# Genetic Parameters for Residual Feed Intake, Feed Efficiency and Average Daily Gain in Landrace Pigs

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*Abstract*

Residual feed intake (RFI) is the difference between the actual feed intake (AFI) and the expected feed intake (EFI). RFI has become an increasingly important trait and is being considered as a more practical approach to evaluate feed efficiency (FE) in livestock. Data from 479 purebred Landrace pigs involved in a performance test were used in this study. Pigs were housed in an individual pen and fed ad libitum the same formula diet consisting of 2,950 kcal/kg of ME and 16% crude protein. Clean water was available to the pigs at all time. Pigs were weighed at the beginning and end of the test, backfat thickness (BF) was measured at the end of the test and feed intake was recorded. EFI was predicted using the model that included sex and common litter effects as well as covariates of average daily gain (ADG) and BF. Variance components were estimated using an animal model by the restricted maximum likelihood (REML) method. The heritability estimate for RFI was low ($0.16 \pm 0.10$), while the estimates for FE and ADG were moderate ($0.33 \pm 0.15$ and $0.38 \pm 0.17$, respectively). The moderate favorable genetic correlation was estimated between RFI and FE ($-0.55 \pm 0.27$). The genetic correlations between RFI and ADG, and FE and ADG were not significantly different from zero ($0.02 \pm 0.38$ and $0.15 \pm 0.31$ respectively). Considering heritabilities of FE and RFI, the results indicated that selections for improving FE were possible. Genetic correlation indicated that selection for reduced RFI would increase FE without adversely affecting ADG.

## Introduction

Feed represents the largest cost item for pork production, accounting for more than 65% of the total cost (Rauw et al., 2006). The prices of animal feed ingredients have increased as a result of an increase in demand for such ingredients, which are not only used as livestock feed, but also used as raw material for biodiesel production (Cai et al., 2008). Holm et al. (2004) reported that a reduction in the cost of swine feed could be achieved through an improvement in feed efficiency (FE). In other words, cost of swine feed could be reduced by selection for pigs that have abilities to maintain their growth rate with a lower amount of feed intake.

The swine industry in Thailand does not focus on improving FE because grower-finisher pigs are usually kept in group, leading to meal sharing, and as a result, there is usually no data on any individual pig's feed intake. Thus, FE data for each individual pig cannot be calculated. In order to collect individual pig's feed intake, each pig must have its own pen, and doing so would require more labor and increase the production costs. Nevertheless, a report showed that selection via FE leads to an inconsistent outcome because FE data is not a directly measurable trait. It is usually derived from the ratio of feed intake to weight gain (Hoque et al., 2009).

Several researchers suggested that the selection based on residual feed intake (RFI) could lead to a genetic improvement in FE (Kennedy et al., 1993; Rauw et al., 2006; Hoque and Suzuki, 2008; Hoque et al., 2009). RFI is the residual portion between the amount of feed the animal is expected to eat, and what the animal actually eats (Mrode and Kennedy, 1993; Hoque et al., 2007). RFI trait is more heritable than FE trait. Hoque et al. (2007) showed that selection based on RFI leads to a more predictable and constant outcome than selection based on FE. Moreover, there is a lack of research on RFI trait in Thailand. This study is the first to consider RFI for pig in Thailand. Therefore, the purpose of this study was to examine the RFI in pigs that were raised in Thailand and genetic parameters of RFI, FE, and ADG in order to guide and promote the development of swine genetics in Thailand.

## Materials and Methods

**Data:** All animals in the current study were cared for in accordance with the guideline of the Department of Livestock Development, Ministry of Agriculture and Cooperative, Thailand. In this study, 486 Norwegian Landrace (93 boars, 264 gilts and 129 castrates) pigs were performance tested in a certified PRRSV-free herd. The herd was located in the central part of Thailand, between latitudes 15°9' N and longitude 100°1' E. The test was performed during the period of July 2010 to November 2011. The studied pigs were offspring of breeding pigs that have been raised in Thailand and genetically-selected for their productivity and reproductive traits.

**Swine Testing**: The performance testing was done in an open building without any cooling system and with a double-gabled, tiled roof, concrete floor, and a bird-net covering the building. Pigs were kept in individual pens, measured 0.8 meters by 1.5 meters, with one feed station and one nipple water dispenser. A group of pigs, comprising 4 to 48 healthy pigs, was tested weekly. A total of 27 groups of pigs, amounting to 486 pigs, were tested. After about one week of adaptation to the conditions of their new pens, pigs were tested from approximately 12 to 25 weeks of age. All pigs were given ad libitum access to the same feed containing approximately 2,950 Kcal/kg ME and 16 % crude protein. The feed was free of both antibiotics and growth hormone. All pigs had access to water via nipple water dispensers at all time.

**Data recording:** Data of daily feed intake were recorded every other day for the whole test period. All pigs were weighed at the beginning and end of the test period. Ultrasonic BF thickness was measured, in mm, at the same time as final body weight. The ultrasonic records were taken on four different sites: 2.5 cm in front of the last rib, immediately behind the shoulder blades, and the highest and lowest values measured by sliding the probe from loin to ham by ultrasound scanner (Medata Lean Streak) in accordance with Holm et al. (2004). In the analyses, the average of four measures per animal was used.

Pigs with an abnormally low feed intake for a period of longer than 15 days and pigs that died before the end of the test, together amounting to seven pigs, were excluded from the analyses. In total, 479 data entries from 91 boars, 260 gilts and 128 castrates were analyzed.

**Studied Traits**: The traits analyzed were RFI, FE and ADG from starting to the end of performance test. ADG for each pig was calculated individually from the difference between starting body weight and end test body weight divided by the number of days on test. FE was calculated as daily feed intake divided by ADG. RFI was computed as the difference between the actual feed intake (AFI) and the expected feed intake (EFI). The daily AFI was computed as the difference between accumulations of supplied and leftover feed during test period divided by the number of days on test. For further analyses, AFI was corrected for sex and common litter effects, using the following model: $AFI_{ijk} = \mu + sex_i + litter_j + e_{ijk}$ where $AFI_{ijk}$ is actual feed intake; $\mu$ is the adjusted mean; $sex_i$ is the effect of sex (i =1, 2, 3); $litter_j$ is the effect of common litter effect (j = 1, 2, …, 103); $e_{ijk}$ is the random error term. The daily EFI was estimated from a multiple linear regression model that included ADG and BF thickness after adjustment for the fixed effects of sex and common litter effect. The general regression model is $EFI_{ijk} = \mu + sex_i + litter_j + b_1 ADG_{ijk} + b_2 BF_{ijk}$ where $EFI_{ijk}$ is EFI; $\mu$ is the adjusted mean; $sex_i$ is the effect of sex (i =1, 2, 3); $litter_j$ is the effect of common litter effect (j = 1, 2, …, 103); $b_1, b_2$ are partial regression coefficient; $ADG_{ijk}$ is the ADG (k =1, 2, …, 479); $BF_{ijk}$ is the average BF thickness (j = 1, 2, …, 479). RFI of each pig was derived from the difference between the adjusted AFI and the EFI, as follow: $RFI_{ijk} = AFI_{ijk} - (\mu + sex_i + litter_j + 0.001664 \times ADG_{ijk} + 0.041544 \times BF_{ijk})$

**Statistical Analysis:** The variance and covariance estimates were derived using restricted maximum likelihood (REML) method (Patterson and Thompson, 1971) via REMLF90 application (Misztal, 2001). The studied traits were analyzed simultaneously by using the following animal model: $y = Xb + Za + e$ where **y** is the observation vector of studied traits (RFI, FE and ADG); **X** and **Z** are the known incidence matrices for fixed and random effects, respectively; **b** is the vector of fixed effects; **a** is the vector of additive genetic effects; and **e** is the vector of residuals. The expectations and variance matrices of the observation and random effect factors were assumed to be: $y \sim N(X\beta, ZGZ' + R)$; $a \sim N(0, G)$; $e \sim N(0, R)$. The (co)variance matrices of random effect factors in **a** and **e** were assumed to be: $v\begin{bmatrix} a \\ e \end{bmatrix} = \begin{bmatrix} G \otimes A & 0 \\ 0 & R \otimes I \end{bmatrix}$, where **A**

is the additive genetic relationship matrix between animals; **I** is the identity matrix; **G** and **R** are the variance and covariance matrices for the vectors **a** and **e**, respectively.

The model used for RFI, FE and ADG included fixed effects of sex and common litter effect. For RFI and ADG, non-genetic effects of contemporary group (testing year-month) were included in the models. Average BF thickness was also included as covariate in the model used for FE and ADG. In addition, final age and final weight were included as covariates in the model used for FE. Fixed and covariate effects included in the statistical models are summarized in Table 1.

**Table 1**   Fixed and covariate effects included in the statistical models for the studied traits

| Traits[1] | Fixed effects[2] | | | Covariate effects[3] | | |
|---|---|---|---|---|---|---|
| | Sex | Litter | YMT | FAGE | FWT | BF |
| RFI | * | * | * | - | - | - |
| FE | * | * | - | * | * | * |
| ADG | * | * | * | - | - | * |

[1] RFI = residual feed intake, FE = feed efficiency, ADG = average daily gain
[2] Sex = sex of animals (boar, gilt and castrate), Litter = common litter effect,
YMT = contemporary group (testing year-month)
[3] FAGE = final age, FWT = final weight, BF = backfat thickness
*$p<0.05$

**Table 2**   Descriptive statistics for all traits

| Trait | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Starting age (day) | 85.22 | 4.14 | 72.00 | 92.00 |
| Final age (day) | 178.97 | 12.81 | 142.00 | 224.00 |
| Starting weight (kg) | 24.50 | 6.35 | 9.10 | 63.13 |
| Final weight (kg) | 98.80 | 13.34 | 54.00 | 133.00 |
| Testing period (day) | 93.76 | 12.30 | 56.00 | 140.00 |
| Average daily gain (g/day) | 798.09 | 121.77 | 401.00 | 1,176.00 |
| Backfat thickness (mm) | 7.27 | 0.64 | 5.50 | 9.00 |
| Actual feed intake (kg/day) | 1.88 | 0.33 | 0.82 | 2.81 |
| Adjusted actual feed intake[1] (kg/day) | 1.52 | 0.20 | 0.81 | 2.31 |
| Expected feed intake[1] (kg/day) | 1.46 | 0.21 | 0.74 | 2.12 |
| Residual feed intake (kg/day) | 0.06 | 0.19 | -0.66 | 0.93 |
| Feed efficiency | 0.43 | 0.07 | 0.24 | 0.91 |

[1] Adjusted value by fixed effects of sex and common litter effect

## Results

**Descriptive Statistics:** Means, standard deviations, minimum and maximum values of each studied trait are presented in Table 2. The average age at the starting and at the end of the performance test were 85.22 ± 4.14 and 178.97 ± 12.81 days of age, respectively. The average corresponding weights were 24.50 ± 6.35 and 98.80 ± 13.34 kg body weight, respectively. On average, pigs had an ADG of 798.09 ± 121.77 g/day. Average BF measured at the end of the performance test was 7.27 ± 0.64 mm. The average RFI was 0.06 ± 0.19 kg/day. The average FE was 0.43 ± 0.07.

Distribution of RFI of each studied pig is shown in Figure 1. The result revealed that 62.21% of RFI values was higher than zero (0.01 to 0.93 kg/day). This demonstrates that for most pigs the AFI was higher than the EFI, since RFI was calculated from the difference between AFI and EFI. Nevertheless, pigs

that possess good feeding capability are pigs that have lower AFI than EFI or have a negative value of RFI. Of all the studied pigs, 37.79% or 181 pigs had lower RFI than zero.

**Variance Components:** Variance and covariance components of each studied trait are presented in Table 3. The additive genetic variance for RFI, FE and ADG were 37.35 (g/day)², 6.49, and 4,181 (g/day)², respectively. The corresponding error variance were 198.5 (g/day)², 13.24 and 6,765 (g/day)², respectively.

**Genetic Parameters:** Heritabilities, genetic and phenotypic correlations of the studied traits are presented in Table 4. The estimated heritability of RFI was low, whereas the heritability estimates of FE and ADG were moderate. Genetic correlation between RFI and FE was slightly high and favorable. On the other hand, ADG had no genetic correlation with RFI nor FE

because the genetic correlations were not significantly different from zero, considering from their standard error. Phenotypic correlation between RFI and FE was high and consistent with its genetic correlation; however, there is no phenotypic correlation between RFI and ADG. On the other hand, the phenotypic correlation between FE and ADG was low and favorable.

**Table 3** Estimates of additive genetic variance (on the diagonal), residual variance (in parentheses), genetic covariance (above the diagonal) and phenotypic covariance (below the diagonal) for residual feed intake (RFI), feed efficiency (FE) and average daily gain (ADG)

| Trait | RFI | FE | ADG |
|---|---|---|---|
| RFI | **37.35** (198.5) | -8.54 | 7.16 |
| FE | -55.50 | **6.49** (13.24) | 24.09 |
| ADG | -2.53 | 68.45 | **4,181** (6,765) |

**Table 4** Estimates of heritability ± SE (on the diagonal), genetic correlation ± SE (above the diagonal) and phenotypic correlation (below the diagonal) for residual feed intake (RFI), feed efficiency (FE) and average daily gain (ADG)

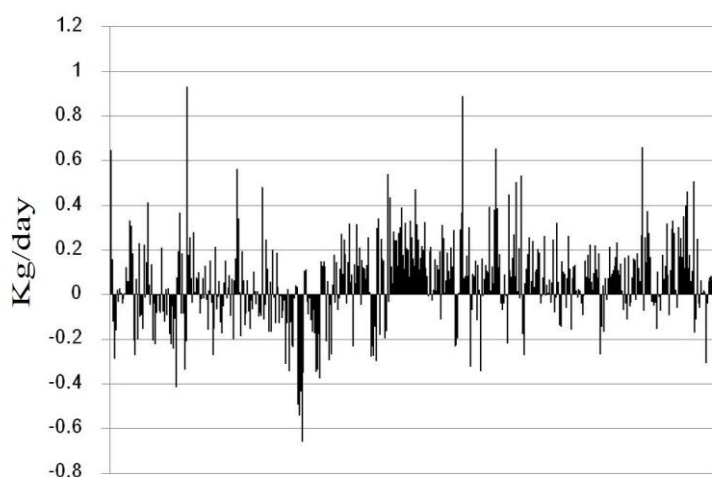| Trait | RFI | FE | ADG |
|---|---|---|---|
| RFI | **0.16 ± 0.10** | -0.55 ± 0.27 | 0.02 ± 0.38 |
| FE | -0.81 | **0.33 ± 0.15** | 0.15 ± 0.31 |
| ADG | -0.00 | 0.15 | **0.38 ± 0.17** |



**Figure 1** Distribution of residual feed intake (RFI) of each studied pig

## Discussion

***Descriptive Statistics:*** Growth rate (798.09 g/day) of pigs used in this study resembles the ADG value in the study by Imboonta et al. (2007), which studied male and female purebred Landrace pigs (780 g/day), during 9 to 22 weeks of age in Thailand. Pigs used in this study had low BF with a low variation (7.27±0.64 mm). The average BF in this study is lower than previously reported in other studies (Kerr et al., 2003; Holm et al., 2004; Imboonta et al., 2007). The low variation of BF may have been the result of pig selection and the difference in feed calories. The studied pigs were fed low-calorie feed (2,950 Kcal/kg), which could partially explain the low BF value. This hypothesis is consistent with the study by Apple et al. (2004), which reported that pigs fed lower calories had a lower BF (lowered by 1.2 mm) , comparing between 3,480 and 3,300 Kcal/kg, as fed basis.

RFI of the studied pigs consisted of both positive and negative values (-0.66 to 0.93 kg/day). Negative value of RFI indicated that AFI of pigs was less than their EFI, thus those pigs had good FE. The lowest value of RFI was -0.66 kg/day. Nevertheless, the pig with the lowest RFI still showed normal ADG value (859 g/day, data not shown). Therefore, the present study demonstrates the possibility of pig selection based on RFI in this particular herd.

The average of FE in this study was 0.43. FE is simply the reciprocal of FCR, and thus our FE is equal to 2.33 when converted into FCR. FE was found to be higher than previously reported (0.39) by Cai et al. (2008). Considering the FCR value, our finding was lower than FCR (2.55) that was reported by Mrode and Kennedy (1993). This possibly demonstrates that the pigs used in this study possessed superior FE traits, which may be because the pigs used in this study were born from the breeding pigs that were subjected to continuous FE selection.

***Genetic Parameters:*** This study is the first study on RFI of pigs in Thailand. The current study showed that RFI had a fairly low heritability (0.16), which was similar to the values (0.18 and 0.17) reported in the studies by Von Felde et al. (1996) and Johnson et al. (1999), respectively. Nevertheless, the estimated

heritability value of RFI trait in this study was lower than the values shown by several studies, ranging from 0.20 to 0.39 (Mrode and Kennedy, 1993; Johnson et al., 1999; Hoque et al., 2009). The differences in heritability estimates may have resulted from different analysis models and different factors included in the models, which were used for AFI adjustment and EFI estimation, resulting in different RFI. Moreover, Kennedy et al. (1993) stated that factors such as digestive ability, the amount of energy needed for survival, protein and energy-storing capability of the pigs contributed to the heritability values. Still, the variation in the heritability estimates is acceptable, and RFI can be a selection candidate. This can be demonstrated by the study of Cai et al. (2008), in which selection for reduced RFI was performed in a Yorkshire herd with heritability estimate of 0.29; after four generations of selection, pigs showed a 96 g/day decrease in RFI.

The heritability estimate of FE was moderate (0.33), which is lower than the estimate of 0.50, studied in Norwegian Landrace pigs (Holm et al., 2004). Nevertheless, the estimated heritability value of FE is at a high enough level to be passed on genetically and can be used as a selection candidate in developing swine genetics.

The heritability estimate of 0.38 for ADG in the present study was similar to those previously reported (Lo et al., 1992; Ducos et al., 1993; Imboonta et al., 2007), but was lower than the estimates (0.43) reported by Mrode and Kennedy (1993) in Duroc, Yorkshire and Landrace pigs and lower than the estimate (0.48) reported by Hoque et al. (2009). Nevertheless, several studies reported that the heritability estimates of ADG were in the low range of 0.10 to 0.24 (Bereskin et al., 1976; Ferraz and Johnson, 1993; Johnson et al., 1999), which could have resulted from various factors such as different styles of pig raising (Jungst et al., 1981), different feeding regime (Robison and Berruecos, 1973) as well as different genetic background, since, size of the studied herd was small and breeding pigs were selected continuously that might result in low genetic variation. However, the resulting heritability estimate indicates that selection for ADG is possible and will show a fairly good result.

The genetic correlation between RFI and FE was favorable and fairly strong (-0.55). This indicates that pig selection based on low RFI will also lead to pigs with high FE, which is desirable for producers. Only a small number of existing studies reported the genetic correlation between RFI and FE, as most studies instead reported the genetic correlation between RFI and FCR, which was in the range of 0.57 to 0.86 (Gilbert et al., 2006; Gilbert et al., 2007; Hoque et al., 2007). Nevertheless, FCR is inversely correlated with FE; therefore, the result of this study is consistent with previous studies in that pig selection based on lower RFI will result in lower FCR, which also translates into pigs with higher FE. The genetic relationship between RFI and ADG in this study shows that the two traits are not genetically related, which is consistent with previous studies. The genetic correlation between RFI and ADG was so weak that it was not significantly different from zero (Mrode and Kennedy, 1993;

Johnson et al., 1999; Gilbert et al., 2006; Hoque et al., 2007). This shows that pig selection based on RFI will not affect ADG, similar to how FE and ADG were not genetically related, which was consistent with the studies by Suzuki et al. (2005) and Hoque et al. (2007) (-0.09 ± 0.07 and -0.10 ± 0.07, respectively).

In conclusion, this study shows that the heritability estimates of RFI, FE, and ADG are sufficiently significant to serve as bases of selection for the purpose of improving FE either directly or indirectly via RFI. This study also shows that pig selection based on low RFI leads to better FE while having no notable effect on weight gain.

## Acknowledgements

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# บทคัดย่อ

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## การใช้อาหาร และอัตราการเจริญเติบโตต่อวันในสุกรพันธุ์แลนด์เรซ

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ปริมาณอาหารที่กินเหลือ (RFI) เป็นความแตกต่างระหว่างปริมาณอาหารที่สัตว์กินได้จริง (AFI) กับปริมาณอาหารที่คาดว่าสัตว์จะกินต่อวัน (EFI) RFI เป็นลักษณะที่มีความสำคัญ และถูกนำมาใช้ในการประเมินประสิทธิภาพการใช้อาหารในปศุสัตว์มากขึ้น การศึกษาครั้งนี้ได้ทำการทดสอบสมรรถภาพการผลิตของสุกรพันธุ์แท้แลนด์เรซ จำนวน 479 ตัว สุกรที่เข้าทดสอบถูกเลี้ยงไว้คอกละหนึ่งตัว ให้กินอาหารและน้ำแบบเต็มที่ สุกรทุกตัวได้รับอาหารสูตรเดียวกันตลอดการทดสอบ ซึ่งเป็นอาหารที่มีพลังงาน 2,950 กิโลแคลอรี/กิโลกรัม และโปรตีน 16 เปอร์เซ็นต์ ชั่งน้ำหนักสุกรเมื่อเริ่มและสิ้นสุดการทดสอบ วัดความหนาไขมันสันหลัง (BF) เมื่อสิ้นสุดการทดสอบ บันทึกปริมาณอาหารที่กินได้ทั้งหมด เมื่อสิ้นสุดการทดสอบทำการประมาณค่าประสิทธิภาพการใช้อาหาร (FE) และทำนายค่า EFI จากสมการทำนายที่ประกอบด้วยอิทธิพลของเพศ อิทธิพลของสิ่งแวดล้อมจากครอกเดียวกัน และความแปรปรวนร่วมของอัตราการเจริญเติบโต (ADG) และ BF ประมาณค่าองค์ประกอบความแปรปรวนของลักษณะที่ศึกษา โดยใช้แบบหุ่นของตัวสัตว์และวิเคราะห์องค์ประกอบความแปรปรวนด้วยวิธี REML ผลการศึกษาพบว่า ค่าอัตราพันธุกรรมของ RFI มีค่าต่ำ (0.16 ± 0.10) ในขณะที่ค่าอัตราพันธุกรรมของ FE และ ADG มีค่าปานกลาง (0.33 ± 0.15 และ 0.38 ± 0.17 ตามลำดับ) ค่าสหสัมพันธ์ทางพันธุกรรมระหว่าง RFI กับ FE มีค่าปานกลางและเป็นไปในทิศทางที่พึงประสงค์ (-0.55 ± 0.27) อย่างไรก็ตามค่าสหสัมพันธ์ทางพันธุกรรมระหว่าง RFI กับ ADG และ FE กับ ADG มีค่าไม่ต่างจากศูนย์ (0.02 ± 0.38 และ 0.15 ± 0.31 ตามลำดับ) ผลจากการศึกษาชี้ให้เห็นว่า FE และ RFI มีความแปรปรวนทางพันธุกรรมเพียงพอที่จะทำการคัดเลือกเพื่อปรับปรุง FE ของสุกร และ การคัดเลือกเพื่อลด RFI จะทำให้ FE เพิ่มขึ้นโดยไม่ส่งผลกระทบต่อลักษณะอัตราการเจริญเติบโตของสุกร

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