interaction between sex and inoculation dose in broiler chickens. Sex effects have not been included in most studies of avian coccidiosis. The data in this experiment show that there were fundamental differences between sexes in response to *Eimeria* inoculation. Therefore, the sex factor should be taken into account in the evaluation of disease resistance.

Dose effects were also observed in all parameters except NO9 in the statistical model. The linear terms for dose effects were significant for most parameters, and the quadratic terms for some parameters were significant for some measurements in stepwise polynomial regressions. Oocyst shedding has been found to be positively correlative to inoculation doses (Lillehoj and Ruff, 1987). Plasma carotenoid and BW gain were negatively correlated to inoculation doses (Conway et al., 1993, Allen, 1997b). The NO$_3$ + NO$_2$ concentrations were not infective dose-dependent when inoculation doses were low (Allen, 1997b). The concentrations were positively correlated to inoculation doses with large number of oocysts (Allen, 1997a), which were equivalent to doses in this experiment. Interaction between sex and dose existed for concentrations of NO$_2$ + NO$_3$ and IFN-γ. In this experiment, the inoculation of $10^8$ oocysts appeared to be the optimal dosage based on the correlations among the parameters and the regression analysis of the dose effects (linear and quadratic). The measurements might be time sensitive. Different challenge doses may display different response patterns of the parameters. Therefore, the optimal dose should be determined for certain sampling time in order to see the response patterns.

Correlations between some measurements have been observed in coccidia-infected chickens in other studies. Body weight gains were correlated with plasma color-
Chickens infected with *E. maxima* showed gradual increases in NO$_2^-$ + NO$_3^-$ concentrations and decreases in carotenoid concentrations PI (Allen, 1997a,b). A significant negative correlation between these two parameters was also observed in this study.

In terms of correlations among the parameters, BW gains from Days 6 to 9 PI showed a better correlation with other parameters than other weight gain measurements. Additionally, the BW gain in this period was also less correlated to initial BW, BWO. Therefore, this BW gain may be more useful for disease evaluation than the weight

### TABLE 3. Correlation coefficients (r) and P-values between parameters from male and female chickens infected with *Eimeria maxima*

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Oocyst</th>
<th>BWG0-6</th>
<th>BWG6-9</th>
<th>BWG0-9</th>
<th>CRTN6</th>
<th>NO6</th>
<th>CRTN9</th>
<th>NO9</th>
<th>IFN9</th>
<th>BW0</th>
</tr>
</thead>
<tbody>
<tr>
<td>BWG6-9</td>
<td>r</td>
<td>-0.124</td>
<td>-0.185</td>
<td>-0.163</td>
<td>-0.046</td>
<td>0.346</td>
<td>-0.247</td>
<td>0.121</td>
<td>0.197</td>
<td>-0.076</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.274</td>
<td>0.100</td>
<td>0.148</td>
<td>0.687</td>
<td>0.002</td>
<td>0.027</td>
<td>0.286</td>
<td>0.098</td>
<td>0.500</td>
</tr>
<tr>
<td>BWG0-9</td>
<td>r</td>
<td>-0.233</td>
<td>0.464</td>
<td>0.868</td>
<td>0.099</td>
<td>-0.187</td>
<td>0.093</td>
<td>0.036</td>
<td>-0.041</td>
<td>0.354</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.322</td>
<td>0.000</td>
<td>0.000</td>
<td>0.380</td>
<td>0.097</td>
<td>0.413</td>
<td>0.750</td>
<td>0.733</td>
<td>0.001</td>
</tr>
<tr>
<td>BWG6-9</td>
<td>r</td>
<td>-0.498</td>
<td>0.648</td>
<td>0.803</td>
<td>0.240</td>
<td>-0.288</td>
<td>0.224</td>
<td>0.036</td>
<td>0.067</td>
<td>0.385</td>
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<tr>
<td></td>
<td>P</td>
<td>0.026</td>
<td>0.002</td>
<td>0.000</td>
<td>0.032</td>
<td>0.010</td>
<td>0.046</td>
<td>0.749</td>
<td>0.573</td>
<td>0.000</td>
</tr>
<tr>
<td>BWG0-9</td>
<td>r</td>
<td>-0.402</td>
<td>0.912</td>
<td>0.901</td>
<td>0.173</td>
<td>-0.240</td>
<td>0.159</td>
<td>0.063</td>
<td>0.040</td>
<td>0.374</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.079</td>
<td>0.000</td>
<td>0.000</td>
<td>0.124</td>
<td>0.032</td>
<td>0.158</td>
<td>0.579</td>
<td>0.738</td>
<td>0.001</td>
</tr>
<tr>
<td>CRTN6</td>
<td>r</td>
<td>-0.431</td>
<td>0.569</td>
<td>0.517</td>
<td>0.595</td>
<td>-0.365</td>
<td>0.664</td>
<td>-0.104</td>
<td>-0.076</td>
<td>0.109</td>
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<td>P</td>
<td>0.058</td>
<td>0.009</td>
<td>0.020</td>
<td>0.006</td>
<td>0.001</td>
<td>0.000</td>
<td>0.359</td>
<td>0.517</td>
<td>0.338</td>
</tr>
<tr>
<td>NO6</td>
<td>r</td>
<td>-0.534</td>
<td>-0.520</td>
<td>-0.791</td>
<td>-0.731</td>
<td>-0.464</td>
<td>-0.377</td>
<td>0.360</td>
<td>0.306</td>
<td>-0.130</td>
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<tr>
<td></td>
<td>P</td>
<td>0.015</td>
<td>0.019</td>
<td>0.000</td>
<td>0.000</td>
<td>0.039</td>
<td>0.001</td>
<td>0.000</td>
<td>0.009</td>
<td>0.250</td>
</tr>
<tr>
<td>CRTN9</td>
<td>r</td>
<td>-0.814</td>
<td>0.418</td>
<td>0.631</td>
<td>0.571</td>
<td>0.625</td>
<td>0.561</td>
<td>-0.069</td>
<td>-0.154</td>
<td>0.165</td>
</tr>
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<td>P</td>
<td>0.000</td>
<td>0.067</td>
<td>0.003</td>
<td>0.009</td>
<td>0.003</td>
<td>0.010</td>
<td>0.545</td>
<td>0.196</td>
<td>0.143</td>
</tr>
<tr>
<td>NO9</td>
<td>r</td>
<td>-0.027</td>
<td>0.165</td>
<td>-0.045</td>
<td>0.042</td>
<td>-0.079</td>
<td>0.416</td>
<td>-0.041</td>
<td>0.058</td>
<td>-0.156</td>
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<tr>
<td></td>
<td>P</td>
<td>0.911</td>
<td>0.486</td>
<td>0.851</td>
<td>0.862</td>
<td>0.741</td>
<td>0.068</td>
<td>0.863</td>
<td>0.626</td>
<td>0.167</td>
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<tr>
<td>IFN9</td>
<td>r</td>
<td>0.363</td>
<td>-0.255</td>
<td>0.421</td>
<td>-0.380</td>
<td>-0.045</td>
<td>0.474</td>
<td>-0.264</td>
<td>0.095</td>
<td>0.253</td>
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<tr>
<td></td>
<td>P</td>
<td>0.139</td>
<td>0.307</td>
<td>0.082</td>
<td>0.120</td>
<td>0.858</td>
<td>0.047</td>
<td>0.289</td>
<td>0.707</td>
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<tr>
<td>BW0</td>
<td>r</td>
<td>0.084</td>
<td>0.559</td>
<td>0.410</td>
<td>0.528</td>
<td>0.351</td>
<td>-0.277</td>
<td>0.061</td>
<td>0.095</td>
<td>0.214</td>
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<tr>
<td></td>
<td>P</td>
<td>0.726</td>
<td>0.010</td>
<td>0.072</td>
<td>0.017</td>
<td>0.129</td>
<td>0.237</td>
<td>0.800</td>
<td>0.690</td>
<td>0.394</td>
</tr>
</tbody>
</table>

1. Correlation coefficients and P-values above and below the diagonal are based on all infected groups and the group infected with 10$^6$ oocysts, respectively, with standardization.

2. BW0 = BW before inoculation; BWG0-6 = BW gain between inoculation and Day 6 postinoculation (PI); BWG6-9 = BW gain between Days 6 and 9 PI; BWG0-9 = BW gain between inoculation and Day 9 PI; oocyst = fecal oocyst production between Day 5 and 9 d PI; CRTN6 = plasma carotenoid levels at Day 6; CRTN9 = plasma carotenoid levels at Day 9; NO6 = NO$_2^-$ + NO$_3^-$ levels in plasma collected at Day 6; NO9 = NO$_2^-$ + NO$_3^-$ levels in plasma collected at Day 9; IFN9 = interferon-γ ELISA OD reading in plasma collected at Day 9 PI.

### TABLE 4. Correlation coefficients (r) and P-values between infection indexes (II) and measured parameters from male and female chickens infected with 10$^6$ *Eimeria maxima* oocysts

<table>
<thead>
<tr>
<th>Parameters</th>
<th>GN</th>
<th>GC</th>
<th>GI</th>
<th>GO</th>
<th>GNC</th>
<th>GNI</th>
<th>GNO</th>
<th>GCI</th>
<th>GCO</th>
<th>GIO</th>
<th>GNCI</th>
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</tr>
<tr>
<td>BWG6-9</td>
<td>r</td>
<td>-0.95</td>
<td>-0.90</td>
<td>-0.84</td>
<td>-0.87</td>
<td>-0.92</td>
<td>-0.87</td>
<td>-0.89</td>
<td>-0.86</td>
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<td>-0.82</td>
<td>-0.88</td>
<td>-0.86</td>
</tr>
<tr>
<td></td>
<td>P</td>
<td>0.00</td>
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</tbody>
</table>

1. BW0 = BW before inoculation; BWG6-9 = BW gain between Days 6 and 9 postinoculation (PI); oocyst = fecal oocyst production between Day 5 and 9 d PI; CRTN9 = plasma carotenoid levels at Day 9 PI; NO6 = plasma levels at Day 6; IFN9 = plasma interferon-γ at Day 9 PI.

II = Σ ((individual value of a parameter – mean of the parameter in the group) × C/SD), where C is a factor. The factor is 1 for parameters positively correlated to oocyst counts and -1 for those negatively correlated to oocyst counts, e.g., GNCIO = (oocyst – mean)/SD – (BWG6-9 – mean)/SD – (CRTN9 – mean)/SD + (IFN9 – mean)/SD + (NO9 – mean)/SD. The letters G, N, C, I, and O represent that parameters BWG6-9, NO9, CRTN9, IFN9, and oocyst output were included in II calculation.
gains from Days 0 to 6 or Days 0 to 9 PI. Similarly, NO6 displayed correlations with other parameters, whereas NO9 did not. NO2 + NO3 concentrations started to increase 3 d after infection and reached peaks at Day 5 PI (Allen, 1997a). After Day 6 PI, NO2 + NO3 concentrations declined. These results indicate again that sampling time is important.

To date, there are no other reports about correlations between IFN-γ concentration and other parameters. In the present study, IFN-γ concentration at Day 9 PI was positively correlated to NO6 concentrations, and NO6 displayed a highly negative correlation with BWG6-9. Production of NO2 + NO3 and INF-γ in serum increased during host response to infection of Eimeria (Ovington and Smith, 1992, Ovington et al., 1995). The IFN-γ concentration may be very useful for evaluation of genetic resistance. In this experiment, only nine plasma samples in each group collected from Day 9 PI were used for IFN-γ measurement because of a shortage of plasma samples. Further investigations may yield a clearer understanding of this parameter.

It has been reported that one or two parameters measured from chickens with coccidiosis do not truly reflect the genetic resistance of an individual (Bumstead and Millard, 1987, Caron et al., 1997). Oocyst shedding, BW gain, and lesion score are the most common measurements for evaluating genetic resistance to coccidiosis. However, the low correlations between BW gains and lesion scores (Caron et al., 1997) and between gross and microscopic lesion scores (Idris et al., 1997) creates doubts of usefulness of lesion scores in evaluating genetic resistance. Body weight gain is considered not to be a sensitive measurement of coccidiosis. It usually requires large inoculation dosages to produce response (Conway et al., 1990). In addition, genes controlling growth may influence body weight gain more than genes governing disease resistance. For example, in this study, there was a high correlation between BW gain and initial BW, BW0. If weight gain is the only parameter for genetic analysis of coccidiosis resistance, we may end up mapping genes controlling growth rather than genes involved in coccidiosis resistance. Oocyst production has been used as the indicator of susceptibility to coccidiosis in mice (Rose et al., 1996) and in chickens (Bumstead and Millard, 1992). Although this parameter appears to be unique in avian coccidiosis, it is difficult to remove the technical error in sampling and counting. Therefore, inclusion of other correlated parameters may more accurately estimate the true status of genetic resistance to coccidiosis in an individual. Plasma carotenoid measurement was found to be a very sensitive parameter in avian coccidiosis, and it is considered an excellent indicator of intestinal physical integrity (Conway et al., 1990). Oocyst production, NO2 + NO3 concentrations at 6-d PI, and carotenoid concentrations were correlated to BW gains. These parameters may also be included to offset the disadvantage of using body BW as the only parameter, which is correlated to initial body weight, BW0. Body weight gain is the ultimate economic trait of broiler chickens for the poultry industry. The combination of BW gain with other correlated parameters may serve as a better indicator of genetic resistance to coccidiosis.

Infection indices calculated in this study may be better reflective indicators of genetic resistance or susceptibility to coccidiosis. The II displayed much higher correlation coefficients with the correlated parameters than those among the parameters. The II estimation is still premature and subjective. The data were collected during a short experimental time. Further investigations of the relationships among the parameters and including new parameters will greatly improve the understanding of genetic resistance to coccidiosis.

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