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Original article

Purebred and crossbred performances from a Japanese quail line with very small body size

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Abstract – In this study on Japanese quail, heterosis for weight, growth rate, and fitness traits were estimated and growth curves were fitted to traits and were compared. Crossing (SR) was performed between females of a very small line (SS) which was selected for low body weight at the age of six weeks and males of a randombred population (RR) from the same origin. Heterosis for female body weight was observed at 4 and 6 weeks of age, but it was not significant for adult size in males and females. The four growth curve models of Brody, Logistic, Gompertz and Bertalanffy were compared and the Gompertz model was the most suitable. Heterosis by the Gompertz model was negative for the age at the point of inflexion and the age at the 90% body weight of the asymptote in both sexes, but it was larger for the second trait. There was no heterosis for fertility and viability from 6 weeks up to 100 days of age in the female, but it was significant for hatchability and survival rate up to 6 weeks of age. Large heterosis was found for the age at first egg, the number of eggs and the total egg weight up to 100 days of age. However, the average egg weight of SR was lighter than that of RR, showing no heterosis.

growth / productive trait / heterosis / japanese quail

Résumé – **Performances en race pure et en croisement d'une lignée de caille japonaise ayant une très petite taille.** Dans cette étude, l'effet d'hétérosis sur le poids, la vitesse de croissance et les caractères de fitness a été évalué chez des cailles japonaises ; de même, leurs courbes de croissance ont été ajustées et comparées. Un croisement (SR) a été réalisé entre des femelles issues d'une lignée de taille très petite (SS) sélectionnée pour un faible poids corporel à l'âge de six semaines et des mâles pris au hasard dans une population (RR) de même origine. Un effet d'hétérosis a été observé sur le poids corporel des femelles à l'âge de 4 et 6 semaines ; en revanche, à l'âge adulte, l'effet sur la taille n'a été significatif ni chez les mâles ni chez les femelles. Quatre modèles de courbe de croissance ont été comparés : courbes de Brody, logistique, de Gompertz et de Bertalanffy. Le modèle de Gompertz a été le plus adéquat. L'effet d'hétérosis avec le modèle de Gompertz a été négatif dans les deux sexes sur l'âge au point d'inflexion et l'âge à 90 % du poids corporel à l'asymptote. C'est pour ce dernier critère que l'effet a été le plus important. Il n'y a eu aucun effet d'hétérosis sur la fertilité et la viabilité, de 6 semaines à 100 jours d'âge chez les femelles. En revanche, un effet significatif a été observé sur l'aptitude à la couvaison et le taux de survie jusqu'à l'âge de 6 semaines.

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L'effet d'hétérosis a été important sur l'âge au premier œuf, le nombre d'œufs et le poids total de l'œuf jusqu'à l'âge de 100 jours. Toutefois, le poids moyen des œufs du croisement SR a été plus faible que celui de la population RR, et n'a montré aucun effet d'hétérosis.

croissance / caractéristiques de production / hétérosis / caille japonaise

1. INTRODUCTION

Since the availability of Japanese quail as an experimental animal was reported [8, 29], many results on artificial selection [3, 7, 10, 13, 17, 20] and on inbreeding depression [9, 19, 25, 26, 28] have been presented. Also, several reports on heterosis, which is contrary to the inbreeding depression, have been published [4, 14, 16, 21, 24]. In a recent work, Piao et al. [22] crossed females from a heavy line with males from a randombred control line. There was a remarkable heterosis effect in the growth rate of the F_1 generation, but their body weight was half way between that of their parents.

On the contrary, there are many reports on heterosis for various fitness traits, and the results vary widely. A previous study [22] found that there was a remarkable heterosis in the hatchability, survival rate, viability, and the age at first egg, though there was no heterosis in fertility.

In this study, in order to estimate heterosis for weight, growth rate and fitness traits, crossing was performed between females of a very small line, which was selected on low body weight at the age of six weeks, and males of a randomly bred population from the same origin.

2. MATERIALS AND METHODS

2.1. Quail lines, selection procedures and management

In our laboratory, a long term divergent selection experiment on body weight at six weeks of age was performed with Japanese quail, and three lines were constituted. All three lines were developed from the same randombred population. In the present work, two lines were used, line RR, the random mating control and line SS that was selected for low body weight. At every generation, each line was made up of about 30 full-sib families. In line SS, 4 birds of each sex per family were first selected randomly as candidates for selection. Then, at 6 weeks of age, the lightest male and female candidates from each family were selected to be the breeders for the next generation at 15 weeks of age. In line RR, random selection took place at 15 weeks of age.

Single pair mating was carried out in both lines. To avoid close inbreeding, matings were between birds with no common ancestor in the 4 preceding generations.

During the experiment, feed for egg laying quail (24% CP, 2710 kcal metabolic energy) was given to the quails, and it was supplemented by fish meal (66% CP) to increase the CP contents of the diet to 28%. Food and water were given ad libitum. Birds were kept in a room maintained at about 33 °C during the first week, 28 °C during the second week, and at 15~25 °C from the 3rd week onwards. Artificial lighting was used 24 h a day until the second week, and then the light period was gradually reduced in the third week; 21 h during the first day, 18 h during the second day and 14 h during the 3rd day. After this age, lighting was fixed at 14 h per day throughout the experiment.

2.2. Production of experimental quail

In this experiment, pure line RR males and SS females were obtained from the selection lines for purebred matings. To produce the F_1 cross, twenty contemporary SS females from the 79th selection generation were also selected from different full-sib families, and twenty RR males were randomly chosen the same way, to produce cross birds (SR) from single pair matings.

Table I. Equation for four growth curve models used in this study.

Model	Yt	Asymptote	Slope	Inflection point
Brody	$A\ (1 - Be^{-Kt})$	A	K	∞
Logistic	$A\ (1 + Be^{-Kt})^{-1}$	A	K	0.5
Gompertz	$Ae^{-Be^{-kt}}$	A	K	0.368
Bertalanffy	$A\ (1 - Be^{-Kt})^3$	A	K	0.296

Yt: predicted body weight at age t (week); A: asymptote (mature body weight); e: general logarithm; K: rate of growth (slope); B: constant of integration; t: time (week).

Two fourteen-day egg collections were carried out. The first one started on the 4th day of mating, and the eggs were incubated at 37.7 °C and 70% humidity. The eggs which did not hatch were broken and checked visually for fertilization.

In the three groups (SS, RR and SR), the records of fertility, hatchability, viability, as well as body weight (every week) and the four egg laying traits (the age at first egg, the number of eggs and the total weight by the age of 100 days, the average egg weights laid between the age of ninety-one and one hundred days) were obtained. There were between 54 and 159 birds studied in the 6 (sex × group) combinations.

2.3. Method of statistical analysis

Data from the two hatches were pooled after it was checked that there was no significant ($P > 0.05$) difference between replicates for the main production traits. In the analysis of body weight and all egg-laying traits, the abnormal values were excluded according to the Smirnov displacement test [27] at the significance level of five percent.

The differences in fertility, hatchability, survival rate and viability between the lines were analyzed by the χ^2 test. The unit of heterosis was estimated as $[(F_1\text{-M})/\text{M}\times100\%]$ in which M: parental means and F_1: crossbred means.

Growth curves were fitted to the mean weekly values of the body weight of each line by using the equations for the four growth curve models (Brody, Logistic, Gompertz, and Bertalanffy) described in Table I, and the mature body weight, error variance and coefficient of determination were obtained for each one. The Gompertz growth curve model, which gave the smallest error variance for the age and weight at the inflection point and at the 90% weight of the asymptote was computed for each genetic group and sex.

3. RESULTS

The weight and its heterosis (%) for SS, RR and SR males and females at the ages of four, six, ten and fifteen weeks are shown in Table II.

At each age, the differences in body weight between the three groups, SS, RR and SR were significant ($P < 0.01$) and the RR quail were about twice as heavy as the SS birds. SR crossbreds were intermediate between the two parental lines, although the weight of SR females at the age of four or six weeks was a little above that of the average of the value of the parents. Heterosis for females was positive at 4 and 6 weeks of age, but adult SR body weight was intermediate for both sexes.

The mature body weight, the error variance, and the coefficient of determination are shown in Table III.

The coefficient of determination with the Brody model was between 0.976 and 0.994, which was a little smaller than with the other three models. The coefficient of determination with the Logistic, Gompertz,

Table II. Weekly body weight (means ± SD) in three genetic groups of Japanese quail, and heterosis.

Sex	Line	No. of birds	Weeks			
			4 weeks	6 weeks	10 weeks	15 weeks
	SS	54	36.0 ± 4.3	47.8 ± 4.6	52.3 ± 4.6	52.5 ± 3.9
Male	RR	152	87.2 ± 6.6	102.1 ± 6.9	107.2 ± 6.9	109.1 ± 7.3
	SR	109	63.3 ± 4.5	71.9 ± 5.3	77.6 ± 5.3	80.3 ± 5.7
Heterosis (%)[1]			2.8	4.1	–2.7	–0.6
	SS	76	37.4 ± 4.9	51.0 ± 4.2	67.0 ± 6.5	71.2 ± 4.8
Female	RR	159	90.0 ± 6.8	115.6 ± 11.5	138.0 ± 10.3	140.2 ± 12.3
	SR	101	67.4 ± 4.3	92.8 ± 6.4	103.0 ± 7.5	106.2 ± 7.2
Heterosis (%)[1]			5.8	11.4	0.5	0.5

[1] The percentages of heterosis are estimated as [(F_1-M)/M] × 100; F1: crossbred means, M: parental means.
SS: small line, RR: randombred population, SR: SS(♀) × RR(♂) crossbred population.

Table III. Asymptote (A), error variance (EV) and coefficient of determination (R^2) estimated with four growth curve models for purebred and crossbred male and female quail.

Model		SS		RR		SR	
		♂	♀	♂	♀	♂	♀
Brody	A	56.2	80.8	114.9	154.4	82.7	115.7
	EV	65.8	34.7	519.2	538.8	197.1	307.9
	R^2	0.981	0.994	0.986	0.981	0.976	0.980
Logistic	A	52.2	69.5	107.3	138.6	76.9	103.9
	EV	8.6	59.2	‡ 13.5	158.0	37.5	74.3
	R^2	0.997	0.990	0.999	0.994	0.995	0.995
Gompertz	A	53.1	72.0	108.8	141.7	78.2	106.3
	EV	‡ 6.6	15.8	29.5	‡ 36.0	‡ 30.5	‡ 24.7
	R^2	0.998	0.997	0.998	0.998	0.996	0.998
Bertalanffy	A	53.7	73.5	109.4	143.5	78.8	107.6
	EV	13.9	‡ 8.6	74.8	56.2	45.7	41.3
	R^2	0.996	0.998	0.995	0.997	0.994	0.997

‡: Indicates the growth curves with the closest fit.
SS: small line, RR: randombred population, SR: SS(♀) × RR(♂) crossbred population.

and Bertalanffy models was 0.990 or higher. Although the error variances with the Bertalanffy model for the SS females and with the Logistic model for the RR males were a little smaller than that with the Gompertz model, the error variance with the Gompertz model remained consistently small for all 6 groups.

The asymptote (A) for the Gompertz model was nearly identical to the weight observed at fifteen weeks for each one of the 6 sex-line combinations.

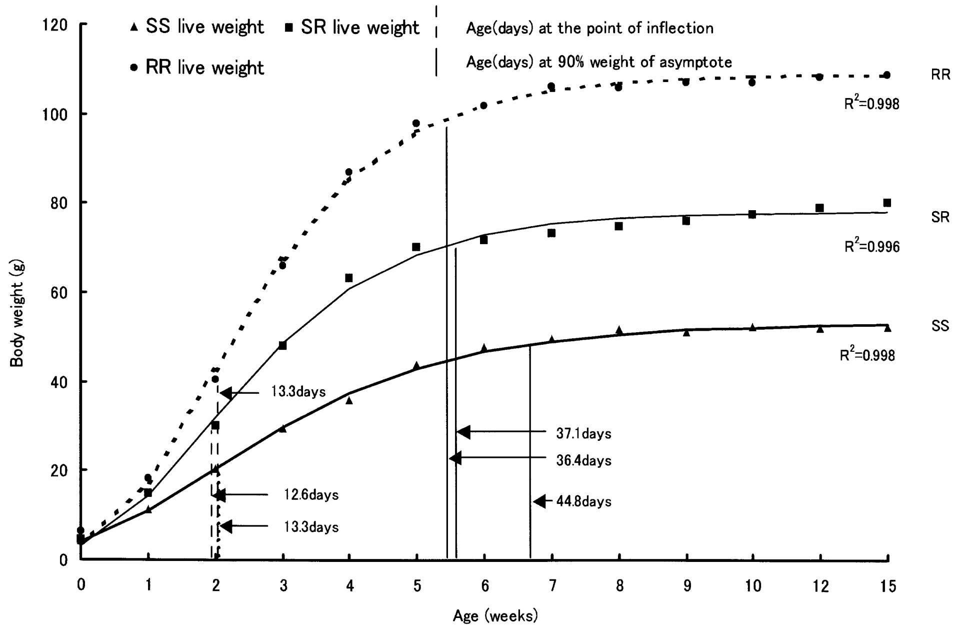

Figure 1. Growth curves of male Japanese quail with the Gompertz model in purebred lines and their cross.

The body weight curve, the age and weight at the inflection point, as well as the age at the 90% weight of the asymptote body weight, and asymptotic live weight obtained with the Gompertz model are shown in Figures 1 and 2, for males and females, respectively.

In the males, the age at the inflection point, when the growth rate is the highest, was 12.6 days for the SR group. It was 13.3 days for the RR and SS groups. Heterosis (%) was rather high for the age at the inflection point. The age at the 90% asymptotic body weight was 36.4 days for the RR quail, 37.1 days for the SR birds, and 44.8 days for the SS males.

In the females, the age at the inflection point of the SR and RR was 16.8 days, and it showed some heterosis ($P < 0.05$). Similarly, the age at 90% of the asymptotic body weight was the youngest of all in crossbreds, with a significant heterosis ($P < 0.05$).

For each line, mean values and heterosis for fitness traits and egg laying performances are shown in Tables IV and V, respectively.

The fertility observed from the SR eggs was significantly lower than that of the RR eggs. Since the hatchability of the SR eggs was 67.1 %, which was higher than that of the RR or SS eggs, it showed some heterosis ($P < 0.01$). Concerning the survival up to the age of six weeks, it was the highest for SR (81.4%), and heterosis was highly significant ($P < 0.01$). Regarding the survival rate of females up to one hundred days of age, it was a little lower for the SR group than for the SS or RR females.

Furthermore, the age at the first egg of the SR females was obviously younger than that of the SS or the RR birds, showing a

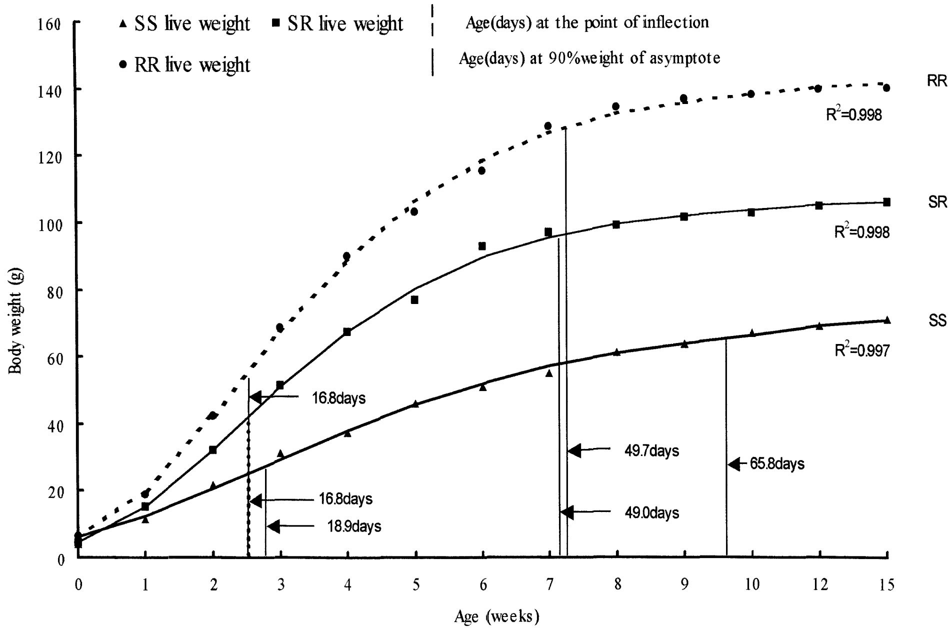

Figure 2. Growth curves of female Japanese quail with the Gompertz model in purebred lines and their cross.

Table IV. Fitness traits in purebred and crossbred quail, and heterosis.

Line	Fertility (%)	Hatchability (%)	Survival rate (%)[1]	Viability (%)[2]
SS	67.8 (350/516)	58.5 (302/516)	43.4 (131/302)	98.7 (76/77)
RR	85.8 (557/649)	65.6 (426/649)	73.2 (312/426)	97.5 (159/163)
SR	78.3 (307/392)	67.1 (263/392)	81.4 (214/263)	97.1 (101/104)
SS-RR	–18.0**	–7.2**	–29.8**	1.2
RR-SR	7.5**	–1.5	–8.2*	0.4
SR-SS	10.5**	8.6**	38.0**	–1.6
Heterosis (%)[3]	2.0	8.1**	39.6**	–1.0

[1] Survival rate up to 6 weeks of age; [2] Viability from 6 weeks to 100 days of age in females; [3] Heterosis: see Table II.
**: $P < 0.01$, *: $P < 0.05$.

strong heterosis. Heterosis was found for the number of eggs and the total egg weight up to the age of one hundred days. There were wide differences between the genetic groups in the average egg weight and the egg weight of the SR was smaller than that of the RR, but there was no heterosis.

4. DISCUSSION

Since only a one-way cross was performed in this experiment, there may be some confounding between heterotic and reciprocal effects. Generally, however [4, 15, 16], performances for productive traits

Table V. Egg laying traits (means ± SD) in purebred and crossbred quail, and heterosis.

Line	Number	Age at first egg (days)	Number of egg to 100 days[1]	Total egg weight (g)[1]	Average egg weight (g)[2]
SS	72	63.4 ± 10.4	20.7 ± 10.1	144.8 ± 71.7	7.3 ± 0.5
RR	160	46.8 ± 5.5	50.1 ± 6.7	453.1 ± 73.6	9.5 ± 0.6
SR	96	41.4 ± 2.8	53.0 ± 5.0	452.4 ± 40.8	9.0 ± 0.4
SS-RR		16.6**	–29.4**	–308.3**	–2.2**
RR-SR		5.4**	–2.9**	0.7	0.5**
SR-SS		–22.0**	32.3**	307.6**	1.7**
Heterosis (%)[3]		–24.9**	49.7**	51.3**	7.1

[1] Numbers of egg and total egg weight to 100 days of age; [2] Average egg weight from 91 to 100 days of age; [3] Heterosis: see Table II.
**: $P < 0.01$.

in reciprocal crosses of Japanese quail are similar.

The small line for this experiment was half the weight of the randomly bred population in both the males and females, making a remarkable difference in weight as in the reports by Moritsu et al. [16] and Baik and Marks [1]. They conducted line crossing after divergent selection for body weight, and observed that the weight of the crossbred at the age of four weeks was a little lower than the average weight of their parental lines, which almost paralleled the results of this experiment. In the breeding works by Chahil et al. [2], Okamoto et al. [21] and Gerken et al. [6], in which the parental lines were not much different in weight, there was no heterosis. Moreover, Sato et al. [24] reported that heterosis of the cross between closely related lines was low, except for the weight at hatching. On the contrary, Baik and Marks [1] crossed two lines which were given feed with different levels of protein and had a similar size at generation 27, and found a significant heterosis. Moreover, Minvielle et al. [15] reported a remarkable heterosis from crossing two lines from different origins with little body weight difference, but which were selected by modified reciprocal recurrent selection on early egg production. Piao et al. [22] recently reported that in the cross between a large body weight line (LL) and the RR line, the weight of the F_1 was intermediate between the parental lines and mature body weight of F_1 had a negative heterosis. Overall, crosses between lines with very different body weight showed little heterosis that was negative primarily because selection for low body weight is associated with major dominant genes [1, 16].

Few studies examined the growth pattern of crossbred populations [22, 24]. In the former work, growth of crossbreds was slightly better than that of highly inbred populations, and the coefficient of determination of the body weight curve from the Gompertz model was above 0.996 for all groups. Piao et al. [22] also reported that the growth patterns of the parental lines and the F1 population were well adjusted by using the Gompertz growth curve. Similar results were obtained in the present experiment, and the RR and SR had similar ages at the inflexion point and ages at the 90% of the asymptotic body weight, which indicate common growth curve stages in the two groups and confirm that the growth pattern of quails can be explained, satisfactorily by the Gompertz model.

There are many reports on fertility, hatchability, survival rate, and viability of crossbred populations [11, 21, 23]. Marks et al. [12], Okamoto [20], Darden and Marks [5], as well as Nestor et al. [18] determined that fertility, hatchability, and survival rate of lines undergoing artificial selection for body weight lines decreased, and that this inbreeding depression depended on the selection method and on the size of the population. According to Marks [11] and Okamoto et al. [21], there is heterosis for the % fertile eggs when the dam of the cross comes from the line with higher fertility. On the contrary, Sato et al. [23] conducted close inbreeding, and found negative heterosis in the F_1 of inbred lines. In the present experiment, dams come from a small weight line with low fertility. Also, in a previous study [22] we found that the fertility of the F_1 was better than that of the LL, which had low fertility, but was lower than the mid-parent value. These results indicate that there was no heterosis in the % fertile F_1 eggs, which could be expected since fertility was mainly a trait of the purebred dam of the F_1 crossbreds.

Regarding hatchability, Sato et al. [23] reported a remarkable heterosis, but Okamoto et al. [21] found negative heterosis. Usually, however, crossing enhances fitness and favorable heterosis is obtained. In this work again heterosis was obtained for hatchability as expected, but once they had reached the adult stage, the survival rate was similar in all groups indicating that fully grown quail were equally robust.

As reported in other works [15, 16, 21, 22], heterosis was obtained for egg number and age at first egg. Minvielle et al. [15] examined long-term egg laying traits, and obtained an even larger heterosis effect on the number of eggs laid. They also reported that the effect was more remarkable after the age of six months. Piao et al. [22] also found that the heterosis for the number of eggs and total weight of eggs depends on the age at the first egg and on the rate of the egg laying. Moreover, Sato et al. [23] and Moritsu et al. [16] found some heterosis for egg weight as in the present work.

To conclude, the growth of the crossbred SR population from pure lines greatly differing in body weight followed closely the mid-parent values, and the growth pattern was well fitted when using the Gompertz growth curve for the three groups. Significant heterosis was found for parameters of the growth curve, but not for final body weight. As expected, there was heterosis for hatchability, viability, and egg number.

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