THE EFFECTS OF INTENSIVE INBREEDING (BROTHER X SISTER) ON VARIOUS TRAITS IN JAPANESE QUAIL (COTURNIX COTURNIX JAPONICA)

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This is to certify that the

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ABSTRACT

THE EFFECTS OF INTENSIVE INBREEDING (BROTHER X SISTER)
ON VARIOUS TRAITS IN JAPANESE QUAIL
(COTURNIX COTURNIX JAPONICA)

By

Alwin William Kulenkamp

The purpose of this study was to determine in Japanese quail the effects of consecutive brother x sister matings on egg production, egg weight, fertility, hatchability, three and seven-week livability and body weights at three and seven weeks of age. A goal was to establish inbred lines for future studies.

The foundation stock from which the birds for this experiment originated was a population of Japanese quail maintained at Michigan State University as a closed flock for the past ten years. The immediate progenitors of the first generation of full sibs were a select group of aged individuals having been in production for about seven months with the less viable birds having been eliminated by natural selection. Control matings were made from this stock and were carried along each generation with an effort to avoid any close inbreeding.

A total of 974 full-sib matings and 285 control matings occurred over a period of five generations. Seventeen inbred lines with varying number of matings in the first generation were started. In this experiment an inbred line is defined as including all birds for any given

generation that were derived from an original parental pair. This does not mean that developing inbred lines in the classical sense of consecutive brother x sister matings was followed, i.e. in most cases more than one mating per inbred line was made each generation thus forming many sublines within the original line. Six of these lines survived the five consecutive generations of full-sib matings. Lines were lost throughout the experiment from varying causes which were centered on declines in reproductive performance. Individual lines varied considerably as to the effects of inbreeding on the various traits studied. The group of inbred lines that survived for five generations had shown a better than average performance in the first generation for all traits, except livability, than had the lines that were lost.

Weighted linear regression coefficients of the deviations of mean inbred population performance from the mean control performance were calculated on inbreeding level. Negative values were obtained for all traits except three-week body weight and egg weight. Tests for non-linearity were significant for all traits except three-week livability and egg weight. Data for egg weights were collected only in generations three through five. Of the traits measured, fertility, hatchability and average weekly egg production were affected most by inbreeding with the fifth generation means being lowered as compared to the control mean by about 40 percent. Three and seven week livabilities were reduced by about 20 and 26 percent, respectively. Body and egg weights were reduced the least with values ranging from 4.8 percent for egg weight to 11.2 percent for seven-week female body weight.

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To my wife and son

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INTRODUCTION

Inbreeding is generally defined as the mating of individuals more closely related to each other than the average relationship of the population. In dioecious animals the intensity can range from very slight to brother-sister or youngest parent and offspring matings which are the most intense forms possible.

The consequences of inbreeding stem from the fact that the closer the relationship of two animals the more genes they tend to have in common; thus, any offspring resulting from a mating of these two individuals would be more homozygous than offspring from a random mating. Wright (1922) devised a measurement of this effect which is applicable to all systems of mating regardless of how irregular they might be. This measurement is the correlation between the uniting gametes which produce the offspring. It was designated by the letter "F" and is computed using the formula $F_x = \Sigma[(1/2)^{n+n'+1} (1+F_A)]$ (Wright, 1923). F_x is the inbreeding coefficient of the individual in question, while n and n' are the number of generations between a common ancestor and the sire and dam, respectively, whereas F_A is the inbreeding coefficient of the common ancestor. The portion within the brackets is that part contributed by any given common ancestor to the coefficient of inbreeding of an individual. These parts are summed for all common ancestors of the individual.

The general effects of inbreeding observed in most animals are lowered reproductive fitness and decreased growth and vigor. Nevertheless, inbreeding does have some useful aspects. Linebreeding, a mating system designed to keep relationship to a prized individual high, has the inevitable consequence of mild inbreeding. The development of inbred lines of small laboratory mammals for the purpose of reducing the genetic variation among them is well known. The formation of several inbred lines and then selecting the better ones for crossing is done by some poultry breeders so as to take advantage of hybrid vigor.

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.

The purpose of this study was to measure the effects of continuous brother-sister matings of Japanese quail and to establish inbred lines of this species.

REVIEW OF LITERATURE

Since the literature on inbreeding in chickens is rather extensive it will be discussed under the following headings: hatchability, egg production, fertility, body weight or growth, egg weight, mortality, sexual maturity and a general view for chickens. Literature pertaining to other species of domestic birds is presented in the remaining section.

Hatchability

Most of the early inbreeding work with chickens was done at a rather high intensity with regular systems of either full sib, one-half sib or parent-offspring mating types [Cole and Halpin (1922), Dunn (1923, 1928), Goodale (1927), Jull (1929a, 1929b and 1933), Dumon (1930), Dunkerly (1930), Hays (1934) and Knox (1946)]. The results of most of these researchers show that hatchability drops drastically with inbreeding, the largest decline occurring with the first generation of inbreeding followed by a slower rate of decline as inbreeding continued. The detrimental effects of inbreeding on hatchability apparently cannot be overcome by selection; however, Knox (1946) reported that he was able to maintain high hatchability through five successive generations of full-sib or equivalent matings. He attributed his success to selection, in that the unselected inbreds showed a drop in performance whereas the selected inbreds remained at a constant high level.

Most of the more recent studies of inbreeding in the domestic fowl have not been restricted to a rigid form of mating system, e.g. only brother x sister matings, and have thus resulted in a much slower rise in the inbreeding coefficient than was the case in the earlier studies. This change in the mating systems occurred primarily because of the poor results of most of the earlier investigators who utilized a regular mating system. This, of course, results in a wide variation of level of inbreeding between individuals within an inbred line thus necessitating an average figure for the measure of the level of inbreeding for a particular line. Dumon (1930) was the first to report on inbreeding of the former type. Full-sib and parent-offspring matings were also conducted at the same time. In a not-too-detailed report he showed that close inbreeding was much more detrimental to hatchability and chick livability than was "removed" inbreeding. Subsequently, many researchers have reported the effects of inbreeding where irregular mating systems were employed. Waters (1932) reported that the results of seven generations of inbreeding showed that prospects of establishing several vigorous inbred lines were good. Few details were published in this report. Later papers, presumably dealing with the same population of birds, showed that the lines descended primarily from a single male out of four original males mated to seven females (Waters and Lambert, 1936a and 1936b). These authors showed that over a period of nine years, six lines were developed with inbreeding coefficients ranging from 41 to 82 percent. Intense selection for high hatchability apparently paid off even though a slow and gradual decline was noted; however, an average hatchability of greater than 60 percent was obtained from the latest generation. The influence of inbreeding on hatchability was studied in fifteen inbred lines of Single Comb White Leghorns originating from nine different base populations by Waters (1945b) over a period of six years. With few exceptions, only parents with at least 70 percent hatchability were allowed to continue the lines. Average inbreeding coefficients at the end of the six-year period ranged from 25 to 59 percent. Overall hatchability dropped from more than 80 percent to a low point of 62 percent after three years and then rose to about 70 percent in the last year. The sharp drop was attributed to four lethal genes that were discovered in the flocks; while the rise during the later years was thought to have resulted from the elimination of these from most of the lines. Waters (1945b) thought that unknown lethals probably still remained. Recently, regression of performance on level of inbreeding, usually intra-sire and/or intra-year, has been used to measure the effects of inbreeding [Wilson (1948a, 1948b), Shoffner (1948), Blow and Glazener (1953) and Morris (1962)]. Significant negative regressions were reported by three of these authors (Table 1). These must be looked at with caution in view of earlier observations that inbreeding effects on hatchability may not be linear [Goodale (1927), Jull (1929a, 1929b and 1933)]. Bernier et al. (1951) lends support to this reservation.

Hatchability seems to be affected more by the coefficient of inbreeding of the embryo than the coefficient of inbreeding of the dam [Jull (1933), Shoffner (1948), Düzgünes (1950) and Blow and Glazener (1953)]. The only conflicting evidence has been reported by Wilson

Table 1. Coefficients of regression of performance on inbreeding level reported in chickens.

Author	Hatchability (%)	Fertility (%)	Egg prod.[1]	Egg wt.	Body wt.		Mortality (%)	
					Broilers	Layers	Chick	Adult
Wilson (1948a, 1948b)								
Simple regression								
"F" dam	-.16	+.11	-.14				+.27	
"F" offspring	-.10	+.16	-.06				+.26	
Partial regression								
"F" dam independent of "F" offspring	-.19	+.01	-.22				+.20	
"F" offspring independent of "F" dam	+.05	+.15	+.12				+.10	
Shoffner (1948)	-.436*		-.926*	-.002 oz		-.004 lb		
Glazener _et al_. (1951)					-.1297 oz			
Blow & Glazener (1953)	-.371		-.302	-.018 gm		-1.004 gm		
Stephenson _et al_. (1953)			-.43					
MacLaury & Nordskog (1956)							+.33	+.21
Tebb (1958)			-1.174*					

*Regression coefficients reported to be significantly different from zero.

[1]Wilson and Stephenson _et al_. report rate of lay, Shoffner reports survivor production to 500 days of age, Blow and Glazener report survivor's first 6 month production and Tebb reports hen-housed production from the beginning of lay until October 1 of the first laying year.

(1948b) who showed, through simple and partial regressions of hatchability on inbreeding, that the dam had slightly more effect (Table 1).

Egg Production

Egg production was observed to be lower due to inbreeding as seen from some of the early work presented by Cole and Halpin (1922), Dunn (1923, 1928), Goodale (1927), Dunkerly (1930) and Jull (1933), in which such close inbreeding as full sib matings was practiced without any direct selection for this trait. Most of these authors indicated that sexual maturity was delayed and that this was part of the reason for the lower production in the inbred birds. Hays (1934) conducted an experiment in which a standard for selection was established for several characters which affect egg production. The effect of inbreeding was measured as the difference in the proportion of individuals which met the standard for each generation of inbreds and controls, respectively. The degree of inbreeding was either that of full or half-sib matings. It was found that inbreeding had a deleterious effect on most of the characters affecting egg production.

Tebb (1957, 1958) and Morris (1962) studied the effects of inbreeding in populations selected for egg production where the inbreeding coefficient increased only because of limited flock size. These authors showed that even under these conditions losses in egg production characters can be substantial. An extensive investigation into the effects of inbreeding on egg production in the domestic fowl was made by Stephenson *et al*. (1953). Twenty-three inbred and three control lines involving 9,999 White Leghorn chickens within the period from 1932 to 1946 were studied. Apparently, no selection for egg production was practiced. The coefficient of inbreeding ranged from 0 to 85 percent in these lines during the last year. Egg production rate was determined by dividing the number of eggs laid by the number of trapnest days up to a maximum of 364 days after the first egg was laid. This period was also arbitrarily divided into three subperiods each with its respective egg rate. A significant negative regression coefficient (Table 1) was determined for egg production on inbreeding when the effects of lines, years, and year by line interaction were removed by the least squares method. No significant differences were found among the regression coefficients when they were calculated separately for each of the three arbitrary periods. This indicated that inbreeding affects egg production equally throughout the production period. Finally an analysis of variance showing significant mean squares for line, year and interaction effects strongly suggested that line and year differences were real and that different lines were affected uniquely by inbreeding with regard to egg production.

Shoffner et al. (1953) presented an equally extensive study of 16 inbred lines from which more than 25,000 chicks were hatched and approximately 9,000 pullets were housed and tested during the period from 1937 to 1950. Of the 16 lines used, ten were Single Comb White Leghorns, two were New Hampshires, one was White Plymouth Rocks, one was Barred Plymouth Rocks and two were of crossbred origin. Selection was a continuous process emphasizing egg production, mortality, and hatchability. The level of inbreeding varied from line to line with the average increase in the inbreeding coefficient ranging from a low of 3.1 percent to a high of 10.3 percent per generation. One-half of the lines were lost or culled during the period. The average increase in the inbreeding coefficient of the lines that were lost was almost twice that of the surviving lines. Egg production was measured as the survivor production of those birds that lived until 500 days of age. Of all the traits measured, egg production was the only one that was consistently affected by inbreeding in that 15 out of the 16 lines showed a decrease from the level of the base population for this trait. In the 8 lines that were lost, a decrease of almost three times that of the 8 lines that remained was observed. Considering all inbred lines, the average change in egg production from the base population was -27.0 eggs, which represents a 17 percent loss. This loss in egg production occurred in spite of a relative average selection differential, expressed as a percentage of the average performance, of 7.1 percent on sire's side and 18.9 percent on the dam's side. Even though egg production was generally lowered due to inbreeding, there were marked differences between lines as to the severity of the effect. This general observation was also noted by Düzgünes (1950) who reported that two out of four inbred lines showed a significant decrease in egg production while the other two remained unchanged.

More favorable results were reported by Waters and Lambert (1936a and 1936b). Although inbreeding caused a small decline in egg production, a reasonable level of production was maintained even when the average inbreeding coefficient exceeded 80 percent. Some indirect selection took place in that large family size was favored. Work of Knox (1946) and Yamada *et al.* (1958) also tended to show that high egg production and inbreeding are not incompatible.

Several authors have reported regression coefficients of the effects of inbreeding on egg production. These are listed in Table 1. These must be looked at with caution because inbreeding effects on egg production may not always be linear according to Stephenson _et_ _al_. (1953).

Fertility

The effects of inbreeding on fertility are quite variable as shown by the different results of various investigators.

Dunkerly (1930) reported experiments using White Wyandotte, Rhode Island Red and White Leghorn breeds of chickens. Fertility was generally lower in the inbred birds than in the non-inbred birds. He used two systems of mating both of which were sire-daughter; however, in one case the daughter was a product of a brother-sister original mating while in the other case the daughter was not inbred, giving coefficients of inbreeding for the embryos of 37.5 and 25 percent, respectively. Fertility was, in most cases, lower for the matings involving the higher coefficient of inbreeding.

Inbreeding effects on four distinct lines of White Leghorn chickens (high and low egg producers and high and low egg weight lines) propagated by single male matings, showed a significant increase in infertility only in the high egg weight line whereas no significant difference was seen in the other three lines (Düzgünes, 1950). Average coefficients of inbreeding of chicks hatched after three years of inbreeding ranged from .27 for the high egg weight line to .43 for the high egg production line.

In a study of inbreeding, outcrossing and crossbreeding, Bernier *et al*. (1951) reported that inbreeding appeared to affect fertility only when the mated birds were inbred, e.g., mating non-inbred relatives resulted in no decrease in fertility; however, when the related pair were inbred, fertility was lowered. Williams and McGibbon (1954) showed a two-day difference in average duration of fertility of males from two inbred lines when reciprocally mated with the females of these lines.

Whenever any form of selection has been practiced for fertility no change due to inbreeding has been reported. Jull (1933), Waters and Lambert (1936a and 1936b), and Knox (1946) reported no change in fertility due to inbreeding even though the rate of inbreeding was intense. Wilson (1948a) reported positive regressions for fertility on inbreeding of either the dam or the offspring. Some selection, usually of the magnitude of less than one standard deviation, was done for fertility. The mating system used was quite irregular resulting in little change in the average coefficient of inbreeding from year to year.

Body Weight or Growth

Growth, as measured by how many times the chicks increased their hatching weights to three weeks of age, decreased in White Leghorn stock by the third generation of full sib mating. A value of 1.91 for the inbreds as compared to 2.36 for the controls was obtained (Dunn, 1923, 1928). Negative regressions of mature body weight on inbreeding were obtained by Shoffner (1948) and Blow and Glazener (1953); however, these regressions were small and nonsignificant. Glazener *et al*. (1951)

obtained a significant regression of -.1297 oz. for 12 week body weights of New Hampshire and Barred Plymouth Rock broilers (Table 1). Most workers were unable to show any significant change in mature body weights of chickens even with inbreeding as close as full sib with or without selection for the trait [Goodale (1927), Hays (1934, 1935), Waters and Lambert (1936b), and Knox (1946)].

Egg Weight

There is general agreement among the published results of several investigators that inbreeding has little overall effect on egg size of a population [Dunn (1923), Waters and Lambert (1936a and 1936b), Waters (1945a), Shoffner (1948) and Blow and Glazener (1953)]. Hays (1934) actually found an increase in winter egg weight in inbred Rhode Island Red hens as compared with controls. When he mated inbred and non-inbred males with closed flock females a larger egg weight was obtained from the progeny of the inbred males (Hays, 1935). Dunn (1923) and Waters (1945a) reported that different lines tended to have either large or small egg size and it was concluded by Waters that the egg size of a line tended to remain at whatever size it was when inbreeding started.

Mortality

Viability of inbred birds was found to be generally reduced with inbreeding even though some selection accompanied each generation of matings [Dunn (1923, 1928), Hays (1934, 1935), Wilson (1948b) and Shoffner *et al*. (1953)]. MacLaury and Nordskog (1956) studied mortality data collected from 25 inbred lines over a period of 15 years and involving over 30,000 chicks. Inbreeding coefficients ranged from 0 to

83 percent. Significant positive regression values for brooder, range and layer mortality were obtained; the latter two were measured on females only (Table 1). The regressions were calculated three different ways: simple regression, regression of values corrected for control flock mortality, and least squares method.

No significant regressions of viability on inbreeding coefficient were obtained by Tebb (1958); however, the average inbreeding coefficient of the birds that died was slightly larger than that of birds that survived. The inbreeding in this flock of birds was generally quite low with about a two percent increase per generation.

Jull (1933), working with close inbreeding of White Leghorns, and Morris (1962), working with mild inbreeding of White Leghorns, presented data in which no appreciable effect of inbreeding on chick viability was noted. No direct selection for lower mortality was practiced by either of the authors.

Sexual Maturity

Most of the investigators reporting on this trait showed that sexual maturity, as measured by age at first egg, was usually increased with inbreeding [Dunn (1923, 1928), Jull (1933), Hays (1934, 1935), Shoffner (1948), Shoffner _et al_. (1953), Blow and Glazener (1953), and Glazener _et al_. (1951)]. Waters and Lambert (1936b) reported a decrease in the number of days to attain sexual maturity when data from six lines were analyzed. In another paper the same year (Waters and Lambert 1936a) data were presented for three lines, presumably part of the six reported above, which showed no change in age at first egg. In yet another report by the senior author but from a different population of birds, no change in age to sexual maturity as a result of inbreeding was found (Waters, 1945c).

General

Inbreeding of chickens has been shown to have a general deleterious effect on most productive characters of economic importance. No one has been able to improve a line of chickens by inbreeding alone. There appears to be considerable variability between populations and lines within the populations as to the effects inbreeding has upon them. Inbreeding affects various characters differently in different lines; however, the general concensus seems to be that hatchability is the most uniformly affected with reductions in egg production, viability, and an increase in time to sexual maturity. Body and egg weights seem to be the least affected.

Intensive selection appears to be necessary in order to establish useful, viable, inbred lines of chickens.

Other Species

Little work on inbreeding of domestic birds has been reported in species other than the chicken. Three abstracts of papers presented at Poultry Science meetings have dealt with inbreeding of turkeys. Buss (1955) and Moreng and Thornton (1957) presented conflicting evidence. Buss reported fertility was the major factor affected whereas Moreng and Thornton said hatchability and livability were affected the most, while fertility was slightly affected by inbreeding in these birds. Abplanalp and Woodard (1967) started two sets of 15 inbred lines utilizing full sib matings. Their results parallel many chicken experiments in that only three lines of the first set survived to a level of 50 percent inbreeding while 12 lines of the second set survived to the 37.5 percent level. Declines in hatchability, mortality and body weights were recorded. Egg size and age to first egg appeared unaffected.

Only one significant study on inbreeding of the Japanese quail has been done. This work was published in 1966 by Sittmann et al. Three male quail were imported from Taiwan and mated with 15 of their control females to start the base population. The offspring of these matings were then carried along four generations via mass matings after which pair matings were made. Lines starting with full sib matings from this base population were begun in the fifth generation and continued to the ninth generation. Continuous full sib matings as well as crosses of inbred lines were done within this period of time. Also, a cyclical mating system with alternating generations of full sib matings and crosses between inbred lines was used. The results of the full sib matings were disasterous with complete reproductive failure by the third generation.

For each ten percent increase in inbreeding of the progeny a seven percent and 11 percent decline was observed in fertility and hatchability, respectively. Other production traits were affected to a lesser extent.

Maternal inbreeding supposedly had an important effect on hatchability and viability of young birds; however, this was measured by mating unrelated, inbred individuals together and observing the progeny. In this case both the sire and dam were inbred; therefore, any conclusions on maternal inbreeding must be made assuming inbreeding of the sire had no effect. Effects of heterosis on hatchability, again attributed to be maternal in origin, was evident upon observing offspring resulting from a four-way cross between inbred sib-lines.

The only other inbreeding experiment on Japanese quail found in the literature was by Iton (1967). This work was done at the same university as that of Sittmann *et al*. (1966), presumably from the same population of quail. Few details are available and type of mating system used or level of inbreeding attained were not reported. Three inbred lines were reared for seven generations in three different environments: hot dry, cool dry, or hot humid. Inbreeding was reported to have caused depression in all traits studied.

OBJECTIVES

1. To establish highly inbred viable lines of Japanese quail.
2. To study the effects of continuous successive brother x sister matings in Japanese quail (*Coturnix coturnix japonica*) on:
    a. Egg production
    b. Egg weight
    c. Fertility
    d. Hatchability
    e. 3-week livability
    f. 7-week livability
    g. 3-week body weights
    h. 7-week body weight - males
    i. 7-week body weight - females

EXPERIMENTAL PROCEDURE

The Foundation Stock

The Japanese quail used in producing inbred lines via brother-sister matings in this experiment originated from a population of birds that had been maintained by the Poultry Science Department of Michigan State University for at least ten years and an estimated minimum of 20 generations on a closed flock random mating basis. Small numbers in a few generations probably had produced a minimal amount of inbreeding in this base population. No reliable records are available on this population prior to the present study; however, some indication of performance can be obtained from 87 pairs of quail, part of which were the immediate progenitors of the first generation of full sibs used in this study. These birds were caged September 5, 1967. The estimated age of the birds at that time was eight to ten weeks of age. Records from three hatches beginning one week after caging show that reproductive performance of these birds was good with average fertility of 71.4 percent and average hatchability of 86.3 percent. The first hatch had a low fertility average of only 63 percent while the third hatch increased to 79 percent. Thus, the overall average of 71.4 percent is probably a low estimate of performance for fertility in these birds. Hen-housed egg production averaged a little over 51 percent for the 28-day period.

Offspring for the first generation full sib matings were not saved until the above birds had been in production for about seven months. Natural selection reduced the population by about 50 percent; thus, offspring for the inbreeding experiment were obtained only from the most viable parents. The first full sib matings were made July 7, 1968. Control matings were made from this stock and were carried along each generation. In order to avoid inbreeding in a small population of controls the matings were limited to only those individuals which had no more than four great-great grandparents in common. At least 20 percent of all matings made were controls with a low of 24 pairs mated in the first generation to a high of 80 pairs mated in the second generation.

Management Procedures

Housing

A. Adult birds

Two 9'8" x 15'4" windowless pens each containing 96 quail cages were utilized for the matings involved in this study. All of the cages in one of the rooms were 4" x 7" while the other room contained 36 5" x 8" cages and 60 6" x 8" cages. Air movement was regulated by a thermostatically controlled fan. Lighting was provided on a 24-hour basis by one 60 or 100 watt incandescent bulb from the ceiling in each pen.

B. Chicks

Brooding the quail chicks was accomplished by using a Petersime Brood Unit Battery Model 2 S D which was constructed specifically for quail. This unit consisted of six decks, each with its own thermostatically controlled heating element. Each deck was divided into two 27" x 39" pens. The floors of the pens were constructed of 1/4" wire mesh so the quail chicks could stand without stepping through. Later, at about three to four weeks of age, this was replaced with 1/2" size mesh floors. Room lights were controlled by a time clock on a regime of 15 1/2 hour light and 8 1/2 hour dark. A small light bulb was placed in the heating area of the pen for at least the first week, thereby inducing the chicks to move to this area when the room lights were turned off at night. Also, for the first week, paper towels were placed in this area with feed on them. Shallow trough feeders especially constructed for quail were placed in the unheated part of the pen. Jar waterers with either wire mesh or perforated plastic rings fitted into their bases to minimize drowning were used.

Incubation and Egg Handling

Eggs were gathered daily, marked, and placed small end down in regular chicken egg flats and stored up to one week in an egg holding room at the Michigan State University Poultry Science Research and Teaching Center. They were then brought to the incubation laboratory for sorting and setting. The eggs were sorted by cage number and set small end down in Jamesway 252 incubators. Wire mesh baskets were designed to fit in the cradles of the Jamesway tray. In this manner, one tray would hold about 420 eggs as compared to only 180 chicken eggs. When enough of these baskets were not available, egg flats cut to fit the cradles were used. The temperature in the setter was held at 99.5° F with a relative humidity of about 60%. The eggs were turned automatically every two hours. Transfer into pedigree baskets was done on the 14th day of incubation at which time the eggs were placed in a hatcher where a temperature of 98.5° F and a relative humidity of 70% were maintained.

Unlike the procedure used by Sittmann et al. (1966), who stored their eggs up to two weeks prior to setting, the eggs in this experiment, with few exceptions, were held up to one week only. More inbred chicks were expected to be hatched from a given number of eggs with this procedure because Sittmann reported a much reduced hatchability of eggs, from inbred birds, which were stored one to two weeks as compared with eggs stored up to one week. No such reduction in hatchability was noted for eggs laid by Sittman's control birds. Previous experience at Michigan State University showed that hatchability was reduced in Japanese quail eggs which were stored one to two weeks as compared to storage up to one week.

Bird Handling and Matings

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 days. This was felt to be an improvement over Sittmann's procedure of not removing any chicks until the 19th day of incubation because chicks that hatched earliest were possibly the most viable of the lot. Letting them go without feed and water for three to four days probably reduced their chances of survival. All chicks from a given hatch were placed in one pen of the brooding unit after they were removed from the hatcher. Feed and water were provided *ad libitum*. The feed was a specially-formulated quail ration, the ingredients of which are listed in Appendix A. With the exception of two or three excessively large hatches, the chicks remained in the single pen until they were at least three weeks of age after which they were separated into two pens. Sexes were separated prior to six weeks of age. Full sibs and controls were mated and placed in cages at 7 1/2 weeks of age except for those from the first 13 hatches when this was done at 6 1/2 weeks of age. Matings were made within hatches whenever possible so that the age of the mated pair would be equal. Whenever mates were not available from a given hatch, the birds were held either on the floor or in other cages in anticipation of obtaining a mate who might be in a similar predicament in a future hatch. If a full sib died after being placed in a cage, it was replaced with another full sib if extras were available. Thus, emphasis was placed on making all possible matings of full sib pairs within the limitations of the facilities available; however, at all times the equal-aged pair was favored. No artificial selection was practiced at any time during the experiment. Control matings were made from each hatch. At least 20 percent of the matings were control matings. All surviving matings were maintained for a period of at least eight weeks; however, most matings were maintained for 13 weeks.

Data Collection and Analysis

Daily egg production records, from which soft-shelled and broken eggs were excluded, were kept for each mating. Within each generation, least square estimates and standard errors of the mean weekly egg g

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production, corrected for age effects, were obtained for each inbred line and the controls. In this experiment an inbred line is defined as including all birds for any given generation that were derived from an original parental pair. This does not mean that developing inbred lines in the classical sense of brother x sister matings was followed, i.e. in most cases more than one mating per inbred line was made each generation thus forming many sublines within the original line. For any given week, records of all birds that were alive at the beginning of the week were used. This could be put into conventional terms as hen-housed production on a weekly basis. Data for the analysis were collected for a 13-week period corresponding to the eighth through 21st week of age.

Egg weight was not recorded until the third generation after which time bi-weekly weights to the nearest hundredth gram were taken on the eggs produced in the week immediately preceding the weighing. All of the eggs from a given female for a seven-day period were weighed in a group from which an average egg weight was obtained. Least square estimates of mean egg weight and standard errors for each line within each generation were obtained using these values and correcting for the effect of age. Data from ages eight through 21 weeks were included in the analysis.

Fertility was measured as the percent of the eggs set from any given mating that hatched plus all of the unhatched eggs which showed any degree of development as judged by macroscopically observing the interior contents of the eggs. The percentages were changed to twice the arcsin of their square roots prior to analysis (Winer, 1962).

Least square estimates and standard errors, corrected for age and hatch effects, were obtained for each line within each generation. Data were used only from matings in which the age of the sire and dam was equal and from a period from eight through 21 weeks of age.

Hatchability was measured as the percent of the fertile eggs that hatched by the 19th day of incubation. These data were handled in the same manner as the data for fertility.

Livability was calculated as the percent of the hatched birds in a given family and a given hatch that were alive at three and seven weeks of age. All birds accidentally killed and those which lost wing bands were excluded from analysis. Because of the number of birds involved it was decided that necropsies would be made only if unusually high mortality occurred in this study. Least square estimates of the mean livability and the standard errors were calculated, correcting for age of dam and hatch effects for each line within each generation. Data for the analysis were collected from an eight-week period corresponding to the maternal ages of 8-16 weeks.

Body weights at three and seven weeks of age were measured to the nearest gram for each bird. It was desirable to weigh birds during a period of rapid growth, therefor three weeks of age was chosen as a suitable time. Little or no effect of egg size and/or sex on body weights would be expected at this age. Seven week weights were taken because it was necessary for the birds to be handled at this time. Also it was the time when the birds were approaching sexual maturity. Family averages for each hatch were taken from the period of maternal ages of 8-16 weeks. These were used in calculating the least square means for lines in each generation, correcting for age of dam and hatch effects. Seven-week weights were analyzed separately by sex.

The least square analysis was accomplished through the use of the 3600 computer located on the Michigan State University campus.

RESULTS AND DISCUSSION

This study involved data from approximately 50,000 Japanese quail hatching eggs. All eggs were incubated and those which failed to hatch were broken to determine infertile and dead germs. From these eggs approximately 25,000 chicks were hatched. Most of these were wing banded and placed in pens to be raised for control and inbred matings.

One control and 17 inbred lines were started with the first generation of matings. The number of full sib matings per inbred line ranged from one to 12 for the first generation (Table 2). The total number of full sib matings for the first generation (hereafter designated (FSM_1) was 79 while the number of control matings was 24.

Fifty-one (64.6%) of the 79 FSM_1 had offspring which survived to the time of mating. From these, 283 second generation full sib matings (FSM_2) 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 FSM_2 were able to produce offspring capable of making third generation full sib matings (FSM_3). Two more lines were lost at this point. In the third generation, there were 58 control matings and 214 FSM_3. Only 45 (21%) of the 214 FSM_3 were able to carry to the fourth generation producing offspring for 181 FSM_4. One additional line was lost at this stage. Sixty-seven control matings were made in the fourth generation. Five lines were lost in the fourth

Table 2. **Summary of the number of matings involved for the control and inbred lines.**

	Line number																	
	2	7	17	20	22	23	24	40	43	49	53	70	72	73	75	89	95	Total
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. of FSM_5 matings producing offspring			2		11		28					12	14			37		104

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

generation; however, the percent of the matings going on to produce fifth generation full sib matings (FSM_5) increased to 31.5 percent. Thus, six lines with a total of 217 FSM_5 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.

Control Line Performance

Table 3 contains the summary of performance data for the control birds used in this experiment. These data show that the overall performance of the controls was generally high. Furthermore, mean performance from generation to generation for most traits remained at a relatively constant level thus indicating that environmental effects on these traits did not change much throughout the five generations.

Egg production showed a gradual but steady increase from generation to generation even though no intentional selection was practiced. Possibly, natural selection played a role in that large families would tend to have a greater chance of having an offspring mated in the following generation than would small families.

For no discernible reason, fertility dropped sharply in the third generation even though no such drop was seen in the other traits.

Three-week body weights showed about a 13 percent decline by the fifth generation; however, no such change occurred in the 7-week weights. One possible reason for the decline in three-week body weights was that the average size of the hatches increased as time went on, thereby causing more crowded growing conditions resulting in more competition

Table 3. Summary of performance for control line.

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	3.6	0.3	24	3.9	0.3	80	4.4	0.2	58	4.7	0.4	67	4.8	0.2	56
Egg weight[3]	-----	---	--	-----	---	--	10.8	0.2	34	10.4	0.3	57	10.5	0.1	51
Fertility[4]	94.7	1.1	13	95.3	0.7	46	88.8	0.7	49	90.5	0.9	60	91.2	0.9	52
Hatchability[4]	92.5	1.1	13	92.3	0.7	46	92.0	0.7	45	94.6	0.9	57	94.3	1.0	51
3 wk. livability[5]	98.1	0.7	16	97.3	0.4	60	97.2	0.8	42	98.3	0.3	56	98.1	0.7	50
7 wk. livability[5]	94.8	1.1	14	96.5	0.5	60	95.8	1.0	42	96.9	0.4	56	96.7	1.0	50
3 wk. body weight[5] (males and females)	58.1	1.8	16	56.0	1.4	60	54.0	2.0	42	49.9	1.3	55	50.5	2.0	50
7 wk. body weight[5] (males)	104.6	2.7	13	103.0	1.8	54	105.1	3.2	41	105.3	1.4	54	104.9	2.5	48
7 wk. body weight[5] (females)	120.4	4.0	14	122.2	2.4	54	120.8	3.8	39	119.1	2.3	49	119.3	5.2	49

[1]Measurements for egg production, egg weight, fertility and hatchability are for eggs produced by the parents for the generation under which they are listed. Measurements for the remaining traits are for the offspring of these parents.
[2]Least square estimates of mean weekly egg production corrected for age effects based on number of hens alive at the beginning of each week for a 13 wk. period extending from 8-21 wks. of age. No. refers to number of hens involved.
[3]Least square estimates of mean egg weight in grams, corrected for age of hen. No. refers to number of hens involved.
[4]Least square estimates of mean percent fertility and percent hatchability corrected for age of the mated pair and hatch effects. No. refers to the number of matings involved (only matings in which the age of the sire and dam was equal were used).
[5]Least square estimates of mean 3 wk. and 7 wk. percent livability, 3 wk. body weights in grams (combined sexes), 7 wk. body weight in grams for males and 7 wk. body weight in grams for females, corrected for age of dam and hatch effects. No. refers to the number of families involved.

for feed and water; however, observation of the standard errors indicates that variation did not increase in these hatches as compared to that in earlier hatches. This may mean that if more competition did exist, all birds were affected about the same.

Inbred Lines Lost Prior to Fifth Generation

Inbred lines 2, 23, and 29 failed in the first generation of full-sib matings primarily because of poor livability and poor egg production. These lines were not included in the least squares analysis because of the small amount of information obtained from them.

Lines 53 and 75 were lost in the second generation. In examining Tables 4 and 5 it can be seen that performance of certain traits varied widely between these lines. In the first generation for line 75, with the exception of hatchability, most traits concerning reproduction were not much different than for the controls. Although hatchability was lowered it still remained at a level sufficient to produce enough offspring which survived to make 22 FSM_2.

The primary reason for the demise of line 75 was the very poor egg production of the 22 pair of FSM_2. This, coupled with poor fertility and hatchability, produced only two offspring that survived past three weeks of age and these were both males. In contrast, line 53 started out with poor reproduction in the first generation resulting in only enough offspring to make two FSM_2, one of which produced no eggs while the other was discarded accidentally two weeks after the mating was made.

Table 4. Summary of performance for inbred line 53.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	1.8	0.7	4	0.9	0.9	2									
Egg weight[3]	--	--	--	--	--	--									
Fertility[4]	57.3	5.3	3												
Hatchability[4]	64.9	6.0	3												
3 wk. livability[5]	100.0	4.7	4												
7 wk. livability[5]	100.0	8.0	3												
3 wk. body weight[5] (males and females)	49.8	4.6	3												
7 wk. body weight[5] (males)	89.0	8.1	1												
7 wk. body weight[5] (females)	100.1	9.7	2												

*See Table 3 for footnotes.

Table 3. Summary of [illegible]

Table 5. Summary of performance of inbred line 75.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	4.0	0.5	5	1.8	0.3	11									
Egg weight[3]	--	--	--	--	--	--									
Fertility[4]	97.4	1.8	3	13.3	1.7	8									
Hatchability[4]	71.8	1.8	3	9.6	2.9	4									
3 wk. livability[5]	94.1	1.2	4												
7 wk. livability[5]	95.4	1.7	4												
3 wk. body weight[5] (males and females)	47.0	2.3	4												
7 wk. body weight[5] (males)	96.8	3.0	4												
7 wk. body weight[5] (females)	109.7	5.0	4												

*See Table 3 for footnotes.

Body weights for the first generation were considerably less for these two lines than for birds of the control population at both three and seven weeks of age.

Line 20 (Table 6) was the only remaining line that failed to produce any FSM_4. Egg production in this line was fairly good through the second generation and then showed a moderate drop in the third generation. Fertility was low from the beginning. Hatchability was very high the first generation, then plummeted to 25 percent in the second generation with a further decrease in the third generation. The chicks that managed to hatch lived exceptionally well which probably was the prime reason the line survived three generations of full sib mating. Body weights in the first generation were all above the control values but dropped below these values in the third generation. This was especially noticeable in the seven-week female weights.

Half of all lines lost in this experiment were lost in the fourth generation. Three of the lines (Lines 7, 43 and 73; Tables 7, 8, and 9) were lost because there was for each line only one FSM_4 and in each case no eggs were secured from this single mating. Two other lines (Lines 40 and 95; Tables 10 and 11) produced offspring in the fourth generation but none lived beyond three weeks of age.

The performance in the first generation of four of these five lines for egg production, three week livability and seven week livability was generally good and usually approached or exceeded the control values. Line 40 was lower than the control line for all three of these traits. Fertility and hatchability data were available for only four of these lines in the first generation. In two of the four lines

Table 6. Summary of performance for inbred line 20.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	3.1	0.6	5	3.4	0.5	2	2.4	0.4	6						
Egg weight[3]	--	--	--	--	--	--	10.0	0.3	4						
Fertility[4]	30.1	7.5	1	68.7	3.0	2	41.3	3.4	5						
Hatchability[4]	99.6	9.8	1	25.4	3.1	2	17.1	4.3	4						
3 wk. livability[5]	99.9	4.4	1		**		99.6	8.3	3						
7 wk. livability[5]	99.9	5.5	1		**		100.0	10.2	3						
3 wk. body weight[5] (males and females)	62.4	4.4	1		**		45.1	6.6	2						
7 wk. body weight[5] (males)	107.8	6.0	1		**		104.6	10.2	1						
7 wk. body weight[5] (females)	126.5	7.9	1		**		95.4	10.1	2						

*See Table 3 for footnotes.

**No data were available for the 8 wk. period covered by the analysis; however, progeny were obtained from a later period to carry to the next generation.

Table 7. Summary of performance for inbred line 7.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	4.6	0.4	10	2.1	0.2	66	2.4	0.2	28	0.8	1.7	1			
Egg weight[3]	--	--	--	--	--	--	10.3	0.2	15						
Fertility[4]	99.1	1.1	7	65.3	0.8	24	34.9	1.2	14						
Hatchability[4]	67.3	1.1	7	53.9	0.9	20	31.3	1.3	12						
3 wk. livability[5]	94.0	0.8	9	80.1	0.6	22	95.0	2.8	11						
7 wk. livability[5]	87.8	1.1	9	78.1	0.7	22	94.4	4.0	11						
3 wk. body weight[5]	55.2	1.8	9	48.1	1.7	22	41.5	3.8	5						
7 wk. body weight[5] (males)	97.7	2.6	9	95.9	2.2	18	49.5	9.6	1						
7 wk. body weight[5] (females)	112.6	4.0	9	108.8	3.3	15	101.4	6.9	4						

*See Table 3 for footnotes.

Table 8. Summary of performance for inbred line 43.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	3.4	0.7	2	3.6	0.3	16	2.1	0.2	16	0.5	1.0	1			
Egg weight[3]	--	--	--	--	--	--	9.8	0.2	9						
Fertility[4]	100.0	2.8	1	77.8	1.1	9	20.6	1.5	9						
Hatchability[4]	92.1	2.7	1	66.1	1.2	7	50.2	1.8	6						
3 wk. livability[5]	96.7	2.5	1	66.8	0.9	8	79.5	4.1	6						
7 wk. livability[5]	93.0	3.7	1	62.8	1.2	8	78.9	5.2	6						
3 wk. body weight[5] (males and females)	52.8	3.3	1	43.1	2.1	7	30.8	4.6	3						
7 wk. body weight[5] (males)	96.2	4.6	1	87.7	2.9	6	78.4	7.6	1						
7 wk. body weight[5] (females)	109.0	7.1	1	102.0	3.7	7	93.4	9.0	2						

*See Table 3 for footnotes.

Table 9. Summary of performance for inbred line 73.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	3.7	0.4	12	2.8	0.2	35	2.0	0.4	13						
Egg weight[3]	--	--	--	--	--	--	9.0	0.2	11						
Fertility[4]	75.6	1.2	10	46.2	0.7	24	51.9	1.4	11						
Hatchability[4]	83.2	1.2	10	52.4	0.9	20	33.8	1.6	11						
3 wk. livability[5]	95.8	0.9	11	92.3	0.7	23	85.9	2.4	8						
7 wk. livability[5]	95.7	1.2	11	87.6	0.9	23	76.2	3.0	8						
3 wk. body weight[5] (males and females)	50.0	1.9	11	46.1	1.8	19	41.8	3.5	6						
7 wk. body weight[5] (males)	100.8	2.7	10	95.5	2.5	13	93.6	4.9	6						
7 wk. body weight[5] (females)	110.8	4.1	11	102.4	3.5	13	129.2	12.0	1						

*See Table 3 for footnotes.

Table 10. Summary of performance for inbred line 40.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	2.8	0.6	3	3.2	0.4	11	4.1	0.4	8	2.6	0.7	3			
Egg weight[3]	--	--	--	--	--	--	9.1	0.2	7	8.6	0.7	2			
Fertility[4]		**		20.4	2.2	5	89.1	1.7	8	3.4	5.4	1			
Hatchability[4]		**		45.2	3.0	4	45.8	1.6	7	9.8	8.1	1			
3 wk. livability[5]	89.0	1.9	2	97.1	1.8	4	48.9	3.4	7	0.0	--	2			
7 wk. livability[5]	87.5	2.4	2	98.8	2.3	4	49.1	4.2	7	0.0	--	2			
3 wk. body weight[5] (males and females)	52.4	2.9	2	50.4	3.0	4	41.6	4.2	4						
7 wk. body weight[5] (males)	105.3	4.0	2	99.7	3.8	4	87.5	6.5	3						
7 wk. body weight[5] (females)	113.7	5.6	2	105.5	5.8	3	93.3	7.5	3						

*See Table 3 for footnotes.

**No matings with age of sire and dam equal.

Table 11. Summary of performance of inbred line 95.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	4.5	0.4	6	4.8	0.6	4	3.8	0.5	3	3.8	1.0	1			
Egg weight[3]	--	--	--	--	--	--	9.1	0.3	3	9.2	0.7	1			
Fertility[4]	32.7	1.8	4	55.3	1.7	4	38.6	3.4	3	30.5	5.4	1			
Hatchability[4]	45.6	2.9	3	47.7	1.8	4	19.7	4.3	3	7.9	8.1	1			
3 wk. livability[5]	99.0	2.2	4	93.0	1.3	4	98.1	4.2	2						
7 wk. livability[5]	95.7	3.4	4	92.9	1.8	4	96.8	5.3	2						
3 wk. body weight[5] (males and females)	54.6	3.1	4	50.4	2.6	4	45.7	4.7	2						
7 wk. body weight[5] (males)	100.9	4.6	3	100.0	3.4	4	96.4	6.5	2						
7 wk. body weight[5] (females)	120.0	7.1	4	105.8	4.8	4	101.8	9.0	1						

*See Table 3 for footnotes.

(Lines 7 and 43) fertility was above the control line value while in the other two lines it was below. Three of the four lines were lower in hatchability than was the control line. Body weights for the five lines were generally less than the control line values in the first generation.

Subsequent generations showed an increased amount of variability among the traits both between and within the lines; however, by the third generation the performance in most traits was lower than in the first generation.

Inbred Lines Surviving Five Generations of Full Sib Matings

Six of the 17 original inbred lines survived through five consecutive generations of full sib matings to attain an inbreeding coefficient of 67 percent. The summaries of performance of these lines are contained in Tables 12 to 17.

Weekly average egg production for these lines in the first generation was exceptionally good. It ranged from 4.8 to 6.0 eggs with each line exceeding the control line value; however, it should be noted that the hens producing eggs in the FSM_1 were not inbred. Fertility in four of the six lines exceeded that in the control line; however, the other two lines had low fertility values. Hatchability was generally good for all lines in the first generation with values ranging from 77.8 to 95.5 percent. The control line value for this trait was 92.5 percent. Livability and body weights were more variable from line to line in the first generation than were egg production, fertility and hatchability. In all but one line first generation performance for three

Table 12. Summary of performance for inbred line 17.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	5.6	0.8	1	3.8	0.3	15	3.2	0.2	44	3.1	0.4	43	1.8	0.5	3
Egg weight[3]	--	--	--	--	--	--	9.4	0.2	29	9.3	0.3	38	9.6	0.4	3
Fertility[4]	100.0	3.1	1	96.1	1.4	7	77.9	0.8	23	15.4	1.2	17	39.7	5.2	2
Hatchability[4]	93.7	2.9	1	60.9	1.3	7	50.9	0.9	22	52.4	1.4	15	81.2	6.6	2
3 wk. livability[5]	76.9	2.9	1	75.0	0.7	10	77.4	1.0	22	64.8	1.1	18	48.2	4.5	2
7 wk. livability[5]	75.2	4.4	1	71.8	0.9	10	66.9	1.3	22	61.7	1.4	18	51.8	6.0	2
3 wk. body weight[5] (males and females)	53.7	3.6	1	46.0	1.9	10	37.9	2.3	18	41.8	2.4	11	40.9	5.0	1
7 wk. body weight[5] (males)	96.1	6.0	1	93.2	2.5	7	84.3	3.6	13	91.5	2.8	7	84.7	6.2	1
7 wk. body weight[5] (females)	115.1	7.1	1	104.0	3.2	8	93.0	4.2	16	97.8	4.3	7	105.1	12.5	1

*See Table 3 for footnotes.

Table 13. Summary of performance for inbred line 22.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	4.8	0.4	10	3.2	0.3	46	3.9	0.2	25	4.1	0.4	21	2.8	0.2	20
Egg weight[3]	--	--	--	--	--	--	9.6	0.2	19	10.0	0.3	20	10.0	0.2	15
Fertility[4]	95.2	1.3	8	50.7	0.8	29	70.1	1.0	19	50.3	1.2	14	38.5	1.4	14
Hatchability[4]	77.8	1.4	8	61.2	1.0	24	59.3	1.1	14	64.8	1.3	12	40.3	1.7	8
3 wk. livability[5]	92.7	1.0	9	90.3	0.7	22	85.5	1.2	16	83.0	0.6	15	55.9	2.0	11
7 wk. livability[5]	92.6	1.3	9	78.0	1.0	22	82.4	1.5	16	73.2	0.7	15	39.5	2.7	11
3 wk. body weight[5] (males and females)	54.4	2.0	9	47.2	1.9	18	47.6	2.4	11	47.3	1.8	13	43.3	2.4	8
7 wk. body weight[5] (males)	98.5	2.8	8	94.7	2.4	16	95.3	3.6	11	102.1	1.8	11	99.2	3.9	7
7 wk. body weight[5] (females)	115.1	4.2	8	104.1	4.0	11	109.7	5.1	9	107.9	3.4	12	98.5	12.5	1

*See Table 3 for footnotes.

Table 14. Summary of performance for inbred line 24.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	6.0	0.8	1	4.1	0.3	11	3.1	0.3	10	4.0	0.4	16	2.6	0.2	62
Egg weight[3]	--	--	--	--	--	--	9.2	0.2	8	9.9	0.4	14	10.2	0.1	42
Fertility[4]	99.7	3.1	1	37.1	1.9	4	3.1	1.4	7	80.4	1.4	10	52.1	0.9	34
Hatchability[4]	95.5	2.9	1	93.2	2.4	2	75.1	2.8	3	59.7	1.3	10	49.0	1.1	31
3 wk. livability[5]	65.7	2.9	1	82.3	0.9	8	92.8	4.3	2	91.4	0.6	13	84.4	0.9	28
7 wk. livability[5]	59.8	4.4	1	78.4	1.2	8	93.0	5.4	2	80.3	0.7	13	82.6	1.2	28
3 wk. body weight[5] (males and females)	48.2	3.6	1	43.4	2.1	8	45.4	4.7	1	47.4	1.7	12	45.8	2.2	24
7 wk. body weight[5] (males)	102.1	5.2	1	94.4	2.7	8	105.0	7.7	1	101.5	1.8	11	94.4	2.8	20
7 wk. body weight[5] (females)	122.2	7.9	1	100.6	4.1	6	106.2	8.0	1	110.6	3.1	9	112.5	5.4	19

*See Table 3 for footnotes.

Table 15. Summary of performance for inbred line 70.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Genration 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	5.2	0.8	1	2.6	0.4	13	3.2	0.3	11	3.4	0.4	33	2.5	0.2	42
Egg weight[3]	--	--	--	--	--	--	9.5	0.3	4	9.4	0.3	24	9.3	0.1	28
Fertility[4]	100.0	3.1	1	87.8	2.7	6	83.5	3.1	4	62.2	1.2	22	39.4	1.1	18
Hatchability[4]	81.9	2.9	1	26.5	2.1	5	84.7	2.9	4	49.4	1.2	17	37.1	1.3	14
3 wk. livability[5]	75.1	3.5	1	89.3	1.3	5	78.0	1.5	7	82.2	0.6	18	77.2	1.5	11
7 wk. livability[5]	59.8	5.6	1	81.1	1.8	5	73.5	1.9	7	79.8	0.8	18	55.6	2.1	11
3 wk. body weight[5] (males and females)	48.6	3.6	1	51.5	3.5	5	48.6	2.9	7	44.3	1.7	16	39.5	3.3	8
7 wk. body weight[5] (males)	92.5	5.2	1	95.3	3.6	4	96.7	4.1	7	95.0	1.9	14	98.1	3.8	6
7 wk. body weight[5] (females)	108.5	9.1	1	119.2	4.8	4	110.0	5.0	3	104.1	3.1	13	97.6	7.6	4

*See Table 3 for footnotes.

Table 16. Summary of performance for inbred line 72.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	4.8	0.6	4	4.2	1.0	1	5.1	0.5	6	4.1	0.4	17	2.2	0.2	36
Egg weight[3]	--	--	--	--	--	--	11.1	0.3	5	9.6	0.4	17	9.6	0.2	21
Fertility[4]	45.3	6.2	2		**		99.9	2.4	5	85.2	1.4	11	56.8	1.5	14
Hatchability[4]	84.2	5.7	2		**		69.6	2.0	3	66.3	1.3	11	30.6	1.7	13
3 wk. livability[5]	100.0	2.9	3	98.2	2.3	1	87.0	1.7	5	81.1	0.6	15	83.4	2.0	14
7 wk. livability[5]	100.0	3.7	3	99.1	3.1	1	83.0	2.1	5	75.1	0.7	15	71.3	2.9	14
3 wk. body weight[5] (males and females)	58.4	3.6	3	60.7	3.5	1	55.2	2.9	5	44.9	1.7	13	38.2	3.3	7
7 wk. body weight[5] (males)	96.7	5.2	2	107.3	4.6	1	104.8	4.4	4	97.5	1.8	13	88.5	4.5	5
7 wk. body weight[5] (females)	130.6	12.4	1	129.6	5.2	1	121.6	5.1	5	102.6	3.2	11	89.7	7.4	5

*See Table 3 for footnotes.

**No matings with age of sire and dam equal.

Table 17. Summary of performance for inbred line 89.*

	Generation 1[1]			Generation 2[1]			Generation 3[1]			Generation 4[1]			Generation 5[1]		
	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.	Mean	S.E.	No.
Egg production[2]	5.1	0.4	9	3.2	0.3	26	3.7	0.3	27	3.4	0.4	44	4.2	0.2	54
Egg weight[3]	--	--	--	--	--	--	9.6	0.2	21	9.4	0.3	31	10.4	0.1	49
Fertility[4]	49.9	1.3	5	54.0	0.8	17	61.5	0.9	21	62.1	1.3	15	82.4	0.9	38
Hatchability[4]	92.9	1.5	5	67.3	0.9	13	61.2	1.0	13	77.5	1.2	14	77.5	1.1	33
3 wk. livability[5]	91.8	1.0	4	89.2	0.7	14	75.5	1.1	14	82.6	0.6	23	81.3	0.9	36
7 wk. livability[5]	91.6	1.4	4	76.9	0.9	14	69.9	1.4	14	77.7	0.7	23	77.6	1.2	36
3 wk. body weight[5] (males and females)	52.5	2.1	4	48.9	1.8	13	44.6	2.4	10	47.1	0.7	17	47.7	2.2	33
7 wk. body weight[5] (males)	103.0	2.9	4	98.5	2.7	11	97.4	3.7	7	102.2	1.8	11	98.7	2.8	26
7 wk. body weight[5] (females)	118.2	4.4	4	111.0	3.3	9	104.9	4.6	8	103.8	3.2	16	106.7	5.4	28

*See Table 3 for footnotes.

and seven week livability, three week body weights and seven week male body weights measured less than in the control line. First generation inbred female body weights at seven weeks of age were greater than those of the control line females in two and less than the control line females in four of the six lines.

In subsequent generations egg production for all of the six lines showed a decline. Although the decline was not consistent with each succeeding generation, all values for the six lines were considerably less in the fifth generation than in the first generation.

Fertility in the two surviving lines which had shown low fertility in the first generation was greater in the fifth generation than in the first, and was equal to or greater than that for the other four lines where fertility was substantially lower in the fifth generation than in the first. Again the change was not consistent from generation to generation.

Hatchability of the six lines was lower in the fifth generation than in the first. Two of the six lines showed a consistent decline with each succeeding generation while the other four lines showed fluctuations from generation to generation.

In four of the six lines livability to three and seven weeks of age was lower in the fifth generation than in the first. Of the other two, one showed a substantial rise in livability in the second generation as compared to the first and a still further increase in livability in the third generation with livability remaining at a high level through the fifth generation. The remaining line had higher livability for both the three and seven week categories in generations two, three and four as compared to the first generation but then dropped again in the fifth generation to levels near those of the first generation.

Average body weights showed considerable variation from generation to generation. Of all body weight measurements, female body weight at seven weeks of age seemed to be most affected by inbreeding with at least a ten gram difference between the first generation and fifth generation values.

Average egg weights, which were taken only from the third through the fifth generation, were generally less for the six inbred lines than for the control line. Little change from generation to generation was evident for three of the lines whereas two of the lines showed an increase in egg weight by the fifth generation while the remaining line showed a decrease of 1 1/2 grams from the third to the fourth generation and then remained at that level.

Of all the six lines surviving the five generations of full sib matings, performance in the fifth generation for all the traits measured was highest in line 89. This line showed the least amount of change through the successive generations of inbreeding. This good performance is reflected by the large number of matings (38) that produced offspring in the fifth generation (Table 17). Line 24 had the next highest number of matings (28) that produced offspring in the fifth generation; however, this represents only 45 percent of the total number of matings in the fifth generation for line 24 as compared to 70 percent for line 89. This reflects the poorer performance of line 24 for egg production, fertility and hatchability in this generation.

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 non-linearity were calculated for each trait. These results are listed in Table 18.

Upon examination of Figures 1 to 4 it can be seen that performance as a whole for all the inbred lines was always less than the control line performance between 25 and 67 percent levels of inbreeding. For all but two of the traits studied the regression coefficients were negative in sign (Table 18). 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 18 cannot be used as adequate predictors of performance for any given level of inbreeding.

In order to determine which traits were affected most by inbreeding, changes relative to control line performance for each generation were calculated. These are listed in Table 19. It can be seen

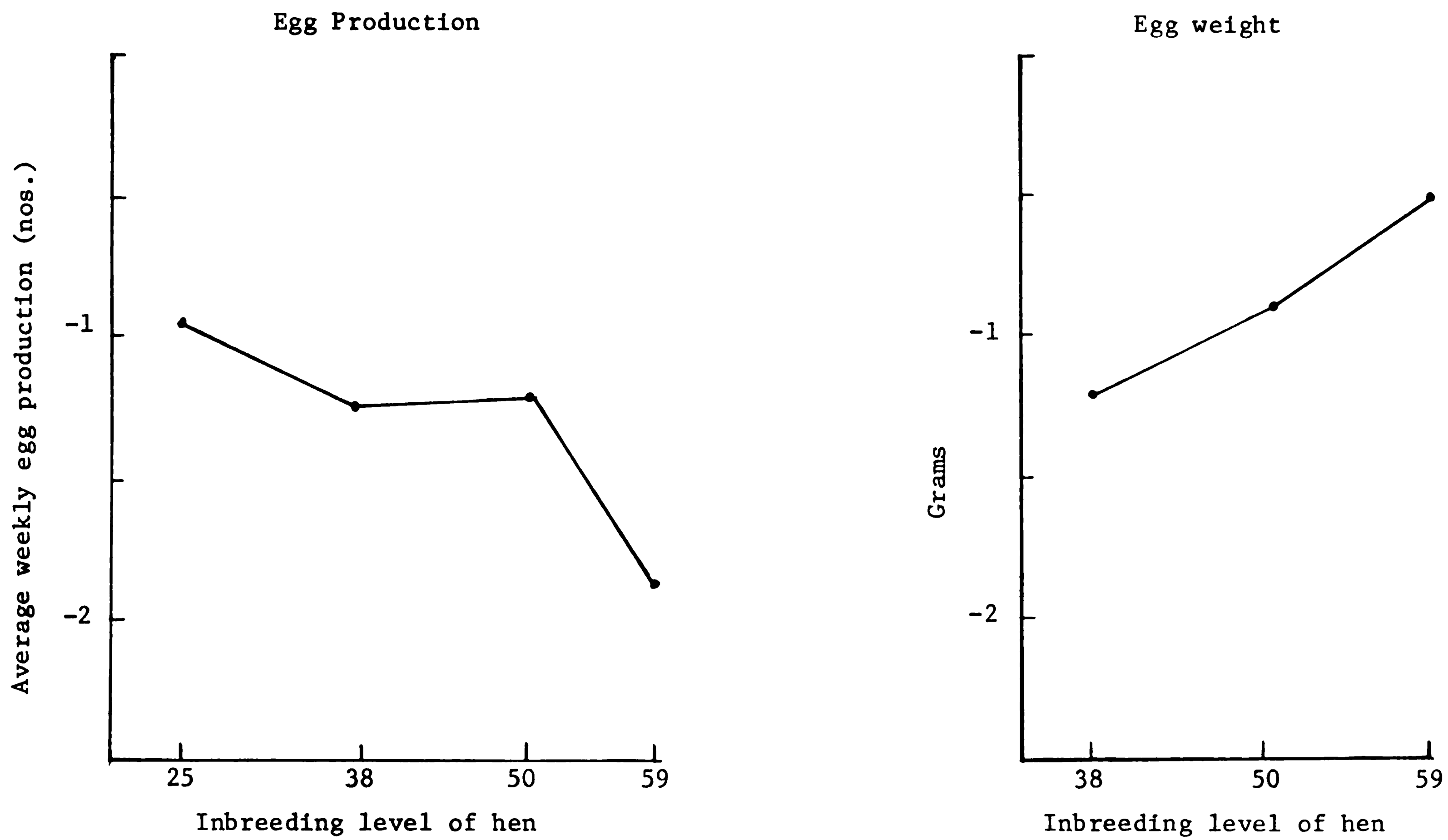

Figure 1. Deviations of weighted mean values of inbred population from control values.

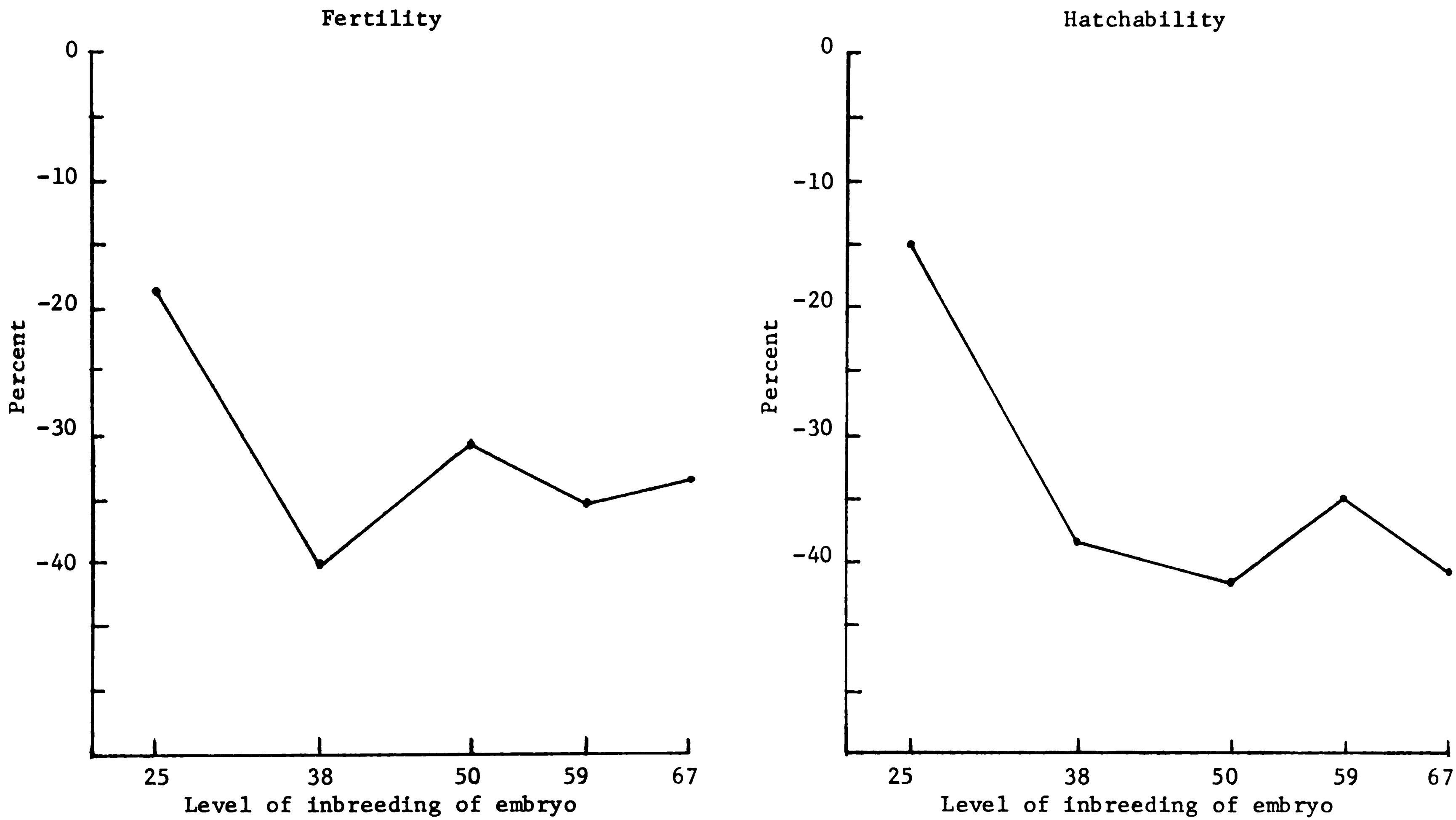

Figure 2. Deviations of weighted mean values of inbred population from control values.

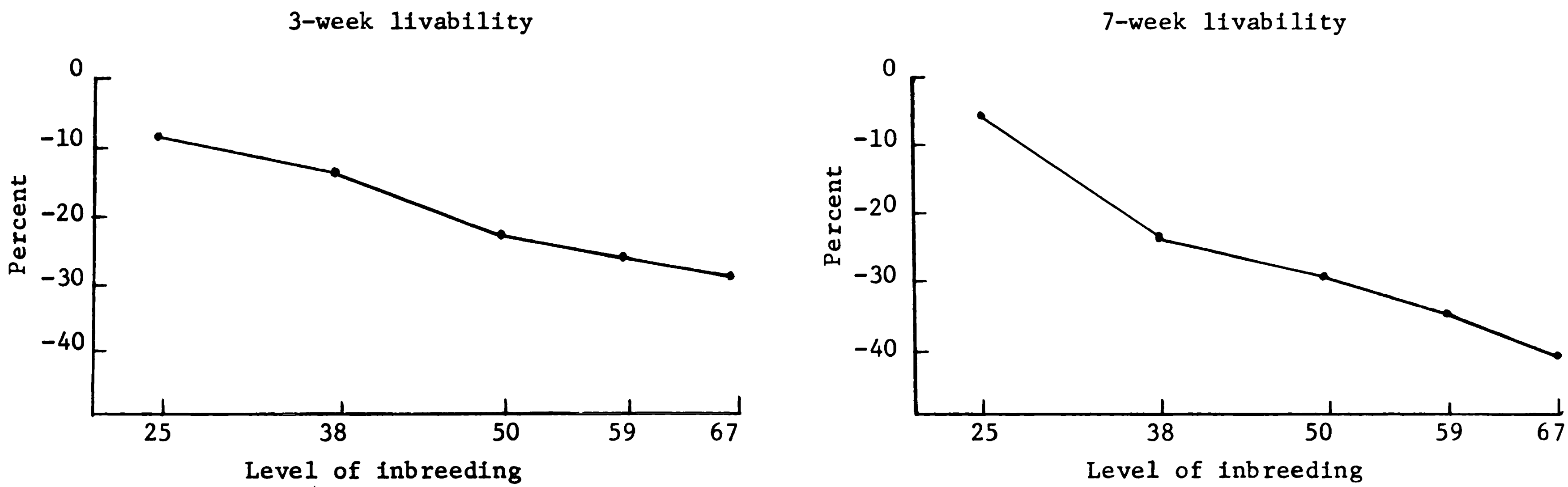

Figure 3. Deviations of weighted mean values of inbred population from control values.

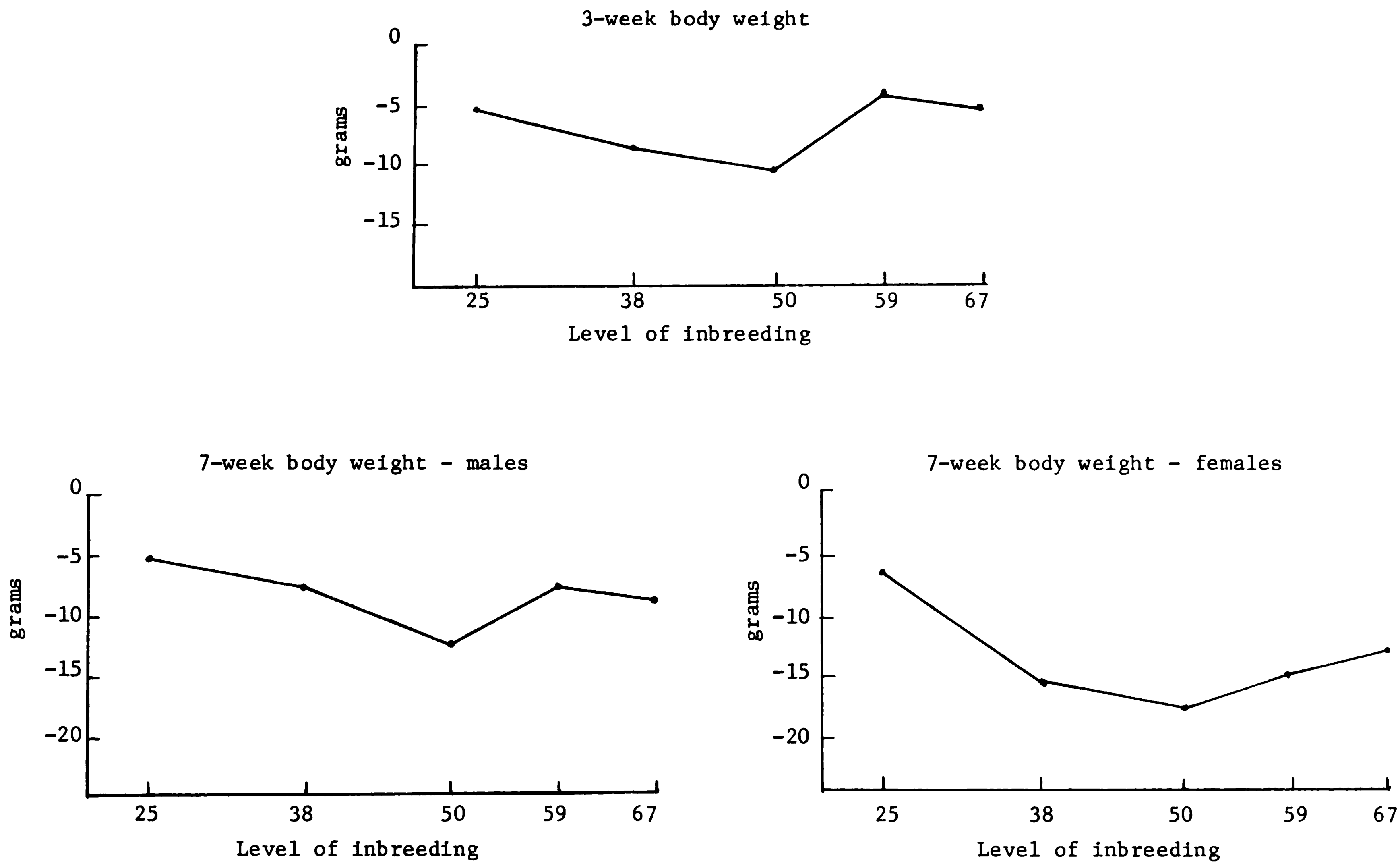

Figure 4. Deviations of weighted mean values of inbred population from control values.

Table 18. Weighted linear regression coefficients of performance on inbreeding expressed as deviations of inbred population from control population means.[1]

Trait	Regression Coefficient
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.

Table 19. 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

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

GENERAL DISCUSSION

A common explanation for the degenerative effects of inbreeding is that most deleterious genes present in a population are recessive in character and, under random mating conditions, are usually "hidden" by the dominant genes. The resultant loss of heterozygosity with a concomittant rise in the homozygous state uncovers these hidden recessives thereby reducing the performance of the population. Therefore, whether or not a particular pair of individuals chosen from a random mating population would have fewer deleterious recessives than another given pair is largely a consequence of chance. Of course, if the original population has a large number of deleterious genes to begin with, the chances of choosing a pair of individuals with only a few would be much lower than if the original population contained lesser numbers of the deleterious genes.

In any case, since chance plays an important role in determining which parental pairs are superior, the larger the number of original parental pairs the better should be the chances of selecting some with a favorable genetic makeup. Also, if the original population had been under any form of selection, natural or otherwise, the number of deleterious recessives should be reduced, therefore any particular pair chosen from it should have greater chances of possessing a favorable genetic make-up.

The present study was undertaken with the foregoing in mind. The original population of birds, as has already been pointed out in the experimental procedure section, was a more or less select population resulting from many generations of closed flock matings plus selection of the immediate parents on the basis of longevity along with the necessary reproductive performance needed to secure the offspring for the first generation.

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 FSM_1 since three of the six lines that survived the five consecutive generations of full-sib matings had only one mating the first generation (Table 2).

Furthermore, in order to determine whether those lines having greater than the average number of FSM_1 were more capable of surviving the subsequent five generations of inbreeding than were those lines with less than the average number of FSM_1, the following χ^2 test was conducted:

	Above mean no. of FSM_1		Below mean no. of FSM_1		
	O	E	O	E	Total
Lines surviving	2	2.47	4	3.53	6
Lines lost	5	4.53	6	6.47	11
Total	7		10		17

$\chi^2 = .0009$

This non-significant test indicates that in this experiment large numbers of FSM_1 did not increase the survival chances of any given line and that the genetic make-up of the original parental pair played an important role in whether or not a line survived through several consecutive generations of full-sib matings.

The observed variability among traits both within and between inbred lines in this experiment was not an unusual consequence of inbreeding. In chickens it was found by Shoffner (1948), Düzgünes (1950) and Stephenson et al. (1953) that different lines responded differently to inbreeding. This again was probably due mostly to the variation in the original genetic composition of the base birds used. Also, part may have been due to what Lush (1948) attributes to unpredictability of results from inbreeding due to the tossing around of the gene frequencies irrespective of the size or variability of their effects.

Data in Table 20 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, than did the group of inbred lines that were lost prior to the fifth generation. This suggests that selection in the first generation, especially for egg production and hatchability, should aid in removing those lines that may not survive in subsequent generations of inbreeding. A very striking observation was that mortality was considerably greater at both three and seven weeks of age in the surviving group of inbred lines than in the non-surviving group. This could mean that in those families with poor livability the birds that survived were those that were best able to cope with the effects of inbreeding.

The overall performance of the inbred population was non-linear for all traits except two (Table 18 and Figures 1 to 4). Linear

Table 20. 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 generations.[1]

	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[2]	-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.

declines in performance would be expected if the decline were due only to dominance effects [Lush (1948) and 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 is involved. Kempthorne (1957) shows the relation of the mean of inbred populations not only to be dependent upon the linear dominant effect but in addition curvilinearily 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 always dependent upon gene frequency [Lush (1948)]. Even though no intentional selection was practiced, natural selection played a very large role by eliminating, at varying times throughout the five generations of inbreeding, a total of 11 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.

The fact that egg weights increased with increased inbreeding levels over the period of inbreeding measured for this trait is noteworthy; however, without the information from the first two generations it cannot be known whether or not an initial drop actually occurred. It has already been pointed out in the literature review that in chickens most investigators found little effect on egg weight due to inbreeding; however, two experiments conducted by Hays (1934; 1935) showed that in Rhode Island Red chickens egg weight was increased by inbreeding.

SUMMARY AND CONCLUSIONS

1. For the first time consecutive brother x sister matings in Japanese quail were made for five generations. Prior to this experiment no one had reported successfully passing three generations of consecutive brother x sister matings.
2. Six of 17 original lines remained viable at the end of five generations of brother x sister matings.
3. Individual inbred lines of Japanese quail respond differently to consecutive generations of brother x sister matings.
4. The group of inbred lines that survived five generations of full-sib matings as compared to those lines lost had on the average better performance in the first generation except for livability. This indicates selection in the first generation would aid in developing viable inbred lines.
5. Performance for the inbred population as a whole was reduced with inbreeding. Linear regression coefficients calculated for weighted deviations from the control line performance on inbreeding were negative for all traits measured except 3-week body weight and egg weight. The regressions for all traits except 3-week livability and egg weight showed a significant non-linear relationship with inbreeding level.

6. Of the traits measured, fertility, hatchability and weekly egg production were affected the most by inbreeding with livability being affected moderately and egg and body weights being affected the least.

7. In the fifth generation, overall performance of the inbred population expressed as percent change from the control performance for the various traits was as follows: fertility, -36.7; hatchability, -43.1; weekly egg production, -39.2; three week livability, -19.9; seven week livability, -26.2; three week body weight, -10.9; seven week male body weight, -8.1; seven week female body weight, -11.2 and average egg weight, -4.8.

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APPENDIX

APPENDIX

Quail Breeder Ration 25%

Ingredient	% of Ration
Ground yellow corn	40.90
Soybean meal, 49% protein	37.00
Alfalfa meal, 17% protein	5.00
Dried whey	2.50
Meat and bone scraps, 50% protein	2.50
Fish meal, 60% protein (menhaden)	2.50
Ground limestone	5.00
Dicalcium phosphate (24% Ca., 18.5% Phos.)	1.50
Salt, iodized	0.50
Vitamin trace-mineral premix[1]	0.60
Fat	2.00

[1]Dawes Number 5004, Michigan State Turkey.