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# Feed Restriction Influences Growth Performance and Blood Glucose in Faster- and Slower-Growing Chickens

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**XZ designed the experiments. LZ, ZW, LY and GS managed the chicken and performed the experiments. QZ, YW, HY, ZZ and DL helped in the experimental work. ZQ wrote the article. AMS, ZN and YT helped in preparation of the manuscript.**

**Key words**
**Broiler, Genotype, Feed Restriction, Blood Glucose, Muscle**

## ABSTRACT

Feed restriction during the growing period is a common practice in husbandry to limit body weight gain during the grower period in broiler breeders. However, whether the chickens with different genetic background have the same response to feed restriction is not reported, herein we evaluated three levels of feed restriction effects on growth performance and blood glucose concentrations in faster- and slower-growing chicken (different genotypes). In the present study, birds were restricted to 100% to full feed in faster- and slower- growing broilers groups. Body weight gain, feed consumption, blood glucose concentrations were measured on each week from d 1 per 70, and the weight gain of skeletal muscle and viscera were measured on d 7, 28, 49 and 70. The daily voluntary intake of feed was recorded and designed as a 100% diet amount (full feed). Genotype affected body weight, feed consumption, weights gain of breast muscle, leg muscle and liver ($p < 0.05$). Feed restriction also affected body weight gain, feed consumption, and leg muscle weight ($p < 0.05$). In faster- growing stock, chickens with full feed were heavier, but their leg muscles were lighter than 80% feed group, and there was a compensatory growth for the 80% feed group on d 49 and 70. The blood glucose on d 7 was higher in slower- growing group than the faster- growing group. Results also showed there was a high negative correlation between blood glucose with body weight and feed consumption in both genotypes. Generally, feed restriction affected body weight and leg muscle weight but did not influence blood glucose in the faster- and slower-growing broilers. Moreover, though 80% feed restriction reduced body weight gain on d 49 in faster-growing chickens, it promoted leg muscle weight.

## INTRODUCTION

Poultry farming, especially the broiler meat production, has arisen as one of the fastest growing agribusiness industries in the world. In poultry industry, feed contributes about 65-70% of the total cost of production (Rubel and Beg, 2018; Rubio *et al.*, 2003). Feed restriction (FR) is a common practice in husbandry to limit body weight gain in grower period and thereby to exerting reproductive ability in later period in broiler breeders (Abudabos *et al.*, 2018). Some studies reported the FR strategies affected growth characteristics, blood parameters and immunity (Jang *et al.*, 2009; Urdaneta-Rincon and Leeson, 2002). van der Klein (2017) found feed restriction had differential effects on males and females. Females had higher relative fat pad, breast muscle, and liver and leg weights than those of males on d 35 (van der Klein *et al.*, 2017). Study on the nutrition restriction of fat- and lean-line broiler breeder hens during the laying period on offspring performance, blood biochemical parameters, and hormone levels indicated that there were interactions maternal nutrition by line for glucose and insulin (Li *et al.*, 2019).

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Excessive fat deposition in chickens with rapid growth are associated with increased concentrations of insulin and glucagon in plasma and insulin resistance (Paswan *et al.*, 2013; Shiraishi *et al.*, 2011; Sumners *et al.*, 2014). . There was difference in insulin sensitivity and glucose clearance rates between the hypophagic (low weight) and hyperphagic (high weight) lines of chicken. Chicken maintained blood glucose homeostasis by gluconeogenesis during FR period, up to 37% of glucose was converted to lactate by the intestinal wall before transferred to the circulation (Demir *et al.*, 2004). Fed-restricted broilers had higher blood glucose concentrations than the fed ad libitum (Boostani *et al.*, 2010), which may be attributed to better feed conversion and digestibility coefficients (Silas *et al.*, 2014). In chickens, intra- cerebro ventricular (ICV) injections of insulin inhibited feed consumption in a layer, but not in broiler type chicks, suggested genetic influences on insulin resistance in chickens (Shiraishi, *et al.*, 2011). Selection for body weight gain also influenced the broilers' blood glucose (BG) levels compared with the insulin-related parameters in commercial-type chicks (Sumners, *et al.*, 2014). Fasting and delayed access to feed after hatch triggered a compensatory BG elevation whereby a low but not a high body weight line had higher BG level than the control groups (Zhao *et al.*, 2014).

No study was carried to determine the nutrition restriction effect on growth performance and blood glucose hemostasis in the broilers with different growth rates. Thus, the objective of the present study was to determine the effects of different levels of feed restriction on growth performance and blood glucose levels in the faster- and slower- growing chicken stocks.

## MATERIALS AND METHODS

*Animal/birds care*

All procedures for raising and slaughtering chickens were approved by Institutional Animal Care and Use Committee of Sichuan Agricultural University. The methods were carried out in accordance with the approved guidelines.

*Chickens and experimental design*

In this study, a total of 270 1-day-old male chicks were selected, (135) from the HS1, a slow- growing line selected 5 generations for meat-production at Sichuan Agricultural University and a (135) faster- growing stock, Cobb 500.. The HS1 originated from the cross between the Hungarian Babolna layer and a local partridge shank chicken, introduced from Guangdong provinces in China obtained from the branch company of Chia Tai Group, Chengdu, China. The morphological characteristics male and female chicken are displayed in Figure 1. All chicks were raised in batteries with wire mesh floor from day one. Whole experiment lasted 70 days.


Fig. 1. Images of chicken HS1 and Cobb 500.

Each stock was randomly divided into 3 groups (G1, G2, and G3) and fed the same diet with 100%, 90%, and 80% full amount respectively. There were 3 replicates of 45 chicks per group. There were 18 units (15 chicks per unit). The standard feed allotted was determined from a pre-experiment (Table I), in which the voluntary intake of chickens was measured daily and considered as 100% diet amount.

*Feeding and housing management*

A corn-soy diet was provided as powder form during the first 7 days post-hatch, and then changed to pellet. The diets consisted of 21.4% CP and 3,015 Kcal of ME/kg to d 28, followed by 19.9% CP and 3,100 kcal of ME/kg from d 29 to 42, and 18% CP and 3,180 kcal of ME/kg from d 43 to 70. Water was provided during the research period.

**Table I. Individual feed allowances (g) for faster- and slower-growing broiler stocks in the preliminary experiment[1].**

| Period (day) | Stock | |
|---|---|---|
| | Faster- growing | Slower- growing |
| 0-7 | 22.7 | 18.2 |
| 8-14 | 53.9 | 43.1 |
| 15-21 | 95.1 | 76.1 |
| 22-28 | 140.3 | 112.2 |
| 29-35 | 179.9 | 143.9 |
| 36-42 | 208.4 | 166.7 |
| 43-49 | 224.7 | 179.8 |
| 50-56 | 225.7 | 180.6 |
| 57-63 | 231.6 | 185.3 |
| 64-70 | 219.7 | 175.8 |

[1] 100% diet amount group.

The light: dark photoperiod was 24: 0 during the first 7 d post hatch and gradually decreased to 19 h on d 20. The light intensity was 25 Lux during the first 3 days, and 10 Lux on d 14, after which it was decreased to 5 Lux.

The heat was provided by a coal-fired boiler, and the temperature was maintained by the sub-atmospheric pressure ventilation system. During the first 3 days after hatch, the room temperature was maintained at 36°C, and then gradually decreased to 24°C on d 28.

*Vaccination*

Chicks were vaccinated with Marek's disease, H9 avian influenza, Newcastle disease, and H5 avian influenza on d 1,8,10 and 24, respectively.

*Measurements*

Chicks were subjected to a daily FR program from d 1 to 70. On d 7, 14, 21, 28, 35, 42, 49, 56, 63, and 70, after 12 h- fasting each bird's body weight (BW) (g) and feed consumption (FC) per unit were determined, and blood glucose (mmol/L) of 2 individuals randomly selected from each unit was measured with a glucometer on a drop of blood from a brachial vein prick at 9:00 am according to the method used by Kurihara *et al.* (2006). Feed conversion ratio (FCR) was calculated as feed consumption divided by body weight gain (Wang and Xu, 2008). And on d 7, 28, 49, and 70, each of four individuals with body weights between 95% and 105% of the average stock weight from 3 replicates were selected and slaughtered according to the National Experimental Animal Slaughter Standard of China as mentioned in the study of Dou *et al.* (2017), the breast muscle, leg muscle, and liver were sampled immediately from each chicken. Breast muscle (BM) included both right and left pectoralis major and minor muscles, and leg muscle (LM) consisted of right and left drum and thigh muscles without bone.

*Statistical analysis*

All data were analyzed using the GLM procedure of JMP Pro v.10 (SAS Institute). When there was F test significant, Tukey's test was further used for multiple comparison analysis; statistical significance was considered at $p<0.05$.

The model for analyzing the carcass traits, including breast muscle weight (BM), leg muscle weight (LM), liver weight (LV), and abdominal fat weight (AF) was as following:

$$Y_{ijk}=\mu+S_i+D_j+A_k+(S\times D)_{ij}+(D\times A)_{jk}+(S\times A)_{ik}+(S\times D\times A)_{ijk}+e_{ijk}$$

Where $Y_{ijk}$ = the performance of chicken of stock i, feed diet j, at age k. The value of $\mu$ = the general mean, $S_i$ = the effect of stock i (i = 1 and 2; faster and slower growing) , $D_j$ = the effect of diet fed j (j = 1, 2, and 3; 100%, 90%, and 80% full diet), Ak = the effect of age k (k = d 7, 28, 49, and 70), $(S \times D)_{ij}$ = the interaction effect of stock i and diet j, $(D \times A)_{jk}$ = the interaction effect of diet j and age k, $(S \times A)_{ik}$ = the interaction effect of stock i and age k, $(S \times D \times A)_{ijk}$ = the interaction effect among stock i, diet j and age k, and $e_{ijk}$ = the random residual effect.

Multiple comparison analysis for body weights (BW), blood glucoses (BG), and feed consumptions (FC) at each time point among diet feds were also analyzed by Tukey's test.

## RESULTS

*Growth performance and blood glucose*

Body weight, feed consumption, and blood glucose of two stocks with three feed levels from d 1 to 70 are summarized in Figs. 2-4, respectively. The amount of diet fed and stock influenced BW and FC ($p < 0.05$). On d 42, the BW of faster- growing stock were heavier than the slower- growing stock (1646.6 and 689.1 g, $p < 0.05$, Fig. 2), and the BW of 100% fed group was greater than that of 80% fed group (1646.6 and 1378.1 g, $p < 0.05$). For the slower- growing stock, the BW of 100% and 80% fed groups were close to each other. Meanwhile, there was no significant BW difference between 100% and 80% fed groups in the faster- growing stock on d 56 ($p > 0.05$). Also, FC of faster- growing stock was greater than slower- growing stock on d 21 (54.7 and 28.3 g, respectively, $p < 0.05$, Fig. 3), and there was greater FC in 100% than 80% group in the faster- growing stock (54.7 and 48.0 g, p < 0.05). For the slower- growing stock, the FC between 100% and 80% fed groups were closed to each other. However, the 90% did not differ from the other groups for traits of BW and FC on d 21. Though the amount of diet fed did not affect BG in either stock, the slower- growing stock had higher BGs than faster- growing stock on d 7 (p < 0.05, Fig. 4).

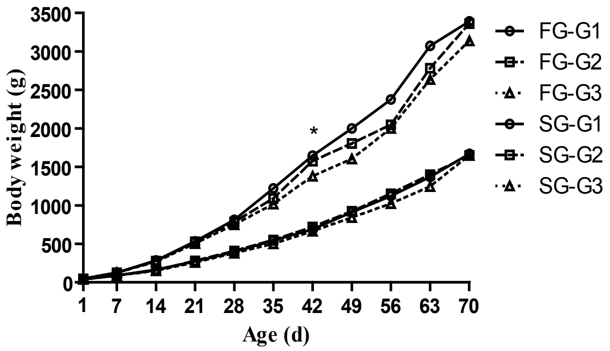


Fig. 2. Body weights (Mean ±SE) of two stocks with different levels of feed restriction from d 1 to 70. FG and SG represent faster- and slower-growing stocks, respectively. G1, G2, and G3 represent broilers fed with diet amount of 100%, 90%, and 80%, respectively. When significant, differences between FG and SG chickens are marked as * (p < 0.05).

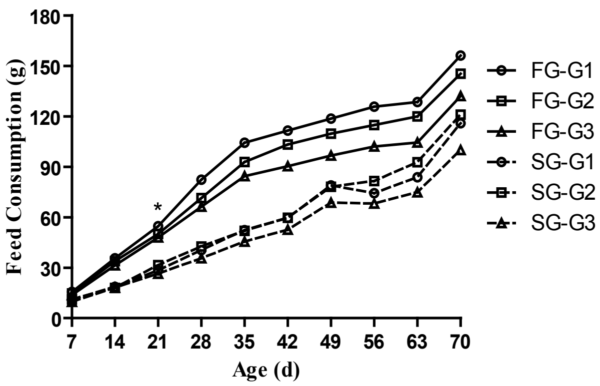


Fig. 3. Feed consumption (Mean ±SE) of two stocks with different levels of feed restriction from d 7 to 70. For abbreviations and other statistical details, see Figure 2.

*Effects of age, stock and diet amount*

The weights of BM, LM, and LV on each week were heavier (p < 0.05) than the former week and the weight of abdominal fat (AF) on d 70 was greater that on d 28 (p < 0.05), though the difference between d 28 and 49 was not significant (Table II).

The weights of BM, LM, and LV were greater (p < 0.05) for the faster- growing stock than the slower-growing group (Table II). The LM was heavier for the 80% group than 100% fed group (p < 0.05), with 90% being intermediate between them and did not differ from either.

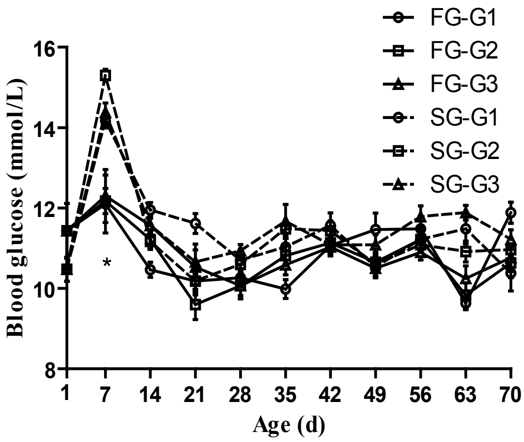


Fig. 4. Blood glucose (BG) (Mean ±SE) of two stocks of chicken with different levels of feed restriction from d 1 to 70. For abbreviations and other statistical details, see Figure 2.

*Effect of interaction of age by stock on carcass traits*

The age by stock interactions was significant (p < 0.05) for BM, LM, and LV (Table II). The BM and LM of faster-growing stock were heavier than the slower-growing stock on d 49 and 70 (p < 0.05), respectively and the differences of BM and LM between two stocks were not significant on d 7 and 28. The LV weights in faster-growing stock on d 28, 49, and 70 were heavier than the slower-growing stock (p < 0.05, Table III).

*Effect of interation of age by diet amount on carcass traits*

There was an interaction of age by the diet amount on LM (Table II). The 80% fed group was heavier than 90 and 100% fed group on d 70 (Table IV, p < 0.05), However, there were no significant differences among the groups on d 7, 28 and 49 (p > 0.05).

*Effect of interation of stock by diet amount on carcass traits*

There was a stock by diet amount interaction on LM (p < 0.05, Table II), the faster- growing stock had heavier LM for the 80% than the 100% fed groups (p < 0.05), with no significant difference between 80% and 100% feed group in slower-growing stock (Table V).

**Table II. Effects of age, stock, and diet amount on weights of skeletal muscle, liver, and fat on d 7, 28, 49 and 70 (Mean ± SEM).**

| Factors | Traits | | | | |
|---|---|---|---|---|---|
| | n | BM [1] (g) | LM [1] (g) | LV [1] (g) | AF [1] (g) |
| **Age** (d) | | | | | |
| 7 | 24 | 2.71±0.26$^{d}$ | 1.74±0.14$^{d}$ | 2.98±0.29$^{a}$ | - |
| 28 | 22 | 34.32±4.31$^{c}$ | 30.99±3.07$^{c}$ | 18.99±2.04$^{a}$ | 4.96±0.64$^{b}$ |
| 49 | 23 | 106.69±13.90$^{b}$ | 93.96±8.71$^{b}$ | 29.26±2.37$^{b}$ | 8.44±0.97$^{b}$ |
| 70 | 24 | 195.50±24.52$^{a}$ | 194.18±17.07$^{a}$ | 43.72±3.88$^{b}$ | 17.01±2.22$^{a}$ |
| p-value | | 0.0001 | 0.0001 | 0.0001 | 0.0001 |
| **Stock** | | | | | |
| Faster- growing | 48 | 131.96±3.97$^{a}$ | 108.42±3.55$^{a}$ | 32.37±0.95$^{a}$ | 10.07±1.17$^{a}$ |
| Slower- growing | 45 | 37.65±4.13$^{b}$ | 52.02±3.70$^{b}$ | 15.11±0.99$^{b}$ | 10.21±1.23$^{a}$ |
| p-value | | 0.0001 | 0.0001 | 0.0001 | 0.94 |
| **Diet amount** | | | | | |
| 80% | 31 | 94.60±4.96$^{a}$ | 91.17±4.44$^{a}$ | 24.76±1.19$^{a}$ | 10.13±1.47$^{a}$ |
| 90% | 30 | 81.84±5.06$^{a}$ | 78.28±4.53$^{ab}$ | 24.94±1.21$^{a}$ | 12.14±1.51$^{a}$ |
| 100% | 32 | 77.98±4.86$^{a}$ | 71.21±4.35$^{b}$ | 21.51±1.16$^{a}$ | 8.15±1.44$^{a}$ |
| p-value | | 0.05 | 0.01 | 0.08 | 0.19 |
| **Interaction** | | | | | |
| A×S[2] | | 0.001 | 0.001 | 0.001 | 0.61 |
| D×S | | 0.11 | 0.02 | 0.20 | 0.20 |
| A×D | | 0.46 | 0.03 | 0.20 | 0.32 |
| A×S×D | | 0.73 | 0.03 | 0.95 | 0.50 |

[a-d] Values without the same lowercase in a column differed significantly.
[1] BM, breast muscle weight; LM, leg muscle weight; LV, liver weight; AF, abdominal fat weight.
[2] A, S, and D represent effects of age by stock and diet amount.

*Effect of interation of age by stock and diet amount on carcass traits*

There was a significant 3-way interaction of age by diet amount and stock for LM (Table II). Faster- growing stock fed 80% diet had heavier LM than 90% diet ($p < 0.05$), while there was no difference among groups in slower- growing stock on d 70 (Table VI).

*Correlation between BW, BG, FC and FCR*

Spearman's rank correlations between BW and BG, FC, and FCR were -0.43, 0.99, and 0.43 ($p < 0.01$), respectively, whereas the correlation between BG and FC was -0.47 ($p < 0.01$).

## DISCUSSION

Feed restriction program during the grower period are profitable for reducing breeding cost and improving feed efficiency in broiler breeders. Broiler and layer embryos have different embryonic development patterns, which affect energy utilization and embryonic heat production (Nangsuay *et al.*, 2015). Noy and Sklan (2001) described that blood glucose of broiler did not change with age during the first 5 days post-hatch. In the present study, two weeks after hatch, there was a change of blood glucose more severe in slower- growing stock than faster- growing stock which reflects a different energy utilization rate at early age. Considering that blood glucose was negatively correlated with body weight and feed consumption in the current study, we presumed that slower- growing stock, compared with the faster- growing one may maintain higher blood glucose level with less feed intake.

The effects on production and performance depend on the level of feed restriction applied (Sahraei, 2012). Ross 308 broiler with 15% feed restricted had a reduction in body weight (Urdaneta-Rincon and Leeson, 2002). Novel *et al.* (2009) reported a great restriction (50% *ad libitum*) significantly lowered breast muscle weight than fed 100% *ad libitum* from d 22 to 42 post- hatch, whereas the weights of breast muscle, liver, and abdominal fat were not affected by feed restriction in the present study. Growth rate was also different in faster- and slower- growing stock with feed restriction. There was a compensatory growth for feed restricted group in faster- growing stock on d 56, while it was not observed in slower- growing stock (Hu *et al.*, 2018).

**Table III. Effect of interactions of stock by age on the muscle and liver weights on d 7, 28, 49 and 70 (Mean ± SEM).**

| Traits | Age (d) | Stocks | |
|---|---|---|---|
| p-value | | Faster- growing | Slower- growing |
| BM (g)[1] | 7 | 3.77±0.23[d] (12) [2] | 1.65±0.19[d] (12) |
| (0.001) | 28 | 52.28±3.37[c] (12) | 16.36±0.86[c] (10) |
| | 49 | 169.88±6.44[b] (12) | 43.49±1.76[b] (11) |
| | 70 | 302.91±21.06[a] (12) | 89.09±3.47[a] (12) |
| LM (g) | 7 | 2.29±0.10[d] (12) | 1.19±0.14[d] (12) |
| (0.001) | 28 | 42.61±3.21c[c] (12) | 19.37±0.70[c] (10) |
| | 49 | 131.74±5.89[b] (12) | 56.18±2.16[b] (11) |
| | 70 | 257.03±21.86[a] (12) | 131.34±4.81[a] (12) |
| LV (g) | 7 | 4.00±0.24[d] (12) | 1.95±0.30[d] (12) |
| (0.001) | 28 | 27.13±1.60[c] (12) | 10.85±1.37[c] (10) |
| | 49 | 39.59±1.55[b] (12) | 18.93±0.61d[b] (11) |
| | 70 | 58.74±4.55[a] (12) | 28.69±5.49[a] (12) |

[a-d] Values without the same lowercase in a column differed significantly.
[1] BM, breast muscle weight; LM, leg muscle weight; LV, liver weight.
[2] The number in brackets represents sample size.

**Table IV. Effect of interaction of age by diet amount on leg muscle weights (g) (Mean ± SEM).**

| Age (d) | Diet amount | | |
|---|---|---|---|
| | 80% | 90% | 100% |
| 7 | 1.68±0.26[d] (8) [1] | 1.84±0.28[d] (8) | 1.71±0.24[d] (8) |
| 28 | 30.73±5.62[c] (7) | 34.68±5.41[c] (7) | 27.56±4.5[c] (8) |
| 49 | 104.25±17.8[b] (8) | 95.7±13.48[b] (7) | 82.2±13.17[b] (8) |
| 70 | 228.01±39.1[a] (8) | 181.1±23.4[a] (8) | 173.4±23.4[a] (8) |

[a-d] Values without the same lowercase in a column differed significantly ($p < 0.05$).
[1] The number in brackets represents sample size.

**Table V. Effect of interaction of stock by diet amount on leg muscle weights (g) (Mean ± SEM).**

| Diet amount | Stocks | |
|---|---|---|
| | Faster- growing | Slower- growing |
| 80% | 129.89±32.84[a] (16) [1] | 57.40±14.01[c] (15) |
| 90% | 99.15±23.16[b] (16) | 52.45±16.12[c] (14) |
| 100% | 96.21±23.18[b] (16) | 46.22±11.37[c] (16) |

[a-c] Values with different letters in a row or column differ significantly ($p < 0.05$).
[1] The number in brackets represents sample size.

**Table VI. Effect of interaction of age by stock and diet amount amount on leg muscle weights (g) on d 7, 28, 49, and 70 (Mean ± SEM).**

| Age (d) | Diet | Stocks | |
|---|---|---|---|
| | Amount | Faster- growing | Slower- growing |
| 7 | 80% | 2.24±0.24[a] (4) [1] | 1.13±0.22[a] (4) |
| | 90% | 2.43±0.10[a] (4) | 1.25±0.33[a] (4) |
| | 100% | 2.21±0.20[a] (4) | 1.21±0.24[a] (4) |
| 28 | 80% | 44.20±4.73[a] (4) | 17.27±0.73[b] (3) |
| | 90% | 47.66±4.48[a] (4) | 21.70±1.27[b] (3) |
| | 100% | 35.98±6.83[a] (4) | 19.15±0.93[b] (4) |
| 49 | 80% | 150.68±5.05[a] (4) | 57.86±4.06[c] (4) |
| | 90% | 129.03±9.10[ab] (4) | 61.90±0.91[c] (3) |
| | 100% | 115.53±8.02[b] (4) | 48.90±1.73[c] (4) |
| 70 | 80% | 322.45±33.82[a] (4) | 133.58±5.90[bc] (4) |
| | 90% | 217.50±40.67[b] (4) | 144.76±5.12[bc] (4) |
| | 100% | 231.13±16.95[bc] (4) | 115.70±7.10[c] (4) |

[a-c] Values without the same lowercase in a row or column for an age differed significantly ($p < 0.05$).
[1] The number in brackets represents sample size.

Compared with the mammalians, insulin signaling in muscle is peculiar to chickens and is strictly depend on insulin in fed status (Simon *et al.*, 2012). This may be because, in the fed state, insulin would stimulate muscle protein accretion by inhibiting proteolysis through inhibition of atrogin-1 expression, in addition to stimulating cell amino transport and protein synthesis (Dupont *et al.*, 2008). Our results demonstrated that the increased diet amount from 80% to 100% resulted in a significant loss of leg muscle weight in the faster- growing stock, whereas a change in diet amount did not substantially impact leg muscle weight of the slower- growing stock. This suggests stocks with different genetic background differs in muscle yield to diet restriction.

## CONCLUSION

Generally, body weight, but not the blood glucose concentration for slower- and faster- growing chickens was significantly affected by feed restriction. Moreover, modest feed restriction reduced body weight on d 49 for the faster- growing chickens, and there was a compensatory growth for leg muscle in the faster- not the slower-growing chickens during the juvenile age.

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*Statement of conflict of interest*

The authors declare no conflict of interest.

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