

Relationship between Residual Feed Intake and Production Traits in a Population of F₂ Ducks

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Improving feed efficiency is important for decreasing feed cost in poultry production, because feed account for approximately 70% of the total production costs. The selection of feed efficiency may affect other important economic traits. Therefore, the objectives of this present study was to evaluate the relationships of the residual feed intake (RFI) with live body weight, carcass weight, carcass composition, and size of small intestines in a population of F₂ Pekin ducks. Nine-hundred and eighty F₂ ducks were derived from a cross between 40 Pekin ducks and 10 Mallard ducks. The results showed no significant correlation of RFI with live body weight and eviscerated carcass weight. RFI had negative effects on breast meat weight and gizzard weight. A positive correlation of RFI with abdominal fat weight, skin weight, and jejunum length was detected. Our results indicated that the selection of RFI could improve the feed efficiency of ducks without affecting their carcass compositions.

Key words: carcass composition, duck, residual feed intake, small intestine

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Introduction

Feed intake and feed efficiency are economically important traits for ducks. Improvement in feed efficiency would reduce the amount of feed required for growth, the production cost, and the amount of nitrogenous waste produced (Zhang and Aggrey, 2003). A commonly used measure is feed conversion ratio (FCR; i.e., feed intake:body weight gain), but current genetic selection programs for reducing feed costs in farm animals are focused on residual feed intake (RFI), because selection on FCR can lead to unfavorable changes in the component traits (Crews, 2005).

RFI is defined as the difference between the actual feed intake and the expected feed requirements for maintenance and gain of body weight (Koch *et al.*, 1963). Previous studies have shown that RFI is moderately heritable, with values of heritability ranging from 0.14 to 0.49 (Pakdel *et al.*, 2005; Aggrey *et al.*, 2010; Begli *et al.*, 2016; Zhang *et al.*, 2017).

In contrast to FCR, RFI is independent of growth and

maturity patterns. Therefore, RFI should be a more sensitive and precise measurement of feed utilization (Robinson and Oddy, 2004), and presently, an increasing number of farms have been choosing RFI instead of FCR for reducing animal feed costs. Genetic selection for reducing RFI will decrease feed intake and improve feed efficiency without affecting growth performance negatively (Herd *et al.*, 2004; Mrode and Kennedy, 2010). In poultry, growth traits have made a great progress through genetic selection; a 50–60% increase in growth rate has been attributed to genetic selection (Robins and Phillips, 2011; Drouilhet *et al.*, 2014). Phenotypic and genetic selection for feed efficiency could have significant effects on carcass compositions. However, there is lack of information describing the effect of selection for altering RFI on carcass composition traits of ducks, and its effects on carcass traits need to be better understood. Therefore, the objective of the present study was to investigate the relationship of RFI with carcass composition and small intestinal length in an F₂ duck population.

Materials and Methods

Population and Animal Husbandry

The present study was conducted at the Institute of Animal Sciences, Chinese Academy of Agricultural Sciences (CAAS), Beijing, China. The care and use of all the ducks used in this experiment were approved by the Animal Care and Use Committee of the Institute of Animal Sciences of the CAAS.

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Table 1. Ingredients and chemical composition of feedstuff from hatching until 14 d and diets from 15 to 70 d (% as fed)

Ingredient	Diets (0 to 14 d)	Diets (15 to 70 d)
Corn	58.23	59.22
Wheat bran		11.94
Soybean meal	36.17	25.32
Soybean oil	2.03	
Limestone	1.20	1.20
Dicalcium phosphate	1.40	1.40
Sodium chloride	0.30	0.30
DL-Methionine	0.17	0.12
Vitamin and trace mineral premix	0.50 ¹	0.50 ²
Total	100.00	100.00
Calculated composition		
Metabolizable energy, ° kcal/kg	2,900	2,700
Crude protein	21	18
Methionine	0.50	0.40
Cystine	0.36	0.32
Lysine	1.10	0.90
Calcium	0.88	0.86
Nonphytate phosphorus	0.39	0.38

¹ The following were supplied per kilogram of total diet: Cu (CuSO₄·5H₂O), 10 mg; Fe (FeSO₄·7H₂O), 60 mg; Zn (ZnO), 60 mg; Mn (MnSO₄·H₂O), 80 mg; Se (NaSeO₃), 0.3 mg; I (KI), 0.2 mg; Cr (Cr₂O₃), 0.15 mg; choline chloride, 1,000 mg; vitamin A (retinyl acetate), 10,000 IU; vitamin D₃ (cholecalciferol), 3,000 IU; vitamin E (dl- α -tocopheryl acetate), 20 IU; vitamin K₃ (menadione sodium bisulfate), 2 mg; thiamin (thiamin mononitrate), 2 mg; riboflavin, 8 mg; pyridoxine hydrochloride, 4 mg; cobalamin, 0.02 mg; calcium-d-pantothenate, 20 mg; nicotinic acid, 50 mg; folic acid, 1 mg; biotin, 0.2 mg.

² The following were supplied per kilogram of total diet: Cu (CuSO₄·5H₂O), 10 mg; Fe (FeSO₄·7H₂O), 60 mg; Zn (ZnO), 60 mg; Mn (MnSO₄·H₂O), 80 mg; Se (NaSeO₃), 0.3 mg; I (KI), 0.2 mg; Cr (Cr₂O₃), 0.15 mg; choline chloride, 750 mg; vitamin A (retinyl acetate), 8,000 IU; vitamin D₃ (cholecalciferol), 3,000 IU; vitamin E (dl- α -tocopheryl acetate), 20 IU; vitamin K₃ (menadione sodium bisulfate), 2 mg; thiamin (thiamin mononitrate), 1.5 mg; riboflavin, 8 mg; pyridoxine hydrochloride, 3 mg; cobalamin, 0.02 mg; calcium-d-pantothenate, 10 mg; nicotinic acid, 50 mg; folic acid, 1 mg; biotin, 0.2 mg.

³ The values are calculated according to the metabolizable energy of chickens (Ministry of Agriculture of China, 2004).

The F₁ resource population of ducks came from a cross between 40 female Pekin ducks and 10 male Mallard ducks. Pekin duck is a famous breed, with characteristics of fast growth and excellent fattening. The Mallard duck is a native duck with slow growth and high immune capacities that are distributed in the southeastern part of China. The F₁ birds were generated by using either breed as male and female parents. A total of 980 F₂ ducks were finally used in this experiment.

The ducks were fed on the floor for the first two weeks. Thereafter, all the ducks were transferred to individual cages until they were sacrificed. For the first three days after hatching, the ducklings were exposed to continuous lighting (24 L:0 D); subsequently, a 20 L:4D light regimen was used until the ducks were sacrificed for analysis. Ingredient composition and chemical composition of feedstuff used in this study is presented in Table 1. The ducks were not vaccinated against any disease. Feed and water were provided *ad libitum*. Feed intake and body weight of each individual were measured every week from 15 days to 70 days, and the

carcass traits were assessed after all the ducks were slaughtered at 70 days of age.

Carcass Composition

At 10 weeks of age, the 980 ducks studied were fasted for 12 h before they were slaughtered. The slaughtered ducks were defeathered, and the carcass weights including body, breast meat, wing, leg meat, and skin were measured and recorded. In addition, the length of duodenum, jejunum, and ileum were measured, and gizzard, liver, and abdominal fat were weighed. The length of duodenum, extending from the pylorus to pancreatic loop, jejunum, extending from the pancreatic loop to distal caecum, and ileum, extending from distal caecum to the ileocaecal junction were measured.

Statistical Analyses

RFI values were obtained using the PROC REG procedure in SAS software package (SAS System, version 9.2; SAS Institute, Cary, NC). The Pearson product-moment correlation procedure in SAS was used to analyze the relationship of RFI with live body weight, carcass compositions, and small intestinal traits. RFI was calculated according to Zhang *et al.*

(2017).

$$RFI = FI - (a + b_1 \times BW_{70}^{0.75} + b_2 \times BWG),$$

where, *FI* is the feed intake, $BW_{70}^{0.75}$ is the 70 d old metabolic weight, *BWG* is the weight gain from 3 weeks to 10 weeks of age, *a* is the intercept, and b_1 and b_2 are partial regression coefficients of *FI* on $BW_{70}^{0.75}$ and *BWG*, respectively.

Results

Table 2 shows the effect of sex and the regression of RFI on live body weight and carcass traits. The female ducks had significantly lower body weight, eviscerated carcass weight, breast meat weight, skin weight, wing weight, and leg meat weight than the male ducks had. RFI was not significantly correlated with live body weight, eviscerated carcass weight, leg meat weight, and wing weight. RFI had a significant positive correlation with skin weight and a significant negative correlation ($P < 0.05$) with breast meat weight, indicating that skin weight increases and breast meat weight decreases when RFI increases.

The effect of sex and RFI on carcass composition traits are presented in Table 3. The gizzard weight, liver weight, and heart weight were significantly higher in the males than the females ($P < 0.05$). Abdominal fat weight and spleen weight showed no significant differences between male and female ducks. RFI had significant negative effects on gizzard weight, whereas it had a significant positive effect on abdominal fat weights ($P < 0.05$). These results suggest that high feed conversion efficient ducks had larger gizzards and lesser abdominal fat weight.

The effect of sex and RFI on small intestinal morphometric measurements are shown in Table 4. The jejunum length of the male ducks was significantly longer than that of female ducks ($P < 0.05$). However, there was no significant difference in the length of the duodenum and ileum between male and female ducks. RFI had a significant positive correlation on jejunum length.

Discussion

In poultry, 90% of the phenotypic changes in the past 50

Table 2. Mean values of live body weight and carcass traits, and their correlation coefficients with residual feed intake

Item	Number	FI (g)	RFI	BW (g)	ECW (g)	BM (g)	Skin (g)	Wing (g)	Leg (g)
Male	495	4892	1.15	1978 ± 251.36 ^a	1592 ± 162.38 ^a	177.01 ± 31.88 ^a	388.00 ± 86.35 ^a	151.14 ± 18.70 ^a	186.89 ± 28.40 ^a
Female	485	4872	-0.02	1804 ± 242.97 ^b	1463 ± 148.56 ^b	166.78 ± 30.05 ^b	363.47 ± 92.02 ^b	138.62 ± 17.36 ^b	170.76 ± 25.00 ^b
<i>P</i> -value	0.576	0.673	0.234	0.000	0.000	0.000	0.000	0.000	0.000
RFI ^A	—	0.494	—	0.004	0.046	-0.298	0.449	-0.045	-0.008
<i>P</i> -value	—	0.000	—	0.922	0.303	0.013	0.000	0.414	0.877

^{a,b} Means within a column for each factor with different superscripts differ significantly ($P < 0.05$).

^A Correlation coefficients.

FI: feed intake; BW: body weight; ECW: eviscerated carcass weight; BM: breast meat.

Table 3. Means of carcass composition traits and their correlation coefficients with RFI

Item	Number	Liver (g)	Gizzard (g)	Heart (g)	Abdominal fat (g)	Spleen (g)
Male	495	37.61 ± 7.44 ^a	55.80 ± 9.57 ^a	12.03 ± 1.83 ^a	32.30 ± 11.78	2.21 ± 0.31
Female	485	33.71 ± 5.92 ^b	48.33 ± 8.71 ^b	11.32 ± 1.72 ^b	32.75 ± 13.65	2.15 ± 0.23
<i>P</i> -value		0.000	0.000	0.000	0.74	0.56
RFI ^A		0.130	-0.262	0.188	0.422	0.001
<i>P</i> -value		0.117	0.025	0.061	0.000	0.323

^{a,b} Means within a column for each factor with different superscripts differ significantly ($P < 0.05$).

^A Correlation coefficients.

Table 4. Means of small intestinal morphometric traits and their correlation coefficients with RFI

Item	Number	Duodenum length (cm)	Jejunum length (cm)	Ileum length (cm)
Male	495	27.08 ± 2.84	119.67 ± 13.20 ^a	14.96 ± 1.50
Female	485	26.19 ± 2.78	115.84 ± 13.24 ^b	14.24 ± 1.48
<i>P</i> -value		0.158	0.024	0.086
RFI ^A		0.097	0.111	0.052
<i>P</i> -value		0.076	0.044	0.345

^{a,b} Means within a column for each factor with different superscripts differ significantly ($P < 0.05$).

^A Correlation coefficients.

years were due to selection process on the genetic backgrounds (Havenstein *et al.*, 2003). RFI is a heritable trait and is closely related to production efficiency. In some studies, heritability for RFI was estimated to vary from 0.44 to 0.83 in growing ducks (Drouilhet *et al.*, 2014; Zhang *et al.*, 2017). In order to improve the feed efficiency of poultry, the genetic selection of RFI traits has attracted more and more attention. In the present study, the effects of selection for altering RFI on the carcass and small intestine traits of 980 F₂ ducks were analyzed to provide more detailed information on the correlations of RFI with the production traits of ducks, which has been seldom reported.

Body weight and Carcass Characteristics

The results indicated that there were sex-specific differences in almost all the traits studied. The male ducks had significantly higher body weight, carcass weight, breast meat weight, and sebum weight than those of female ducks, which is consistent with the findings on chickens (Faria *et al.*, 2010). Evidently, selection on RFI would affect the related traits. There was no significant correlation between body weight, eviscerated carcass traits, and RFI. RFI, a term proposed by Koch *et al.* (1963), refers to the fraction of feed intake that is not explained by the maintenance and production requirements without affecting the performances. Previous studies confirmed that RFI is independent of weight and growth efficiency (Archer *et al.*, 1998; Basarab *et al.*, 2003; Aggrey *et al.*, 2010). Zhang *et al.* (2017) found similar results for body weight between low- and high-RFI groups of ducks. Therefore, selection on RFI can improve animal feed efficiency without affecting their feed intake and growth rates.

Carcass Composition

The results showed that there was a significant difference in gizzard, heart, and liver weights between female and male ducks in the F₂ population. There was a significant negative correlation between RFI and gizzard weight, and a positive correlation between RFI and abdominal fat weight. The negative correlations between gizzard weight and RFI showed that ducks with high feed conversion usually had larger gizzards. Larger gizzard may enhance digestive ability and improve intestinal absorption efficiency. Stimulating the development of the gizzard may improve the function of the small intestine through better feed flow regulation (Svihus, 2014).

Abdominal fat is considered a waste product and is one of the main compartments for fat deposition in ducks. Therefore, reducing the deposition of abdominal fat is a strategy of reducing the cost of production. Our data showed that female ducks had slightly higher abdominal fat deposits than male ducks had; however, this difference was not significant. Similar results were reported in chickens (Bogosavljevic-Boskovic *et al.*, 2010). In the present study, there was a significant positive correlation between abdominal fat deposition and RFI, indicating that abdominal fat of the ducks with high feed conversion efficiency and low RFI was significantly lower than those of the ducks with less feed conversion efficiency and high RFI.

Small Intestinal Morphometric Characteristics

The early development and function of the digestive tract affect the growth and subsequent performance of ducks. The present study shows that the effect of sex on the length of jejunum is significant, and that the length of jejunum is positively correlated with RFI. Begli *et al.* (2017) reported that total intestine length was longer in male chickens than in female chickens. Jejunum is the main site for nutrient absorption. Previous studies have shown that protein, fat, and starch are absorbed mainly in the jejunum (Riesenfeld *et al.*, 1980; Sklan and Hurwitz, 1980), and that water and minerals are mainly absorbed in the ileum (Svihus, 2014). In addition, Jackson and Diamond (1996) reported that increased intestinal length improves nutrient absorption.

This study suggested that selection on RFI could affect carcass composition traits, and have positive effects on feed intake and jejunum length of ducks. The ducks with high RFI had higher feed intake and a stronger ability to deposit abdominal fat. The present study indicated that selection for low RFI could be useful for reducing the cost of feeding and improving the efficiency of production, which provides insights into the effects of RFI on production traits of ducks, and provides a theoretical basis for the application of RFI in duck breeding.

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References

- Aggrey SE Karnuah AB, Sebastian B and Anthony NB. Genetic properties of feed efficiency parameters in meat-type chickens. *Genetics Selection Evolution*, 42: 25. 2010.
- Archer JA, Pitchford WS, Hughes TE and Parnell PF. Genetic and phenotypic relationships between food intake, growth, efficiency and body composition of mice post weaning and at maturity. *Animal Science*, 67: 171-182. 1998.
- Basarab JA, Price MA, Aalhus JL, Okine EK, Snelling WM and Lyle KL. Residual feed intake and body composition in young growing cattle. *Canadian Journal of Animal Science*, 83: 189-204. 2003.
- Begli HE, Torshizi RV, Masoudi AA, Ehsani A and Jensen J. Longitudinal analysis of body weight, feed Intake and residual feed intake in F₂ chickens. *Livestock Science*, 184: 28-34. 2016.
- Begli HE, Torshizi RV, Masoudi AA, Ehsani A and Jensen J. Relationship between residual feed intake and carcass composition, meat quality and size of small intestine in a population of F₂ chickens. *Livestock Science*, 205: 10-15. 2017.
- Bogosavljevic-Boskovic S, Mitrovic S, Djokovic R, Doskovic V and Djermanovic V. Chemical composition of chicken meat produced in extensive indoor and free range rearing systems. *African Journal of Biotechnology*, 9: 9069-9075. 2010.
- Crews JD. Genetics of efficient feed utilization and national cattle evaluation: a review. *Genetics and Molecular Research*, 4: 152-165. 2005.
- Drouilhet L, Basso B, Bernadet MD, Cornuez A, Bodin L, David I,

- Gilbert H and Marie-Etancelin C. Improving residual feed intake of mule progeny of Muscovy ducks: genetic parameters and responses to selection with emphasis on carcass composition and fatty liver quality. *Journal of Animal Science*, 92: 4287–4296. 2014.
- Faria PB, Bressan MC, Souza XR, Rossato LV, Botega LMG and Gama LT. Carcass and parts yield of broilers reared under a semi-extensive system. *Revista Brasileira De Ciência Avícola*, 12: 153–159. 2010.
- Havenstein GB, Ferket PR and Qureshi MA. Growth, livability, and feed conversion of 1957 versus 2001 broilers when fed representative 1957 and 2001 broiler diets. *Poultry Science*, 82: 1500–1508. 2003.
- Herd RM, Oddy VH and Richardson E. Biological basis for variation in residual feed intake in beef cattle. 1. Review of potential mechanisms. *Australian Journal of Experimental Agriculture*, 44: 423–430. 2004.
- Jackson S and Diamond J. Metabolic and digestive responses to artificial selection in chickens. *Evolution*, 50: 1638–1650. 1996.
- Koch RM, Swiger LA, Chambers D and Gregory KE. Efficiency of feed use in beef cattle. *Journal of Animal Science*, 22: 486–494. 1963.
- Mrode RA and Kennedy BW. Genetic variation in measures of food efficiency in pigs and their genetic relationships with growth rate and backfat. *Animal Production*, 56: 225–225. 2010.
- Pakdel A, Arendonk JAMV, Vereijken ALJ and H. Bovenhuis. Genetic parameters of ascites-related traits in broilers: correlations with feed efficiency and carcass traits. *British Poultry Science*, 46: 43–53. 2005.
- Riesenfeld G, Sklan D, Bar A, Eisner U and Hurwitz S. Glucose absorption and starch digestion in the intestine of the chicken. *Journal of Nutrition*, 110: 117–121. 1980.
- Robins A and Phillips CJC. International approaches to the welfare of meat chickens. *World's Poultry Science Journal*, 67: 351–369. 2011.
- Robinson D and Oddy V. Genetic parameters for feed efficiency, fatness, meat area and feeding behaviour of feedlot finished beef cattle. *Livestock Production Science*, 90: 255–270. 2004.
- Sklan D and Hurwitz S. Protein digestion and absorption in young chicks and turkeys. *Journal of Nutrition* 110: 139–144. 1980.
- Svihus B. Function of the digestive system. *Journal of Applied Poultry Research*, 23: 306–314. 2014.
- Zhang W and Aggrey S. Genetic variation in feed utilization efficiency of meat-type chickens. *World's Poultry Science Journal*, 59: 328–339. 2003.
- Zhang Y, Guo ZB, Xie M, Zhang Z and Hou S. Genetic parameters for residual feed intake in a random population of Pekin duck. *Asian-Australasian Journal of Animal Sciences*, 30: 167–170. 2017.