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The Effects of Intensive Inbreeding (Brother $\times$ Sister) on Various Traits in Japanese Quail¹

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ABSTRACT Five consecutive generations of full-sib matings in Japanese quail reduced the initial 17 inbred lines to six. In general, fertility, hatchability and egg production were affected to a greater extent by inbreeding than were body weights and egg weights.

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INTRODUCTION

JAPANESE quail have been shown to be useful laboratory animals (Padgett and Ivy, 1959). Viable inbred lines of these birds could possibly be beneficial in this capacity as attested to by the use that has been made of inbred lines of rats and mice. Furthermore, Japanese quail are very suitable for avian genetic studies, primarily because of their unusually short reproductive cycle, and secondarily, because of their small body size which allows large numbers of individuals to be raised at a reasonably low cost of maintenance.

Only one report of inbreeding of Japanese quail was found (Sittmann *et al.*, 1966). These researchers were unable to go beyond the third generation of consecutive full-sib matings because of a complete loss of reproductive fitness and concluded that development of viable

inbred lines of Japanese quail would require a less intense form of inbreeding. The present study was undertaken in an attempt to, if possible, produce inbred lines of Japanese quail and, in the process of so doing, to determine the effects of intensive inbreeding in this species.

MATERIALS AND METHODS

The Foundation Stock. The population of Japanese quail from which birds for this study originated had been maintained by the Department of Poultry Science, Michigan State University, as a closed population for at least 20 generations. Furthermore, the immediate parents were selected on the basis of longevity in that they had been in production for at least seven months. Of ninety-five mated pairs of quail present at the start of production only about one-half remained after seven months. Only 17 pair produced sufficient offspring for making one or more full-sib matings.

Control matings were made from this stock and were carried along each generation. In order to keep inbreeding in a small population of controls at a mini-

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mum, these matings were limited to those individuals which had no more than four great-great grandparents in common.

Management Procedures. The mated pairs were housed in cages 10.1×17.8 cm., 12.7×20.3 cm. or 15.2×20.2 cm. Lighting was provided on a 24-hour basis. Water and a ration containing 25% protein were supplied *ad libitum*. All chicks from a given hatch were reared in a single pen of a Petersime Brood Unit Battery constructed specifically for quail. Except for two or three exceptionally large hatches, the chicks remained in the single pen until they were at least three weeks of age after which they were separated at random into two pens. Sexes were separated before the birds became sexually mature. Lighting for the chicks was provided on a $15\frac{1}{2}$ hour light and $8\frac{1}{2}$ hour dark schedule. Water and the same 25% protein ration used for the breeders were supplied *ad libitum*.

Standard incubation procedures were followed for all hatches. With few exceptions, eggs were held only up to one week prior to setting; whereas Sittmann *et al.* (1966) had stored eggs up to two weeks. Dry chicks were removed from the hatcher and banded on the 17th day of incubation while the later-hatching chicks were removed and banded on the 18th and 19th day of incubation. Sittmann *et al.* (1966) did not remove any chicks until the 19th day of incubation.

Full-sibs and controls were mated and placed in cages at either $6\frac{1}{2}$ or $7\frac{1}{2}$ weeks of age. Matings were made within hatches whenever possible so that the age of the mated pair would be equal; otherwise, between hatch matings were made so as to obtain as many full-sib matings as possible within the limitations of the facilities. No artificial selection of birds was practiced. Control matings were

made from each hatch and comprised at least 20 percent of all matings.

Daily egg production records were kept through 21 weeks of age. Fertility and hatchability were measured for the same period of time. Beginning with the third generation, bi-weekly weights of the prior week's eggs from each female were recorded as a group and then averaged. Livability was recorded at three and seven weeks of age as were body weights.

RESULTS

One control and 17 inbred lines were started with the first generation of matings. In this experiment an inbred line was defined as including all birds for any given generation that were derived from an original parental pair. This does not mean that inbred lines were developed in the classical sense of making consecutive brother $\times$ sister matings; rather, in most cases, more than one mating per inbred line was made each generation, thus forming many sublines within the original line. The number of full-sib matings per inbred line ranged from one to 12 for the first generation (Table 1). The total number of full-sib matings (hereafter designated FSM) for the first generation (FSM₁) was 79 while the number of control matings was 24.

Fifty-one (64.6%) of the 79 FSM₁ had offspring which survived to the time of mating. From these, 283 second generation full-sib matings (FSM₂) were made. Three lines failed to carry to the second generation. Eighty control matings were made in the second generation. Only 70 (about 25%) of the 283 FSM₂ produced offspring for third generation full-sib matings (FSM₃). Two more lines were lost at this point. In the third generation, there were 58 control matings and 214 FSM₃. Only 45 (21%) of the 214 FSM₃ were able to carry to the fourth

TABLE 1.—*Summary of the number of matings involved for the inbred lines and control matings*

	Line number																	Total
	2	7	17	20	22	23	24	40	43	49	53	70	72	73	75	89	95	
No. of FSM ₁ matings	2	10	1	5	10	1	1	3	2	1	4	1	4	12	6	10	6	79
No. of FSM ₁ matings producing FSM ₂ matings	0	9	1	1	8	0	1	2	2	0	1	1	1	11	4	5	4	51
No. of FSM ₂ matings	66	15	2	46			11	11	16		2	13	1	44	22	26	8	283
No. of FSM ₂ matings producing FSM ₃ matings	12	7	2	11			5	4	5		0	3	1	10	0	7	3	70
No. of FSM ₃ matings	28	44	6	25			10	8	16			11	6	17		34	9	214
No. of FSM ₃ matings producing FSM ₄ matings	1	13	0	10			1	3	1			3	3	1		9	1	45
No. of FSM ₄ matings	2	43		21			16	3	1			33	17	1		44	1	181
No. of FSM ₄ matings producing FSM ₅ matings	0	3		8			12	0	0			12	12	0		10	0	57
No. of FSM ₅ matings				3	20		62					42	36			54		217
No. FSM ₅ matings producing offspring			2		11		28					12	14			37		104

No. of control matings	Generation				
	1	2	3	4	5
	24	80	58	67	56

generation. They produced offspring for 181 FSM₄. Two additional lines were lost at this stage. Sixty-seven control matings were made in the fourth generation. Four lines were lost in the fourth generation; however, the percent of the matings going on to produce fifth generation full-sib matings (FSM₅) increased to 31.5 percent. Thus, six lines with a total of 217 FSM₅ remained at the beginning of the fifth generation. Although offspring were obtained from each of these six lines in the fifth generation, almost half of the total number of matings failed to produce any offspring. Fifty-six control matings were made in the fifth generation.

Least square estimates of the mean performance of the overall population were obtained for each of the traits measured. In the case of egg production and egg weights, corrections were made for age effects; while corrections for age of dam and hatch effects were made in the case of fertility, hatchability, livability and body weights.

Overall Performance of the Inbred Population. Average deviations from control line performance were computed for the inbred population by combining the results of all inbred lines on a weighted basis for each generation. The weighting factors were the number of matings or the number of families involved per inbred line,

depending upon which trait was being considered. The deviations were then plotted against the level of inbreeding at each generation. These are presented in Figures 1 to 4. Weighted linear regressions of performance on inbreeding level were computed for each trait following a procedure given by Steel and Torrie (1960). Tests for nonlinearity were calculated for each trait. These results are given in Table 2.

Upon examination of Figures 1 to 4 it can be seen that at all levels of inbreeding, performance as a whole for all the inbred lines was always less than the control line performance. For all but two of the traits studied, the regression coefficients were negative (Table 2). Positive regression coefficients were obtained for 3-week body weight and egg weight. Significant tests for non-linearity were obtained for all traits except 3-week livability and egg weight. In examining Figure 3 it appears that the response to inbreeding of 7-week livability is also linear between 38 and 67 percent levels of inbreeding. In view of these findings, most of the regression coefficients in Table 2 cannot be used as adequate predictors of performance of birds at any given level of inbreeding.

In order to determine which traits were affected most by inbreeding, changes relative to control line performance for each

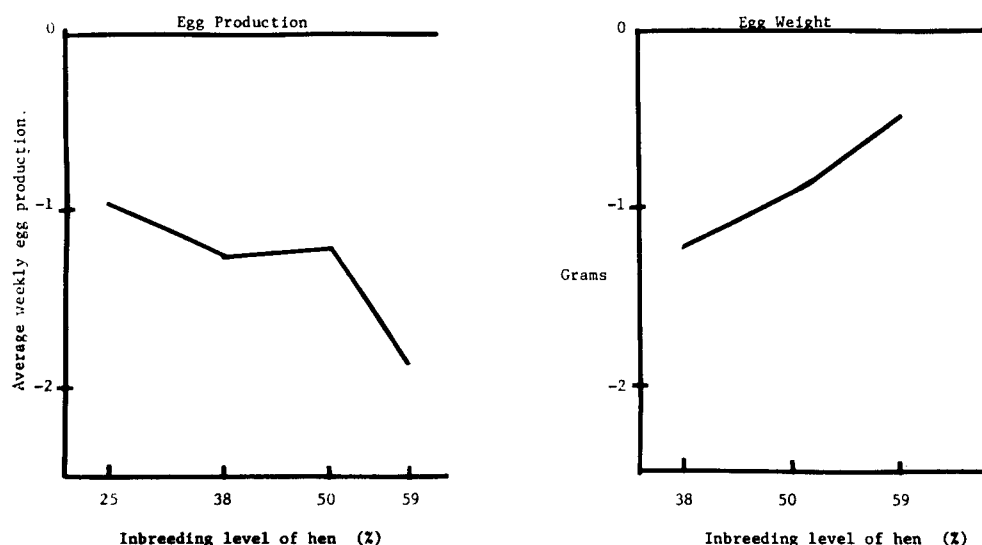


FIG. 1. Deviations of weighted mean values of inbred population from control values.

generation were calculated. These are listed in Table 3. It can be seen from this table that, in general, fertility, hatchability and egg production were affected to a greater extent by inbreeding than were body weights and egg weights. These findings are in general agreement with most of the published results on inbred-

ing effects in chickens. For most of the traits the biggest change occurred after the first generation, with performance remaining fairly stable thereafter.

DISCUSSION

A common explanation for the degenerative effects of inbreeding is that most

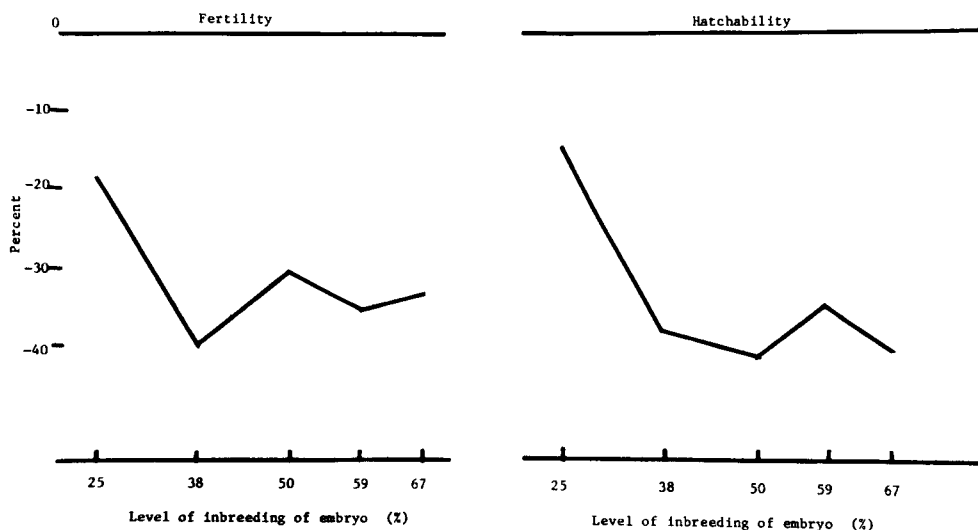


FIG. 2. Deviations of weighted mean values of inbred population from control values.

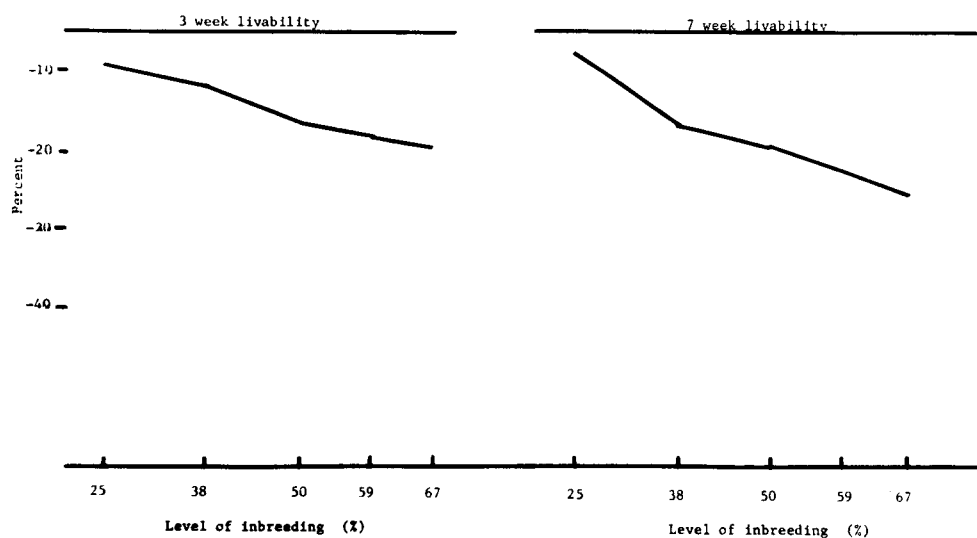


FIG. 3. Deviations of weighted mean values of inbred population from control values.

deleterious genes present in a population are recessive in character and under random mating conditions, are usually "hidden" by the dominant genes. The resultant rise in homozygosity due to inbreeding uncovers these hidden recessives thereby reducing the performance of the population. It would follow then, that the fewer the number of these deleterious recessives in the base population

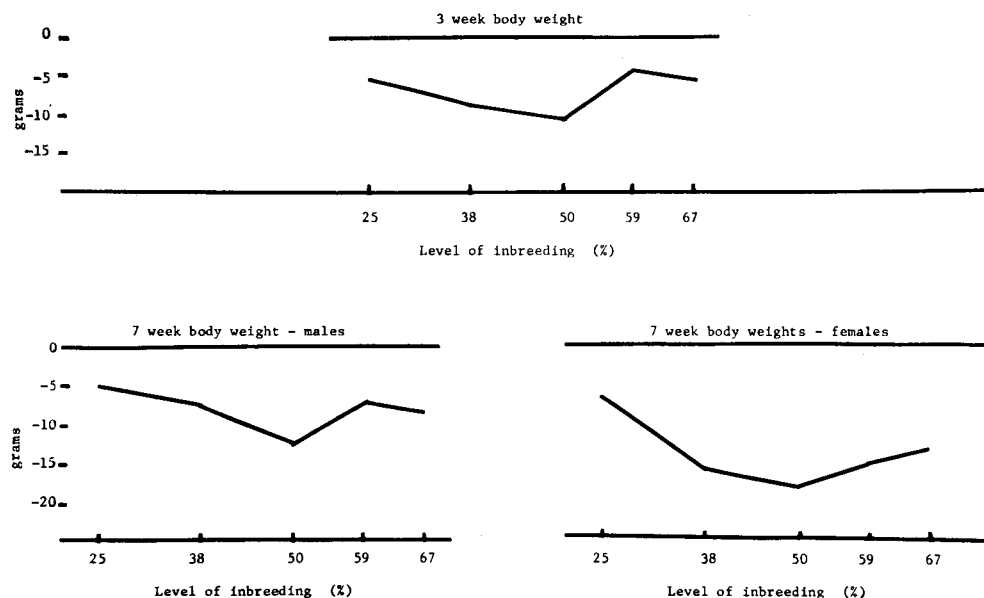


FIG. 4. Deviations of weighted mean values of inbred population from control values.

the better would be the chance of choosing some pairs from it for the initial step that would be successful in producing inbred lines by brother-sister matings. If the original population had been under any form of selection for any length of time the number of the deleterious recessives should be reduced, therefore, any particular pair chosen from it should have greater chances of possessing a favorable genetic makeup. The present study was undertaken with the foregoing in mind.

The survival of inbred lines through five successive generations of full-sib matings in this experiment did not appear to depend upon large numbers of first generation full-sib matings since three of the six lines that survived had only one mating in that generation.

Data in Table 4 show that the group of inbred lines which survived the five generations of full-sib matings performed better in the first generation for all traits, except livability, 3-week body weights and 7-week male body weights, than did the group of inbred lines that were lost prior to the fifth generation.

TABLE 2.—*Weighted linear regression coefficients of performance on inbreeding expressed as deviations of inbred population from control population means¹*

Fertility	-.084 percent
Hatchability	-.262 percent
3 wk. body wt.	+.060 grams
7 wk. body wt. (male)	-.122 grams
7 wk. body wt. (female)	-.062 grams
3 wk. livability	-.264 percent ²
7 wk. livability	-.262 percent
Egg production	-.023 eggs
Egg wt.	+.040 grams ²

¹ For all traits except egg production and egg weight, regression coefficients were calculated from data obtained during the first five generations of full sib matings. For egg production, data was from the first four generations and for egg weights from generations three through five.

² Linear. All the other traits resulted in significant tests for non-linearity.

This suggests that selection in the first generation, especially for egg production and hatchability, might aid in removing those lines that may not survive in subsequent generations of inbreeding. A very striking observation was that mortality was greater to both three and seven weeks of age in the surviving group of inbred lines than in the nonsurviving group.

The overall performance of the inbred

TABLE 3.—*Relative change from generation to generation in performance of inbred population as compared to control population (percent change from control)*

Generation	Fertility	Hatchability	Body wts.			Livability		Ave. weekly egg production	Ave. egg wt.
			3 wk.	7 wk. male	7 wk. female	3 wk.	7 wk.		
1	-19.6	-16.1	-9.3	-5.1	-5.6	-4.3	-3.0	-24.4	
2	-42.1	-41.4	-15.5	-7.3	-13.1	-12.0	-17.4	-24.6	
3	-34.1	-45.5	-19.6	-11.9	-14.9	-16.7	-20.6	-28.4	-11.1
4	-38.8	-37.0	-8.8	-7.2	-12.8	-18.3	-23.1	-25.7	-8.6
5	-36.7	-43.1	-10.9	-8.1	-11.2	-19.9	-26.2	-39.2	-4.8

TABLE 4.—*Comparison of first generation performance of the inbred lines that survived five generations of full-sib matings with those lines that were lost in prior generations¹*

	Fertility (%)	Hatchability (%)	Body wts. (gms.)			Livability (%)		Ave. weekly egg production	
			3 wk.	7 wk. male	7 wk. female	3 wk.	7 wk.		
Surviving inbred lines	-16.84	-7.70	-5.72	-5.54	-3.52	-9.04	-5.61	+1.40 ²	-.592 ³
Inbred lines lost	-19.71	-19.58	-5.21	-5.10	-8.22	-2.56	-1.28	-.025 ³	-1.21 ³

¹ Performance is measured as the average deviations of the inbred line means from control line means weighted by the number of matings or families involved for each inbred line.

² Egg production from first full sib pair matings, i.e., the eggs were produced by non-inbred hens.

³ Egg production from second generation full sib matings, i.e., the eggs were produced by hens with coefficient of inbreeding of 25 percent.

population was non-linear for all traits except two (Table 2 and Figures 1 to 4). Linear declines in performance would be expected if the decline were due only to dominance effects (Lush, 1948; Kempthorne, 1957). If there were no dominance or other genetic effects such as epistasis and no selection, the mean performance of an inbred population should theoretically remain the same. The non-linear response observed for most traits in this experiment suggests that something more than dominance alone was involved. Kempthorne (1957) showed the relation of the mean of inbred populations to be dependent not only upon the linear dominant effect, but, in addition, curvilinearly related to the dominant interactions involved, e.g., dominant epistasis. This may in part explain why the curvilinear responses were observed in this experiment; however, in order for these theoretical considerations to hold, gene frequency must not change over the generations because the mean of a population is dependent upon gene frequency (Lush, 1948). Although no intentional selection was practiced, natural selection played a large role by eliminating, at varying times throughout the five generations of inbreeding, a total of eleven of the 17 original lines. This could very well have changed gene frequencies for the various traits, in which case the population mean could have changed by this avenue as inbreeding progressed.

Sittmann *et al.* (1966) also reported non-linear effects of inbreeding in Japanese quail.

Since the control and inbreds were derived from the same population, it is likely that initial egg weights were similar. Unfortunately, egg weights were not taken until after the second generation of inbreeding at which time the controls were laying larger eggs. Thereafter, egg size for the inbreds increased to the end of the experiment but never reached that of the controls. In chickens, most investigators found little effect on egg weight due to inbreeding; however, Hays (1934, 1935) showed that in Rhode Island Red chickens, egg weight was increased by inbreeding.

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