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## Influences of altitude on growth curves in Tibetan chicken and its hybrid

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**Abstract** Tibetan chicken is a precious resource in Qinghai-Tibet Plateau, China. In order to study its growth rhythm and heterosis of its hybrid, three groups comprising Tibetan chicken (T), Dwarf Recessive White (D) and Tibetan × Dwarf Recessive White (TD) were reared under the same management conditions at low and high altitudes. Body weight and shank length were measured, and growth curves were fitted using Richards model. The results showed that the model fitted well with the chickens' growth courses in weight and shank with  $R^2$  at more than 0.99. The high-altitude might retard the growth of chickens, with decreases in inflection point values, final values and maximal growth rates, and prolongation of inflection point time. The final weight, inflection point weight, and maximal growth rates of Tibetan chicken were 1008.3 g, 477.9 g and 11.69 g respectively at low-altitude, and 525.3 g, 229.5 g, and 5.12 g at high-altitude. This showed a decline of 47.9%, 52.0%, and 56.8% at the high-altitude; the degree of influence of altitude was less than that of Dwarf Recessive White. The TD had high heterosis in weight gain, and at high-altitude the heterosis of final weight, inflection point weight, and maximal growth rates were 59.5%, 56.8% and 52.3% respectively. Therefore, the Tibetan × Dwarf Recessive White cross was good for improving the Tibetan chicken.

**Keywords** Tibetan chicken, growth curve, altitude, Richards model, heterosis

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### 1 Introduction

The environment at high altitude is unusual with hypobarism and hypoxia in character. Notably, hypoxia influences the life activity of an organism and changes the animal in terms of genetics, physiology, morphology, etc. There are many studies that have been carried out on hypoxic effects on animal physiology and pathology (Endo et al., 2001; Wu, 2002), and effects of high altitude or hypoxia on egg hatchability (Zhang et al., 2005; Zhang et al., 2006). But research on the influence of high altitude on animal growth has not been enough. The Tibetan chicken (*Gallus gallus*) is a unique resource of poultry in Qinghai-Tibet Plateau, China. Along long times of natural selection and domestication, it has become a primitive poultry breed with characteristics of good adaptation to high altitude, high ability to look for foods, and endurance to coarse rearing. The Tibetan chicken is similar to the red jungle fowl in bodily form, color, and living habits. Although small in body and slow in growth, Tibetan chicken has tender meat and better adaptation to high altitude, and has become an irreplaceable breed resource to develop the poultry industry in the highlands.

Fitting analysis of growth curves is one of the main research methods for animal development rhythm, and is the basic work of animal breeding and production. Perfect growth curves can provide a basis for developing strategies of feeding, managing and disease prevention for animals, and comparing genetic traits between different breed types, different relatives and different sexes. Presently, some non-linear mathematical models have been proposed, including Brody, Logistic, Gompertz, von Bertalanffy, the Richards model, etc. (Darmani-Kuhi et al., 2003). The Richards model was chosen in this experiment, and it encompasses the Brody ( $n = -1$ ), Gompertz ( $n = 0$ ) and Logistic ( $n = 1$ ) equations for particular values of parameter  $n$ . As  $n$  varies over the range  $-1 < n < \infty$ , the point of inflection of the Richards model occurs at any fraction of the terminal weight. Therefore, the Richards equation is fitted for either fast early growth or slow early growth.

In this experiment, the different influences of high altitude on Tibetan chickens, lowland chickens, and their hybrid were compared, the growth patterns were fitted by Richards model, and the growth traits and heterosis were analyzed, which provided a foundation for utilizing the resource of Tibetan chickens.

## 2 Materials and methods

This experiment was carried out both in Beijing and Linzhi, Tibet of China. The altitude in the Beijing region is 100 meters and in Linzhi 2900 meters, representing the low and high altitude environment respectively. Three groups of eggs comprising Tibetan (T), Dwarf Recessive White (D), and a filial generation from Tibetan × Dwarf Recessive White (TD) were incubated and reared both in Beijing and Linzhi (The eggs were transported to Linzhi by air). The chicks were reared in three phases: from hatch to four weeks, from five to eight weeks, and from nine to thirteen weeks. They were separated and fed starter diets (metabolism energy (ME) 12.12 MJ·kg<sup>-1</sup> and crude protein (CP) 210 g·kg<sup>-1</sup>), secondary diets (ME 12.54 MJ·kg<sup>-1</sup> and CP 200 g·kg<sup>-1</sup>), and upper diets (ME 13.17 MJ·kg<sup>-1</sup> and CP 180 g·kg<sup>-1</sup>), respectively. Food and water were available *adlibitum* at all times. Temperature was maintained at approximately 35°C for the first week after hatching, then decreased gradually to 20°C at the age of 4 weeks.

Chicken weight and shank length were measured at hatch and at 2, 4, 6, 8, 10 and 13 weeks of ages. Each group had 150 chickens with wing number at hatch in order to ensure 60 complete individual data at the end

of the experiment. Incomplete data due to loss or death were discarded.

The Richards model is of the following form (Knizetova et al., 1991):

$$W_t = a \times (1 + b \times e^{-r \times t})^{-1/n}, n > -1, n \neq 0, \text{ and } r > 0$$

where  $W_t$  is the live weight in grams at the age of  $t$  weeks,  $a$  is the asymptotic or predicted final weight,  $b$  is the integration regulating parameter,  $r$  is the ratio of the relative intensity of growth that estimates the maturation rate of the curve, and  $n$  is the parameter of curve shape. The equation  $a/(1+b)^{1/n}$  represents initial weight,  $-r^{-1} \ln(nb)$  is the time to inflection,  $a/(n+1)^{1/n}$  is weight at inflection, and  $ar/7(n+1)^{1/n+1}$  is maximal gain per day.

The growth curve parameters were estimated with the arithmetic of Gauss-Newton, and the object of the interception process was the minimum of the residual sum of squares with 0.001 of convergence criterion. The multi-correlation coefficient ( $R^2$ ) was used to evaluate the general goodness-of-fit of the model. The non-linear procedure NLIN of SAS 8.02 was used for parameter estimation.

## 3 Results and analysis

### 3.1 Weight growth

The weight data of chickens reared at low and high altitudes (Table 1) were fitted using the Richards model, and the results are presented in Table 2. The Richards model provided high fitness for the profiles, with  $R^2$  at more than 0.99.

**Table 1** The weight of chickens at low and high altitudes (g)

| altitude      | breed | hatch         | 2 weeks       | 4 weeks       | 6 weeks        | 8 weeks         | 10 weeks        | 13 weeks        |
|---------------|-------|---------------|---------------|---------------|----------------|-----------------|-----------------|-----------------|
| low altitude  | T     | 27.4 ± 2.29c  | 74.0 ± 12.6d  | 141.5 ± 32.2d | 245.1 ± 66.2e  | 381.6 ± 93.6e   | 556.4 ± 148.8e  | 761.4 ± 212.6e  |
|               | D     | 48.4 ± 4.57a  | 196.5 ± 25.8a | 392.6 ± 62.7a | 825.0 ± 138.7a | 1158.1 ± 230.7a | 1609.8 ± 313.2a | 2097.7 ± 444.6a |
|               | TD    | 46.6 ± 3.42a  | 152.9 ± 16.7b | 312.6 ± 47.5b | 612.9 ± 77.7b  | 907.9 ± 125.6b  | 1218.8 ± 173.4b | 1666.8 ± 242.3b |
| high altitude | T     | 28.5 ± 2.46c  | 45.3 ± 8.74fg | 82.1 ± 18.0e  | 147.2 ± 29.0f  | 219.3 ± 39.0fg  | 277.9 ± 46.6h   | 377.8 ± 68.6h   |
|               | D     | 33.8 ± 3.07bc | 52.7 ± 9.02e  | 82.7 ± 14.2e  | 151.9 ± 22.9f  | 254.8 ± 44.6f   | 339.0 ± 76.8fg  | 504.6 ± 130.6g  |
|               | TD    | 35.1 ± 2.95b  | 47.4 ± 7.25f  | 73.4 ± 13.6f  | 137.8 ± 30.1f  | 249.1 ± 58.3f   | 372.0 ± 94.2f   | 604.8 ± 140.1f  |

Note: T, D, and TD represent Tibetan, Dwarf Recessive White and Tibetan × Dwarf Recessive White chickens, respectively. Values within a column without a common letter in their superscripts differ at  $P < 0.05$ .

**Table 2** The parameters of Richards model for weight growth of chicken

| altitude      | breed | $R^2$  | $a$    | $R$    | $b$     | $n$     | initial weight/g | time to inflection/week | weight at inflection/g | maximal daily gain/g·d <sup>-1</sup> |
|---------------|-------|--------|--------|--------|---------|---------|------------------|-------------------------|------------------------|--------------------------------------|
| low altitude  | T     | 0.9996 | 1008.3 | 0.2994 | 11.3917 | 0.7477  | 34.80            | 9.10                    | 477.9                  | 11.69                                |
|               | D     | 0.9987 | 2986.9 | 0.1943 | 0.2184  | 0.0491  | 53.45            | 7.68                    | 1318.5                 | 29.77                                |
|               | TD    | 0.9996 | 2788.0 | 0.1521 | -0.2192 | -0.0598 | 44.49            | 8.54                    | 994.2                  | 22.98                                |
| high altitude | T     | 0.9985 | 525.0  | 0.2256 | 2.9964  | 0.4447  | 23.29            | 8.46                    | 229.5                  | 5.12                                 |
|               | D     | 0.9951 | 573.8  | 0.6580 | 1710.9  | 2.6129  | 33.21            | 9.85                    | 351.0                  | 9.13                                 |
|               | TD    | 0.9989 | 876.1  | 0.3693 | 73.1986 | 1.2130  | 25.15            | 11.10                   | 455.2                  | 10.85                                |

Note: T, D, and TD represent Tibetan, Dwarf Recessive White and Tibetan × Dwarf Recessive White chickens, respectively.

At low altitude, group T had lower values of final weight (1008.3 g), weight at inflection (477.9 g), and maximal daily gain (11.69 g·d<sup>-1</sup>), and had longer time to inflection (9.10 w (week)) compared with group D (2986.9, 1318.5, 29.77, and 7.68, respectively). The values of these parameters in TC were moderate and the heterosis of these parameters were 39.6%, 10.7%, 10.8%, and -1.8%, respectively.

The values of final weight, weight at inflection, and maximal daily gain of chickens reared at high altitude were decreased compared with the chickens reared at low altitude, and in T they decreased by 47.9%, 52.0%, and 56.8% respectively, and in D by 80.8%, 72.4%, and 69.3%, respectively, and in TD by 68.6%, 54.2%, and 52.8%, respectively. The heterosis of these values at high altitude were 59.5%, 56.8%, and 52.3%, which were higher than the heterosis at low altitude.

### 3.2 Shank length growth

The shank length data of chickens reared at low and high altitude (Table 3) were fitted using the Richards model, and the results are presented in Table 4. The Richards model also provided high fitness for these profiles with R<sup>2</sup> at more than 0.99. The values of time to inflection in shank length came early compared with the values in weight.

At high altitude, the values of final shank length, length at inflection, and maximal daily gain of chickens were decreased compared with those of the chickens reared at low altitude, and in T they decreased by 3.6%, 4.0%, and 25.3%, respectively, and in D by 26.4%, 8.6%, and 46.9%, respectively, but in TD the final shank length and the maximal daily gain decreased by 34.0% and 30.4% respectively, and the length at inflection in TD increased

by 17.2%. The values of time to inflection in T, D, and TD delayed 1.68, 23.3, and 31.2 d, respectively. The results show that the stress of high altitude on shank growth in T was smaller than that in lowland chickens.

### 3.3 Absolute growth rate

The absolute growth equation of the Richards model is as follows:

$$(d_w/d_t) = \hat{W}_t r (a^n - \hat{W}_t^n) / (n a^n).$$

The expected absolute gains in weight were calculated using the equation, and the absolute growth curves are shown in Fig. 1. It is obvious that the absolute growth rate of T was the slowest, and the difference in the rate between low and high altitudes was the lowest. The absolute growth curve of TD was close to that of D, which exhibited obvious heterosis (shown in Fig. 2). At low altitude, heterosis was relatively stable (about 20%), and at high altitude, it was under zero during the early phase, but was high during the late phase, with the value reaching 130% at the age of thirteen weeks.

### 3.4 Relative growth rate

Relative growth rate is usually used to describe the growth of biomass and expressed as percentage growth of weight at a given time. The relative growth equation of the Richards model is as follows:

$$(d_w/d_t) / \hat{W}_t = r (a^n - \hat{W}_t^n) / (n a^n).$$

The relative growth curves of the three groups of chickens reared at low and high altitudes are presented in Fig. 3. The T group had lower early relative growth rate

**Table 3** The shank length of chickens at low and high altitudes (mm)

| altitude      | breed | hatch         | 2 weeks        | 4 weeks       | 6 weeks        | 8 weeks        | 10 weeks       | 13 weeks       |
|---------------|-------|---------------|----------------|---------------|----------------|----------------|----------------|----------------|
| low-altitude  | T     | 25.89 ± 0.91a | 28.29 ± 1.82f  | 32.88 ± 3.38e | 44.91 ± 5.48d  | 55.07 ± 6.98d  | 60.57 ± 8.71bc | 69.38 ± 12.00e |
|               | D     | 26.11 ± 0.95a | 37.11 ± 0.91a  | 47.69 ± 3.53a | 60.22 ± 5.22a  | 72.10 ± 6.12b  | 78.01 ± 6.99ab | 81.05 ± 7.38c  |
|               | TD    | 26.54 ± 0.87a | 35.15 ± 2.26b  | 44.69 ± 4.61b | 64.66 ± 4.65a  | 76.05 ± 6.71a  | 87.87 ± 8.07a  | 97.79 ± 10.59  |
| high-altitude | T     | 26.01 ± 0.93a | 30.03 ± 1.67g  | 36.59 ± 3.18d | 42.58 ± 3.92de | 52.71 ± 4.52de | 57.92 ± 4.92cd | 65.38 ± 4.67ef |
|               | D     | 26.06 ± 0.95a | 34.44 ± 1.51bc | 37.98 ± 2.27d | 42.94 ± 2.45d  | 48.03 ± 3.09f  | 53.67 ± 4.50d  | 62.21 ± 5.61f  |
|               | TD    | 26.39 ± 1.05a | 30.94 ± 1.61f  | 34.99 ± 2.58e | 43.10 ± 4.18d  | 50.87 ± 5.49ef | 64.17 ± 5.91bc | 73.46 ± 7.45d  |

Note: T, D, and TD represent Tibetan, Dwarf Recessive White and Tibetan × Dwarf Recessive White chickens, respectively. Values within a column without a common letter in their superscripts differ at P < 0.05.

**Table 4** The parameters of the Richards model for shank length growth of chicken

| altitude      | breed | R <sup>2</sup> | a     | r      | b       | n       | initial length/mm | time to inflection/week | length at inflection/mm | maximal gain/mm·d <sup>-1</sup> |
|---------------|-------|----------------|-------|--------|---------|---------|-------------------|-------------------------|-------------------------|---------------------------------|
| low-altitude  | T     | 0.9995         | 70.11 | 0.7866 | 2154.6  | 6.7058  | 22.32             | 7.34                    | 51.71                   | 0.75                            |
|               | D     | 0.9992         | 81.79 | 0.6616 | 140.0   | 4.5255  | 27.40             | 5.19                    | 56.06                   | 0.96                            |
|               | TD    | 0.9983         | 114.3 | 0.2072 | 1.0911  | 0.4518  | 22.33             | 4.26                    | 50.08                   | 1.02                            |
| high-altitude | T     | 0.9969         | 67.58 | 0.5971 | 605.7   | 6.5594  | 25.44             | 7.58                    | 49.65                   | 0.56                            |
|               | D     | 0.9956         | 63.25 | 0.9286 | 33477.4 | 12.2805 | 27.08             | 8.52                    | 51.24                   | 0.51                            |
|               | TD    | 0.9916         | 75.45 | 0.8637 | 17285.5 | 9.2531  | 26.28             | 8.72                    | 58.67                   | 0.71                            |

Note: T, D, and TD represent Tibetan, Dwarf Recessive White and Tibetan × Dwarf Recessive White chickens, respectively.

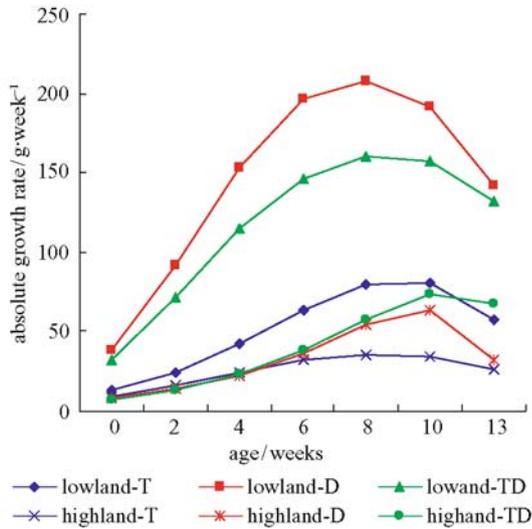


Fig. 1 Absolute growth curves at low and high altitudes

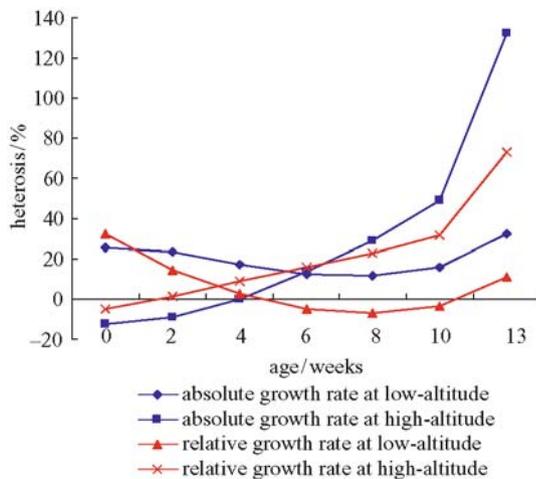


Fig. 2 The heterosis of Tibet x Dwarf Recessive White in traits of absolute growth rates and relative growth rates

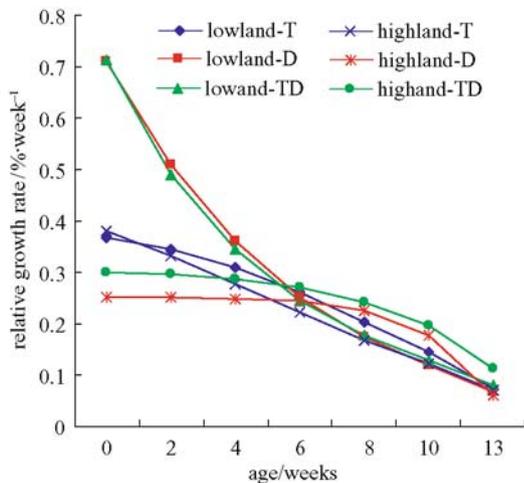


Fig. 3 Relative growth curves at low and high altitudes

than the D group when they were both reared at low altitude, but when they were both reared at high altitude the decrease in early relative growth rate was larger in D than that in T, and T was higher than D. The shape of the relative growth rate curves of the TD group was similar to that of D, and the level of TD was a little lower at low altitude and was higher at high altitude than that of D. The heterosis of TD in terms of relative growth rate is shown in Fig. 2. At low altitude, the heterosis was high at the early phase, and was low at the late phase. But at high altitude, the heterosis was below zero at the early phase, and was high at the late phase.

### 4 Discussion

Our experiment showed that the Richards model fitted well with the weight and shank length growth courses in Tibetan, Dwarf Recessive White, and the hybrid F<sub>1</sub> chickens that were reared at low and high altitudes, and it was a good model for studying the growth and influence of altitude on Tibetan chicken.

Tibetan chicken is a primitive and minitype breed, its growth mode is different from that of broiler chickens. The values of time to inflection, inflection point weight, and final weight in Tibetan chicken were 9.10 w, 477.9 g, and 1008.3 g at low altitude, and 8.46 w, 229.5 g, and 525.3 g at high altitude, respectively. The values of time inflection of shank length growth, length at inflection, and final length in Tibetan chickens were 7.34 w, 51.71 mm, and 70.11 mm at low altitude, and 7.58 w, 49.65 mm, and 67.58 mm at high altitude, respectively. The increase in final weight, weight at inflection, and growth rate was favored for meat production, and can increase meat yield. Simultaneously, the reduction of time to inflection means the advance of body and sexual maturity and shorter time to marketing. The growth parameters of hybrid F<sub>1</sub> were greatly improved compared with Tibetan chickens, the heterosis was significant, and meat production was markedly increased at high altitude. Therefore, the Tibetan x Dwarf Recessive White cross was good for improving the Tibetan chicken.

The environment at high altitude restrained the growth rate of chickens, and changed the growth mode. Our experiment showed that the stress of high altitude decreased the chicken's initial weight, final weight, weight at inflection, maximal growth rate, absolute and relative growth rates, and retarded the time to inflection. The results were consistent with the report of the high altitude environment simulated using a hypobaric cabin (Bond et al., 1996; Durkot et al., 1996). Hypoxia is the main factor that influences chickens' growth at high altitude. Guillard and Klepping (1985) reported that the appetite of animals reared at hypoxic conditions decreased. Sustained hypoxia would restrain the release of growth hormone

(GH), and decrease daily body gain (Zhang and Du, 2000). There were influences of high altitude on growth of shank length, but the degree of the influence was less than that on weight growth, which indicated that the restriction of hypoxia on muscle growth was greater than on bone growth in chickens.

The decrease of body weight and size is one of the strategies for animals to adapt to high altitude (Monge and Leon-Velarde, 1991). The Tibetan chickens have the characteristics of smaller size and lesser change in weight at inflection, final weight, time to inflection, and growth rate with different altitude as compared to Dwarf Recessive White chickens, and have good adaptation to environments of high altitude.

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