Feed efficiency in the laying duck: Appropriate measurements and genetic parameters

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ABSTRACT The objective of this study was to characterize residual feed intake (RFI) in common laying ducks by a) adjusting position and duration of the measurement period and b) estimating genetic parameters of RFI. The feed intake (FI), BW, and egg mass laid (EML) were recorded for 64 I444 common ducks at the beginning (–35 wk of age) and the middle (41–48 wk of age) of the laying curve. Much feed wastage was observed at the beginning of the laying curve and led to biased FI data. However, when laying was well-established, weekly and fortnightly FI measurements were well correlated phenotypically (Rp from 0.84 to 0.92 and from 0.91 to 0.94, respectively for weekly and fortnightly FI) with the measurements over the whole 2-mo period. Regarding egg mass laid, phenotypic correlations between the one-week measurements and the measurements over the whole 2-mo period were more variable than those for FI, ranging from 0.74 to 0.94, and similar to whatever was the period of measurement. The RFI was investigated in a second experiment based on 384 common female ducks, for which FI, EML, BW, and BW gain were recorded at 39 wk of age. The RFI was determined by multiple regression of FI on metabolic BW and EML. Heritability values of FI and RFI were 0.34 and 0.24, respectively. In addition, if the heritability values obtained for BW (0.65) and BW gain (0.09) were consistent with studies in chickens, the very low EML estimates (0.06) were unexpected. The RFI was strongly genetically linked to FI (Rg = +0.89) but appeared to be independent from BW. Selection based on RFI should therefore reduce the FI of animals without clearly modifying the other components. Moreover, the correlated responses on reproductive traits seem favorable because lower RFI values increase the number of eggs produced per year as well as the hatchability and fertility rates.

Key words: feed efficiency, laying duck, genetic parameter, residual feed intake

INTRODUCTION

In France, the common duck is mainly used in cross-breeding programs with Muscovy drakes to produce mule ducks for fatty liver production. These ducks, the dams of mule ducks, are almost exclusively reared in hatcheries. In contrast, in Asia, the biggest market for the Pekin duck, with about 400 million animals sold each year (Klein-Hessling, 2007), the common duck is bred mainly to produce eggs for human consumption and as a source of meat at an older age. The selection of these waterfowl, therefore, focuses essentially on reproductive traits, such as egg production and female fertility in pure and cross breeds (Marie-Etancelin et al., 2008b). The French breeder market is mainly dominated by 2 companies: Orvia and Grimaud Frères Sélection; the latter is also the leader for Pekin duck selection in Asia by selecting grand-parental stocks in France and multiplying parental stocks in China.

Nevertheless, as for all livestock, feeding the ducks constitutes the primary farming cost, especially because the animals have a long productive career. Feed efficiency is therefore a crucial farming cost, especially because the animals have a long productive career. Feed efficiency is therefore a crucial farming cost, especially because the animals have a long productive career. Feed efficiency is therefore a crucial farming cost, especially because the animals have a long productive career. Feed efficiency is therefore a crucial farming cost, especially because the animals have a long productive career. Feed efficiency is therefore a crucial farming cost, especially because the animals have a long productive career.

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RFI and its components differ by species and animals experiments. The use of this selection criterion has fully demonstrated its effectiveness in mammals and in avian breeds, such as laying hens (Bordas et al., 1992), and many studies have been carried out to evaluate its genetic or physiological consequences (Tixier-Boichard et al., 2002). However, as far as we know, the genetic aspects of feed intake (FI) in laying ducks have not been studied until now. First, this paper aims to determine the best and cheapest way to evaluate feed efficiency and its component traits during laying, and second, to estimate the genetic determinism of RFI in common laying ducks and whether it is genetically linked to other economic traits.

MATERIALS AND METHODS

Populations, Rearing, and Feeding System

Results were obtained from 2 animal designs, for which hatching, breeding, and measurements were carried out at the INRA waterfowl experimental farm (UEPFG, Benquet, France). Experimental procedures were performed in accordance with French National Guidelines for the care and use of animals for research purposes (Certificate of Authorisation to Experiment on Living Animals no. 7740, Ministry of Agriculture and Fish Products).

In both experiments, the FI of common laying ducks was measured. As FI depends on production, maintenance requirements, and changes in body composition, we recorded feed consumption, egg mass laid, BW, and BW gain (difference between BW at the end of the test period and at the beginning of the test period). The aim of the first design was to define the best period of the laying curve to record feed efficiency information, whereas the second design aimed to estimate the genetic determinism of feed efficiency in laying ducks.

First Design. A flock of 64 common female ducks from the INRA I444 strain (a light Pekin strain selected for fertile period duration) was procreated in one hatching batch. The birds received an ad libitum starting diet containing 16.0% CP and 2,900 kcal of ME/kg from birth to 5 wk old. Then they received a commercial pelleted duck feed containing 16.5% CP and 2,700 kcal of ME/kg. Animals were bred in a collective pen with a natural lighting program until 12 wk of age, and then in individual cages with individual feeders with a lighting program of 16L:8D per day. During 2 periods of 8 wk (P1 and P2, respectively; Figure 1), the weekly FI was recorded for each duck. The FI was defined as the amount of distributed feed at the beginning of the week minus the remaining uneaten feed at the end of the week. Similarly, daily laid eggs were weighed to estimate the daily egg mass laid. Animal ages varied from 28 to 35 wk during P1 (W28–W35) and from 41 to 48 wk during P2 (W41–W48).

Second Design. In total, 384 common female ducks were produced over a period of 2 yr and 3 annual batches, from a cross between 2 INRA strains, I444 and I37 (a synthetic heavy common duck strain) belonging to a QTL detection program (Marie-Etancelin et al., 2008a). The experimental setup was similar to the first design for feeding and breeding conditions, except that animals were transferred to individual cages at 10 to 12 wk old, according to hatching batches. Feed intake measurements were performed at an age of 39 wk on average. Testing was performed during one week in the first year and during 2 wk in the second year. During each test period, daily laid eggs were weighed, including abnormal eggs (the weights of broken eggs were assumed to be equal to the average weight of normal.

Figure 1. Periods (P1 and P2) of feed intake recording on the theoretical duck laying curve.
eggs laid by the duck during the week). Animals were weighed at the beginning (for both years) and at the end (only for the second year) of the test period.

The reproductive traits of the ducks were recorded up to 52 wk of age. First, the total number of eggs laid per female and the rate of abnormal eggs (broken eggs, soft eggs, porous shell, double yolk) were recorded, and second, the fertility rate (fertilized eggs/incubated eggs) and the hatchability rate (hatched eggs/fertilized eggs) were recorded over a 4-wk period with 2 artificial inseminations per week (crossbred mating with Muscovy drakes, INRA strain I66).

### Statistical Analysis

For the first design, correlation coefficients among intake performances were estimated using the CORR procedure of SAS (SAS Institute, 1999).

For the second design, all performances were adjusted to remove the fixed effects of year and hatching batches with the following model:

\[
y = \mu + \text{year} + \text{hatch} + e,
\]

where \( y \) is the measurement of FI, egg mass laid (EML), BW, BW gain (ΔW), FCR (the ratio between FI and the EML), number of eggs at 1 yr, abnormal eggs rate, fertility rate, and hatchability rate; \( \mu \) is the intercept; hatch and year are fixed effects; and \( e \) is the random residual assumed to be normally distributed with mean 0 and variance \( \sigma^2 \). Phenotypic correlation coefficients among adjusted performances were estimated using the GLM procedure of SAS (SAS Institute, 1999).

To qualify feed efficiency, we estimated the RFI as a linear function of FI and outputs, such as EML, ΔW, and maintenance requirements (BW\(^{0.75}\)). The power value of BW was chosen equal to 0.75 because it is the most frequently used. Moreover, in the laying hen, the power value may vary in the range of 0.5 to 1 without affecting the efficiency of the prediction (Tixier-Boichard et al., 2002).

So, for a given population, we defined RFI by multiple regression equations, already used by Byerly (1941) to limit food costs in laying hens:

\[
\text{FI} = \mu + a \times \text{BW}^{0.75} + b \times \Delta W + c \times \text{EML} + d
\]

or \( \text{FI} = \mu + a \times \text{BW}^{0.75} + c \times \text{EML} + d \) (if ΔW not available),

where \( a, b, \) and \( c \) are regression coefficients of FI on metabolic BW (BW\(^{0.75}\)), ΔW (if available), and EML, respectively. The variable \( d \) (or RFI) is the residual of the previous equation: an animal with strong negative RFI values should be more efficient because it consumes less than the regression predicts it should. By definition, RFI is phenotypically independent from the traits for which it has been adjusted.

The effects of year on RFI were tested using the following model:

\[
\text{FI} = \mu + \text{year} + a \times \text{BW}^{0.75}(\text{year}) + c \times \text{EML}(\text{year}) + d.
\]

Coefficients of the multiple regression and their \( P \) value were estimated using the GLM procedure of SAS (SAS Institute, 1999).

To estimate genetic parameters, the pedigree data included 501 records obtained by tracing back 5 generations of ancestors (on both male and female sides) for 264 laying females measured in the study. The variance components (additive genetic and residual) were estimated using VCE 4.2.5 software (Groeneveld, 1997) in multi-trait analysis, according to an animal model including the year effect. The model was the same for each trait and had the following structure:

\[
y = \mu + \alpha + e,
\]

where \( y \) is the measurement of FI, EML, BW, ΔW, RFI, number of eggs at 1 yr, abnormal eggs rate, fertility rate, and hatchability rate; \( \mu \) is the intercept; \( \alpha \) is the random additive genetic effect; and \( e \) is the random residual effect.

### RESULTS

#### Analysis of FI Measurements at Distinct Periods During the Laying Curve (First Design)

The average FI of the flock was 313 ± 96 g/d during P1 and only 256 ± 58 g/d during P2. These FI values are broadly consistent with the estimates usually obtained with food distributed in linear collective feeders. Individual average FI over 8-wk period distributions were clearly different in mean; \( P < 0.0001 \) for period fixed effect. Moreover, comparison of mixed models (with or without heterogeneous variance for period random effect) showed a significant difference in dispersion between the 2 periods, with a stronger dispersion of data during P1 (Figure 2). Presence of feed wasters during P1 may explain the upper range of the data. In fact, the mean FI value during period 2 is consistent with the usual feed consumption of a flock of 45 wk old ducks (about 250 g/d), whereas the consumption level of the first period seems to be too high and variable.

To appreciate the representativeness of a short period of FI measurements in laying ducks, we estimated, for each period of 8 wk, phenotypic correlations (Rp) between a) each weekly intake measurement over the period and b) weekly FI measurements and the AFI of the corresponding period. Similar analysis was carried out for the EML trait.
Phenotypic correlations between the weekly intakes over a period were highly variable, ranging from 0.50 to 0.95 (results not shown); the mean values of these correlations were 0.75 ± 0.11 and 0.76 ± 0.05, respectively for P1 and P2 (average of the correlations between each pair of weekly intakes). The higher SE in P1 confirmed the nonrobustness of FI measurements during this period. Weekly measurements displayed high correlations with the average FI of the corresponding period (Figure 3), ranging from 0.83 to 0.93, whatever the period. The correlations were particularly high for the middle weeks of the period. Moreover, if we averaged 2 consecutive weeks of FI measurements, correlations with the period FI increased even more (Figure 3). For EML, correlations between week measurements and the average of the period were more variable than for FI, ranging from 0.74 to 0.94. As for FI, correlations increased when fortnightly estimations were used. Nevertheless, the results for P2 did not provide a more robust prediction of the EML during the 8 wk than P1. The result was unexpected as at the later ages, most of the egg weights are more consistent, and then correlations between fortnight egg mass and period egg mass were expected to be higher.

Residual FI: Phenotypic and Genetic Analysis (Second Design)

Phenotypic Aspects of RFI and Its Components. The FI of laying ducks was determined for 192 females each year. As a food-wasting phenomenon specific to some females was reported (pellets observed under the cages, but not weighed), which could lead to a bias in FI estimations, we excluded from the analysis the identified wasteful females. The FI was therefore recorded for 104 and 160 ducks in 2005 and 2006, respectively. For this data set (Table 1), the mean FI value was 265 g/d, whereas the BW and EML were respectively approximately 2.62 kg and 73.3 g/d. Using model 1, a significant (P < 0.001) difference appeared for FI and BW between the 2 yr: In 2005, animals were heavier at the beginning of the test period and ate more feed during the test. The FCR during laying was approximately 4.1, with no difference between the 2 yr. The ΔW (only estimated in 2006) was about 8.9 g/d, which is equivalent to only 12% of the average daily egg mass. Regarding the reproductive traits, the total number of eggs laid at the age of 1 yr was 206.4, with no difference observed between the 2 yr, whereas the fertility and hatchability rates (65.9 and 70.1%, respectively) were higher in 2006 compared with 2005. The percentage of abnormal eggs also increased in 2006, with more than 10.6% in 2005. Whatever the trait, there was no significant effect of the hatching batch.

The phenotypic correlations between FI and the other components of feed efficiency were computed separately year by year (Table 2). The FI showed correlations with BW (0.24 and 0.29 in 2005 and 2006, respectively) and egg mass (0.18 and 0.34 in 2005 and 2006, respectively). The phenotypic correlation between FI and ΔW was 0.25 in 2006. Correlations were higher during the second year, when measurements were recorded over a 2-wk period instead of only 1 wk during the first year.

To compute the RFI, we applied multiple regressions, first on the 2006 data set only, with (model 2a) or without (model 2b) the ΔW (Table 3). The pheno-
The regression coefficients for BW and EML were strongly significant (P < 0.001), whereas the coefficient for ΔW was only weakly significant (P = 0.02). The variation percentage explained by the model was little improved (model 2b vs. model 2a) with the introduction of the ΔW trait. Indeed, R^2 increased only by 2 points (from 0.25 to 0.27), and the correlation between RFI was 0.98 for both equations (results not shown). When model 3 was applied to the entire data set, RFI was shown to be significantly different for the 2 yr. The part of the phenotypic variance of FI accounted for by the model was also 26%. The coefficients of the intercept and the EML trait (Table 4) were significantly different between years (P < 0.001). Regarding the metabolic BW coefficients, the level of significance was nearly reached (P = 0.053) for the year effect. Therefore, further analyses were performed using the within-year multiple-regression model (model 3).

Heritabilities and Genetic Correlations. The heritability estimates were approximately 0.34 for FI and 0.24 for RFI (Table 5). Body weight heritability was high (0.65), whereas EML and ΔW heritabilities were close to zero. Body weight was genetically linked to FI (Rg = +0.55), but EML and ΔW were not. Hence, the genetic correlations estimated between FI and the feed efficiency components demonstrate that a selection on food consumption will mainly modify the maintenance requirements (BW).

The strong genetic correlation observed between FI and RFI (Rg = +0.89) showed that the more effective the animal is, the less the animal eats. The RFI seemed to be genetically independent of BW (Rg = +0.12 ± 0.23). Genetic correlations between RFI with EML and ΔW are very strong (−0.65 and 0.57, respectively) but very uncertain, as shown by very high SE (0.60 and 0.41, respectively).

The heritabilities of reproductive traits were consistent with values found in literature (Marie-Etancelin et al., 2008b), ranging from 0.20 for the number of eggs at 1 yr of age to 0.46 for the abnormal eggs rate (Table 6). Genetic correlations between reproductive traits and RFI showed favorable relationships: The decrease of RFI should enhance reproductive traits, by increasing the amount of eggs produced per year, the hatchability rate, and, to a lesser extent, the fertility rate, by reducing the percentage of abnormal eggs.

### DISCUSSION

The objective of the first part of this study was to determine the adequate measurement period for collecting accurate RFI data in common laying ducks. At the beginning of laying period, FI measurements seemed to be spurious because of substantial food wastage under the cages. Moreover, the laying status of the female ducks (well-established laying or still sporadic) also affected the energetic requirements of the females and modified the ranking of animals for FI from one week to another. Therefore, to obtain reliable measurements of feed consumption, the beginning of laying period (P1) should be avoided.

When the laying was well established (P2), correlations between weekly measurements and the FI over the whole 8-wk period were always higher than 0.84 (up to 0.92) and were consistent with results found by Bordas and Mérat (1975) in laying hens. They estimated that the correlation between food consumption recorded over a short period (16 d) and a long period (3 mo) was 0.84. When we averaged our FI measurements over 2 consecutive weeks, correlations with the period FI average increased even more and reached 0.94; we hence obtained a better and more stable estimation of consumption during the given period. Thus, the ex-

#### Table 1. Mean, SD, and ANOVA of studied traits (second design)

<table>
<thead>
<tr>
<th>Item</th>
<th>Trait</th>
<th>N</th>
<th>Mean ± SD</th>
<th>Fixed effect</th>
<th>Least square means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feed intake (g/d)</td>
<td>FI</td>
<td>264</td>
<td>265 ± 46</td>
<td>*** ns</td>
<td>277 253</td>
</tr>
<tr>
<td>Total eggs mass (g/d)</td>
<td>EML</td>
<td>264</td>
<td>73.3 ± 15.6</td>
<td>ns ns</td>
<td>— —</td>
</tr>
<tr>
<td>BW (g)</td>
<td>BW</td>
<td>264</td>
<td>2,620 ± 289</td>
<td>*** ns</td>
<td>2,733 2,514</td>
</tr>
<tr>
<td>BW gain (g/d)</td>
<td>ΔW</td>
<td>158</td>
<td>8.9 ± 4.7</td>
<td>ns</td>
<td>— —</td>
</tr>
<tr>
<td>Feed conversion ratio</td>
<td>FCR</td>
<td>264</td>
<td>4.1 ± 3.1</td>
<td>ns ns</td>
<td>— —</td>
</tr>
<tr>
<td>Out of test period</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eggs number at 1 yr</td>
<td></td>
<td>264</td>
<td>206.4 ± 39.9</td>
<td>ns ns</td>
<td>— —</td>
</tr>
<tr>
<td>Abnormal eggs (%)</td>
<td></td>
<td>264</td>
<td>15.1 ± 16.0</td>
<td>*** ns</td>
<td>10.6 18.3</td>
</tr>
<tr>
<td>Fertility rate</td>
<td></td>
<td>261</td>
<td>65.9 ± 23.7</td>
<td>*** ns</td>
<td>56.5 70.7</td>
</tr>
<tr>
<td>Hatchability rate</td>
<td></td>
<td>256</td>
<td>70.1 ± 20.4</td>
<td>*** ns</td>
<td>62.9 74.4</td>
</tr>
</tbody>
</table>

1FI = feed intake; EML = egg mass laid; ΔW = BW gain; and FCR = feed conversion ratio.

### Table 2. Phenotypic correlations between feed efficiency components

<table>
<thead>
<tr>
<th>Year</th>
<th>FI with</th>
<th>BW</th>
<th>EML</th>
<th>ΔW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0.24</td>
<td>0.18</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>0.29</td>
<td>0.34</td>
<td>0.25</td>
<td></td>
</tr>
</tbody>
</table>

FI = feed intake; EML = egg mass laid; ΔW = BW gain
A measurement carried out over a short 2-wk period can provide an accurate estimation of the FI of the duck during a long laying period (at least 8 wk). Nevertheless, the longer the measurement period is, the more reliable the estimation will be. Therefore, the choice of the FI measurement period was crucial to obtain reliable data: The test period must not be placed too early during the laying curve and must be at least 2 wk long.

The objective of the second study was to estimate the genetic parameters of RFI. In 2006, even though measurements were carried out over a 2-wk period, the genetic correlations we observed between FI and BW, EML, or ΔW were low (0.29, 0.34, and 0.25, respectively) compared with those obtained by Bordas and Mérat (1974) in laying hens with a 4-wk measurement period. Their estimates were 0.57 for FI and BW, 0.49 for FI and egg mass produced, and 0.42 for FI and BW change. As a consequence, our predictive model explained only 26% of the phenotypic variance. We could hypothesize that the duration over which measurements were collected affects the precision of the measurements, and that over longer periods, the technical bias that could be introduced (for FI or other traits) is reduced for the estimation of RFI. In laying hens, the part of the phenotypic variance of FI explained by the model is generally higher than that observed here, between 30 and 90% (Luiting and Urff, 1987; Byerly et al., 1980). Nevertheless, the multiple regression coefficients for female Rhode Island Red reported by Bordas

Table 3. Coefficients of the multiple regression estimated on 2006 data, depending on the model

<table>
<thead>
<tr>
<th>Model</th>
<th>R square</th>
<th>Value</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a</td>
<td>0.27</td>
<td>Coefficient</td>
<td>0.65</td>
<td>1.72</td>
<td>1.23</td>
<td>-81.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P-value</td>
<td>***</td>
<td>*</td>
<td>***</td>
<td>ns</td>
</tr>
<tr>
<td>2b</td>
<td>0.25</td>
<td>Coefficient</td>
<td>0.66</td>
<td>/</td>
<td>1.33</td>
<td>-78.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P-value</td>
<td>***</td>
<td>***</td>
<td>ns</td>
<td></td>
</tr>
</tbody>
</table>

1Model 2a: \[ FI = \mu + a \times BW^{0.75} + b \times \Delta W + c \times EML + d \]; Model 2b: \[ FI = \mu + a \times BW^{0.75} + c \times EML + d \] (if ΔW not available).

*0.005 < P < 0.01; *** P < 0.001.

![Figure 3.](https://academic.oup.com/ps/article-abstract/91/5/1065/1549705)
et al. (1992) was close to our coefficients (−83 vs. −81.5 for the intercept; 1.75 vs. 1.72 for ΔW, 0.69 vs. 1.26 for EML; and 3.75 vs. 0.65 for metabolic BW; the coefficients for metabolic BW and the intercept reported by Bordas et al. (1992) were divided by 28 to correct for the duration of measurements). Including the change in BW in the multiple regression improved the accuracy of the model very marginally, we could hypothesize that our r² were lower than those in hens because the precision of EML measurements over a 2-wk period was lower in ducks than in hens. As food composition is unchanged in our experiment, another possibility to improve our model’s prediction would be to take into account the ambient temperature, which was, according to Combs (1968), the most relevant environmental factor to be considered because high temperatures are known to decrease RFI in pigs, for example (Labroue et al., 1999).

The estimation of the heritability for RFI was of approximately 0.24, which is situated in the large range of published estimations for laying hens (0.05–0.60; Arboleda et al., 1976; Luiting and Urff, 1987; Katle and Kolstad, 1991; Tixier-Boichard et al., 1995). This result confirmed that RFI is, as in other species, selectable in laying ducks. The high heritability values for BW (0.65) and FI (0.34), as well as the low heritability value for ΔW (0.09), were in agreement with the estimations of Luiting and Urff (1991a) and Tixier-Boichard et al. (1995). Indeed, the latter authors found heritability values of 0.56, 0.43, and 0.14 for BW, FI, and ΔW, respectively, for female Rhode Island Red hens. Cheng et al. (1995) reported a heritability value close to 0.50 for the BW of Tsaiya ducks. Our heritability estimation for EML was very low (0.06) and contrasted with that of Tixier-Boichard et al. (1995), who established an EML heritability value of 0.69. Nevertheless, Luiting and Urff (1991b) reported a heritability value for EML in White Leghorn hens lower than 0.30, which decreased over time and occasionally reached zero values.

The strong genetic correlation estimates we show here between FI and RFI is higher than that usually reported for laying hens (from 0.20–0.60 for Luiting and Urff, 1991b; 0.40 ± 0.04 for Tixier-Boichard et al., 1995) or growing turkeys (0.47 for Case et al., 2010). Nevertheless, all results show that the more effective the animal is, the less it eats. Moreover, as for laying hens (Fairfull and Chambers, 1984), estimates of genetic correlations between RFI and the components of feed efficiency in ducks were low (0.12 for BW) or with a high SE for other traits; RFI was therefore only genetically linked clearly to FI. This result is of great interest, as a selection based on RFI would decrease FI without modifying the genetic level of BW. Additional results are needed to control the effect of RFI selection on EML and ΔW.

As reviewed by Tixier-Boichard et al. (2002), correlated responses to selection on RFI were investigated across species and 5 main groups of traits were identified: heat production, behavior, body composition, physiological indicators, and reproduction. Our favorable genetic correlations between reproductive traits and RFI were consistent with results in hens. In laying hens, Bordas and Mérat (1993) found that, at the 17th generation of lines selected for feed efficiency, the hatching rate was 30% higher than in a low RFI line, with delayed embryo development in the high RFI line, with about 10 h difference in the time of hatching. Morisson et al. (1997) confirmed these results and also showed that high RFI lines display poorer performances at fertilization and lesser production of motile spermatozoa.

Before considering selection on RFI for fatty liver production, we needed to evaluate the correlations between RFI and other traits, such as the fattening of the animals, behavior, and heat adaptation. Concerning heat adaptation, Bordas et al. (1992) reported that selection on RFI criterion modifies mean heat production or dissipation. In laying hens, El-Kazzi et al. (1995) demonstrated that adiposity and lipid contents at various parts of the carcass were higher in the low RFI line. For growing ducks, Guy et al. (2002) showed that the selection on FCR led to a lower growth rate but also to a higher adult BW and less fattening, which was not the goal of such a selection. As in fatty duck production, the most important economic trait is feed efficiency.

Table 4. Within-year regression coefficients of feed intake on metabolic BW, egg mass laid (EML), and intercept

<table>
<thead>
<tr>
<th>Year</th>
<th>Intercept</th>
<th>BW⁰.⁷⁵</th>
<th>EML</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>37.17</td>
<td>0.31</td>
<td>0.32</td>
</tr>
<tr>
<td>2006</td>
<td>23.89</td>
<td>0.66</td>
<td>1.31</td>
</tr>
</tbody>
</table>

P-value: ns (5.3%) **

** 0.001 < P < 0.005.

Table 5. Genetic parameters (heritabilities on the diagonal and genetic correlations above) of feed intake components¹

<table>
<thead>
<tr>
<th></th>
<th>FI</th>
<th>BW</th>
<th>ΔW</th>
<th>EML</th>
<th>RFI</th>
</tr>
</thead>
<tbody>
<tr>
<td>FI</td>
<td>0.34 ± 0.06</td>
<td>0.55 ± 0.17</td>
<td>−0.07 ± 0.47</td>
<td>0.09 ± 0.33</td>
<td>0.89 ± 0.07</td>
</tr>
<tr>
<td>BW</td>
<td>0.65 ± 0.11</td>
<td>−0.84 ± 0.43</td>
<td>−0.45 ± 0.38</td>
<td>0.12 ± 0.23</td>
<td></td>
</tr>
<tr>
<td>ΔW</td>
<td>0.09 ± 0.13</td>
<td>0.88 ± 0.19</td>
<td>−0.65 ± 0.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EML</td>
<td>0.06 ± 0.05</td>
<td>0.57 ± 0.41</td>
<td>0.24 ± 0.11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RFI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹FI = feed intake; EML = egg mass laid; ΔW = BW gain; RFI = residual feed intake.
during growth, it would also be essential to evaluate the relationship between RFI during reproduction and RFI during growth. In pigs, Gilbert et al. (2010) estimated a genetic correlation of 0.35 to 0.37 between these 2 estimates of RFI. However, in beef cattle, Renand et al. (2010) showed that these 2 traits were independent. In turn, Luiting et al. (1994) indicated that genetic selection for a low RFI lead to the production of less active animals. This aspect was confirmed by Altan et al. (2004) in Japanese quail, where an increase of RFI lead to a longer duration and lesser induction of tonic immobility.

We did not overlook the impact of all environmental factors and genotype-environment interactions. Despite showing that RFI is a good way to improve feed efficiency, Carré et al. (2008) highlighted in broilers the existence of many interactions between poultry genetics and feeding parameters. Thus, in laying hens, Bordas and Minvielle (1997) have shown that the overconsuming line was better adapted to high temperatures with a lesser decrease in egg production and ΔW.

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**REFERENCES**


**Table 6. Genetic parameters of reproductive traits**

<table>
<thead>
<tr>
<th>Item</th>
<th>No. of eggs at 1 yr</th>
<th>Abnormal eggs (%)</th>
<th>Fertility rate</th>
<th>Hatchability rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heritability</td>
<td>0.20 ± 0.11</td>
<td>0.46 ± 0.11</td>
<td>0.32 ± 0.10</td>
<td>0.24 ± 0.11</td>
</tr>
<tr>
<td>Correlations with RFI</td>
<td>−0.68 ± 0.39</td>
<td>0.57 ± 0.23</td>
<td>−0.32 ± 0.26</td>
<td>−0.067 ± 0.20</td>
</tr>
</tbody>
</table>

1RFI = residual feed intake.


