Correlated Responses to Selection for Increased Intramuscular Fat in a Chinese Quality Chicken Line

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ABSTRACT The correlated response in traits encompassing meat quality, carcass, sexual maturity, egg production, and egg quality traits arising from selection for increased intramuscular fat (IMF) content of breast muscle were investigated in the fifth generation of a selection experiment including a line (F) selected for increased IMF and a randombred control line (C). The results showed that breast muscle IMF content in the F line (4.25%) was significantly higher ($P < 0.001$) than that in the C line (3.80%) after 5 generations of selection. The same trend was observed in IMF content in thigh muscle (20.03 vs. 19.41%, $P < 0.05$). The shear force of breast muscle in the F line was lower than that in the C line (1.82 vs. 2.12 kg, $P < 0.01$), whereas increases occurred in BW ($P < 0.05$), carcass weight ($P < 0.05$), breast muscle weight ($P < 0.001$), breast muscle percentage of live weight ($P < 0.05$), abdominal fat weight ($P < 0.001$), ovarian weight at 90 d of age ($P < 0.05$), and egg weight ($P < 0.05$) in the F line, relative to the C line. Age at first lay in the F line was 4.84 d earlier than that in the C line ($P < 0.001$). No differences were found between the 2 lines ($P > 0.05$) in the following traits: drip loss, meat color ($L^*$, $a^*$, and $b^*$), carcass percentage, thigh muscle weight, thigh muscle percentage, abdominal fat percentage, first egg weight, egg number (until 43 wk), Haugh units, shell thickness, and egg shape. The results of the present study demonstrated that selection for breast muscle IMF leads to desirable changes in meat quality, carcass, sexual maturity, and egg production traits.

Key words: correlated selection response, intramuscular fat content, meat quality, carcass trait, sexual maturity

INTRODUCTION

Consumers’ preference for colored-feather and slow-growing meat-type chickens is growing in certain regions of the world (Rizzi et al., 2007). In China, for example, this type of chicken represents almost 50% of the market share of meat-type birds. In general, colored-feather and slow-growing meat-type chickens are mainly bred from the native breeds, and indicators of meat quality such as flavor, color, and texture are the main attributes that attract customers when purchasing chicken products.

The content of intramuscular fat (IMF, fat or lipid content extracted from muscle) has become an important indicator of meat quality and has played a critical role in consumer acceptance of fresh pork (NPPC, 1995). Previous studies showed that IMF is associated with the flavor of pork (Van Oeckel et al., 1999; Schwab et al., 2006), and with the juiciness of beef, as detected by taste panelists (Thompson, 2004). In a swine selection program, genetic selection for IMF has been used to improve meat quality (Suzuki et al., 2005a,b). The IMF also plays an important role in the quality (flavor and juiciness) of chicken meat (Chizzolini et al., 1999; Chen et al., 2005).

Due to genetic relationships (e.g., linkage and pleiotropy) among meat quality, rate of growth, carcass traits, sexual maturity, and egg production traits, correlated responses may occur when selection is based upon IMF. Suzuki et al. (2005b) reported that IMF increased and some meat quality characteristics changed with selection over 7 generations for meat production traits and IMF in the loin of swine. Little information exists, however, in chickens on correlated responses to selection for IMF. The purpose of the current study was to examine the direct selection response of IMF and correlated responses of other production traits after 5 generations of selection.

MATERIALS AND METHODS

Selection and Maintenance of Lines

The selection program began in 2000 with a base population consisting of 150 males and 700 females of a pure...
line of a commercial yellow-feathered chicken breed (Jingxing 100, bred by Institute of Animal Science, Chinese Academy of Agricultural Sciences). From this base population, 40 sires and 400 dams were randomly chosen as the founder animals of the line selected for increased IMF (line F). Simultaneously, 20 sires and 150 dams from the same base population were randomly chosen to produce the first generation (G) of a randomized control line (line C). In line C, about 40 sires and 200 dams continued to be chosen randomly from G1 to G5. Hens were inseminated artificially using the pooled semen of all sires on the same day during the egg collection period. For line F, half-sib (G0 to G3) and full-sib (G4 and G5) families were used to derive the mean family value of IMF, with a 1:3 to 5 ratio of males to females in each sire family. There were 18 to 25 progeny per family in G0 to G3 (from 1 hatch) and 9 to 15 progeny per full-sib family in G4 and G5 (obtained from 2 hatches) retained before 90 d of age. In each generation and family, at least 3 male and 3 female chickens were slaughtered at 90 d of age under industrial conditions after fasting overnight. The IMF was determined (described below), and the mean, within a family, was the phenotypic value upon which selection was based. The same selection criteria were performed in each generation as follows: the selected breeders must have a mean family value for IMF above the line average; the progeny per family (G0 to G3, sire family; G4 and G5, dam family) must be more than 5 females and 5 males; no more than 3 male breeders were used from any selected family; at least 40 sire families must be chosen as breeder stock in each generation. If any family was not chosen for measuring IMF content, the birds of this family were eliminated. Starting at 41 wk of age, random mating of selected males and females was used, the only restriction being mating between full or half-sibs. The number of families and chickens tested for IMF and the mean values for all male and female birds in each generation are presented in Table 1.

All birds were wing-banded after hatching and reared under the same conditions in step-stair caging at the experiment station of the Institute of Animal Sciences, Chinese Academy of Agricultural Sciences. Feed and water were provided ad libitum until 90 d of age. A commercial corn-soybean diet was provided at same nutritional level for each generation. A starter diet (12.12 MJ/kg, 20% protein) was fed from 0 to 8 wk, a grower diet (11.7 MJ/kg, 17% protein) between 9 and 18 wk, a pullet diet (11.5 MJ/kg, 16% protein) from 19 to 24 wk, then an adult diet (11.5 MJ/kg, 16% protein) from 25 to 43 wk of age.

The present used chickens from the fifth generation of selection. At 90 d of age, 78 females from 26 full-sib families in line F (only from the first hatch) and 76 females from line C (the same hatch as for the F line) were selected randomly and slaughtered to test for IMF, meat quality, and carcase traits under the conditions as described. The remaining birds of each line were reared until 43 wk. Daily egg production per hen was recorded from the day of first lay to 43 wk. At 43 wk of age, egg quality traits were measured on 2 eggs from each hen. All tested birds (numbers are presented in each table) were from the same hatch.

### Measurements and Analyses of Traits

Body weights were measured for each live bird at 90 d of age. The selected birds were fasted overnight then slaughtered under industrial conditions. Carcasses were dissected into deboned, skinless thighs and breasts immediately after slaughter. These tissues were weighed (thigh muscle; breast muscle, BMW), vacuum-packed, and stored at 4°C until further analysis. The weight of carcass, including feet and head, and abdominal fat (AFW) were recorded. Abdominal fat, consisting of adipose tissues surrounding the proventriculus and gizzard lying against the inside abdominal wall, and that located around the cloaca was collected, as described by Ain et al. (1996).

The ratios of each of these weights to BW at 90 d of age were expressed as percentages: carcass, abdominal fat, breast muscle, and thigh muscle. Muscle samples were collected from the entire right side of breast and thigh muscle for the assessment of IMF. Before performing chemical analysis for IMF, the sample of breast and thigh muscle was obtained after removing any visible fat surrounding and lying between muscles, as described by Ricard et al. (1983). The left breast muscle was measured for drip loss (pectoral major muscle), shear force (pectoral major muscle), and color determination (entire pectoral minor muscle).

Intramuscular fat content of muscle was determined by extraction with petroleum ether in a Soxhlet apparatus (AOAC, 1990; Zerehdaran et al., 2004), and expressed as percentages on the basis of weight of dry muscle tissue.
Table 2. Changes in BW and carcass traits (means ± SE) after 5 generations of selection for intramuscular fat (F line) compared with randombred controls (C line)

<table>
<thead>
<tr>
<th>Trait(^1) (units)</th>
<th>F line (n = 78)</th>
<th>C line (n = 76)</th>
<th>Difference (F − C)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BW90 (g)</td>
<td>1,009.24 ± 13.14</td>
<td>961.17 ± 14.09</td>
<td>48.07 ± 19.21</td>
<td>*</td>
</tr>
<tr>
<td>CW (g)</td>
<td>831.89 ± 10.98</td>
<td>791.13 ± 11.65</td>
<td>40.76 ± 15.97</td>
<td>*</td>
</tr>
<tr>
<td>CP (%)</td>
<td>82.52 ± 0.21</td>
<td>82.65 ± 0.17</td>
<td>−0.001 ± 0.00</td>
<td>NS</td>
</tr>
<tr>
<td>BMW (g)</td>
<td>123.67 ± 2.21</td>
<td>112.87 ± 1.83</td>
<td>10.8 ± 2.89</td>
<td>***</td>
</tr>
<tr>
<td>BMP (%)</td>
<td>12.2 ± 0.16</td>
<td>11.8 ± 0.16</td>
<td>0.40 ± 0.00</td>
<td>*</td>
</tr>
<tr>
<td>TMW (g)</td>
<td>126.66 ± 3.38</td>
<td>122.72 ± 2.43</td>
<td>3.94 ± 4.24</td>
<td>NS</td>
</tr>
<tr>
<td>TMP (%)</td>
<td>12.78 ± 0.15</td>
<td>12.76 ± 0.14</td>
<td>0.001 ± 0.00</td>
<td>NS</td>
</tr>
<tr>
<td>AFW (g)</td>
<td>49.93 ± 1.34</td>
<td>43.30 ± 1.29</td>
<td>6.63 ± 2.25</td>
<td>***</td>
</tr>
<tr>
<td>AFP (%)</td>
<td>4.79 ± 0.11</td>
<td>4.66 ± 0.11</td>
<td>0.13 ± 0.00</td>
<td>NS</td>
</tr>
</tbody>
</table>

\(^1\)BW90 = BW at 90 d of age; CW = carcass weight; CP = carcass percentage; BMW = breast muscle weight; BMP = breast muscle percentage; TMW = thigh muscle weight; TMP = thigh muscle percentage; AFW = abdominal fat weight; and AFP = abdominal fat percentage.

\(^2\)Percentage indicates that values were expressed as a fraction (%) of BW at 90 d of age.

*P ≤ 0.05; **P ≤ 0.01; ***P ≤ 0.001.

Table 3. Changes in meat quality traits (mean ± SE) after 5 generations of selection for intramuscular fat (IMF; F line) compared with randombred controls (C line)

<table>
<thead>
<tr>
<th>Trait(^1) (units)</th>
<th>F line (n = 78)</th>
<th>C line (n = 76)</th>
<th>Difference (F − C)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breast IMF(_1) (%)</td>
<td>4.25 ± 0.12</td>
<td>3.80 ± 0.11</td>
<td>0.45 ± 0.00</td>
<td>***</td>
</tr>
<tr>
<td>Breast IMF(_2) (%)</td>
<td>1.23 ± 0.03</td>
<td>1.08 ± 0.02</td>
<td>0.15 ± 0.00</td>
<td>***</td>
</tr>
<tr>
<td>Thigh IMF(_1) (%)</td>
<td>20.03 ± 0.19</td>
<td>19.41 ± 0.16</td>
<td>0.62 ± 0.00</td>
<td>*</td>
</tr>
<tr>
<td>Thigh IMF(_2) (%)</td>
<td>5.33 ± 0.04</td>
<td>5.19 ± 0.04</td>
<td>0.14 ± 0.00</td>
<td>*</td>
</tr>
<tr>
<td>Drip loss (%)</td>
<td>3.76 ± 0.02</td>
<td>4.32 ± 0.03</td>
<td>0.56 ± 0.00</td>
<td>NS</td>
</tr>
<tr>
<td>Shear value (kg)</td>
<td>1.82 ± 0.08</td>
<td>2.12 ± 0.08</td>
<td>−0.30 ± 0.11</td>
<td>**</td>
</tr>
<tr>
<td>L*</td>
<td>42.67 ± 0.34</td>
<td>43.34 ± 0.38</td>
<td>−0.67 ± 0.51</td>
<td>NS</td>
</tr>
<tr>
<td>a*</td>
<td>5.05 ± 0.14</td>
<td>5.19 ± 0.19</td>
<td>−0.14 ± 0.23</td>
<td>NS</td>
</tr>
<tr>
<td>b*</td>
<td>14.34 ± 0.14</td>
<td>14.59 ± 0.18</td>
<td>−0.25 ± 0.22</td>
<td>NS</td>
</tr>
</tbody>
</table>

\(^1\)Breast IMF\(_1\) = intramuscular fat content of breast muscle expressed as percentage of dry weight; breast IMF\(_2\) = intramuscular fat content of breast muscle expressed as percentage of fresh (wet) weight; thigh IMF\(_1\) = intramuscular fat content of thigh muscle expressed as percentage of dry weight; and thigh IMF\(_2\) = intramuscular fat content of thigh muscle expressed as percentage of the fresh (wet) weight. L* = lightness; a* = redness; and b* = yellowness.

*P ≤ 0.05; **P ≤ 0.01; ***P ≤ 0.001.

and fresh muscle tissue, respectively. Color measurements were made by a spectrophotometer (model WSCS, Shanghai Shenguang Ltd., Shanghai, China) using the CIELAB system (L* = lightness; a* = redness; and b* = yellowness). Each sample was evaluated at 3 locations. Drip loss was determined by the filter paper method of Kauffman et al. (1986). The left breast was weighed and placed in a plastic bag and freely suspended, minimizing contact with the bag, using a steel wire hook at 4°C. Muscle samples were wiped and weighed after 24 h to evaluate the drip loss, which was expressed as a percentage of the initial muscle weight.

Shear force was measured using a universal Warner-Bratzler testing machine (MTS Synergie 200, G-R Manufacturing Company, Manhattan, KS). Muscle samples, stored at 4 for 24 h as noted, were cooked individually within their plastic bags using water at 80°C to reach an internal temperature of 70°C followed by chilling to room temperature. Strips 1.0 cm (width) × 0.5 cm (thickness) × 2.5 cm (length) parallel to the muscle fibers were prepared from the medial portion of the meat and sheared vertically (Molette et al., 2003). Shear force was expressed in kilograms.

Eggs were weighed and the breadth and length were measured to calculate the shape index (breadth/length × 100). After weighing, the eggs were broken on to a flat surface and the height of the albumen was measured halfway between the yolk and the edge of the inner thick albumen at 3 places, using an albumen height gauge (Mitutoyo, Miyazaki, Japan). Thickness of the shells (after manual removal of inner and outer shell membranes) was measured at 3 places (top, middle, and bottom) using a micrometer (Mitutoyo).

**Statistical Analyses**

Descriptive statistics, including the test of the normality of the distribution for each trait, t-test, and ANOVA were analyzed with SAS software version 8.02 (SAS Institute, 1999). The main effect was line.

**RESULTS**

**Growth and Carcass Traits**

The differences, between the 2 lines (F and C) after 5 generations of selection for IMF in BW and carcass traits...
are presented in Table 2. The BW (P < 0.05) and carcass weight (P < 0.05) in the F line were significantly higher than in the C line, respectively, but there was no significant difference (P > 0.05) in carcass percentage in the 2 lines. Significant differences occurred in BMW (P < 0.001) and BWP (P < 0.05) between the 2 lines, whereas no differences were found in thigh muscle weight and thigh muscle percentage (P > 0.05). The AFW in the F line was significantly higher than that in the C line (49.93 vs. 43.30 g, P < 0.001), but there was no difference (P > 0.05) in abdominal fat percentage between the 2 lines.

**IMF and Meat Quality Traits**

Selection responses for IMF and other meat quality traits in the fifth generation are shown in Table 3. Selection for increased IMF for 5 generations resulted in a difference (0.45%, P < 0.001) in IMF content of breast muscle (dry weight basis) between the 2 lines, with means of 4.25% in the F line and 3.80% in the C line. For thigh muscle, the response in IMF in the F line was also higher than that in the C line (20.03 vs. 19.41%, P < 0.05). The same tendency was found for IMF content of fresh (i.e., wet weight) breast (P < 0.001) and thigh muscle (P < 0.05).

Mean shear force was 1.82 kg for the F line and 2.12 kg for the C line (P < 0.01; Table 3). There was no difference (P > 0.05) detected in drip loss nor color (L* = lightness; a* = redness; and b* = yellowness) between the 2 lines.

**Sexual Maturity, Egg Production, and Quality Traits**

Changes in 3 sexual maturity traits are presented in Table 4. Ovarian weight at 90 d of age in the F line was significantly higher (P < 0.05) than in the C line. Day of first lay was 4.84 d earlier in the F line than in the C line (P < 0.001). There was no significant difference (P > 0.05) between the lines in the weight of the first egg.

Among egg production and egg quality traits, significant changes (P < 0.05) were observed in egg weight after selection for IMF (Table 5), though egg number did not differ substantially between the 2 lines. Similarly, albumen height (expressed in Haugh units), shell thickness, and egg shape did not differ (P > 0.05) between the lines. It seems that the increased level of fatness observed in the F line was apparently of no consequence in terms of egg production and quality.

**DISCUSSION**

**Direct Selection Response of IMF**

In the study, direct response to selection for increased breast muscle IMF was evaluated. After 5 generations of selection, higher IMF (11.8%) was achieved. Although genetic drift could exist in the control line, genetic gain for this trait based on the performance of full- and half-sibs was 0.45% IMF (4.25 vs. 3.80% in the control line). Newcom et al. (2005) reported that, in a selection experiment for percentage of loin IMF based on sib carcass measurement in Duroc swine, the phenotypic mean of IMF in generation 0 and generation 3 was 3.61 and 3.87%, respectively (the difference was 0.26%), with estimated genetic gain of 0.97%. Although there may be some differences between swine and chicken for adipose and muscle tissue, this genetic gain by selection for increased IMF in swine was similar to that obtained here with chickens.

In a previous study, the heritability of breast muscle IMF at 90 d of age in the F line was estimated to be 0.22 (Zhao et al., 2006), which indicates that IMF is moderately heritable. Together with the results of practical selection response described here, it can be speculated that IMF, which is of great interest for the quality poultry industry, is a moderate genetically influenced trait, which can be increased through family selection.

**IMF and Meat Quality**

In the current study, changes in IMF content of thigh muscle were observed as correlated responses to selection on IMF in breast muscle. Zhao et al. (2006) previously reported that the genetic correlation between breast and thigh IMF was 0.89, which is consistent with the response to practical selection obtained here.

Shear force, which measures the textural integrity of cooked products (Lonergan et al., 2003), is an objective measurement of the tenderness of meat. If meat has a lower shear force value, it indicates that the meat is more tender. In the present study, meat from the selected line had a significantly lower shear force value than that in the control line, implying that selection for increased IMF may have increased the tenderness. This is consistent with results observed in pigs. Many studies have estimated the genetic correlation between IMF and tenderness in pig, with a mean value of 0.15 (Sellier, 1998). The IMF is also favorably associated in pigs with flavor, juiciness
analyses on larger data sets. 

A randombred line of Japanese quail. After 5 generations positively correlated with sexual maturity (R = 0.516) in by Reddish et al. (2003), abdominal fat pad weight was a factor in the process of sexual maturation. In the report (1995) have indicated that fat deposition was an important influence by chronological age, BW, and body composition. Dunnington and Siegel, 1984). Yannakopoulos et al. (2005) have demonstrated that reproductive performance of hens decreases as birds become heavier and fatter, and this is especially evident for broiler breeders. Many studies have demonstrated that reproductive performance of hens decreases as birds become heavier and fatter, and this is especially evident for broiler breeders (Appleby et al., 1994). Yu et al. (1992) also reported that, in females, the capacity for rapid early growth coupled with free access to feed leads to enhanced adult fatness and poor reproductive performance. Chen et al. (2006) reported that the correlation between egg production and AFW was negative (r² = −0.21) when birds were fed 290 g of feed/hen per d. In the present study, although AFW of F-line hens was higher than that of the C-line hens, egg number and egg quality were not obviously changed in the fifth generation. Whether the egg number and egg quality will be changed with continued selection for increased IMF is unknown.

### IMF and Carcass Traits

In the current experiment, the AFW of the line selected for IMF was significantly greater than that of control line in agreement with an earlier report (Zhao et al., 2006) of a positive genetic correlation between IMF and AFW, but not with that of Zerehdaran et al. (2004) in which there was virtually no genetic correlation (0.02) between breast muscle IMF and AFW. In the latter study, selection for reducing AFW did not automatically result in a change in intramuscular fat and probably meat quality in broilers. Similarly, Cahaner et al. (1986) found that considerable changes in the amount of adipose tissue were not accompanied by substantial changes in inter- or intramuscular fat in broilers. Hrdinka et al. (1996) reported that abdominal and subcutaneous fat had similar fatty acid composition and differed significantly from that of IMF in breast muscle. Considering the relationship between IMF and AFW in broilers in the current studies and their inconsistency with the findings of others, further study is needed.

Selection for IMF leads to substantial changes in BW in the present study. This was expected, given the estimated genetic correlation between BW and IMF (0.36 for the F line of Jingxin chickens, Zhao et al., 2006) and 0.75 in Beijingyou chickens (another native Chinese breed; Chen et al., 2005). In addition, in the present experiment, the BW of the F line was also higher than that of the C line. This outcome agrees with a previous report (Zerehdaran et al., 2004) of IMF and BW being correlated (0.12), but not with another study (Chen et al., 2005) estimating that the genetic correlation between IMF and breast meat yield was −0.13. These results should motivate further genetic analyses on larger data sets.

### IMF and Sexual Maturity

Sexual maturity was defined as age first lay and is influenced by chronological age, BW, and body composition (Dunnington and Siegel, 1984). Yannakopoulos et al. (1995) have indicated that fat deposition was an important factor in the process of sexual maturation. In the report by Reddish et al. (2003), abdominal fat pad weight was positively correlated with sexual maturity (R = 0.516) in a randombred line of Japanese quail. After 5 generations of selection in the present study, day of first lay was 4.84 d earlier than that of controls. This observation supports the conclusions of Oruwari and Brody (1988), who stated that there was a minimum body fat threshold needed for sexual maturity. In China, early sexual maturity is a desired character in quality chickens. Wei et al. (2002) have selected for comb size and the day of first lay in local chicken lines (Yin xiang-ma chicken) to advance sexual maturity. Selection for increased IMF, as used here, may also cause earlier sexual maturity in chickens. At the same time, ovarian weights at 90 d of age in the F line were higher than in the C line. This result, consistent with the day of first lay, indicates that birds of F line reached sexual maturity earlier than those of the C line.

### IMF and Egg Production

Though there are very few studies on expected or realized correlated responses for egg production and egg quality traits to selection for IMF, the correlation between fatness and reproductive performance is quite clear. Many studies have demonstrated that reproductive performance of hens decreases as birds become heavier and fatter, and this is especially evident for broiler breeders (Appleby et al., 1994). Yu et al. (1992) also reported that, in females, the capacity for rapid early growth coupled with free access to feed leads to enhanced adult fatness and poor reproductive performance. Chen et al. (2006) reported that the correlation between egg production and AFW was negative (r² = −0.21) when birds were fed 290 g of feed/hen per d. In the present study, although AFW of F-line hens was higher than that of the C-line hens, egg number and egg quality were not obviously changed in the fifth generation. Whether the egg number and egg quality will be changed with continued selection for increased IMF is unknown.

### Acknowledgments

We thank Sun Dong-xiao for her comments and W. Bruce Currie for language suggestions on the manuscript.

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