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I am submitting herewith a dissertation written by Nazar Thannoon Taha entitled "A Genetic Study of Crooked Toes and Crooked Keels in Chickens." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

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A GENETIC STUDY OF CROOKED TOES
AND CROOKED KEELS IN CHICKENS

A Dissertation
Presented for the
Doctor of Philosophy
Degree

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Nazar Thannoon Taha

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ABSTRACT

The objectives of this study were to estimate for the skeletal deformities of crooked toes and crooked keels in chickens: (1) the sire and dam effects, (2) the heritability and (3) genetic and phenotypic correlations.

Data were collected from measurements of crooked toes and crooked keels on 1316 offspring, at 98 days of age, from matings of 19 sires and 168 dams of Single Comb White Leghorns. The analyses of variance were based on half-sib and full-sib analyses of both crooked toes and crooked keels scores within each sex, and all data adjusted for sex. The components of variance and covariance due to sire and dam in the model were used to calculate estimates of heritability and genetic and phenotypic correlations.

It was observed that sex has a significant ($P < 0.001$) effect on the incidence of both crooked toes and crooked keels with males having a greater incidence of crooked toes and crooked keels than females.

The analysis of half-sib data showed significant differences ($P < 0.001$ for male progeny and $P < 0.05$ for female progeny) among sires with respect to the occurrence of crooked toes and crooked keels.

The analysis of variance of the full-sib data adjusted for sex showed significant differences ($P < 0.001$) among sires with respect to type of deformities. Also significant differences ($P < 0.01$) among dams with respect to the incidence of crooked toes score and a significant difference ($P < 0.05$) among dams with respect to keel deformity.

In the full-sib analysis, male progeny showed significant differences ($P < 0.001$) among sires, while the differences among dams were significant ($P < 0.01$) with respect to crooked toes score, and crooked keels score ($P < 0.05$). Differences among sires of female progeny were of low significance ($P < 0.05$), while differences among dams were not significant ($P > 0.05$). With respect to keel scores, the differences in female progeny were of low significance ($P < 0.05$) among both sires and dams.

It was found from the estimates of heritability of crooked toes and crooked keels from half-sib and full-sib analysis adjusted and unadjusted for sex that male progeny gave higher estimates of heritability than females and in most cases the estimates of heritability of keel score were higher than those of toe score.

From the estimates of genetic and phenotypic correlation, it was found that most were very low, indicating that the two diseases are practically independent of each other. The females yielded higher estimates than the males in all cases. The paternal half-sib and full-sib estimates of genetic correlation were higher than other estimates. It is concluded that the genetic effect of the sire on the predisposition to crooked toes and keels of the progeny appears to be greater than that of the dam.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. OBJECTIVES	3
III. REVIEW OF LITERATURE	4
Crooked Toes	4
The Influence of Heredity	4
The Influence of Environmental Factors	5
Crooked Keel	7
The Influence of Heredity	7
The Influence of Environment	8
Heritability Estimates	10
Genetic and Phenotypic Correlations	11
IV. EXPERIMENTAL PROCEDURES	13
Management of the Experiment	13
Collection of Data	14
Crooked Toes	14
Crooked Keel	14
Methods of Analysis	17
V. RESULTS AND DISCUSSION	27
Analysis of Variance	27
The Influence of Sex	27
The Influence of Sire and Dam	27
Estimates of Heritabilities	43
Estimation of Genetic and Phenotypic Correlations	55
VI. SUMMARY	57
LITERATURE CITED	59
VITA	63

LIST OF TABLES

TABLE	PAGE
1. Composition of the Diets	15
2. Analysis of Variance of Half-Sib Data	18
3. Analysis of Variance of Full-Sib Data	19
4. Analysis of Covariance and Half-Sib Sire Components of Covariance	23
5. Analysis of Covariance and Full-Sib Sire and Dam Components of Covariance	24
6. Analysis of Variance of Toe Data From Half-Sib Male and Female Progeny	28
7. Analysis of Variance of Keel Data for Half-Sib Male and Female Progeny	29
8. Analysis of Variance of Half-Sib Toe Data Adjusted for Sex	31
9. Analysis of Variance of Half-Sib Keel Data Adjusted for Sex	32
10. Means of Toe Scores by Sire, Sexes Combined	33
11. Means of Keel Scores by Sires, Sexes Combined	34
12. Analysis of Variance of Toe Data from Male Half-Sibs	35
13. Means of Toe Scores of Males by Sires	36
14. Analysis of Variance of Toe Data From Female Half-Sibs	37
15. Means of Toe Scores of Females by Sires	38
16. Analysis of Variance of Keel Data from Male Half-Sibs	39
17. Means of Keel Scores of Males by Sires	40
18. Analysis of Variance of Keel Data from Female Half-Sibs	41

TABLE

PAGE

19.	Means of Keel Scores of Females by Sires	42
20.	Analysis of Variance of Full-Sib Toe Data Adjusted for Sex	44
21.	Analysis of Variance of Full-Sib Keel Data Adjusted for Sex	45
22.	Analysis of Variance of Toe Data from Male Full-Sibs	46
23.	Analysis of Variance of Keel Data from Male Full-Sibs	47
24.	Analysis of Variance of Toe Data from Female Full-Sibs	48
25.	Analysis of Variance of Keel Data from Female Full-Sibs	49
26.	Estimates of Heritability of Toe and Keel Scores Unadjusted Half-Sib Data	50
27.	Estimates of Heritability of Toe and Keel Scores Adjusted Half-Sib Data	51
28.	Estimates of Heritability of Toe and Keel Scores Unadjusted Full-Sib Data	52
29.	Estimates of Heritability of Toe and Keel Scores Adjusted Full-Sib Data	53
30.	Estimates of Genetic and Phenotypic Correlations between Crooked Toes and Crooked Keels	56

CHAPTER I

INTRODUCTION

Bone deformities in chickens are of considerable practical importance. The defects may range in their effects from total disability and death, through reduced growth and reproductive performance, to a reduction of carcass quality.

Certain skeletal structures are more prone to deformation than others. The toes, legs, sternum and vertebral column are the more commonly deformed structures. These particular structures apparently are subjected to greater physical stresses than are others. For the most part, deformations of these structures have previously been studied as separate disease entities. The possibility exists that the factors producing a certain skeletal defect may also have a broader or more general effect on other parts of the skeleton.

The present study is confined to the influence of heredity on two skeletal abnormalities or diseases commonly referred to as "Crooked toes" and Crooked keels."

Crooked toes is usually characterized by a lateral or medial deviation of either the second, third or fourth digit. Frequently more than one digit is involved and one or both feet may be affected. This condition can easily be confused with the riboflavin deficiency abnormality known as "Curled-toe paralysis," in which the toes turn inward and the bird walks on the dorsal surface of the toes.

In the case of crooked keels, the keel may be bent to the right or left, or show various degrees of concavity, or it may be both concave and bent. Bending to the right side is more common than bending to the left.

Very little research has been devoted to the factors responsible for deformities of the toes and the keels. Even so, the opinion prevails that crookedness of the toes and the keel is due to a combination of genetic, nutritional and managemental factors.

CHAPTER II

OBJECTIVES

The objectives of the present study were to calculate for the skeletal deformities of crooked toes and crooked keels in chickens:

1. Estimates of the sire and dam effects,
2. Estimates of heritability and
3. Estimates of genetic and phenotypic correlations between crooked toes and keels,

in order to assess the prospect of reducing the incidence of crooked toes and crooked keels by breeding methods.

CHAPTER III

REVIEW OF LITERATURE

I. CROOKED TOES

The Influence of Heredity

Crooked toes have been observed for many generations in a small number of birds in the University of California flock of Single Comb White Leghorns by Hicks and Lerner (1949). In 1943, Hicks undertook a selection experiment to increase the incidence of its occurrence. The results of five years of selection showed that the elimination of birds exhibiting crooked toes from the breeding flock maintained the incidence of the abnormality at a low level.

Black et al. (1952) indicated that some strains were susceptible to crooked toes while others were resistant, suggesting that the crooked-toe condition is hereditary.

Nestor (1971) reported the results of an experiment on the frequency of crooked toes in several medium and heavy weight lines of turkeys. He concluded that offspring from matings in which one or both parents had crooked toes exhibited a greater incidence of crooked toes than offspring from parents with normal toes (10.6 vs. 4.0 percent). Medium weight strains of turkeys exhibited a significantly ($P < 0.05$) higher frequency of crooked toes than heavy weight strains, further indicating that the crooked-toe condition is influenced by inheritance.

The Influence of Environmental Factors

Norris et al. (1939) conducted two experiments to determine the effect of floor type and all-night lighting upon the incidence of the crooked-toe deformity, in Rhode Island Red chicks. He found that the numbers of chicks afflicted with crooked toes confined in pens with paper-covered floors were much greater than in pens with wire-mesh floors. The severity index of the lots on paper-covered floors ranged from 1.32 to 1.63, while that of the lots of wire-mesh floors ranged from 0.0 to 0.07. A second experiment confirmed the results obtained in the first experiment, showing that the type of floor on which chicks are confined influences the incidence of crooked toes. However, in this second test a low incidence of the crooked-toe deformity was obtained in chicks confined in pens with wire mesh floors. Thus, it may be that type of floor may not be the basic cause of development of crooked-toe deformity. It was suggested that the incidence of this deformity may be due either to factors inherent in the chicks or to partial dietary deficiency of some unknown essential nutrient. In either case, the effects are revealed only when the floors of the confinement area are of such a character as to produce unusual stresses upon the rapidly developing tarso-metatarsal and phalangeal bones.

Nestor (1971) reported that environmental factors also influence the incidence of crooked toes in turkeys with highly significant differences occurring among four weekly hatches. Supeene (1971) surveyed 63 flocks of turkeys for the crooked-toe condition and reported this condition to be influenced by type of brooding and litter

management. Crooked toes did not appear to be a problem when detoeing was practiced.

Tebong (1972) observed that the incidence of crooked toes was greater in birds reared in light than in birds reared in darkness. Sex had a highly significant ($P < 0.01$) effect on the incidence of crooked toes (males being more susceptible than females). Affliction with crooked toes was positively correlated with body weight and slipped tendon.

Ali (1973) studied the effect of strain and certain nutritional factors on the development of crooked toes in egg laying strains. The birds were kept in continuous light (24 hours a day) throughout the experiment, and the floor of the cage was covered with smooth paper so as to add additional stress. He concluded that there were strain differences with respect to the incidence of crooked toes; although these differences were not statistically significant. Effects of treatments using different levels of protein and vitamins were not significantly different. A positive relationship was found between body weight and crooked-toe condition (the heavier birds showed more crooked toes than did the lighter birds).

Buckland et al. (1976) indicated that there were no significant effects due to strain, sex, or trials or their interaction, on the percentage of crooked toes in a study involving four lighting regimes.

II. CROOKED KEEL

The Influence of Heredity

Warren (1937) found that the influence of heredity was immediately apparent in the first generation from previously selected stock and that multiple factors are apparently responsible for differences in susceptibility to crooked keel. The F_1 generation from a cross of resistant x susceptible strains of Single Comb White Leghorn was intermediate. In back crosses to the crooked-keel strain, 67 percent of the male progeny had crooked keels, whereas, in back crosses to the straight keel strain only 32 percent of the male progeny were affected. In reciprocal crosses Warren found that there was no evidence of sex-linked genes with major effects. He concluded that the crooked keel trait was definitely hereditary.

The results of a study of Buckner et al. (1946) at the Kentucky Experiment Station which concerned the larger bones of 20-week-old laying hens having straight and crooked keels, were consistent with the finding of Warren and together showed that the sternum in the chicken is slower to calcify than the leg bones. This study indicated that crooked keel is a symptom of a constitutional weakness which is hereditary.

Waters (1949) reported on a study of the prevalence of crooked keels among different inbred lines of adult chickens. An initial examination of birds in the different lines during 1947 indicated that crooked keel is a condition appearing more frequently in some lines than in others. An examination of young chickens showed that the cartilage

of the sternal crest was decidedly crooked even in chicks only eight days of age. Therefore, during 1948, a critical examination of the keels of all chickens in all lines was made at 30 days of age and again at 180 days of age. From the data on the chickens belonging to ten unrelated inbred lines reared in a similar environment, it was evident that the tendency for keels to be either crooked or straight was influenced by the genetic constitution of the line. It was concluded that the genes responsible for crooked keels in birds at 30 days of age are different from those causing crooked keels in the same birds at 180 days of age.

Hyre (1954) presented evidence that the tendency for deformed keels in chickens is inherited. It was found, however, that this tendency will not appear unless chicks have access to perches or are subjected to some other stress.

The Influence of Environment

Platt (1932) reported on a study of feeding different levels of cod liver oil with presence or absence of roosts to eight-week-old cockerels. He found that 26.6 percent of the cockerels receiving the basal ration with no oil and having no roost, had crooked keels of varying degrees, whereas, the birds receiving one and 2 percent, respectively, of cod liver oil in their ration and having no roosts had perfectly straight keels in all instances. On the other hand, 66.6 percent of the birds provided the basal ration and roosts had crooked keels; 64.3 percent of those provided the ration containing 1 percent

cod liver oil and roosts had crooked keels and 44.4 percent of the birds which received the ration containing two percent cod liver oil and roosts had crooked keels. However, Platt (1933), in an experiment on the effect of perches on Single Comb White Leghorn cockerels, found that six of 12 birds having access to the three-inch perches had a slight curvature of the keel. Six of the 12 birds having access to two-inch perches had a more marked curvature of the keel, while the keels of seven of 12 birds having one inch perches had a decided crooked keel similar to the letter S. The birds without perches maintained straight keels during the same period.

Warren (1937) reported that, in most instances, birds developing crooked keels will do so before maturity or by about six months of age. Males showed both a slightly higher incidence of crooked keels and greater degree of deformity. Further, the age at which chickens started to roost, the sharpness of the perches and the extent to which the chickens used the perches all influenced the expression of heritable differences in the tendency to develop crooked keels.

Shoffner and Canfield (1957), indicated that there was some difference in the frequency of crooked keels between groups with access to roosts and those having no roosts. The severity of deformity was particularly pronounced under the roost condition.

Johnson and Smith (1944) reported on the relation of vitamin D to keel deformity in young chickens. In several experiments young chicks were fed from hatching to three to five weeks of age on rations extremely low in vitamin D or supplemented with one or more levels of

the vitamin. The level of vitamin D in the ration was observed to have a uniform and highly significant effect on bone ash. The extent of crookedness of keels was fairly closely related to bone ash deposition within individual trials, but the mean keel scores of different trials were quite variable. In some trials consumption of a ration low in vitamin D resulted in severe crookedness of keels, in other trials the extent of crookedness was not serious, regardless of the intake of vitamin D. In all trials the extent of crookedness of the keel was significantly reduced by supplementation of the basal ration with vitamin D.

Leeson et al. (1976) reported on the effect of light and diet on performance and carcass quality of capons. In an experiment with two series of diets differing in protein level and four lighting treatments, it was found that dietary protein and lighting treatment had no significant ($P > 0.05$) effect on the incidence of crooked keel. No differences with regard to crooked keel were noted when the calcium and phosphorus level of these two diet series varied between ratios of 0.8:0.5 and 1.2:0.4.

III. HERITABILITY ESTIMATES

Methods of estimation and biases associated with heritability estimates have been presented in considerable detail by Lush (1948), Lerner (1958), Dickerson (1969), Falconer (1960), and others.

Many researchers have estimated heritability of various poultry traits, but no estimates of heritability of crooked toes and crooked keels have been published.

Dillard et al. (1953) estimated heritability from paternal, maternal and full sib correlation and from intra-sire regression of daughters on dams. Farnsworth and Nordskog (1955) utilized the hierarchial type of analysis to obtain sire, dam and full-sib components of variance to obtain estimates of heritability, based on doubling the full-sib correlation. Abplanalp (1957) estimated heritability by doubling the full-sib correlation which is based on the average of contribution of genetic variability of both sires and dams.

IV. GENETIC AND PHENOTYPIC CORRELATIONS

Early attempts to determine the genetic relationship among traits were restricted by lack of appropriate statistical methods for separating the genetic and environmental portions of phenotypic correlation. Hazel (1943) developed a method of calculating the genetic correlation among traits. Since that time many estimates of the genetic correlation among various traits of poultry have been published.

Dillard et al. (1953) estimated genetic correlation from paternal half-sib, maternal half-sib and full-sib correlations and from intra-sire regression of daughter on dam. Farnsworth and Nordskog (1955) obtained the component of variance and covariance of sire, dam, and full-sib, from the hierarchial type of analysis to obtain estimates of phenotypic and genetic correlations. Abplanalp (1957) estimated the genetic correlation of two traits from the components of covariance between two traits due to sire, dam, and individual deviation. Kenney (1969) reported that the genetic correlation is a function of the covariance

and respective variances of two traits and is subject to the same sources of bias as estimates of variance components.

CHAPTER IV

EXPERIMENTAL PROCEDURES

I. MANAGEMENT OF THE EXPERIMENT

Scores on crooked-toes and crooked-keel condition were made on 1316 offspring of matings of 19 sires and 168 dams of the Single Comb White Leghorn breed. The sires were selected from a large population on the basis of their ability to respond to manual ejaculation. Likewise, the dams were selected on the basis of the rate of egg production during a 30-day pretrial period. Each sire was mated with 10 dams by use of artificial insemination for a period of 15 days. Eggs were collected daily for 16 days, and were held in an egg cooler room. Position of the eggs was changed daily prior to incubation.

The eggs from each dam were set in an individual pedigree basket in two incubators. The chicks were removed from the incubators on June 6, 1979. At that time each chick was wing-banded and its number recorded, identifying it as to sire and dam.

The chicks were randomly divided among five brooding batteries, each having two pens on each of five levels and with each pen having its own heater and thermostat. The floor of each pen was covered with smooth paper so as to add additional stress. At 28 days of age the birds were transferred to floor pens. The pens had wood shavings as litter and were provided with 1 3/4 inch width roosts. At seven days of age the chicks received Newcastle and infectious bronchitis vaccines.

The rations during the experiment are presented in Table 1. The feed and water were supplied ad libitum. All birds were kept in continuous light (24 hours a day) throughout the experiment.

II. COLLECTION OF DATA

Data were collected from the offspring when they were 98 days of age on the incidence and manifestation of crooked toes and crooked keels as described below:

Crooked Toes

Each bird was individually scored for toe deformity according to the following system:

<u>Score</u>	<u>Toe Condition</u>
1	Normal toes
2	Slightly abnormal in one toe
3	Slightly to moderate abnormality in both feet
4	Sever abnormality in one foot
5	Severe abnormality in both feet

Pictorial standards for scores are contained in Figure 1.

Crooked Keel

Each bird was individually scored for keel deformity according to the following system:

<u>Score</u>	<u>Depth of depression in millimeter</u>	<u>Keel condition</u>
1	—	Normal keel
2	2	Slightly abnormal

TABLE 1
COMPOSITION OF THE DIETS

Feedstuffs	Starter	Grower 1	Grower 2
	lb	lb	lb
Yellow corn	63.795	71.875	75.375
Alfalfa meal, 17%	2.500	5.00	5.000
Fish meal	2.5000	2.500	2.500
Vitamin mix	0.6000	0.600	0.600
Deflourinated rock phosphate	1.5000	1.500	1.500
Ground limestone	0.6000	1.000	1.000
Salt	0.4800	0.500	0.500
Manganese sulfate	0.025	0.025	0.025
Coccidiostat	0.050	2.500	—
Soybean oil meal, 50%	27.9500	14.500	13.500
	100.000	100.000	100.000
<u>Analysis of the rations</u>			
Crude protein, %	21.50	17.59	15.16
Metabolizable energy, c/lb	1365	1382	1396
Productive energy, c/lb	957	966	977
Calcium, %	0.89	1.05	1.05
Phosphorus, %	0.71	0.63	0.62
Available phosphorous, %	0.46	0.42	0.42

The starter ration fed for first 4 weeks, Grower 1 fed 5th to 12th week, Grower 2 fed 12th to 14th week.



Score 1



Score 2



Score 3



Score 4



Score 5

Figure 1. Standards used in scoring toes for the degree of crookedness.

<u>Score</u>	<u>Depth of depression in millimeter</u>	<u>Keel condition</u>
3	4	Moderately abnormal
4	6	Considerably abnormal
5	8	Extreme abnormality

III. METHODS OF ANALYSIS

Four kinds of calculations were done in this study:

1. The analysis of variance based on half-sib and full-sib data for both crooked toes and crooked keel scores separately for each sex, and for all data adjusted for sex difference (Tables 2 and 3). The models on which this type of analysis was based were:

- a. For half-sib data

$$Y_{ik} = \mu + a_i + e_{ik}$$

- b. For full-sib data

$$Y_{ijk} = \mu + a_i + b_{ij} + e_{ijk}$$

where

Y_{ik} = is the score of the k th progeny of the i th sire.

Y_{ijk} = is the score of k th progeny of the j th dam mated to the i th sire.

μ = is the general mean.

a_i = is the effect of the i th sire.

b_{ij} = is the effect of the j th dam mated to the i th sire.

e_{ik} = is random variation among individuals within sire groups.

TABLE 2
ANALYSIS OF VARIANCE OF HALF-SIB DATA

Source of Variation	Degrees of Freedom	Composition of Mean Square
Among sires	$S-1$	$s_W^2 + k s_S^2$
Progeny within sires	$k_{..} - S$	s_W^2

S = number of sires.

$k_{..}$ = total number of progeny.

k = average number of progeny per sire.

$$k = \frac{1}{S-1} \left(k_{..} - \frac{\sum k_i^2}{k_{..}} \right)$$

where:

k_i = number of progeny of the i th sire.

TABLE 3
ANALYSIS OF VARIANCE OF FULL-SIB DATA

Variance	Degrees of Freedom	Composition of Mean Square
Among sires	S-1	$s_W^2 + k_2 s_D^2 + k_3 s_S^2$
Among dams within sire	D-S	$s_W^2 + k_1 s_D^2$
Among progeny within sire	$k_{..} - S$	s_W^2

S = number of sires.

D = number of dams.

$k_{..}$ = total number of progeny.

$$k_1 = \frac{1}{S-D} \left(k_{..} - \frac{\sum_{ij} k_{ij}^2}{k_{i.}} \right)$$

$$k_2 = \frac{1}{S-1} \left(\frac{\sum_{ij} k_{ij}^2}{k_{i.}} - \frac{\sum_{ij} k_{ij}^2}{k_{..}} \right)$$

$$k_3 = \frac{1}{S-1} \left(k_{..} - \frac{\sum_i k_{i.}^2}{k_{..}} \right)$$

where:

$k_{i.}$ = number of progeny of the i th sire.

k_{ij} = number of progeny of the j th dam within the i th sire.

e_{ijk} = is random variation among individuals within full-sib groups.

2. The estimation of heritability on the basis of half-sib and full-sib analysis for both sexes and for the adjusted data.

- a. For half-sib

$$h_S^2 = \frac{4s_S^2}{s_S^2 + s_{W_1}^2}$$

Estimates of the standard errors of the heritability estimates were calculated according to formula of Osborne and Patterson (1952):

$$\text{Standard Error} = \sqrt{\frac{2 (s_W^2)^2 (s_W^2 + k s_S^2)^2}{(s_W^2 + s_S^2)^4 k (k.. - S)}}$$

The average number of progeny (k) per sire was computed according to the formula presented by Becker (1975) for unequal numbers of progeny per sire, as shown in Table 2.

- b. Estimates of heritability (h^2) from full-sib data were calculated according to the following formula:

$$h_S^2 = \frac{4 s_S^2}{s_S^2 + s_D^2 + s_{W_2}^2}$$

$$h_D^2 = \frac{4 s_D^2}{s_S^2 + s_D^2 + s_{W_2}^2}$$

$$h_{S+D}^2 = \frac{2 (s_S^2 + s_D^2)}{s_S^2 + s_D^2 + s_{W_2}^2}$$

where:

h_S^2, h_D^2, h_{S+D}^2 = estimate of heritability from the sire, dam, and combined sire and dam components, respectively.

s_S^2 = variance due to sire differences.

s_D^2 = variance due to dam differences within sires.

$s_{W_1}^2, s_{W_2}^2$ = variance due to differences between members half-sib and full-sib groups, respectively.

Standard errors of heritability estimates have not been determined for unbalanced designs. The method used for estimating standard errors was estimation of the variances of the variance of sire and dam as given by Searle (1961, 1970) and Searle (1971), and these estimates were substituted in the variance of h^2 , as outlined by Becker (1975). The standard errors were obtained by taking the square root of the variances of heritabilities.

3. The estimation of genetic and phenotypic correlations between the two diseases on the basis of half-sib and full-sib analysis for each sex separately and for the adjusted data was determined as shown below:

- a. From half-sib:

$$r_g = \frac{COV_S}{\sqrt{s_{S(x)}^2 s_{S(y)}^2}}$$

$$r_p = \frac{COV_W + COV_S}{\sqrt{(s_{W(x)}^2 + s_{S(x)}^2)(s_{W(y)}^2 + s_{S(y)}^2)}}$$

- b. From full-sibs and paternal and maternal half-sib in the full-sib model based on:

1. Sire-components of variance and covariance

$$r_g = \frac{COV_S}{\sqrt{s_{S(x)}^2 s_{S(y)}^2}}$$

2. Dam components of variance and covariance

$$r_g = \frac{COV_D}{\sqrt{s_{D(x)}^2 s_{D(y)}^2}}$$

3. Dam + sire components of variance and covariance

$$r_g = \frac{COV_S + COV_D}{\sqrt{(s_{S(x)}^2 + s_{D(x)}^2)(s_{S(y)}^2 + s_{D(y)}^2)}}$$

$$r_p = \frac{COV_W + COV_S + COV_D}{\sqrt{(s_{W(x)}^2 + s_{S(x)}^2 + s_{D(x)}^2)(s_{W(y)}^2 + s_{S(y)}^2 + s_{D(y)}^2)}}$$

where:

r_g is the estimate of genetic correlation.

r_p is the estimate of phenotypic correlation

COV_S , COV_D , COV_W = are the covariance component of sire, dam, and individuals, respectively,

(Tables 4 and 5).

TABLE 4
ANALYSIS OF COVARIANCE AND HALF-SIB SIRE
COMPONENTS OF COVARIANCE

Source of Variation	Degrees of Freedom	Composition of Mean Product
Among sires	$S-1$	$COV_W + k COV_S$
Progeny within sires	$k_{..} - S$	COV_W

S = number of sires.

$k_{..}$ = total number of progeny.

k is the same as in Table 2.

TABLE 5
ANALYSIS OF COVARIANCE AND FULL-SIB SIRE AND
DAM COMPONENTS OF COVARIANCE

Source of Variation	Degrees of Freedom	Composition of Mean Product
Among sires	$S-1$	$COV_W + k_2 COV_D + k_3 COV_S$
Among dams	$D-S$	$COV_W + k_1 COV_D$
Among full-sibs	$k_{..} - D$	COV_W

S = number of sires.

D = number of dams.

$k_{..}$ = total number of progeny.

k_1, k_2, k_3 are the same as in Table 3.

$s_{S(x)}^2, s_{S(y)}^2, s_{D(x)}^2, s_{D(y)}^2, s_{W(x)}^2, s_{W(y)}^2$ = are the variance components of sire, dam and individuals for toes (x) and keels (y), respectively.

The standard errors of the estimates of genetic and phenotypic correlations were estimated by the method given by Scheinberg (1966). The variances of the mean squares and the mean products along with covariances of the mean squares and the mean products were calculated in different combinations, as outlined by Becker (1975). The standard errors were obtained by taking the square root of the variances of the genetic and phenotypic correlations.

4. Confidence limits on heritability estimates:

An approximate method for determining confidence limits when there are unequal numbers of progeny per sire was outlined by Becker (1975).

The confidence statement is:

$$P_r (4 (1 - k_{\alpha/2}) < h^2 < 4(1 - k_1 - \alpha/2)) = 1 - \alpha$$

where:

$$k_r = \frac{k MS_W F_r}{MS_S + MS_W (k - 1) F_r}$$

F_r = tabled value of the F distribution

r = either $\alpha/2$ or $1 - \alpha/2$

$F = \alpha/2$ is given directly from table using d.f. for MS_S for numerator and d.f. for MS_W for denominator.

$F_{1 - \alpha/2}$ can be obtained by reversing the degrees of freedom and taking the reciprocal of the tabled value.

$1 - \alpha =$ level of confidence.

There is no estimation of confidence limits on full-sib estimates because confidence limits of heritability estimates from full-sib data have not yet been derived for unbalanced designs.

CHAPTER V

RESULTS AND DISCUSSION

I. ANALYSIS OF VARIANCE

The Influence of Sex

The analysis of variance of toes and keels scores for the half-sib analysis with both sexes in the model are presented in Tables 6 and 7, respectively. There was a significant ($P < 0.001$) effect of sex on the manifestation of both crooked toes and crooked keels. The mean of toes scores was 1.160 for the males and 1.197 for the females.

This result is in agreement with the observation of Tebong (1972), who found that sex had a significant ($P < 0.01$) effect on the incidence of crooked toes (males being more susceptible than females), but is in disagreement with the result of Buckland et al. (1976) who reported no significant ($P > 0.05$) effect of sex on the percentage of crooked toes.

The mean of keels scores was 1.525 for the males and 1.383 for the females.

This result is in agreement with the observation of Warren (1937) who reported that males show both slightly higher incidence of crooked keels and greater degree of deformity than the females.

The Influence of Sire and Dam

The analysis of variance of half-sib data shows significant differences ($P < 0.001$) among sires with respect to the occurrence of

TABLE 6
ANALYSIS OF VARIANCE OF TOE DATA FROM HALF-SIB
MALE AND FEMALE PROGENY

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between sexes	1	57.67	57.67***
Among sires	18	46.11	2.56***
Progeny within sire	1296	1154.28	0.89
Total	1315	1258.06	

*** $P < 0.001$.

TABLE 7
ANALYSIS OF VARIANCE OF KEEL DATA FOR HALF-SIB
MALE AND FEMALE PROGENY

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Between sexes	1	6.67	6.67***
Among sires	18	46.06	2.56***
Progeny within sire	1296	741.62	0.57
Total	1315	794.35	

P < 0.001.

crooked toes and crooked keels with the sexes analyzed separately, and for the adjusted data (Tables 6, 7, 8 and 9). The means of crooked toe scores ranged from 1.800 for sire number six to 1.077 for sire number two, and means for crooked keels ranged from 1.920 for sire number eight to 1.183 for sire number 13 (Tables 10 and 11). These results indicate that the sires differ in their ability to transmit resistance or susceptibility to these bone deformities to their progeny.

Analysis of variance of data for toes of half-sib male progeny show significant differences ($P < 0.001$) among sires (Table 12), with a range of means from 2.053 for sire number eight to 1.089 per sire number two (Table 13). However, the female progeny had less striking differences ($P < 0.05$) among sires with respect to crooked toes (Table 14). The range of sire means for toe scores was from 1.676 for sire number six to 1.028 for sire number 13 (Table 15).

Analysis of variance of half-sib male's keels scores showed significant differences ($P < 0.001$) among sires (Table 16), with a range of means from 2.167 for sire number seven to 1.114 for sire number 13 (Table 17). The female progeny showed less striking differences among sire ($P < 0.05$) (Table 18), with a range of means from 1.750 for sire number seven to 1.240 for sire number eight (Table 19).

The analysis of variance of full-sib data adjusted for sex indicated significant differences ($P < 0.01$) among dams with respect to crooked toes as well as significant differences ($P < 0.05$) among dams for keel deformity.

TABLE 8
ANALYSIS OF VARIANCE OF HALF-SIB
TOE DATA ADJUSTED FOR SEX

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among Sires	18	46.32	2.57 ^{***}
Progeny within sire	1297	1154.31	0.89
Total	1315	1200.63	0.91

^{***} P < 0.001.

TABLE 9
ANALYSIS OF VARIANCE OF HALF-SIB
KEEL DATA ADJUSTED FOR SEX

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	46.08	2.56 ***
Progeny within sire	1297	741.63	0.57
Total	1315	787.71	0.60

P < 0.001.

TABLE 10
MEANS OF TOE SCORES BY SIRE, SEXES COMBINED

Sire Number	Mean ^a $\alpha = 0.05$	Number of Chicks
6	1.800a	65
10	1.692ab	65
8	1.591abc	44
9	1.543abc	81
7	1.532abcd	62
17	1.522abcd	67
19	1.500abcd	58
4	1.490abcd	51
13	1.451abcd	71
16	1.450abcd	60
18	1.440abcd	84
12	1.397bcde	73
14	1.352bcde	91
15	1.317bcde	63
11	1.311cde	90
1	1.234cde	56
3	1.179cde	56
5	1.147de	68
2	1.077e	91

^aMeans with the same letters following them are not significantly different ($P > 0.05$), according to the Duncan Multiple Range test.

TABLE 11
MEANS OF KEEL SCORES BY SIRES
SEXES COMBINED

Sire Number	Mean ^a $\alpha = 0.05$	Number of chicks
7	1.952a	62
19	1.810ab	58
12	1.630bc	73
10	1.615bc	65
4	1.569bc	51
16	1.567bc	60
6	1.580bc	65
5	1.485cdef	68
18	1.476cdef	84
17	1.448cdef	67
2	1.407cdef	91
14	1.407cdef	91
11	1.400cdef	90
3	1.357cdef	56
8	1.318cdef	44
15	1.254def	63
9	1.222ef	81
1	1.221ef	76
13	1.183f	71

^aMeans with the same letters following them are not significantly different ($P > 0.05$), according to the Duncan Multiple Range test.

TABLE 12
ANALYSIS OF VARIANCE OF TOE DATA
FROM MALE HALF-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among Sires	18	53.86	2.99***
Progeny within sire	647	823.88	1.27
Total	665	877.75	

*** $P < 0.001$.

TABLE 13
MEANS OF TOE SCORES OF MALES BY SIRES

Sire Number	Mean ^a $\alpha = 0.05$	Number of Male Chicks
8	2.053a	19
17	1.962a	26
9	1.952a	42
10	1.939a	33
6	1.935a	31
13	1.886a	35
7	1.833ab	30
18	1.725ab	40
16	1.697abc	33
19	1.688abc	32
15	1.655abc	29
4	1.629abc	35
14	1.622abc	45
12	1.500abc	36
11	1.380abc	50
1	1.355abc	30
3	1.220bc	41
5	1.176bc	34
2	1.089c	45

^aMeans with the same letters following them are not significantly different ($P > 0.05$), according to the Duncan Multiple Range test.

TABLE 14
ANALYSIS OF VARIANCE OF TOE DATA
FROM FEMALE HALF-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	14.76	0.82*
Progeny within sire	631	308.03	0.49
Total	649	322.79	

* $P < 0.05$.

TABLE 15
MEANS OF TOE SCORES OF FEMALES BY SIRES

Sire Number	Mean ^a $\alpha = 0.05$	Number of Female Chicks
6	1.676a	34
10	1.438ab	32
12	1.297b	37
46	1.269b	26
7	1.250b	32
17	1.244b	41
8	1.240b	25
11	1.225b	40
4	1.188b	16
18	1.182b	44
1	1.152b	46
19	1.148b	27
5	1.118b	34
9	1.103b	39
14	1.087b	46
3	1.067b	15
2	1.065b	46
15	1.029b	34
13	1.028b	36

^aMeans with the same letters following them are not significantly different ($P > 0.05$), according to Duncan Multiple Range test.

TABLE 16
ANALYSIS OF VARIANCE OF KEEL DATA
FROM MALE HALF-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	51.85	2.88***
Progeny within sire	647	432.49	0.67
Total	665	484.34	

P < 0.001.

TABLE 17
MEANS OF KEEL SCORES OF MALES BY SIRES

Sire Number	Mean ^a $\alpha = 0.05$	Number of Male Chicks
7	2.167a	30
19	2.056a	32
12	1.778ab	36
17	1.769ab	26
6	1.742abc	31
18	1.625bcd	40
16	1.606bcd	33
4	1.600bcd	35
10	1.515bcde	33
2	1.467bcde	45
14	1.467bcde	45
5	1.441bcde	34
11	1.440bcde	50
8	1.421bcde	19
3	1.366bcde	41
15	1.241cde	29
1	1.161de	30
9	1.143e	42
13	1.114e	35

^aMeans with the same letters following them are not significantly different ($P > 0.05$), according to Duncan Multiple Range test.

TABLE 18
ANALYSIS OF VARIANCE OF KEEL DATA
FROM FEMALE HALF-SIBS

Source of Variance	Degrees of Freedom	Sum of Squares	Mean Squares
Among sires	18	13.62	0.76 *
Progeny within sire	631	289.99	0.46
Total	649	303.61	

* $P < 0.05$.

TABLE 19
MEANS OF KEEL SCORES OF FEMALES BY SIRES

Sire Number	Mean ^a $\alpha = 0.05$	Number of Female Chicks
7	1.750a	32
10	1.719a	32
5	1.529ab	34
16	1.519ab	27
4	1.500ab	16
12	1.486ab	37
19	1.385ab	26
11	1.350b	40
2	1.347b	46
14	1.348b	46
18	1.341b	44
3	1.333b	15
9	1.308b	39
6	1.294b	34
15	1.265b	34
1	1.261b	46
13	1.250b	36
17	1.244b	41
8	1.240b	25

^aMeans with the same letters following them are not significantly different ($P > 0.05$), according to Duncan Multiple Range test.

The differences among sires were significant ($P < 0.001$) for both types of deformities (Tables 20 and 21).

The analysis of variance of toe scores of male full-sib progeny shows significant ($P < 0.001$) differences among sires. The differences among dams also were significant ($P < 0.01$) for crooked toes (Table 22). The analysis of variance of full-sib keel data for male progeny shows significant ($P < 0.001$) differences among sires, and less pronounced differences ($P < 0.05$) among dams (Table 23).

The analysis of the data on toe scores of the full-sib female progeny revealed differences among sires ($P < 0.05$), while differences among dams were not significant ($P > 0.05$) (Table 24). For the female progeny, the analysis of full-sib data on keel scores shows differences ($P < 0.05$) among both sires and dams (Table 25).

II. ESTIMATES OF HERITABILITIES

The estimates of heritabilities of crooked toes and crooked keels from half-sib analyses, adjusted and unadjusted for sex differences, are presented in Tables 26, 27, 28, and 29. In the tables of half-sib and full-sib analysis of the unadjusted data it can be seen that male progeny showed higher estimates of heritability than the females. This is probably due to the fact that males are more susceptible to leg and keel deformities than females, possibly because males grow faster and have heavier weights than females.

It is suggested from the heritability tables, that selection would be effective in this flock, especially in males, in reducing the

TABLE 20
ANALYSIS OF VARIANCE OF FULL-SIB TOE
DATA ADJUSTED FOR SEX

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	46.32	2.57 ^{***}
Among dams within sire	149	171.47	1.15 ^{**}
Among progeny within dam	1148	982.84	0.86
Total	1315	1200.64	0.91

^{***} P < 0.001.

^{**} P < 0.01.

TABLE 21
ANALYSIS OF VARIANCE OF FULL-SIB KEEL
DATA ADJUSTED FOR SEX

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	46.08	2.56 ***
Among dams within sire	149	106.22	0.71 *
Among progeny within dam	1148	635.41	0.55
Total	1315	787.71	0.91

*** $P < 0.001$.

* $P < 0.05$.

TABLE 22
ANALYSIS OF VARIANCE OF TOE DATA
FROM MALE FULL-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	53.86	2.99 ***
Among dams within sire	144	229.19	1.59 **
Among progeny within dam	503	594.69	1.18
Total	665	877.75	

** P < 0.01.

*** P < 0.001.

TABLE 23
ANALYSIS OF VARIANCE OF KEEL DATA
FROM MALE FULL-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	51.85	2.88 ***
Among dams within sire	144	113.13	0.79 *
Among progeny within dam	503	319.36	0.63
Total	665	484.34	

* $P < 0.05$.

*** $P < 0.001$.

TABLE 24
ANALYSIS OF VARIANCE OF TOE DATA
FROM FEMALE FULL-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	14.76	0.82 [*]
Among dams within sire	147	62.81	0.43 ^{ns}
Among progeny within dam	484	245.23	0.51
Total	649	322.79	

^{ns} $p > 0.05$.

^{*} $p < 0.05$.

TABLE 25
ANALYSIS OF VARIANCE OF KEEL DATA
FROM FEMALE FULL-SIBS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Among sires	18	13.62	0.76*
Among dams within sire	147	80.26	0.55*
Among progeny within dam	484	209.73	0.43
Total	649	303.61	

* $P < 0.05$.

TABLE 26
ESTIMATES OF HERITABILITY OF TOE AND KEEL SCORES
UNADJUSTED HALF-SIB DATA

Variables	Sex	Estimate [*] ± Standard Error
Toe	Male	0.149 ± 0.017
	Female	0.078 ± 0.016
Keel	Male	0.346 ± 0.040
	Female	0.074 ± 0.031

$$^* \text{Estimate of Heritability} = \frac{4 s_S^2}{s_S^2 + s_W^2}$$

TABLE 27
ESTIMATES OF HERITABILITY OF TOE AND KEEL SCORES
ADJUSTED HALF-SIB DATA

Variables	Estimate [*] ± Standard Error
Toe	0.107 ± 0.013
Keel	0.192 ± 0.019

$$* \text{ Estimate of Heritability} = \frac{4 s_S^2}{s_S^2 + s_W^2}$$

TABLE 28
ESTIMATES OF HERITABILITY OF TOE AND KEEL SCORES
UNADJUSTED FULL-SIB DATA

Variable	Sex	Estimate $\pm$ Standard Error		
		S ^a	D ^b	S + D ^c
Toe	Male	0.114 $\pm$ 0.084	0.312 $\pm$ 0.152	0.213 $\pm$ 0.080
	Female	0.094 $\pm$ 0.060	—	—
Keel	Male	0.323 $\pm$ 0.143	0.208 $\pm$ 0.137	0.265 $\pm$ 0.095
	Female	0.045 $\pm$ 0.062	0.254 $\pm$ 0.156	0.149 $\pm$ 0.058

$$^a \text{Estimate of Heritability} = \frac{4s_S^2}{s_S^2 + s_D^2 + s_W^2}$$

$$^b \text{Estimate of Heritability} = \frac{4s_D^2}{s_S^2 + s_D^2 + s_W^2}$$

$$^c \text{Estimate of Heritability} = \frac{2(s_S^2 + s_D^2)}{s_S^2 + s_D^2 + s_W^2}$$

TABLE 29
ESTIMATES OF HERITABILITY OF TOE AND KEEL SCORES
ADJUSTED FULL-SIB DATA

Variables	Estimate $\pm$ Standard Error		
	S ^a	D ^b	S + D ^c
Toe	0.087 $\pm$ 0.002	0.167 $\pm$ 0.020	0.127 $\pm$ 0.010
Keel	0.176 $\pm$ 0.002	0.138 $\pm$ 0.020	0.157 $\pm$ 0.010

$$^a \text{Estimate of Heritability} = \frac{4s_S^2}{s_S^2 + s_D^2 + s_W^2}$$

$$^b \text{Estimate of Heritability} = \frac{4s_D^2}{s_S^2 + s_D^2 + s_W^2}$$

$$^c \text{Estimate of Heritability} = \frac{2(s_S^2 + s_D^2)}{s_S^2 + s_D^2 + s_W^2}$$

incidence and intensity of crooked toes and crooked keels manifestation. However, considering the estimates of heritability of the adjusted data, it is observed that the keel deformity has higher estimates of heritability than does the toe deformity, and this is probably, because keel crookedness is more responsive to hereditary factors than toe crookedness. For purpose for comparison, the estimate of heritability from the full-sib unadjusted data includes the estimates for both paternal half-sib and maternal half-sib variances. No estimation of heritability from maternal half-sibs and the full-sibs for toe score of female progeny was calculated because the estimated dam component of variance was a negative value.

There have been no previously published estimates of heritability of crooked toes and crooked keels with which to compare these results.

The confidence limits on heritability estimates from the half-sib data were:

1. Toe data from half sib adjusted for sex

$$P_r (0.037 \leq 0.107 \leq 0.286) = 0.95$$

2. Keel data from half-sib adjusted for sex

$$P_r (0.088 \leq 0.192 \leq 0.453) = 0.95$$

3. Toe data from half-sib male progeny

$$P_r (0.038 \leq 0.149 \leq 0.424) = 0.95$$

4. Keel data from half-sib male progeny

$$P_r (0.158 \leq 0.346 \leq 0.774) = 0.95$$

5. Toe data from half-sib female progeny

$$P_r (-0.0067 \leq 0.078 \leq 0.290) = 0.95$$

6. Keel data from half-sib female progeny

$$P_r (-0.007 \leq 0.074 \leq 0.2851) = 0.95$$

The confidence intervals distribution are wide, undoubtedly largely as a result of sampling because of the small number of sires that were used in this study. Using a large number of sires would probably reduce this variation.

III. ESTIMATION OF GENETIC AND PHENOTYPIC CORRELATIONS

The estimates of genetic and phenotypic correlations are presented in Table 30.

Most of the estimates are very small which indicates that the two diseases are practically independent of each other. However, the females yielded higher estimates than males in all cases. The paternal half-sib and full-sib estimates were higher estimates of genetic correlation than maternal or other estimates. Thus, the genetic effect of the sire on the predisposition to crooked toes and keels of the progeny appears to be greater than the effect of the dam. Undoubtedly, the genetic and the phenotypic correlations obtained in this study contain large sampling errors because of the relatively small number of sires and matings from which the data were obtained. Using more sires would reduce these sampling errors.

TABLE 30
ESTIMATES OF GENETIC AND PHENOTYPIC CORRELATIONS BETWEEN
CROOKED TOES AND CROOKED KEELS

Sex	Genetic			Phenotypic
	S	D	S + D	
Half-sib				
Male	0.237 ± 0.326	—	—	0.013 ± 0.069
Female	0.589 ± 0.516	—	—	0.045 ± 0.056
Adjusted	0.389 ± 0.287	—	—	0.019 ± 0.057
Full-sib				
Male *	0.323 ± 0.393	-0.281 ± 0.407	-0.020 ± 0.250	0.005 ± 0.023
Female	0.797 ± 0.718	—	—	0.045 ± 0.022
Adjusted	0.478 ± 0.329	0.099 ± 0.231	0.099 ± 0.231	0.019 ± 0.016

* There is no estimate from maternal half-sibs and full-sibs because the estimate of the dam variance component was a negative value.

CHAPTER VI

SUMMARY

The objectives of this study were to estimate for the skeletal deformities of crooked toes and crooked keels in chickens: (1) the sire and dam effects, (2) the heritability and (3) genetic and phenotypic correlations.

Data were collected from measurements of crooked toes and crooked keels on 1316 offspring, at 98 days of age, from matings of 19 sires and 168 dams of Single Comb White Leghorns. The analyses of variance were based on half-sib and full-sib analyses of both crooked toes and crooked keels scores within each sex, and for all whole data adjusted for sex. The components of variance and covariance due to sire and dam in the model were used to calculate estimates of heritability and genetic and phenotypic correlations.

It was observed that sex has a significant ($P < 0.001$) effect on the incidence of both crooked toes and crooked keels with males having a greater incidence of crooked toes and crooked keels than females.

The analysis of half-sib data showed significant differences ($P < 0.001$ for male progeny and $P < 0.05$ for female progeny) among sires with respect to the occurrence of crooked toes and crooked keels.

The analysis of variance of the full-sib data adjusted for sex showed significant differences ($P < 0.001$) among sires with respect to type of deformities. Also significant differences ($P < 0.01$) among

dams with respect to the incidence of crooked toes score and a significant difference ($P < 0.05$) among dams with respect to keel deformity.

In the full-sib analysis, male progeny showed significant differences ($P < 0.001$) among sires, while the differences among dams were significant ($P < 0.01$) with respect to crooked toes score, and crooked keels score ($P < 0.05$). Differences among sires of female progeny were of low significance ($P < 0.05$), while differences among dams were not significant ($P > 0.05$). With respect to keel scores, the differences in female progeny were of low significance ($P < 0.05$) among both sires and dams.

It was found from the estimates of heritability of crooked toes and crooked keels from half-sib and full-sib analysis adjusted and unadjusted for sex that male progeny gave higher estimates of heritability than the females and in most cases the estimates of heritability of keel score were higher than those of toe score.

From the estimates of genetic and phenotypic correlation, it was found that most were very low, indicating that the two diseases are practically independent of each other. The females yielded in higher estimates than the males in all cases. The paternal half-sib and full-sib estimates of genetic correlation were higher than other estimates. It is concluded that the genetic effect of the sire on the predisposition to crooked toes and keels of the progeny appears to be greater than that of the dam.

LITERATURE CITED

LITERATURE CITED

- Abplanalp, Hans, 1957. Genetic and environmental correlations among production traits of poultry. *Poultry Sci.* 36:226-228.
- Ali, Nahil M., 1973. Effects of strains and certain nutritional factors on incidence of toe abnormalities, eyeball and body weights of chickens. Unpublished Master's Thesis, The University of Tennessee, Knoxville.
- Barr, A. J., J. H. Goodnight, J. P. Sall and J. T. Helwig, 1979. A user's Guide to SAS 79. SAS Institute Inc. Raleigh, North, Carolina.
- Becker, W. A., 1975. Manual of procedures in quantitative genetics. Washington State University Press, Pullman, Washington.
- Black, D. J. G., J. Getty and T. R. Morris, 1952. Infra-red brooding and the crooked-toe problem in chicks. *Science* 170:169.
- Buckland, R. B., D. E. Bernon and A. Goldrosen, 1976. Effect of four lighting regimes on broiler performance. Leg abnormalities and plasma corticoid levels. *Poultry Sci.* 55:1072-1076.
- Buckner, G. E., W. M. Insko, Jr. and Amanda Henry, 1946. Deformed bones of chickens. 1. Crooked Keel, 11. Osteopetrosis and Osteoma. *Ky. Agr. Exp. Sta. Bull.* 492.
- Dickerson, G. E., 1969. Techniques for research in quantitative animal genetics. in Techniques and Procedures in Animal Production Research, Am. Soc. Anim. Prod. Publication.
- Dillard, E. U., G. E. Dickerson and W. F. Lamareaux, 1953. Heritabilities of egg and meat production quantities and their genetic and environmental relationships in New Hampshire pullets. *Poultry Sci.* 32:897.
- Duncan, D. B., 1955. The multiple range and F-tests. *Biometrics* 11:1-42.
- Ewing, W. R., 1963. Poultry Nutrition. The Ray Ewing Co., Pasadena, Calif.
- Falconer, D. S., 1960. Introduction to quantitative genetics. ix+365 pp. Ronald Press, New York.

- Farnsworth, G. M. and A. W. Nordskog, 1955. Breeding for egg quality. 3. Genetic differences in shell characteristics and other egg quality characteristics. *Poultry Sci.* 34:16-26.
- Fisher, R. A., 1958. *Statistical Methods for Research Workers* (13th Ed.). Hafner Publishing Co., Inc., New York, N.Y.
- Hazel, L. N., 1943. The genetic basis for constructing selection indexes. *Genetics* 28:476-490.
- Hicks, A. F. and I. M. Lerner, 1949. Hereditary crooked toes in chickens. *Poultry Sci.* 28:625-626.
- Hyre, H. M., 1954. The effect of heredity and environment on keel deformities in White Leghorns. *Poultry Sci.* 38:1061.
- Johnson, S. R. and R. M. Smith, 1944. Relation of Vitamin D to keel bone deformity in young chickens. *Poultry Sci.* 23:510-515.
- Kinney, T. B., Jr., 1969. A summary of reported estimates of heritabilities and of genetic and phenotypic correlations for traits of chickens. *Agri. Handbook No. 363*. Agri. Res. Serv. USDA, Washington, D.C.
- Leeson, S., J. D. Summers and J. P. Walker, 1976. The effect of light and diet on performance and carcass quality of capons. *Poultry Sci.* 55:438-440.
- Lerner, I. M., 1958. *The genetic basis of selection*. 298 pp., illus. New York.
- Lush, J. L., 1948. *The genetics of populations*. Mimeographed. Department of Animal Science, Iowa State University of Science and Technology, Ames.
- National Research Council, National Academy of Sciences, 1977. *Nutrient requirements of poultry—Seventh revised edition*. Washington, D.C.
- Nestor, K. E., 1971. Crooked toes in turkeys. *Poultry Sci.* 41:1887-1888.
- Norris, L. C., C. D. Caskey and J. C. Bauerfeind, 1939. Malformation of the tarso-metatarsal and phalangeal bone of chicks. *Poultry Sci.* 19:219-223.
- Osborne, R. and W. S. Patterson, 1952. On the sampling variance of heritability estimates derived from variance analysis. *Proc. Roy. Soc. Edinburgh* 364:456.

- Platt, C. S., 1932. Early roosting as a cause of crooked keels in S. C. White Leghorn cockerels. *Poultry Sci.* 11:362.
- Platt, C. S., 1933. Crooked keels in relation to width of perch. *Poultry Sci.* 12:333.
- Scheinberg, E., 1966. The sampling variance of the correlation coefficients estimated in genetic experiments. *Biometrics* 22:187-191.
- Searle, S. R., 1961. Variance components in the unbalanced 2-way nested classification. *Ann. Math. Stat.* 32:1161-1166.
- Searle, S. R., 1970. Large sample variances of likelihood estimators of variance components using unbalanced data. *Biometrics* 26:505-524.
- Searle, S. R., 1971. *Linear Models.* John Wiley and Sons, Inc., New York.
- Shoffner, R. N. and T. H. Canfield, 1957. Keel defects in males ranged with and without roosts. *Poultry Sci.* 26:445-446.
- Snedecor, G. W., 1956. *Statistical Methods.* Iowa State College Press, Ames, Iowa.
- Steel, R. G. D. and J. M. Torrie, 1960. *Principles and Procedures of Statistics.* McGraw-Hill Book Co., Inc., New York.
- Supeene, N. J., 1971. Crooked toes in turkeys. *Poultry Dig.* 30:126.
- Tebong, E. D., 1972. A comparative study of photoperiods and housing system in broiler production. Unpublished Master's Thesis, The University of Tennessee, Knoxville.
- Warren, D. C., 1937. Physiologic and genetic studies of crooked keels in chickens. *Kan Agr. Expt. Sta. Tech. Bul.* 44.
- Waters, N. F., 1949. The occurrence of crooked keels among inbred lines of White Leghorns. *Poultry Sci.* 28:725-730.

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