Heterosis for Growth in Reciprocal Crosses of Highly Inbred Lines of Japanese Quail

Katsunori SATO, Hiroyuki FUKUDA, Yoshizane MAEDA*
Yanuarso Eddy HEDianto and Takayoshi INO

Faculty of Agriculture, Okayama University, Okayama-shi, 700

* Faculty of Agriculture, Kagoshima University, Kagoshima-shi, 890

Heterosis effect for growth of crossbreds between highly inbred lines of Japanese quail was examined. Materials consisted of two inbred lines (OO and TT), their reciprocal crosses (TO and OT) and a randombred population. Two inbred lines were established by consecutive full-sib mating through 12 generations ($F = 0.925$). Crossbreds were obtained from the reciprocal crosses (TO: TT males $\times$ OO females and OT: OO males $\times$ TT females). Chicks were hatched and bred according to the usual methods practiced at Okayama University. Individual chicks were weighted at weekly intervals up to 16 weeks of age. Gompertz growth curves were applied to analyze the differences in growth traits among the five quail groups mentioned above.

Heterosis effect for growth was observed in the line crosses throughout the growth period. Heterosis effect in the early growth period (1 to 5 weeks of age for males and 2 to 7 weeks for females) was especially remarkable but not found at 0 week (hatching time). A difference in female body weight was observed between the crossbreds, TO and OT. This difference was considered to be partly due to maternal effect. Analysis with the Gompertz growth curve showed that the growth rate of the crossbreds was higher than that of the original inbred lines throughout the growth period.

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Key words: heterosis, growth, reciprocal cross, inbred line, Japanese quail

Introduction

It is well known that large heterosis effect appears in crosses between the inbred lines of domestic fowl and it has been practically applied to both egg and broiler production. Heterosis for growth has been observed in crossbreds between inbred lines of chickens¹⁻⁷⁾. Although MAEDA *et al.*⁸⁾ studied heterosis for body weight at 3, 6 and 12 weeks of age in Japanese quail, there has been no detailed study on heterosis for growth throughout the growing period.

This study was carried out to estimate heterosis effect for growth in reciprocal crosses between highly inbred lines of Japanese quail.

Materials and Methods

Two inbred lines (lines OO and TT), their reciprocal crosses (TO and OT) and a randombred population of Japanese quail were used in this study. Origins and

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characteristics of these stocks have been described in the previous report⁹). Two inbred lines were established by consecutive full-sib mating through 12 generations ($F = 0.925$). The reciprocal crosses (TO and OT) were performed by pair matings between TT males and OO females and between OO males and TT females. Eggs laid during 12 to 15 weeks of parental age were incubated three times at 7-day intervals. Newly hatched chicks were brooded in a commercial 4-deck battery brooder for chickens under continuous light and a constant temperature of $32 \pm 2^\circ\text{C}$. At 30 days of age, chicks were transferred to a house provided with 14 hours of light daily. Water and food containing 24% protein were provided continuously. Body weights (grams) were measured at hatching and thereafter at weekly intervals up to 16 weeks of age. The number of birds used in inbred lines OO and TT, reciprocal line crosses TO and OT and the randombred line was 17, 22, 42, 53 and 55, respectively for males and 22, 27, 51, 54 and 50, respectively for females. Gompertz growth curves were applied to analyze the differences in growth among the five populations mentioned above.

Statistical analysis of data was performed by the methods of SNEDECOR and COCHRAN¹⁰). Heterosis effect was estimated as the percentage deviation of the means of crossbreds from those of the parental inbred lines.

Results

Fig. 1 shows growth curves of the males from the five populations from 0 to 16 weeks of age. The two inbred lines showed a linear increase in body weight up to 7 weeks of age and slower increases at subsequent ages. Their growth patterns were similar and there was no significant difference in body weight between the two inbred lines at any age. Conversely, the crossbreds (TO and OT) showed rapid increase in body weight up to 6 weeks and a slower increase at later ages. Body weight of OT was slightly higher than that of TO after 6 weeks of age. These crossbreds were superior to both of the inbred lines. The differences in body weight between the crossbreds and inbred lines were statistically significant except for the 0 week (hatching time). These differences tended to increase with age up to 6 weeks and to be relatively constant at subsequent ages. Randombreds showed the best growth among the five populations examined.

Fig. 2 shows growth curves of the females from 0 to 16 weeks of age. Body weight of the inbred lines increased linearly up to 8 weeks of ages. Body weight of inbred line TT was significantly higher than that of inbred line OO except at hatching and 1 week of age. The body weight of crossbreds increased rapidly up to 6 weeks and gradually thereafter. OT showed a higher body weight than TO after 4 weeks of age ; at 9, 10 and 11 weeks, the difference was statistically significant. The crossbreds were consistently superior to both of the inbred lines and the difference in body weight was significant except for the 0 week ($P < 0.05$). On the other hand, the crossbreds were inferior to the randombred group ; difference was significant at any age except 0, 8 and 9 weeks ($P < 0.05$).

Heterosis effects for growth of the crossbreds were presented in Table 1. TO and

Fig. 1. The male growth curve in inbred lines, their reciprocal crosses and randombred population.

●—● : Okayama inbred line (OO), ○—○ : Toyohashi inbred line (TT),
 ■—■ : Toyohashi inbred line (♂) × Okayama inbred line (♀) (TO),
 □—□ : Okayama inbred line (♂) × Toyohashi inbred line (♀) (OT),
 ▲—▲ : Randombred population (RB).

OT showed negative values at 0 week. However, they showed greater heterosis at 1 to 5 weeks for males and at 2 to 7 weeks for females, indicating the values over 20 percentage.

Table 2 shows the parameter values of the Gompertz growth curve for the five populations. The parameter values of A (maximum size) and k (proportionality constant) were significantly higher in the crossbreds and the randombred population than in inbred lines, with the exception of the A value for female in TO. Age at inflexion point was significantly lower in the crossbreds and the randombred population than in the inbred lines. Moreover, body weight at inflexion point showed higher values in the crossbreds and randombreds.

Fig. 2. The female growth curve in inbred lines, their reciprocal crosses and randombred population.

●—● : Okayama inbred line (OO), ○—○ : Toyohashi inbred line (TT),
 ■—■ : Toyohashi inbred line (♂) × Okayama inbred line (♀) (TO),
 □—□ : Okayama inbred line (♂) × Toyohashi inbred line (♀) (OT),
 ▲—▲ : Randombred population (RB).

Discussion

In this study, heterosis effect for growth was found in reciprocal crosses between the highly inbred lines of Japanese quail. MAEDA *et al.*⁸⁾ have also observed heterosis for body weight at 3, 6 and 12 weeks of age in crosses of highly inbred lines of Japanese quail. In crosses between inbred lines of chickens¹⁻⁷⁾, heterosis for growth rate and body weight was observed. Our data are in agreement with these reports. We observed a greater heterosis effect for growth in the early growth period (1 to 5

Table 1 Estimate of heterosis effects in percentage for the growth in the reciprocal crosses ¹⁾

Age (week)	Heterosis percentage ²⁾			
	Male		Female	
	TO	OT	TO	OT
0	- 5.6	- 4.0	- 4.7	- 3.1
1	23.4	20.9	17.4	15.8
2	26.9	21.9	20.2	22.6
3	35.3	31.6	28.9	29.2
4	29.1	27.5	26.5	28.4
5	23.0	22.3	23.3	25.5
6	17.9	19.9	31.3	32.5
7	11.9	13.6	22.3	23.9
8	9.0	9.6	15.4	17.0
9	8.7	10.0	12.0	14.9
10	8.0	9.6	11.4	14.0
11	8.4	9.8	8.7	11.5
12	8.2	10.1	9.0	11.0
13	7.6	10.2	9.3	11.1
14	9.1	11.1	8.8	9.7
15	8.3	10.4	8.4	9.5
16	7.9	9.7	8.5	9.7

¹⁾ TO:Toyohashi inbred line(♂)×Okayama inbred line(♀);OT:Okayama inbred line(♂)×Toyohashi inbred line(♀)

²⁾ Expressed with a following equation:
(Crossbreds means-Parental inbred lines means/Parental inbred lines means)×100

weeks of age for males and 2 to 7 weeks for females). MAEDA *et al.*⁸⁾ reported that heterosis effect in the early growth period resulted from an increase in fractional synthesis rate of protein due to crossbreeding between inbred lines. These results indicate that greater heterosis effect in the early growth period in the crossbreds may be due to an accelerated metabolic rate during the rapid growth period. However, no heterosis effect was found at 0 week (hatching time). BARBATO *et al.*¹¹⁾ reported that hatching weight was influenced by maternal factors expressed through the well-known high dependency of chick weight on egg weight. SEFTON *et al.*¹²⁾ and MARKS¹³⁾ also found high correlation between hatching weight and egg weight in Japanese quail. Thus, it is considered that hatching weight of crossbreds was affected by the egg weight of the dam line, but not by paternal factors.

In comparison of the reciprocal crosses, a heavier body weight was observed in the female when Toyohashi inbred line (TT) was used as the female. In chickens, YAO¹⁴⁾, FRIARS *et al.*¹⁵⁾ and BARBATO *et al.*¹¹⁾ showed that crossbred progeny from high-weight dams were heavier than those from low-weight dams. A similar observation in turkey was reported by BUSS *et al.*¹⁶⁾. HAZEL *et al.*¹⁷⁾, GOODWIN *et al.*¹⁸⁾ and

Table 2. The parameter values of Gompertz growth curve in inbred lines, their reciprocal crosses and randombred population of Japanese quail.

Sex	Group ¹⁾	A ²⁾	b ²⁾	k ²⁾	Inflection point	
					Age(weeks)	Body weight(g)
Male	OO	100.02 ^{a 3)}	2.9941 ^{ab}	0.3350 ^a	3.32 ^a	36.80 ^a
	TT	101.67 ^a	3.0028 ^{ab}	0.3285 ^a	3.39 ^a	37.40 ^a
	TO	105.16 ^b	3.0426 ^a	0.4056 ^b	2.64 ^b	38.68 ^b
	OT	108.07 ^c	3.0563 ^a	0.4265 ^b	2.81 ^c	39.76 ^c
	RB	107.21 ^{bc}	2.9435 ^b	0.4592 ^c	2.39 ^d	39.44 ^{bc}
Female	OO	118.19 ^a	3.0663 ^a	0.2994 ^a	3.86 ^a	43.48 ^a
	TT	126.50 ^b	3.1817 ^b	0.3172 ^a	3.70 ^a	46.54 ^b
	TO	130.04 ^{bc}	3.1971 ^b	0.3766 ^b	3.13 ^b	47.84 ^{bc}
	OT	132.60 ^c	3.2293 ^b	0.3702 ^b	3.22 ^b	48.78 ^c
	RB	132.76 ^c	3.0959 ^a	0.4268 ^c	2.67 ^c	48.84 ^c

1) OO: Okayama inbred line, TT: Toyohashi inbred line, TO: Toyohashi inbred line (♂) × Okayama inbred line (♀), OT: Okayama inbred line (♂) × Toyohashi inbred line (♀) and RB: Randombred population.

2) $y = Ae^{-be^{-kt}}$ (Gompertz equation)

3) Values with different superscripts are significantly different ($P < 0.05$)

WEARDEN *et al.*¹⁹⁾ also found the importance of maternal effects on body weight of chickens. These results are in agreement with the results of our study in Japanese quail. Thus, the reciprocal differences we have observed in body weight of the crossbred females may be partly due to maternal effects, although it is not clear why the effect does not appear in males. Possibly there may be participation of genes on W chromosomes.

In our study⁹⁾ on reproductive traits, it was found that crossing of highly inbred lines produced effective restoration of reproductive performance, such as viability and egg production rate, being similar to randombreds. However, the present investigation on the growth traits showed that the crossbreds did not overtake the randombreds. MERRITT *et al.*²⁰⁾ reported that the relatively greater advantage of crossing breeds and strains was found for traits like egg production than for traits like body weight. YAO¹⁾ also found the larger dominance effect for the highly variable characters, such as egg production and egg production rate compared with the highly heritable character, such as mature body weight. These results indicate that the relative superiority of the crossbreds is greater for reproductive traits which show lower heritability than for the growth traits which are high heritable.

Analysis with Gompertz equation showed that maximum size (A) and proportionality constant (k) were higher in crossbreds than in inbred lines. KNIZETOVA *et al.*³⁾ observed a sharper growth curve and a higher parameters for the growth rate in F₁ hybrids between highly inbred lines of chicken. LAIRD *et al.*²¹⁾ also found a shift of the flexion point to an earlier age in hybrids of inbred lines of mice. Recently, ANTHONY *et al.*²²⁾ reported that some parameters of the growth rate showed higher

values in lines selected for high body weight at 4 weeks of age than in lines selected for low body weight in Japanese quail. Our data also indicate that growth rate of the crossbreds of highly inbred lines was higher than that of parental inbred lines.

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ニホンウズラの高近交系間の正逆交雑種 における成長のヘテロシス

佐藤勝紀・福田弘之・前田芳實*

ヘディアント ヤヌアルソ エディ・猪 貴義

岡山大学農学部 岡山市 700

* 鹿児島大学農学部 鹿児島市 890

ニホンウズラの高近交系間の正逆交雑種におけるヘテロシスについて検討した。材料は2近交系（岡山近交系、豊橋近交系）およびそれらの正逆交雑種と無作為交配集団であった。2近交系は12世代（近交系数92.5%）まできょうだい交配の継続によって作出された。交雑種は豊橋近交系雄と岡山近交系雌の交雑（TO）および岡山近交系雄と豊橋近交系雌の交雑（OT）によって作出された。孵化とヒナの飼育の方法は当研究室の常法に従った。ヒナの体重は個々に16週齢まで毎週測定した。ゴンベルツ成長曲線が上記の5つのウズラ集団の成長の差異を解析するため適用された。

正逆交雑種では、成長のヘテロシス効果が成長過程全

般において認められた。ヘテロシスの効果は特に、初期の成長段階（雄では1～5週齢、雌では2～7週齢）で顕著であった。しかし、0週齢時（孵化時）ではみられなかった。特に、雌の体重では、正逆交雑種（TO, OT）の間で差異が観察された。この差異は一部母性効果に起因することが示唆された。ゴンベルツ成長曲線を用いた解析によって、高近交系間の交雑種での成長速度はその起源となった近交系の場合に比較して成長過程全般にわたって優れていることが明らかになった。

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