Divergent Selection on Feather Pecking Behavior in Laying Hens Has Caused Differences Between Lines in Egg Production, Egg Quality, and Feed Efficiency

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ABSTRACT The correlated changes in egg production, egg quality, and feed efficiency (FE) due to selection for feather pecking (FP) were investigated by analyzing the data from an experiment including 2 divergently selected lines and a control line. The experiment was conducted with hens from 42 to 46 wk (hatch 1) and 39 to 43 wk (hatch 2) of age in the fifth generation of selection. The number of FP bouts per hour in the low FP line (LFP) was lower than the high FP line (HFP; 0.38 vs. 2.01), and total plumage score in line LFP was better than in line HFP (16.9 vs. 11.6). During the 4 wk, egg number and egg mass in line LFP were higher than those in HFP (24.4 vs. 18.3 and 1,223 vs. 1,132 g, respectively). On the other hand, line HFP had greater egg weight (60.7 vs. 59.2 g), albumen height (73.0 vs. 64.9 in Haugh units), shell thickness (38.1 vs. 37.0 mm), and yolk percentage (30.6 vs. 29.5%) than the LFP line. The control line was intermediate for those traits. The residual feed consumption (RFC) was highest in line HFP, lowest in line LFP, and intermediate in line C. Partial regressions of feed consumption (FC) on BW gain and egg mass were not significantly different among the 3 lines, whereas a significant difference in regression on metabolic BW (32.6 g/d in line LFP, 38.0 g/d in control line, and 43.4 g/d in line HFP) was observed. In addition, there was a negative regression of FC per day on plumage score (−1.73 g). The adjustment for plumage score accounted for 60% of the difference between regressions on metabolic BW in lines LFP and HFP. These results indicated that selection for FP has led to a change in egg production, egg quality, and FE. The better FE in line LFP resulted from a lower requirement for maintenance energy. The later was partly accounted for by a better plumage cover.

Key words: selection, feather pecking, feed efficiency, egg production, egg quality

INTRODUCTION

Feather pecking (FP) is one of the most widespread and serious behavioral problems in laying hens. A representative survey revealed that in Switzerland, 37.5% of the flocks were judged by their owners as having problems with FP during the rearing period (Huber-Eicher, 1999). On an individual level, Kjaer and Sørensen (1997) observed that about 50% of pullets and adult hens performed FP. Feather pecking can have a range of harmful consequences. The birds may feel pain when the feathers are removed (Gentle and Hunter, 1990), naked birds are less well protected against physical injuries and bad weather, and naked birds experience a higher risk of receiving cannibalistic pecking (Kjaer and Sørensen, 2002).

Craig and Swanson (1994) stated that genetic selection for behavior traits generally produced significant results within a few generations. Through sire family selection, the incidence of beak-inflicted injuries and FP was reduced after one generation of selection (Craig and Muir, 1993) and was greatly reduced after 6 generations of selection (Muir, 1996). By divergent selection for the number of FP bouts, a significant difference was attained between the high and low selected lines, resulting in high (HFP) and low (LFP) FP lines (Kjaer et al., 2001; Su et al., 2005).

A range of management procedures such as beak trimming, improving rearing conditions and feed, and optimizing the laying environment can be used to reduce FP behavior. These methods, however, have either some shortcomings or difficulties in practical applications. An alternative solution to reduce FP behavior is genetic selection. It has been shown that genetic selection effectively reduces the incidence of beak-inflicted injuries and FP. A range of management procedures such as beak trimming, improving rearing conditions and feed, and optimizing the laying environment can be used to reduce FP behavior. These methods, however, have either some shortcomings or difficulties in practical applications. An alternative solution to reduce FP behavior is genetic selection. It has been shown that genetic selection effectively reduces the incidence of beak-inflicted injuries and FP. Craig and Swanson (1994) stated that genetic selection for behavior traits generally produced significant results within a few generations. Through sire family selection, the incidence of beak-inflicted injuries, causing feather loss and cannibalism, was reduced after one generation of selection (Craig and Muir, 1993) and was greatly reduced after 6 generations of selection (Muir, 1996). By divergent selection for the number of FP bouts, a significant difference was attained between the high and low selected lines, resulting in high (HFP) and low (LFP) FP lines (Kjaer et al., 2001; Su et al., 2005).

Craig and Adams (1984) pointed out that selection for behavioral traits could have a negative effect on productivity and advocated direct selection for productivity to improve adaptability. But Hill (1983) claimed that the use of production performance as an indicator of well-being...
has several potential drawbacks due to the conflict with profits. Given that a continuous increase in mortality caused by cannibalism in all brown layer strain crosses tested at the Random Sample Test stations in Germany has been observed since the late 1980s (Preisinger, 1997), Kjaer and Mench (2003) suggested that selection for higher egg production and lower BW has led to increased cannibalism. This leads to the hypothesis that direct selection for FP can have an influence on production traits. However, there is very limited information about the correlated response to selection for FP. The objective of the present study was, therefore, to investigate possible changes in egg production, egg quality, and feed efficiency (FE) due to selection on FP and to detect the components that may contribute to such changes.

**MATERIALS AND METHODS**

**Populations, Rearing System, and Feeding Experiment**

The data were collected from an experiment with 3 experimental lines of White Leghorn laying hens, among which line LFP was selected for low FP, line HFP for high FP, and the control line was a randomly mated control line. The 3 lines were established in 1995 and derived from the same foundation stock. The foundation line was formed in 1970 as a control population in the Scandinavian selection and cross breeding experiment (Liljedahl et al., 1979) and maintained since then as a randombred line. The 3 lines were established in 1995 and derived from the same foundation stock. The foundation line was formed in 1970 as a control population in the Scandinavian selection and cross breeding experiment (Liljedahl et al., 1979) and maintained since then as a randombred line. Feather pecking behavior was measured at about 30 wk of age by counting FP events (FP pecks) and then grouping the events into a number of bouts (FP bouts). One bout was defined as a series of continuous pecking direct to the same individual. Selection in line LFP and HFP was based on predicted breeding value of FP bouts, while random breeding was maintained in the control line.

The experiment was conducted using hens in the fifth generation of selection. The birds were reared in floor pens covered with a 5 cm thick layer of wood shavings. Temperature was 34°C at 1 d of age and reduced gradually to 20°C at 8 wk of age. This temperature was kept throughout the rest of the experiment. At 18 wk of age, pullets were transferred to 4-bird battery cages and males to single-bird cages. Feed and water were supplied ad libitum during the whole period. The diet for 0 to 5 wk, 6 to 15 wk, and after 15 wk had crude protein contents of 20.5, 13.2, and 16.4% and energy contents of 2,771, 2,842, and 2,651 kcal/kg, respectively.

At 28 to 29 wk of age, females in line LFP and HFP were evaluated for plumage condition. Plumage on back, breast, neck, tail, and wing was scored separately with 1 being worst and 4 being best. The sum of the sores from the 5 parts was taken as total plumage score and used in the present study. After that, the females were transferred from cages to floor pens (2 × 4 m) for recording of FP behavior. Each observation pen held 20 females, 10 of each selection line. Lines were mixed to account for the effects of observation pen and social facilitation in groups of birds. After a settling-in period of 7 to 12 d, FP behavior of the females was recorded by video camera for 3 h. During the recording period incandescent light was supplied with light intensity about 25 lx at ground level.

In general, when selection response is evaluated using least squares methods, a control line is required to separate genetic and nongenetic changes. By using animal-model-based methods, however, selection response can be estimated without the need of control line (Sørensen and Kennedy, 1986). Therefore, in the present selection experiment, FP behavior and plumage score were not measured for the birds in the control line so as to save the cost of measuring FP.

At the end of FP recording period, hens were transferred from floor pens to single-bird cage system (LACO BV, 5405 B Uden, Netherlands) for the recording of individual feed consumption (FC) and egg production. The birds of the 2 selected lines and the control line were assigned to cages with a balance over rows and a random distribution within rows. The ambient temperature around the cages was 20 to 21°C. Feed was supplied ad libitum to the birds by a feed trough built into a silo having a capacity of 2 kg, and one refill was performed during the 4-wk period. Feed consumption was recorded from 42 to 46 wk (hatch 1) and 39 to 43 wk (hatch 2) of age. Body weight at start and at end, egg number, egg weight, and FC during the 4-wk period were recorded individually. Two eggs from each hen were measured for shell thickness, albumen height, and yolk weight.

The number of records for each trait in each line is shown in Table 1. For a detailed description of the testing procedure for FP and selection protocol, see Kjaer et al. (2001). Genetic parameters for FP behavior were presented elsewhere (Su et al., 2005).

**Statistical Analysis**

Egg production, egg quality, BW, and FC were analyzed using the model

\[
y = m + \text{line} + \text{hatch} + e \quad \text{model [1]}
\]

where \(y\) is the observations of egg number, egg weight, egg mass, albumen height, shell thickness, yolk proportion, BW, or FC; \(m\) is the intercept; line and hatch are fixed effects; and \(e\) is the random residual.

The FE was analyzed based on residual FC (RFC), which was FC (g) corrected for metabolic BW (BW\(^{0.75}\), kg for BW), egg mass (EM, g), and BW gain (WG, g) during the 4 wk

\[
\text{RFC} = \text{FC} - b_1 \text{BW}^{0.75} - b_2 \text{EM} - b_3 \text{WG}
\]

where \(b_1\), \(b_2\), and \(b_3\) are regression coefficients of FC on BW\(^{0.75}\), egg mass, and BW gain, respectively.

The effects of the lines on FE were tested using the following model:
FC = \mu + \text{line} + \text{hatch} + b_1\text{BW}^{0.75} + b_2\text{EM} + b_3\text{WG} + e \quad \text{model [2]}

To detect the components that cause the difference in RFC between lines, further analysis was done using a within-line multiple-regression model:

FC = \mu + \text{hatch} + b_1\text{BW}^{0.75} (\text{line}_i) + b_2\text{EM} (\text{line}_i) + b_3\text{WG} (\text{line}_i) + e \quad \text{model [3]}

Moreover a model including plumage score as a covariate was used to analyze the effect of plumage condition on FC:

FC = \mu + \text{hatch} + b_1\text{Plum} + b_2\text{BW}^{0.75} (\text{line}_i) + b_3\text{WG} (\text{line}_i) + e \quad \text{model [4]}

The analyses were conducted using the GLM procedure of the SAS Institute (1994).

**RESULTS**

The mean and CV of the traits are shown in Table 1. The mean was calculated as the average over lines and hatch effects. Phenotypic variation was small for egg weight and shell thickness (CV = 7%); moderate for BW, FC, albumen height, and yolk proportion (12 to 17%); large for plumage score, egg number, and egg mass (27 to 33%); and very large for FP (261%) and BW gain (229%).

Five generations of divergent selection resulted in a large difference in FP behavior between lines LFP and HFP (Table 2). Least squares means for FP bouts per bird each hour was 0.38 in line LFP and 2.01 FP bouts in line HFP. As expected, plumage condition in line LFP (plumage score = 16.9) was better than in line HFP (plumage score = 11.6). These differences between lines were significant. In addition, there were significant differences in BW, BW gain, FC, egg production, and quality traits among the 3 lines.

The BW in the control line was significantly higher than in the 2 selected lines. The HFP and LFP lines did not differ significantly in BW. During the 4-wk period of the experiment, the BW gain in line HFP was significant larger than that in line LFP, and the control line was intermediate. Moreover, FC in line LFP was significantly less than in lines C and HFP, whereas the control and HFP lines did not differ significantly in FC.

For egg production traits, egg weight in line HFP was significantly larger than that in line LFP, whereas number of eggs in line LFP was significantly higher than that in line HFP. In addition, line LFP had a higher egg mass production than line HFP. For egg quality traits, line HFP was significantly higher than line LFP in albumen height, shell thickness, and yolk proportion. For both egg production and egg quality traits, the control line was always intermediate to lines LFP and HFP.

The partial regression coefficients and their standard errors were estimated from model 2. Pooled over the 3 lines, FC was expected to increase 38.8 ± 4.2(SE) g/d with an increase of 1 kg of metabolic BW, 0.984 ± 0.214 g with 1 g of BW gain, and 0.760 ± 0.040 g with 1 g of egg mass.

After accounting for metabolic BW, BW gain, and egg mass (model 2), the difference in RFC among the 3 lines was significant (Table 3). Line HFP had the highest RFC,
line LFP had the lowest RFC, and the control line was intermediate. Thus the RFC in line HFP was higher than line C by 6.68 g/d, and the latter was higher than line LFP by 8.23 g/d during the 4-wk period.

The within-line regression coefficients for each component of FC (model 3) are shown in Table 4. The regression coefficients of FC on egg mass and on BW gain were not significantly different among the 3 lines. However the regression coefficients on metabolic BW showed a significant difference among lines with the highest in line HFP, lowest in line LFP, and intermediate in the control line. On average, the maintenance requirement per kilogram of metabolic BW per day for birds in line HFP was 5.43 g/d higher than the birds in line C, and the requirement for the birds in line C was 5.39 g/d higher than that in line LFP.

When plumage condition was taken into account (model 4), a significant effect of plumage condition on FC was found. The partial regression of FC per day on plumage score was −1.727 g (Table 5). Adjustment for plumage score did not change the partial regression coefficients of FC on egg mass and on BW gain but did change the regression coefficients on metabolic BW. After accounting for plumage score, the difference between the regressions in line LFP and HFP was reduced to 4.22 g, and the difference became statistically insignificant ($P = 0.16$).

**DISCUSSION**

There are very few studies on expected or realized correlated response for important economic traits to selection for or against FP. Bessei (1984) reported that the genetic correlations between FP and BW were 0.20 to 0.66, and phenotypic correlations were −0.03 to 0.10. On the other hand, Kjaer and Sørensen (1997) and Rodenburg et al. (2004) reported a negative genetic correlation between BW and FP. In the present study, it was found that BW at about 40 wk in line HFP was slightly larger than line LFP, but BW in both selected lines was less than the control line. No clear relationship between BW and FP could be detected from the current experiment in which birds from different lines were mixed and reared in floor pens until 18 wk, and individual selection was conducted in the lines LFP and HFP based on predicted breeding value of FP bouts measured at about 30 wk of age.

The present study showed that line LFP produced more, but smaller, eggs, and had a larger egg mass output than line HFP, whereas the control line was intermediate with regard to these traits. This result suggested that selection for or against FP has resulted in correlated responses in egg number, egg weight, and egg mass, and selection against FP was favorable for egg production.

The present study found that albumen height, eggshell thickness, and yolk proportion were highest in line HFP, lowest in line LFP, and the control line was intermediate. The rank for the 3 lines in the egg quality traits was just opposite to the rank in egg production. Some previous studies have shown that there is an unfavorable correlation between egg production and the egg quality traits. Poggenpoel (1986) reported that shell and albumen quality traits had genetic correlations of −0.20 with egg production, and 0.10 with egg weight. Mohapatra et al. (1985) estimated the genetic correlations of egg production to 280 d with Haugh unit score and shell thickness being −0.40 and −0.27, respectively, and the genetic correlations of egg weight with Haugh unit score and shell thickness were 0.14 and 0.16, respectively. Grunder et al. (1991) also found that high egg production was associated with low shell quality. However, the within-line phenotypic correlation in the present study (not presented) was not significant between these traits, except for that between egg weight and shell thickness (0.16) and between egg mass and yolk proportion (−0.10). Further, Hartmann et al. (2000, 2002) showed that the genetic correlation of yolk proportion with egg weight was −0.51, with egg number was 0.56, and with egg mass was 0.59. These results suggested that the opposite rank for egg production and the 3 egg quality traits in the 3 lines cannot explained by the correlation among those traits.

### Table 3. A comparison of residual feed consumption per day between the lines selected for low feather pecking (LFP), the line selected for high feather pecking (HFP), and the control line estimated from model 2

<table>
<thead>
<tr>
<th>Contrast</th>
<th>Difference</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFP – HFP</td>
<td>−14.91</td>
<td>1.22</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LFP – control</td>
<td>−8.23</td>
<td>1.60</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Control – HFP</td>
<td>−6.68</td>
<td>1.51</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

### Table 4. Within-line regression coefficients (Reg.) of feed consumption on metabolic BW ($B_W^{0.75}$), BW gain (WG), and egg mass (EM) in the line selected for low feather pecking (LFP), the line selected for high feather pecking (HFP), and the control line (C), estimated from model 3

<table>
<thead>
<tr>
<th>Line</th>
<th>Reg. of $B_W^{0.75}$</th>
<th>Reg. of WG</th>
<th>Reg. of EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LFP</td>
<td>32.60$^{b}$</td>
<td>1.39$^{a}$</td>
<td>0.750$^{a}$</td>
</tr>
<tr>
<td>C</td>
<td>38.02$^{ab}$</td>
<td>0.40$^{a}$</td>
<td>0.787$^{a}$</td>
</tr>
<tr>
<td>HFP</td>
<td>43.44$^{a}$</td>
<td>0.94$^{a}$</td>
<td>0.745$^{a}$</td>
</tr>
</tbody>
</table>

$^{a,b}$The estimates in each column with no common superscript differ significantly ($P < 0.05$).
The partitioning of energy from feed has been studied intensively in laying hens by using multiple linear regression of FC on metabolic BW, BW gain, and egg mass production. The residual of the regression model is often termed RFC and is used as a measure of FE. Luiting (1990) has studied the literature and reported that physical activity, feathering density, basal metabolic rate, areas of nude skin, and body temperature have a contribution to variation in heat production and therefore also to variation in RFC. Moreover RFC has shown to be heritable (Bentsen, 1983; Luiting and Urff, 1991; Shulman et al., 1994). In the present study, the partial regression coefficient of FC on metabolic BW (pooled over the 3 lines) was 38.8, on BW gain was 0.984, and on egg mass was 0.760, which is consistent with previous studies (e.g., Bentsen, 1983; Shulman et al., 1994). After correction for metabolic BW, BW gain, and egg mass, RFC was larger in line HFP than in line LFP. These results indicated that selection for FP behavior has led to a change in FE. Selection for high FP decreased FE while selection for low FP resulted in a better FE.

The analysis of within-line multiple regressions was conducted to detect the difference between lines in FC per unit of metabolic BW, BW gain, and egg mass. The regression coefficients of FC on egg mass were very similar in the 3 lines, indicating the FC for producing a unit of egg mass was the same in the HFP and LFP lines. On the other hand, the difference between lines HFP and LFP in regressions of FC on metabolic BW was large and statistically significant. On average, with an increase of 1 kg of metabolic BW, the birds in line HFP needed 43.4 g feed per day, whereas the birds in line LFP needed only 32.6 g. Those results indicated that selection for FP caused a change in the requirement of maintenance energy but no change in the FE for BW gain and egg production.

The difference between the HFP and LFP lines in egg production and quality traits as well as in FE could be an accumulated effect of multiple factors. Several previous studies have reported a difference between HFP and LFP birds in several physiological characters. Recently, corticosterone levels after 2 min of manual restraint were measured in 18-wk-old pullets of the same lines as used in the present experiment. Preliminary results showed a tendency, although not significant, to higher levels of corticosterone in the LFP line vs. the control and HFP line (data not shown). These results are in agreement with the studies by Korte et al. (1997, 1999) who reported that HFP hens had a greater plasma norepinephrine response and a lower corticosterone response to manual restraint, compared with LFP hens. These authors also found that HFP hens had higher heart rates than LFP birds during manual restraint. A somewhat similar result was found in the third generation of hens from the lines used in the present study. The heart rate of LFP hens decreased faster during tonic immobility following manual restraint than that of HFP hens (Hjarvard et al., 2000). Cheng et al. (2001) found that the serotonin plasma level in the line selected for high productivity and longevity (lower mortality from cannibalism and flightiness) was lower than the reverse selection line. They argued that a higher serotonin level in the line selected for low productivity and longevity was a reason for the lower egg production. Interestingly, very similar results were found in the current lines with respect to plasma serotonin (i.e., a higher level in the HFP line corresponding with a lower egg production; our unpublished data). These results implied that the differences between low FP and high FP birds in egg production, egg quality, and FE could be in relation to the difference in some physiological characters.

Previous studies have shown that FP could cause feather damage and consequently a loss of heat and higher FC (Tauson and Svensson, 1980; Blokhuis and Wiepkema, 1998) and that FC and the maintenance requirement increase with increasing feather damage (Hughes, 1980; Tauson and Svensson, 1980; Tullett et al., 1980; Gonyou and Morrison, 1983). It has been found in the literature that the correlations between RFC and feather score range from 0 to −0.6. Bentsen (1983) found a genetic correlation of −0.46 between RFC and plumage cover on the neck and chest. The present study showed that plumage condition for birds in line LFP was significantly better than that in line HFP. There was a significant effect of plumage condition on FC. The partial regression of FC on total plumage score was large and negative (−1.727 g). The adjustment for plumage score accounted for 60% of the difference in the regressions on metabolic BW between lines LFP and HFP. This result indicated that better FE in line LFP was partly due to better feather covering.

After adjustment for plumage score, the regression on metabolic BW for birds in line LFP was still 4.2 g lower than the birds in line HFP, although not statistically significant (P = 0.16). This result implies that in addition to plumage condition, other factors contributed to lower requirement for maintenance energy in line LFP. Korte et al. (1997, 1999) reported that high and low FP birds

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**Table 5.** Overall regression coefficient (Reg.) of feed consumption on plumage score, within-line regression coefficients on metabolic BW (BW<sup>0.75</sup>), BW gain (WG), and egg mass (EM) in the line selected for low feather pecking (LFP) and the line selected for high feather pecking (HFP), estimated from model 4

<table>
<thead>
<tr>
<th>Line</th>
<th>Reg. on plumage score</th>
<th>Reg. on BW&lt;sup&gt;0.75&lt;/sup&gt;</th>
<th>Reg. on WG</th>
<th>Reg. on EM</th>
</tr>
</thead>
<tbody>
<tr>
<td>LP</td>
<td>−1.727*</td>
<td>37.98</td>
<td>1.33</td>
<td>0.766</td>
</tr>
<tr>
<td>HP</td>
<td>42.20</td>
<td>0.95</td>
<td>0.767</td>
<td></td>
</tr>
</tbody>
</table>

*Significantly different from 0 (P < 0.001).
had different responses to a threatening situation (coping styles). High FP birds had active coping style (respond to threatening situations by fighting or fleeing), and low FP birds performed passive coping style (respond to threatening situations by conservation-withdrawal; i.e., remaining undetected with becoming immobile). Further studies are needed to evaluate the difference between the 2 coping styles with regard to requirement for maintenance energy, for example investigating the level of catecholamines. Cheng et al. (2001) reported a higher level of epinephrine in the HFP line supposedly causing a higher level of arousal in this line. In addition, Rodenburg et al. (2004) reported a positive correlation between open-field activity and pecking behavior. Similarly, in a recent experiment of activity testing for the birds in the current lines, it was observed that birds in line HFP performed more locomotion than line LFP. Also Brown and Nestor (1974) found that turkeys selected for higher adrenal response to cold stress were more hyperactive. These results implied that birds in line HFP used more energy for activities.

In conclusion, selection for FP or against FP has resulted in a correlated response for egg production, egg quality, and FE. Birds in the low FP line laid more eggs and had greater egg mass; lower egg weight, albumen height, shell thickness, and yolk proportion; and better FE than the birds in the high FP line. The better FE in the low FP line resulted from a lower requirement for maintenance energy. The latter was partly accounted for by a better plumage cover.

REFERENCES


