A STUDY OF THE INHERITANCE OF RATE OF GROWTH AND RATE

OF FEATHERING IN THE DOMESTIC FOWL

By

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INTRODUCTION

A knowledge of the inheritance of the physiological characters, rate of growth and rate of feathering, is of material value to the poultry industry as well as of fundamental value to the geneticist. According to the Agricultural Marketing Service of the United States Department of Agriculture, approximately 900,000,000 chickens were raised in this country during 1941. Approximately 160,000,000 of these were raised in specialized farming areas specifically for broilers and the majority of those raised on all farms were eaten or sold before they reached maturity.

It is generally recognized by poultrymen that the most profitable birds for broilers are those that grow and feather most rapidly. More efficient use can be made of the equipment and labor. Fast-growing birds utilize feed more efficiently than those that grow more slowly because less feed is used for maintenance as the body requirements are maintained for a shorter period before a definite market weight is reached. Poorly feathered broilers are subject to severe market discrimination.

Breeds of the Mediterranean class are efficient producers of eggs and the S. C. White Leghorn is used for commercial egg production more extensively than any other breed and variety. Leghorns usually feather very rapidly and grow comparatively rapidly at first but utilize feed less efficiently as they approach 2 or 3 pounds in weight. Most strains of the heavier breeds and varieties utilize feed more efficiently than the Leghorn, but few strains feather as rapidly.

Some strains of the New Hampshire breed have been bred for rapid growth and feathering and are very efficient for broiler production when used as

pure breeds or when they are crossed with strains of other breeds. However, on the live poultry markets there is usually a discrimination against birds of breeds and varieties other than the Barred Plymouth Rocks or crosses in which the barred plumage pattern is dominant.

The Barred Plymouth Rock has been one of the most popular varieties for a number of years. Previous to the development of the commercial broiler industry, individuals were prized that more nearly met all the description for type and color markings as given in the American Standard of Perfection (2). Until 1935 this standard decreed that males and females should be of equal shade although it had long been known that the males tend to be lighter in color than the females. Spillman (85) and Pearl and Surface (72) observed that the barring character was determined by a dominant sex-linked gene. Since the female is heterozygous for the sex chromosome, she is naturally darker than the male. The influence of this standard, set up primarily for the poultry shows, has affected the progress of the Barred Plymouth Rock breeders in this country in developing birds that are efficient producers of poultry meat at broiler age.

LITERATURE REVIEW

Although it has long been known that the males in each breed usually grow faster and feather more slowly than the females and that birds belonging to the light-weight breeds, such as Leghorns, reach body maturity earlier in life and feather more rapidly than heavy-weight breeds, such as Plymouth Rocks, comparatively little is known concerning the inheritance of these two characters. It is also well known that several changes take place in the plumage of a chicken during its life time. The down that is observed at hatching time is soon superseded by chick feathering, which in turn is replaced in a fairly regular sequence by juvenile feathers and then the adult plumage.

Influence of Egg Size on Rate of Growth. Upp (86), Hays and Sanborn (27), and Funk, Knandel, and Callenbach (18) reported that rate of growth in chicks is not influenced by the weight of eggs from which the chicks were hatched. Hays and Sanborn (28) reported that hen eggs produced chicks that grew faster from 4 to 16 weeks than chicks hatched from pullet eggs.

Effects of Crossbreeding on Growth Rate. Due to the recent interest in broiler production, numerous investigations have been made of the effects of crossbreeding on rate of growth. May (67), Warren (90), Water (95), Jaap and Morris (40), Horlacher and Smith (35), Bice and Tower (6), Knox and Olsen (53), Knox, Quinn, and Godfrey (54), each making a series of crosses, in general found increased acceleration in growth from hybridization as compared with the purebreds. This increased acceleration in weight was maintained for approximately 8 to 12 weeks. However, in the investigations where the F_1 generation was raised to maturity, the average weight was approximately the same as the purebred progeny. In each of the investigations where recipro-

cal matings were reported, except Waters (95), the F_1 generation females differed materially in weight indicating one or more sex-linked genes for rate of growth. However, when the males from the larger breed were crossed with females from the smaller breed, the F_1 males also had a tendency to be larger at 10 weeks of age than those from the reciprocal crosses. Axelsson (5), from the results of crosses involving three breeds of poultry, found no tendency for rate of growth to be sex-linked.

Genetics of Growth Rate. Latimer (56) and Lerner and Asmundson (61) approached the study of rate of growth in a different manner than the investigators previously reviewed. Latimer observed that the rate of growth of the leg bones was higher than the rate of increase of body weight. He also found that the leg bone, with the exception of the femur, increased from hatching time to maturity to a greater extent in males than in females. Lerner and Asmundson (61) used the formula of Minot:

$$R = \frac{W_2 - W_1}{\frac{1}{2}(W_2 + W_1)}$$

in which R measures rate of growth, W_1 hatching weight, and W_2 final weight. Asmundson and Lerner (4), applying Minot's formula to purebred White Leghorns and Barred Plymouth Rocks, found significant differences between families for rate of growth at 2 weeks and 8 weeks, and they concluded that rate of growth was controlled by multiple genetic factors.

Lerner (57) reported a very extensive review of growth. He found that the growth of the pectoralis major muscle and the leg bones, as related to the growth of the entire organism, follows a similar course in the Plymouth Rock and the Minorca breeds of fowl. Hybrids between these two breeds, including first-generation crosses as well as backcrosses of those to both parents, were found to possess the same pattern of growth of the structures

studied as the parents. Sex differences were noted in the values of the coefficient of heterogonic growth, since the females, when compared with the males, showed a higher value for the pectoralis major muscle with respect to body weight and a lower value for the leg length with respect to body weight. The basic genetic complex for the type of growth of parts with respect to the growth of the whole was found to be common to the different breeds of poultry with the exception of the bantams he studied. While in other breeds, hypergony was indicated for muscle and leg bone, he found in bantams hypogony was present for leg bones and an approximation to isogony in the muscle. He suggested that bantams possess growth-retarding factors which affect the different parts.

Growth gradients based on length measurements were observed in the posterior limb as the tarsometatarsus grew at a more rapid rate in relation to the rate of body growth, the tibiotarsus was intermediate in rate of growth, and the femur the slowest. Jaap and Morris (40), from an analysis of variance of the body weight of 6 pure breeds and varieties, obtained highly significant differences between the means when the chickens were grouped according to variety, sire, dam, and sex. Lerner and Asmundenn (62), applying Schmalhausen's (79) growth constants to Warren's (90) data, noted the following points: (1) evidence of sex linkage; (2) differences in growth constants between breeds and strains and between sexes; (3) a decrease of early growth rate due to later hatches is compensated in later stages; (4) differences in early growth rates between breeds reflect differences in adult weight; (5) definitive weights within breeds are independent of the patterns for growth in the early stages. Lerner (58) found that the ratio for the growth of the tarsometatarsus with respect to body weight tends to increase from 4 to 12 weeks and to decrease from 12 to 20 weeks of age. He found that the fluctuations arise as a result of dissimilarity of the growth patterns of the contributing components.

Milby and Henderson (71) compared the rate of growth for different species of poultry. They found that chickens, turkeys, and pheasants grew at practically the same rate during periods of constant growth, but the period was more prolonged for turkeys. Pheasants and chicks grew at the same rate for 15 weeks, but while the pheasants stopped the chickens continued growing to 10 months of age. Migratory ducks and geese had very similar growth rates, and the growth rate for both doubled that for turkeys, but the decline occurred earlier and was much more pronounced. Annin and Halpin (3) found no material difference in growth rate or total weight at 28 weeks between capons and cockerels from either purebreds or crossbreds, between the purebred and crossbred cockerels, or between the purebred and crossbred capons.

The deterious influence of summer temperatures on the rate of growth has been discussed by Kempster and Parker (51) and Kempster (49,50). They found that maximum temperatures that prevailed during the summer are largely responsible for the retarded growth of late-hatched pullets, although the retarded growth is most pronounced at the age of 20 weeks, they found that the retarded chicks eventually obtain the same weight as earlier-hatched chicks.

Effects of Inbreeding on Growth Rate. Dunkerly (16) reported an investigation in which he found little difference between the weights of inbred and outbred birds at sexual maturity. Waters and Lambert (96) found growth rate and adult body weight to be unaffected by different degrees of inbreeding in which some lines were carried as far as the ninth generation. Knox, Quinn, and Godfrey (54) have also found no influence on rate of growth from inbreeding carefully selected strains of Rhode Island Reds and Light Sussex. Godfrey and Marsden (22) made a study of the effects of inbreeding Bronze turkeys as far as the fourth generation of brother-sister matings. They also observed no appreciable effect from inbreeding.

Although the results from breeding practices with laboratory animals are not always directly correlated with the results from animals in a more variable environment, they act as a valuable guide in planning general breeding practices. McPhee and Eaton (70) made an 18-year investigation involving 5 inbred families of guinea pig control stock, and also animals from crosses between the different inbred families. They found that crosses between the light-weight families resulted in a marked increase in growth and weight of the young, crosses between light-weight and heavy-weight families resulted in young whose growth curves approached or coincided with that of the heavy-weight families, but crosses between the 2 heavy-weight families did not result in any significant improvement.

Relation of Rate of Growth to Adult Size. According to Schnetzler(81), the inherited differences in rate of growth are associated with differences in mature body weight. He found that by selecting some of the heaviest females and some of the lightest females and mating them to similar males selected in the same manner he obtained two lines of chicks that were significantly different in weight at 8 weeks of age and that the difference in weight increased until maturity.

Jaap and Morris (40) from their study of 6 breeds and varieties, found rate of growth at 8 weeks a separate entity and not necessarily related to adult weight.

Differential Growth in the Size and Number of Cells. Rensch (76) reported that the difference in size between bantams and larger breeds and differences in size among the various larger breeds is due to differences in cell size as well as in cell number. Buicchianti (8) observed that chick embryos have a rather definite number of cells at particular morphological stages, regardless of the time required to reach those stages. Weller (48) concluded, however, that the differences in size among the breeds of fowl

was due to differences in size of the cells.

Byerly (9) investigated the size of embryos of the same age and from eggs of the same size, from matings of Rhode Island Reds and White Leghorns, and reciprocal crosses between the two varieties. The White Leghorn and hybrid embryos were found to be somewhat heavier than Rhode Island Red embryos of the same age during the first half of the incubation period, but the Rhode Island Red and hybrid embryos were heavier during the latter half. He concluded that the difference decreased or disappeared by hatching time, due to the limitation of food. Henderson (30) observed little difference in the rate of the growth of embryos of White Leghorns, Dark Cornish, and their reciprocal crosses. Castle and Gregory (10) found that crossbred embryos grew faster than purebred embryos. Blunn and Gregory (7) concluded that the rate of cell prolification was greater in the larger breeds than in the smaller size breeds.

Since it was previously known that glutathione stimulates cell prolification, Gregory, Goss, and Asmundson (25) studied the glutathione concentration at different ages and found it to be positively correlated with fast-embryo growth rate and post-hatching growth rate.

Inheritance of Body Size. Numerous crosses have been made by different investigators in an effort to study the inheritance of body size. Punnett and Bailey (74), May (67), Kopec (55), Warren (88), and/Waters (95), each using two breeds that were not considerably different in weight, found that the adult body weight of the F_1 progeny was approximately intermediate between the parental breeds or slightly nearer the larger breed. May and Waters (68), Jull and Quinn (46), Maw (65), and Godfrey and Quinn (23), using breeds that differed very significantly in adult body weight, found the adult progeny to be nearer the weight of the smaller parental breed, suggesting that, possibly, there are dominant genes for small body size. The investigation

of May (67), Kopec (55), Maw (65), and Godfrey and Quinn (23) showed a significant difference between the females of the two reciprocal crosses, indicating that at least one sex-linked gene also is involved.

Lerner (57) and Jull (45) reviewed other investigations concerning the inheritance of body size. From the results of these investigations it is evident that the inheritance of body weight is very complicated and cannot be completely solved by the methods that have been previously used.

Inheritance of Body Shape. Schneider and Dunn (30) reported that body weight is from three to six times as variable as bone measurements. They also observed that the humerus, ulna, femur, and tibiotarsus were 16 percent longer in the males than females. Latimer (56) found a difference of approximately 20 percent between the sexes in the length of those bones, whereas Hutt (36) observed a difference of only 13 percent. Hutt's (36) work also showed that the greatest difference in length between the sexes is in the tarsometatarsus.

Other investigators, including Maw (65) and Lerner (57), have shown that measurements of the appendicular skeleton of the fowl is a more reliable criterion of the actual size of the bird and are less variable than body weights. Measurements of the long bones, particularly the shanks, seem to be the most accurate and practical criteria.

Investigations of Wright (97, 98) and Dunn (15) show that many genes are involved in the inheritance of bone length, with some of the genes having a cumulative effect on the growth of certain parts only. Kopec (55) observed that Buff Orpingtons had longer tibiotarsi and tarsometatarsi than the White Leghorns and the length of these bones in the F_1 progeny obtained from crossing these two breeds were almost as great as in the long-boned parents. Ghigi and Taibell (20) crossed the Indian Game with the Leghorn

and stated that the F_1 generation obtained were approximately the same length as the longer-boned parents.

Maw (65) found that when the females of the smaller breed were sired by males of the larger breed, the leg and wing bones of the progeny were significantly larger than the leg and wing bones from progeny of the reciprocal mating, again indicating one or more sex-linked genes for size. He obtained a correlation of 0.9 between the leg and wing bones of the same bird of the F_2 generation. Maw and Maw (66), in an investigation involving Barred Plymouth Rock matings, obtained data indicating that the type of sire used determines in a large measure the length of back, keel length, and shank length of the male progeny, but had no effect on body weight or other measurements.

Interesting investigations have been reported by Jaap (38),/Jaap and Penquite (41) regarding basic measurements of conformation or shape of the fowl. These investigators found that differences in conformation of live birds may be accurately expressed by determining the relationship between the cube root of their body weight and four linear measurements, shank, length, keel length, anterior depth, and anterior width. They found that growth in shank length ceases by the end of six months of age for males and at five months of age for females, but body growth when measured by keel length continues to the end of ten months of age. The correlations that they obtained between live and dressed birds show that these four measurements will accurately express differences in conformation of not only different lines of chickens but also different lines of turkeys. Jaap and Thompson (43) confirmed the conclusions previously made by Maw and Maw (66) that the body conformation of the sire is transmitted to his progeny.

Jaap (39) reported a thorough investigation of body form in growing chicks. He found that male chicks were heavier than their sisters at two weeks of age. The longitudinal increases in shank length were observed to cease by 16 to 18 weeks of age in all female groups except Light Brahmas. Since shank length was found to rapidly approach its upper asymptate in growth, he suggested that relative growth constants for shank lengths of females may apply only to growth prior to 12 weeks of age. Other evidence suggests that a comparable age in males is 16 weeks. Anterior body depth was found to become relatively smaller between 8 and 12 weeks in both sexes Since heritable differences in conformation manifested between groups could not be readily distinguished until the birds were 12 weeks of age, he concluded that a much greater refinement in the method of describing body form is needed for growing chicks.

Development of Chick Feathering. The earliest work reported was by Davies (13). He reported that the feather germ arises in the embryo about the fifth day of incubation by a massing of the mesodermal cells under the epidermis. The overlying dermis was found next to undergo a thickening and develop into several layers. Each papilla becomes elongated and gradually sinks into a depression and becomes enclosed by a follicle. Each feather was observed to be formed from a thickening of the color of the epidermal cells at the base of the feather papilla. According to Kaupp (47) the feathers develop in definite rows or tracts known as pterylae. The spaces between are known as apteria. Jones (44), from a study of the development of nestling feathers, concluded that the first down and successive feathers are developed from one continuous growth. This conclusion was also reported by Rice, Nixon, and Rogers (77).

Chu (11) describes in detail four successive plumages from hatching to the adult stage. The down first appears on the chick about the tenth day of

incubation and at hatching completely covers the chick, but is replaced subsequently by definite chick feathers by a very gradual process. Before the down is completely replaced by chick feathers, juvenile plumage feathers begin to appear. Due to the orderly manner in which feathers are molted, the change from juvenile to adult plumage is a gradual process.

Considerable variability in the sequence of molting of the juvenile feathers has been observed by Heinroth (29) and by Dwight (17). Dunn and Landauer (16) found that in the Silver-Spangled Hamburg the process of molt occurs in a definite rhythm in a given feather tract and is almost continuous during growth. Warren and Gordon (93,94) studied the sequence of the appearance and replacement of the juvenile flight feathers in White Leghorns, Rhode Island Reds, and Light Brahmas and found an irregular sequence of the molt, but these juvenile remiges undergo at least one complete molt during growth. Marble (63) observed in White Leghorns that two peaks of body molt occur between hatching time and twenty weeks of age and one complete wing and tail feather molt. He found considerable molt on the neck, back, thigh, and breast regions in the female, but no molt was noted in the males at that age or up to 7 and 8 weeks of age. He stated that it was impossible to forecast age at sexual maturity in the females by the degree of primary wing feathers at 8 weeks of age. By a process of dyeing White Wyandottes at 3 weeks and again with a different color of dye at 6 weeks, Radi and Warren (75) found no indication of molt at 7 weeks and only slight evidence of molt at 9 weeks.

Axelsson (5) obtained highly significant correlations between rate of growth at 33 days and the length of the primary, secondary, and tail feathers. He concluded also that the correlation between rate of feathering and rate growth seemed to be of a physiological nature and the difference between two rates may be regarded as hereditarily independent.

Gericke and Platt (19) made observations on the appearance of the first definite feathering in Barred Plymouth Rock chicks and reported that the time of appearance of the tracts varied greatly on the individual birds. As a guide for comparative studies on the appearance of the first feather above the skin on birds fed a normal diet they presented the following table:

Humeral tract (shoulder)	- second-third week
Femoral tract (thigh)	- second-third week
Caudal tract (rump)	- third-fourth week
Pectoral tract (breast)	- third-fourth week
Cervical tract (neck)	- fourth-fifth week
Ventral tract (abdomen)	- fourth-fifth week
Crural tract (leg)	- fourth-fifth week
Dorsal tract (back)	- fifth-sixth week
Alar tract (wing coverts)	- sixth-seventh week
Caput tract (head)	- sixth-seventh week

According to the investigation of Holmes (34), the order of feathering of the tract is first determined in the embryo stage, with each feather tract, as it arises in the embryo, having a definite order. Radi and Warren (75) also observed great variation in the appearance of the first feather of each tract with as much as 8 weeks' variation in the tract of a single bird. They also observed that the White Leghorns tend to develop feathers in some tracts earlier than Rhode Island Reds.

The Genetics of Feather Growth. Although it has long been known that some breeds feather more rapidly than others, it has been only in recent years that any interest has been shown in the differences in the genetic composition of the different breeds. Serebrovsky (82), from a cross of Russian Orloffs and Barred Plymouth Rocks, was first to observe a sex-linked factor for rate of feathering. Without previous knowledge of this work, Warren (97) also made the same observation when he crossed White Leghorn

the male progeny of this cross feathered more slowly than the females.
He concluded, after obtaining F_2 and backcross progeny that slow rate
of feathering is sex-linked and dominant to rapid feathering. Saharova
(78), from a cross of Cochin males and Indian Tavloff females, also noted
that both sexes were slow feathering, whereas in the reciprocal cross
he obtained fast-feathering females and slow-feathering males. From a
series of crosses in which a number of slow-feathering males were crossed
with White Leghorn females, Kinugawa (52) observed that males were
invariably slow-feathering and the females fast-feathering.

Warren (90) discovered the possibility of using this sex-linked factor
for sex identification. He illustrated the fact that when fast-feathering
males are crossed with slow-feathering females, the sex of the progeny
can be accurately determined by the presence or absence of tail feathers
at 10 days. He also showed that the progeny could be sexed with a high
degree of accuracy at hatching time by observing the growth of the primary
and secondary wing feathers. In continuing these investigations, Warren
(91) found that some of his White Leghorns carried an autosomal recessive
gene that retarded feather development. This gene retards the development
of all but the first three secondary flight feathers at hatching time and
the tail feathers at 10 days of age, but does not affect feather develop-
ment beyond the juvenile plumage stage.

McClary and Bearse (69) reported a recessive autosomal factor for
slow feathering in White Leghorn chicks. The slow feathering was noted by
the absence of tail and secondary wing feathers, and the slow growth of
primary wing and body feathers until the chicks were 4 to 6 weeks of age.

The relation of rate of feathering to genetic as well as to environ-
mental factor has been studied by a number of investigators. Gildow (21)

reported that slow-feathering and fast-feathering chicks grew at approximately the same rate. Martin (64) made an investigation of exhibition and production-bred Barred Plymouth Rocks brooded and raised together and reported that the exhibition stock not only grew at a slower rate but also had more slow feathering chicks than the production-bred stock. He concluded that rate of development of feathering over the back is closely related to rate of growth. He also suggested that there is possibly a physiological linkage between the rate of feathering and the quality of barring in Barred Plymouth Rocks.

Gericke and Platt (19) also observed a high relationship between body weight and feather development at 8 weeks of age. Jaap and Morris (40) reported a thorough analysis of the source of variation in rate of feather growth. When conditions of feeding and management were held constant they obtained the following percentages for some of the sources of variation: varieties 4, sire 11, dam 16, sex 20, other sources 49. They also found rate of feathering to be correlated with rate of growth but the degree of determination was rather low.

Since the White Leghorn in almost all cases carries the sex-linked, recessive gene for rate of feathering and also is feathered rather completely at broiler age, it is generally assumed that this gene affects all the feather tracts. However, no data have been reported to show the influence of this gene on tracts other than the remiges and rectices. Jaap and Thompson (42) made the following statement: "If a chick has long and growing pin feathers at hatching, it is almost humanly impossible to make it develop a bare back or feather slowly. If at 10 days after hatching the chick has a 'whiskbroom' tail like Leghorns, it is always well feathered early." No data were included in this publication to substantiate this conclusion.

Darrow (12) reported an investigation of the relation of day-old chick feathering and feathering at 10 days to feathering at broiler age in heavy breeds showing sex-linked early feathering. The number and length of primary and secondary wing feathers and the relative length of the covert feathers in relation to the flight feathers were considered at hatching. At 10 days of age estimations were made of the relative length of wing and tail feathers. The degree of feathering on the back was observed at 6 weeks and each bird was scored according to five arbitrary grades. A strong tendency was found to exist for the day-old chicks having the greater number and length of primary and secondary wing feathers to be better feathered at broiler age. He concluded that the highest correlation is between well developed tail feathers at ten days and good back feathering at six weeks.

Linkage of the Gene for Feather Development with other Genes. A number of investigators, including Haldane (26), Serebrovsky and Wassina (83), Warren (89), Hertwig (32), Hutt (37), and Punnett (73), have reported crossing-over percentages between this gene and other sex-linked genes. Values ranging from 43 to 49 percent have been obtained between the gene for barred plumage and the gene for rate of feathering, which indicates that these two genes are almost on the opposite ends of the sex chromosome. Hutt (37) has suggested the probable order of arrangement of seven of the genes on the sex chromosome to be as follows: (1) head spot, (2) inhibitor of dermal and mesodermal pigment, (3) barring, (4) light iris, (5) light down, (6) silver, and (7) slow feathering. This arrangement has been confirmed by Punnett (73). The crossing-over percentages reported between the gene for rate of feathering and the nearest gene, silver, range from 8 to 14.

MATERIALS AND METHODS

This investigation was started in the spring of 1940. Since previous investigations had shown that a sex-linked gene exists that affected rate of feathering and is loosely linked with a gene for barred plumage, stock was chosen in which the genetic constitution with respect to these two genes is generally known. An exhibition-bred Barred Plymouth Rock cockerel was purchased and crossed with Brown Leghorn pullets that had been purchased previously in order to provide material for hormone studies. A reciprocal cross was made by mating a Brown Leghorn cockerel to production-bred Barred Plymouth Rock pullets already available on the University poultry farm.

The average weight in grams, at approximately 10 months of age, of the females used was 2396 for the Barred Plymouth Rocks and 1619 for the Brown Leghorns. The Barred Plymouth Rock male weight 3000 grams and the Brown Leghorn male weighed 1740 grams at approximately 10 months of age. The Brown Leghorns were about the same weight as those usually found in commercial flocks, but the Barred Plymouth Rocks were slightly lighter. At this same age the shank lengths of these same parental birds were measured and a simplified index of the conformation was calculated from the equation used by Jaap (39) and Lerner (60):

$$\text{Shape ratio} = \frac{\text{Shank length}}{\sqrt[3]{\text{Body weight}}}$$

The shank measurements were obtained in inches for the parental stock and progeny. The shape ratios obtained from the average body weights and shank lengths of the Barred Plymouth Rock and Brown Leghorn females were 0.265 and 0.271, respectively, and 0.324 and 0.317 for the Barred Plymouth Rock and Brown Leghorn males, respectively.

These ratios differ considerably in magnitude from those reported by the other two investigators, since Jaap's measurements were expressed in pounds and inches and Lerner's measurements were expressed in grams and centimeters, respectively.

While Lerner (59) has shown mathematically that under certain conditions this ratio is a function of the allometric or relative growth equation, it is used in this study only as a criterion of the conformation or shape and not as a measure of how the shape of the chicken was attained. Since Lerner (57) has shown that shank length exhibits positive allometry as compared with the body as a whole, Jaap (39) was able to demonstrate that the numerical values of the shape ratio have different values as the bird increases in age. Jaap also reported that heritable differences in conformation could not be distinguished readily until the birds were 12 weeks of age. Hence the use of this equation in determining conformation is of limited value when applied to measurements obtained at 8 weeks of age.

During the spring of 1940 Brown Leghorns and the progeny from the two reciprocal matings were brooded in batteries until 10 days old and then taken to the Maryland Experimental Station poultry range and raised in colony brooder houses with free access to range. In the fall of 1940 backcross and F1 matings were made and the progeny from these matings were brooded in batteries under as uniform conditions as possible. The main object in raising the Brown Leghorns and F1 progeny on range was to grow satisfactory cockerels and pullets for future breeding purposes. Since the F2 backcross progeny were to be held only until they were 8 weeks of age they were not transferred to colony houses. Although this did not provide comparable conditions with those of the birds raised on range it provided more uniform environmental conditions for the F2 and backcross progeny than can usually be maintained under range conditions. The

Maryland Experimental Station mash, which has an analysis of approximately 21 percent protein, was used throughout the growing period.

The chicks were individually pedigreed very soon after they were hatched and at 10 days of age they were weighed individually and observed for growth of tail feathers. When the birds attained 8 weeks of age they were reweighed, measured for shank length, and observed for degree of feather development. The Brown Leghorns and F_1 progeny were observed only for the degree of feathering over the back and shoulders. At the time these first observations were made a knowledge of the degree of feathering of these two tracts was thought to be sufficient, since freedom from "bare backs" has the greatest economic significance on the poultry market. These observations conform in general with those made by Jaap and Morris (40) in which birds were classified primarily on the degree of feathering over the back and wings. However, after an analysis of the results of the observations on the F_1 progeny had been made, the value of information on the degree of feathering of the other tracts was recognized. The F_2 and backcross generations were observed for the degree of feathering on all of the tracts considered by Gericke and Platt (19) and Radi and Warren (75) except the caput tract; i.e., the cervical, dorsal, caudal, humeral, alar, femoral, crural, pectoral, and ventral tracts, respectively. Although a knowledge of the rate of feathering of the caput tract may be of scientific value it has no economic value, since in dressed poultry where the heads are not removed these feathers are not plucked.

The arbitrary system of scoring the estimated degree of feathering on each of the tracts observed varied somewhat from those used by the previous investigators. If no feathers had appeared and the down still persisted, the tract was given a score of zero. If the feathers were sparsely scattered,

many in the pin stage, and areas free from feathering, the tract was scored
as one. The estimated degree of feathering represented by these first two
scores in general agree with the classification used by the previous investi-
gators. In cases of more complete feather development greater emphasis was
given to the presence of pin feathers. If any appreciable degree of pin
feathers was noted, regardless of the length or abundance of feathering,
the tract was not scored higher than three. A score of three was given each
tract that had its complement of feathers and no pin feathers too short to
be easily removed.

Due to the emphasis given to the presence or absence of feathers in the
pin stage, greater consideration was given to the extended and adjacent
areas of the different tracts. The area of the thigh that extends above the
femoral tract was observed as well as the area that is usually feathered within
two or three weeks of age. The breast area was also classified on the basis
of the degree of feathering along the median line of the body where the
pectoral areas eventually meet as well as the area of the two longitŭdinal
tracts that are usually feathered within 4 or 5 weeks of age.

EXPERIMENTAL RESULTS

Comparison of Brown Leghorn and P_1 Progeny. The mean body weight,
shank length, shape ratio, and feather score for the back and shoulder
tracts are given in Table 1 for the Brown Leghorns and progeny from the
reciprocal crosses. It is noted that the means obtained for the F_1 progeny
are higher for body weight and shank length, approximately the same for
shape ratio, and lower for feather score than those obtained for the Brown
Leghorns. Since no progeny from exhibition-bred or production-bred
Barred Plymouth Rocks that had been brooded under the same conditions
were available for observation, it is impossible to determine accurately
the degree of hybrid vigor or heterosis displayed by the F_1 progeny.
Production-bred Barred Plymouth Rocks of similar breeding to the females
involved in this investigation were used in an investigation of feed
utilization by Hess, Byerly, and Jull (33). The average weight obtained
between 7 and 8 weeks of age was 553 grams, including both sexes, fed the
same diet as fed in this investigation but brooded in batteries. Their
birds were not systematically scored for feather development but a large
number was observed to be bare or partially feathered over the back at
approximately 8 weeks of age.

Martin (84) obtained average weights at 2 months of age for exhibition-
bred birds ranging from 219 to 342 grams and from 235 to 337 grams, respectively,
for males and females, depending upon the classification of feather develop-
ment at that age. As has previously been stated his exhibition-bred birds
grew at a slower rate and feathered more slowly than production-bred stock.
On approximately the same basis as was used in this investigation the degree
of feathering of the dorsal tract averaged 0.63 and 1.11, respectively, for
the exhibition males and females. Jaap and Morris (40) in an investigation,

TABLE I

A Comparison of the Brown Leghorn Progeny and
F_1 Progeny from the Two Reciprocal Crosses at
8 Weeks of Age for Body Weight, Shank Length,
Shape Ratio, and Feathering over the Back and
Shoulders

Mating	Sex of Progeny	No. of Progeny	Weight at 8 weeks (Grams)	Shank Length (Inches)	Shape Ratio*	Feathering at 8 weeks	
						Back	Shoulders
Brown Leghorns	Males	29	433.7	2.51	0.305	2.41	2.73
Exhibition-bred Rock x Leghorns	Males	37	463.2	2.35	0.304	2.00	2.25
Leghorn x Production-bred Rocks	Males	34	521.2	2.47	0.307	1.81	2.03
Brown Leghorns	Females	35	425.0	2.27	0.302	2.59	2.28
Exhibition-bred Rock x Leghorns	Females	35	458.1	2.36	0.307	2.45	2.38
Leghorn x Production-bred Rocks	Females	41	504.8	2.43	0.305	2.10	1.98

* See text.

including both sexes at 8 weeks obtained an average body weight of 1.124

pounds (510 grams) and an average feather score over the back and wings of

2.3. In the investigations reported by Warren (90) and Horlacher and Smith

(35) the Barred Plymouth Rocks averaged 384 and 570 grams, respectively,

at 8 weeks of age. The Barred Plymouth Rocks in Gerick and Platt's (19)

investigation that were fed a diet of normal protein content averaged 520

grams at 8 weeks. The average feather scores obtained for the different

feather tracts in their investigation were as follows:

Tract	Males	Females
Caput	1.7	2.6
Cervical	2.4	3.0
Dorsal	1.8	2.7
Caudal	2.1	2.9
Pectoral	3.0	3.0
Ventral	2.4	2.8
Femoral	3.0	3.0
Crural	2.0	2.6
Humeral	3.0	3.0
Alar	1.6	2.6
Total	23.0	28.2

These previous investigations indicate that the average exhibition-bred

Barred Plymouth Rocks grow as slow or slower and feather much more slowly

than Brown Leghorns and the average production-bred Barred Plymouth Rocks

grow at a more rapid rate and feather at a slower rate than Brown Leghorns.

It is also noted that the means for the progeny from the Brown Leghorn

males and Barred Plymouth Rock females exceeded the progeny from the Barred

Plymouth Rock males and Brown Leghorn females for body weight and shank

length, were approximately of the same value for shape ratios, and were

considerably lower for feather scores. These results are contradictory to those previously received in three respects. It will be recalled that in the majority of the investigations reviewed, the progeny of males from a rapid-growing flock and females from a slow-growing flock grew more rapidly than the progeny from the reciprocal matings. Sex-linked genes have been reported for mature size and also postulated for rate of growth. Any effects of sex-linked genes should be evident in comparing the female progeny of the reciprocal matings. Since the Barred Plymouth Rock male used in this investigation was from exhibition stock and the Barred Plymouth Rock females were from production-bred stock, there is also the possibility of one or more autosomal genes showing an effect. Although the male and female progeny from the Brown Leghorn males and Barred Plymouth Rock females are 12.5 percent and 10.2 percent, respectively, heavier than the progeny from the reciprocal cross, the differences are not statistically significant with the small numbers involved.

The second respect in which the F_1 data are contradictory to the investigations previously reported is obvious when the rate of feathering of female progeny from the two reciprocal crosses are compared. Since the daughters of the Brown Leghorn male and Barred Plymouth Rock females carried a recessive gene only for rate of feathering of the remiges and rectices and the daughters of the Barred Plymouth Rock male and Brown Leghorn females carried the dominant slow-feathering gene, it would be assumed on the basis of the previous investigations that the latter would be more completely feathered at 8 weeks than the former. However, according to the average feather score over the back and shoulders shown in Table I, the females carrying the dominant slow-feathering gene are actually more completely feathered than those which carry the recessive gene. Again these differences were found not to be significant.

Since previous investigators obtained significant correlations between rate of growth and rate of feathering, this F_1 data differs in a third aspect. Since the slower-growing progeny feathered more rapidly than the faster-growing progeny from the reciprocal cross, the relationship found by previous investigators may be due to a physiological linkage between the two characters instead of being due to linkage of genes for each of these characters. In an effort to obtain more information regarding this point, F_1 and backcross matings were statistically analyzed in considerable detail.

Statistical Analysis of F_1 and Backcross Matings

Since the results secured from the F_1 progeny indicate that the genes affecting rate of growth at 8 weeks are independent of those affecting the rate of feather development, these two characters are first discussed separately and then their relationship to each other is discussed. In order to simplify the discussion as much as possible, future reference in the text and tables to the two breeds may be designated by letters as follows:

Exhibition-bred Barred Plymouth Rocks - E

Production-bred Barred Plymouth Rocks - R

Brown Leghorns   - L

Body Weight, Shank Length, and Shape Ratio at 8 Weeks of Age. Table II gives the means and standard deviations for body weight and shank length, and the shape ratio for each of the F_1 and backcross matings. It is noted that the mean body weights of the males vary from 583.3 grams for the (E x L) x R mating to 453.7 grams for the L x (L x R) mating. The mean shank lengths vary from 2.76 inches for the (E x L) x R mating to 2.41 inches for the (E x L) x L mating. The shape ratios vary from .333 for the (E x L) x R mating to .309 for the (E x L) x L mating. In the females the mean body

TABLE II

A Comparison of the Progeny of F1 and Backcross
Matings for Body Weight, Shank Length, and the
Shape Ratio of Mean Shank Length and Mean Weight
at 8 Weeks of Age

Mating	Sex of Progeny	No. of Progeny	Body Weight (Grams)		Shank Length (Inches)		Shape Ratio
			Mean	Standard Deviation	Mean	Standard Deviation	
(E x L) x (E x L)	Males	51	484.5	113.7	2.43	0.294	.309
(E x L) x (L x R)	Males	59	472.5	115.9	2.42	0.287	.311
(L x R) x (L x R)	Males	31	549.4	139.4	2.55	0.313	.311
R x (R x L)	Males	51	501.2	90.7	2.54	0.278	.320
R x (L x R)	Males	122	487.3	130.4	2.54	0.305	.321
L x (E x L)	Males	11	554.2	115.0	2.64	0.236	.321
L x (L x R)	Males	47	453.7	90.9	2.42	0.229	.315
(E x L) x L	Males	184	473.7	103.7	2.41	0.265	.309
(E x L) x R	Males	22	583.3	116.4	2.78	0.354	.335
TOTAL	Males	578	490.1	115.8	2.48	0.292	.315
(E x L) x (E x L)	Females	53	456.4	82.4	2.38	0.202	.309
(E x L) x (L x R)	Females	62	435.9	83.1	2.41	0.233	.318
(L x R) x (L x R)	Females	38	548.5	81.8	2.54	0.175	.310
R x (R x L)	Females	40	435.9	65.9	2.50	0.153	.316
R x (L x R)	Females	134	437.6	91.5	2.51	0.219	.319
L x (R x L)	Females	13	433.8	74.1	2.46	0.192	.313
L x (L x R)	Females	78	436.4	94.1	2.37	0.244	.313
(E x L) x L	Females	154	432.5	70.0	2.36	0.183	.312
(E x L) x R	Females	21	503.7	87.6	2.43	0.220	.305
TOTAL	Females	599	464.3	89.5	2.43	0.219	.314

TABLE III

Analysis of Variance of Body Weight and Shank
Length in the F_1 and Backcross Matings

Source of Variation	Sex of Progeny	Body Weight (Grams)			Shank Length (Inches)		
		Degrees of Freedom	Sum of Squares	Mean Square	Degrees of Freedom	Sum of Square	Mean Square
Between Matings	Males	8	488,834	61,104	8	4.3498	.5437
Within Matings	Males	569	7,243,366	12,730	560	44.2235	.0790
TOTAL	Males	577	7,732,200	13,400	568	48.5733	.0855
Between Matings	Females	8	780,932	9,762	8	3.4444	.4305
Within Matings	Females	590	4,007,140	6,792	579	24.7790	.0428
TOTAL	Females	598	4,788,072	8,007	587	28.2234	.0481

weights vary from 548.5 grams for the (L x R) x (L x R) mating to 432.5 grams for the (E x L) x L mating, the mean shank lengths vary from 2.54 inches for the (L x R) x (L x R) mating to 2.36 inches for the (E x L) x L mating, and the shape ratios vary from .319 for the R x (L x R) mating to .309 for the (E x L) x (E x L) mating. Since considerable variation exists among the matings for body weight and shank length, an analysis of variance was made of these F_1 and backcross matings. Since the shape ratios were computed from the means and as they did not differ materially among the different matings, they will not be discussed further. A summary of the analysis of variance is given in Table III. The mean square for between matings is exceedingly higher than the mean square for within matings in each case except the female body weights. Using the method described by Snedecor (34), a value of "F" of 4.80 was obtained, which is highly significant. The mean square between matings is not significantly greater than the mean square within matings for the female body weights. The values of "F" obtained for shank length were 6.83 and 10.06 for the males and females, respectively. The mean squares given for within matings can be used as a reliable measure of variation in comparing any two means given in Table II. In computing the significance of the difference between any two means, the familiar "t" test may be used. For example, the difference between the means previously referred to of 583.3 and 453.7 grams reported, respectively, for the (E x L) x R and L x (L x R) matings may be tested for significance by using the mean square listed for the male body weights and using the corresponding number of birds involved. The "t" value obtained for this mean difference was found to be 6.75 and is highly significant since 569 degrees of freedom were involved in determining the variance within matings.

Since the mean weight of the male progeny of the (E x L) x R mating is higher than either of the mean weights reported for the other matings, the significance of the difference between this mean and the three nearest means were obtained. The "t" values were 1.05, 1.55, and 4.40, respectively, when the difference between this mean was compared with the mean for the male progeny of matings L x (E x L), (L x R) x (L x R), and R x (E x L). Since the same male was used in mating (E x L) x L as in (E x L) x R, the difference between the means for the male progeny was compared and a "t" value of 9.84 was obtained, which indicates a highly significant difference between the genetic factors for rate of growth carried by the production-bred Barred Plymouth Rock females and those carried by the Brown Leghorn females. According to the tables of Snedecor (34) when more than 500 degrees of freedom are involved a "t" value exceeding 2.0 is significant and one exceeding 2.6 is highly significant. Therefore, it can be concluded that the male progeny from mating (E x L) x R grew at a significantly faster rate than the male progeny of any mating other than L x (L x R) and (L x R) x (L x R). However, it should be pointed out that the number of birds obtained for mating (E x L) x R and L x (E x L) are too small to be given much consideration. The "t" values obtained from the difference between the mean weight for mating R x (L x R) and the mean weight for matings (L x (L x R) and (E x L) x L were 3.53 and 2.59, respectively. A value for "t" of 3.69 was obtained for the difference between the mean weights for matings (E x L) x (E x L) and (L x R) x (L x R), which indicates that the genetic factors carried by the exhibition-bred male were significantly different from those carried by the production-bred females.

Further study of Table II shows in general that the mean weights for the female progeny from the different matings are comparable but lower than those given for the males. The difference between the mean weight of 464.3 grams for all the female progeny and 490.1 grams for all the male progeny is highly significant, as the "t" value obtained was 6.33.

Since previous investigators have shown that the bone lengths, especially the long bones, are a more reliable criterion of the body size than body weight, the means of the shank length measurements should be given special consideration. This is especially true since Lerner (57) demonstrated that shank length alone was a valid criterion of the inherited size differences in the fowl. However, when the mean shank length measurements are compared for the male and female progeny of the different F_1 and backcross matings they are in general very comparable to mean body weights. Again, a significant difference exists between the two sexes. A value of 4.88 was obtained for "t" for the difference between the mean of 2.48 and 2.43 inches, respectively, for the male and female progeny.

Although it can safely be concluded that the genetic factors carried by the Brown Leghorn are significantly different from those carried by the Barred Plymouth Rocks, the results are inconsistent regarding the comparison of the genetic factors carried by the exhibition-bred Barred Plymouth Rock male and the production-bred Barred Plymouth Rock females.

Since previous investigators have reported that sex-linked genes exist that affect size, these F_1 and backcross data have been thoroughly analyzed for any possibility of a sex-linked gene affecting rate of growth or shank length at 8 weeks of age. As the two well known dominant sex-linked genes, barring (designated by the letter B) and slow feathering (designated by the letter K) were present in the Plymouth Rocks used as parental stock, the F_1 progeny had the following known genetic composition:

	Males	Females
Barred Plymouth Rocks x Brown Leghorns (R x L)	BbKk	BK-
Brown Leghorns x Barred Plymouth Rocks (L x R)	BbKk	bk-

If a sex-linked gene for rate of growth was present in either of the parental breeds crossed, some linkage should exist between rate of growth and barring or rate of feathering. Since previous investigators, Hutt (37) and Punnett (73), have obtained from 43 to 49 percent crossing over between B & K, it has been suggested that the K gene is at one end of the sex chromosome and the B gene is toward the other end. In the backcross mating of the F_1 to Brown Leghorn females (R x L) x L, crossing over percentages were obtained between B and K of 43.9 and 47.4, respectively, for the males and females. If a sex-linked gene is present near the end where either of the two known genes are located, it should be easily identified, but if its location is near the middle of the chromosome, positive proof of its existence would be more difficult. Since the gene for light down (Li) is located nearer the middle of the chromosome, its presence in the parental stock would have given a more exact test for the location of a sex-linked gene for rate of growth within that area.

The backcross mating (R x L) x L provides a critical test for determining the possibility of a sex-linked gene being present. Since the genetic composition of this mating for the barring and feathering factors was

$$\frac{BK}{bk} \text{ x } \frac{bk}{-}$$

the following should have been produced:

Male	Female
BK- (linkage)	bk
bK- (linkage)	-
Bk- (crossing)	
bK- (crossing)	

If a sex-linked gene for rate of growth exists near either the B or K gene, there should be a significant difference between the mean body weight or shank length of the progeny carrying one of the genes in a

dominant state and the progeny carrying the recessive allelomorph. For example, if a sex-linked gene exists for rate of growth near the gene for barring, there should be a significant difference between the barred and non-barred progeny. The mean body weight, shank length, and shape ratio are given in Table IV for the progeny with each of the four different genetic compositions.

It will be noted that the mean body weight and shank length of the non-barred fast-feathering progeny are higher than the corresponding means of the others for both males and females. The other means, however, are not very consistent. In order to test the significance of the differences among the means given in this table, an analysis was made of the variance in body weight and shank length of the progeny classified according to plumage color and rate of feathering. A summary of this analysis is given in Table V. Again referring to the tables of Snedecor (84), it is found that the "F" value is significant only in the case of the body weight of males and shank length of the females. By using the mean square variation within groups, an accurate "t" test can be made of the differences between any two pairs of means given in Table IV.

According to the different values of "t" that were computed, the mean body weight and mean shank length of the non-barred slow-feathering male progeny are significantly lower than the means of the progeny in either of the other groups. The means for the other three groups of progeny are similar for body weight and shank length and none is significantly different from the other. In the female progeny the non-barred fast-feathering group has significantly higher means for body weight and shank length than either of the other three groups. Very little variation exists among the means of the other three groups for either body weight or shank length. It should also be noticed in Table IV that the shape ratios only range from 0.308 to 0.312 for the male progeny groups and from 0.308 to 0.318 for the female progeny

TABLE IV

The Mean Body Weight, Shank Length, and Shape Ratio
for the Progeny of an F_1 Male Backcrossed to Brown
Leghorn Females, Classified According to Plumage
Color and Rate of Feathering

Class	Sex of Progeny	Genetic Compo- sition	No. of Progeny	Body Weight (Grams)		Shank Length (Inches)		Shape Ratio
				Mean	Standard Devia- tion	Mean	Standard Devia- tion	
Barred – Fast	Male	Bbkk	52	476.7	117.8	2.43	0.305	0.311
Non-Barred – Fast	Male	bbkk	50	497.4	81.1	2.44	0.236	0.308
Barred – Slow	Male	BbKk	41	474.9	102.6	2.43	0.252	0.312
Non-Barred – Slow	Male	bbKk	38	435.2	104.2	2.34	0.255	0.309
TOTAL	Male	––	184	473.7	103.7	2.41	0.265	0.309
Barred – Fast	Female	Bk –	26	416.7	71.4	2.33	0.179	0.312
Non-Barred – Fast	Female	bk –	46	452.5	84.8	2.44	0.169	0.318
Barred – Slow	Female	BK –	35	428.1	59.3	2.32	0.193	0.308
Non-Barred – Slow	Female	bK –	47	424.8	57.2	2.32	0.170	0.309
TOTAL	Female	––	154	432.5	70.0	2.36	0.183	0.312

TABLE V

Analysis of Variance in Body Weight and Shank
Length of the Progeny from an F_1 Male and Brown
Leghorn Females Classified According to Plumage
Color and Rate of Feathering

Source of Variations	Sex of Progeny	Body Weight (Grams)				Shank Length (Inches)		
		Degrees of Freedom	Sum of Squares	Mean Square		Degrees of Freedom	Sum of Squares	Mean Square
Between Groups	Males	3	86,792	28,931		3	.2698	.0899
Within Groups	Males	180	1,881,983	10,455		180	12.5678	.0698
TOTAL	Males	183	1,968,775	10,758		183	12.8376	.0702
Between Groups	Females	3	28,440	9,480		3	.4686	.1562
Within Groups	Females	150	721,135	4,808		150	4.6747	.0311
TOTAL	Females	153	749,575	4,899		153	5.1433	.0336

groups. The shape ratio for the non-barred fast-feathering females is the only one differing appreciably from the mean of all progeny.

Since the mean body weight and mean shank length of the non-barred fast-feathering male and female progeny are higher than the corresponding means for the other three groups, a similar analysis was made of the progeny of two F_1 matings. A summary of this analysis is given in Tables VI and VII. It will be noted in Table VII that the analysis of variance actually gave a lower mean square for within groups than for between groups in the case of body weight and shank length of both sexes. The values of "F" obtained also show that about the same amount of variation exists within the groups as between the groups. Again using the mean square variation within groups, the significance of the difference between the means of any two progeny groups can be determined. Since in the mating $(B \times L) \times (B \times L)$, all of the males were barred and slow feathering, only the females can be compared. Although the barred and non-barred fast-feathering progeny have higher means for body weight than the slow-feathering progeny, neither mean is significantly different from either of the other three. The mean shank length of the non-barred fast-feathering progeny is significantly higher than either of the means for the other three groups. In the mating $(B \times L) \times (L \times B)$, the mean body weight and mean shank length of the non-barring fast-feathering males are significantly greater than the corresponding means for the progeny in the other three groups, except in the case of the mean body weight of the barred fast-feathering progeny. Neither group of the female progeny from this mating differed significantly in mean body weight or mean shank length from either of the other groups.

Since there is a tendency for the non-barred fast-feathering progeny to have a higher body weight and a longer shank length, it is interesting to attempt to determine some genetic cause for this tendency. If one or more

TABLE VI

The Mean Body Weight, Shank Length, and Shape
Ratio of the Progeny from Two F_1 Matings Clas-
sified According to Plumage Color and Rate of
Feathering

Mating and Class	Sex of Progeny	Genetic Compo- sition	No. of Progeny	Body Weight (Grams)		Shank Length (Inches)		Shape Ratio
				Mean	Standard Devia- tion	Mean	Standard Devia- tion	
(E x L) x (E x L)								
Barred - Slow	Males	*	51	484.5	113.7	2.43	0.294	.309
Barred - Fast	Females	Bk -	11	479.0	85.4	2.37	0.253	.303
Non-Barred - Fast	Females	bk -	16	473.1	114.2	2.46	0.203	.316
Barred - Slow	Females	BK -	11	430.3	70.3	2.33	0.212	.309
Non-Barred - Slow	Females	bK -	15	441.2	50.1	2.34	0.154	.307
TOTAL	Females		53	456.4	82.4	2.38	0.202	.309
(E x L) x (L x R)								
Barred - Fast	Males	Bbkk	15	457.5	111.4	2.43	0.328	.315
Non-Barred - Fast	Males	bbkk	13	520.0	82.3	2.50	0.197	.311
Barred - Slow	Males	BbKk	18	471.0	118.6	2.40	0.301	.308
Non-Barred - Slow	Males	bbKk	13	446.0	141.9	2.39	0.310	.313
TOTAL	Males		59	472.5	115.9	2.42	0.287	.311
Barred - Fast	Females	Bk -	15	456.1	91.0	2.42	0.261	.314
Non-Barred - Fast	Females	bk -	22	424.7	83.9	2.44	0.247	.325
Barred - Slow	Females	BK -	11	453.5	81.0	2.46	0.161	.320
Non-Barred - Slow	Females	bK -	14	417.9	83.2	2.35	0.248	.314
TOTAL	Females		62	435.9	83.1	2.41	0.233	.318

* Phenotype representing four Genotypes.

TABLE VII

Analysis of Variation in Body Weight and Shank
Length of the Progeny from Two F_1 Matings Classi-
fied According to Plumage Color and Rate of
Feathering

Source of Variation	Sex of Progeny	Body Weight (Grams)			Shank Length (Inches)		
		Degrees of Freedom	Sum of Squares	Mean Square	Degrees of Freedom	Sum of Squares	Mean Square
Between Groups	Males	4	45,566	11,392	4	.0985	.0246
Within Groups	Males	105	1,383,865	13,180	103	8.8449	.0859
TOTAL GROUPS	Males	109	1,429,431	13,114	107	8.9434	.0836
Between Groups	Females	7	49,964	7,138	7	.2324	.0332
Within Groups	Females	107	774,876	7,242	102	5.0817	.0498
TOTAL GROUPS	Females	114	824,840	7,235	109	5.3141	.0488

sex-linked genes affected materially the rate of growth of the progeny from these matings, the non-barred fast-feathering progeny should have been consistently heavier than the barred slow-feathering progeny and the means for the other two groups of progeny should have been intermediate. Since this is generally true, except in the female progeny from one mating, it can safely be concluded that there is some indication of rate of growth being affected by one or more genes. As stated previously, if a sex-linked gene for rate of growth exists that is located near the middle of the chromosome it should be closely linked with the dominant genes for light down (Li) and light iris (Br).

Since Brown Leghorns are known to mature earlier sexually than production-bred Barred Plymouth Rocks and very much earlier than standard-bred Barred Plymouth Rocks, it is possible that the sex-linked gene (E) for sexual maturity may have influenced the growth results in this experiment. Warren (92) obtained results which indicated that this gene is located between the genes for barring and silver. According to Hutt's (37) proposed arrangement of the genes in the sex chromosome, the sexual maturity gene would necessarily be located near the middle and very closely linked with Li and Br. Several investigators have stated that early sexual maturity and rate of growth are related, but no data have been published to substantiate this conclusion until recently. Gordon (24) obtained a significant correlation between body weight at ten weeks and sexual maturity. Since the F2 and backcross progeny in this investigation were held for 8 weeks only, no data were obtained on sexual maturity. The F1 females from the L x R mating were observed to mature sexually very much earlier than the F1 females from the R x L mating. This was to be expected, since the early sexually maturing Brown Leghorn male transmitted the sex-linked gene for early maturity to his daughters, whereas the early maturing Brown Leghorn females transmitted this gene to their sons only. Since the mean body

weight and shank length for the F_1 females from the L x R mating were almost significantly higher than the means for the F_1 females from the R x L mating, a relationship existed between rate of growth and sexual maturity. How-ever, the same difference existed between the male progeny from the recipro-cal crosses. This could be explained on the basis of the influence of the gene for sexual maturity if it is assumed that the exhibition-bred Barred Plymouth Rock male was homozygous recessive for the gene. Exhibition-bred Barred Plymouth Rocks are usually very late maturing, whereas production-bred Barred Plymouth Rocks vary considerably for this factor. For example, if almost all of the Brown Leghorns and production-bred Barred Plymouth Rocks carried the factor and the exhibition-bred male did not, the genetic composition of the F_1 matings and F_1 progeny would be as follows:

$$F_1 \text{ mating } (R \times L) = ee \times E\text{-} \quad \text{and} \quad (L \times R) = E\text{-} \times E\text{-}$$
$$F_1 \text{ males} = Ee$$
$$F_1 \text{ males} = E\text{-}$$
$$F_1 \text{ females} = e\text{-}$$
$$E\text{-}$$

Further investigational work will be necessary before any definite con-clusions can be made concerning the influence of sex-linked gene on rate of growth.

Degree of Feathering at 8 Weeks of Age. This study included all matings given in Table II except three. The F_1 mating (L x R) x (L x R) was omitted because of the abnormal ratio of fast- and slow-feathering progeny obtained at 10 days of age. In this mating approximately three times as many fast-feathering as slow-feathering chicks were observed, whereas a ratio of approximately 1:1 should have been obtained. The F_1 male was from a dam that gave only slow-feathering sons and the F_1 females were observed to be non-barred and fast feathering. Fertility was obtained in this mating for a short period only. It could be assumed logically that a Brown Leghorn crossed over into the pen and sired some of the chicks except for the fact that the ratio of barred and non-barred was very close to 1:1.

Matings L x (E x L) and (E x L) x R contained too few females to produce a comparable number of progeny with the other matings.

Figures 1 and 2 show a slow-feathering and fast-feathering chick, respectively, at 10 days of age from the backcross mating (E x L) x L. Figure 3 shows a "bare back" barred male at 8 weeks of age from the backcross mating R x (E x L). Figures 4, 5, and 6 show, respectively, a medium feathered male, a medium feathered female, and an almost completely feathered female at 8 weeks of age from the backcross mating (E x L) x L.

Table VIII gives the means and standard deviations for the scores of the degree of feathering over the nine tracts at 8 weeks of age for the different matings classified according to rate of feathering at 10 days of age. The genetic composition of the males and females used in the matings and the progeny is also indicated. The analysis of variance in total feather score is given in Table IX. The values obtained for "F" of 9.37 and 7.96 for the males and females, respectively, are highly significant. The mean square variation obtained within matings or groups was used also in determining the significance of the difference between pairing of the means for each sex in Table VIII.

It is obvious in comparing the means in Table VIII that the highly significant difference obtained between matings by the analysis of variance was due largely to the highly significant difference between the groups that were recessive and those that were homozygous dominant or heterozygous dominant for the sex-linked genes. In the F_1 mating (K x L) x (E x L) all the males were slow feathering at 10 days, but some of the individuals carried the genes KK while others were heterozygous, Kk. It may be significant to note that the highest standard deviation given is for this group of males which may be due to the individuals differing in their genetic composition for the sex-linked gene K. A mean difference of 3.4 was obtained between the fast-

Figure 1. A slow-feathering (Kk or K-) chick at 10 days of age from the backcross mating (E x L) x L.

Figure 2. A fast-feathering (kk or k-) chick at 10 days of age from the backcross mating (E x L) x L.

Figure 3. A "bare back" barred male at 8 weeks of age from the mating R x (E x L) that was homozygous (KK) for the sex-linked gene K.

Figure 4. A medium feathered barred male at 8 weeks of age from the mating (E x L) x L that was heterozygous (Kk) for the sex-linked gene K.

Figure 5. A medium feathered non-barred female at 8 weeks of age from the mating (E x L) x L that was heterozygous (K-) for the sex-linked gene K.

Figure 6. An almost completely feathered barred female at 8 weeks of age from the mating (E x L) x L that was recessive for the sex-linked gene K.

TABLE VIII

A Summary of the Degree of Feathering at 8 Weeks
of Age by Matings of the Sex-linked, Genetically
Fast and Slow Feathering Progeny at 10 Days of
Age

Mating	Sex of Progeny	Genetic Composition of Mating	Rate of Feathering at 10 days of age	No. of Progeny	Genetic Composition	Mean	Standard Deviation
(E x L) x (E x L)	Males	Kk x K-	Slow	49	KK x Kk	13.0	4.66
(E x L) x (L x R)	Males	Kk x k-	Slow	30	Kk	12.7	4.19
(E x L) x (L x R)	Males	Kk x k-	Fast	28	kk	15.9	3.87
R x (E x L)	Males	KK x K-	Slow	51	KK	12.6	2.89
R x (L x R)	Males	KK x k-	Slow	119	Kk	13.8	4.04
L x (L x R)	Males	kk x k-	Fast	47	kk	15.7	2.61
(E x L) x L	Males	Kk x k-	Slow	79	Kk	14.8	3.62
(E x L) x L	Males	Kk x k-	Fast	105	kk	16.4	3.49
TOTAL	Males			508		14.5	3.83
(E x L) x (E x L)	Females	Kk x K-	Slow	25	K-	15.3	3.65
(E x L) x (E x L)	Females	Kk x K-	Fast	27	k-	18.7	3.02
(E x L) x (L x R)	Females	Kk x k-	Slow	24	K-	15.5	3.57
(E x L) x (L x R)	Females	Kk x k-	Fast	33	k-	18.1	2.78
R x (E x L)	Females	KK x K-	Slow	39	K-	17.7	2.56
R x (L x R)	Females	KK x k-	Slow	130	K-	16.3	3.47
L x (L x R)	Females	kk x k-	Fast	78	k-	17.5	2.99
(E x L) x L	Females	Kk x k-	Slow	81	K-	15.5	2.91
(E x L) x L	Females	Kk x k-	Fast	72	k-	18.4	2.97
TOTAL	Females			509		17.0	3.29

TABLE IX

Analysis of Variance in Degree of Feathering at 8 Weeks of Age

Source of Variation	Males			Females		
	Degrees of Freedom	Sum of Squares	Mean Square	Degrees of Freedom	Sum of Squares	Mean Square
Between Matings or Groups	7	906	129.43	8	623	77.88
Within Matings or Groups	500	6,910	13.82	500	4,893	9.79
TOTAL	507	7,816	15.42	508	5,516	10.86

feathering (k-) and slow-feathering (K-) females of this mating. This difference gave a highly significant "t" of 5.54. The mean differences between the progeny from a mating that were fast feathering and those that were slow feathering at 10 days are highly significant in all cases. The "t" values obtained were 4.64 and 4.44, respectively, for the males and females from the mating (E x L) x (L x R), and 4.15 and 6.10, respectively, for the males and females from the mating (E x L) x L. Although all the progeny from the mating L x (L x R) carried the recessive gene, the means were comparable but lower than those for the recessive progeny from the other matings. The only groups carrying the recessive gene that were significantly different were the females from the mating (E x L) x (E x L) and the mating L x (L x R).

The means for the heterozygous male progeny from matings (E x L) x L and R x (L x R) are significantly higher than the mean for homozygous males from the mating R x (E x L). The mean for heterozygous males from the mating (E x L) and (L x R) is also significantly lower than the means for the other two heterozygous groups. The male progeny from the (E x L) x (E x L) mating included homozygous and heterozygous individuals in approximately equal numbers and the mean obtained was intermediate in value.

The mean score for the female progeny from the mating R x (E x L) is significantly higher than the means for the other slow-feathering progeny groups. The mean for the female progeny from the mating R x (L x R) is also significantly higher than the mean for each of the other slow-feathering progeny groups except those from the mating R x (E x L).

The females in each group also had a significantly higher feather score than the corresponding males.

Since significant differences were found to exist between the means for total feather score in every case where fast-feathering and slow-feathering birds at 10 days of age were compared and also between certain progeny groups

with the same genetic composition, a detailed analysis was made of the distribution of the feather score by feather tract for all the progeny. This was necessary in order to determine if all feather tracts contributed equally or disproportionately to the significant differences found for total scores. Percentage distributions of the progeny groups on the basis of feather development for each of the tracts observed are given in Tables X and XI for the males and females, respectively. It will be noted in studying these tables that there is considerable variation among the different progeny groups in the percentage distribution of the individual feather scores for all nine feather tracts. Less variation is noted among the progeny groups for the web, thigh, leg, and breast than for the other five tracts.

In order to determine whether the comparable differences in the percentage distributions are significantly different, Chi-square tests were made for the more important comparisons. The chi-square values obtained for each of the comparisons made are given for each feather tract in Table XII. A table reported by Hendricks, Quinn, and Godfrey (31) shows that the normal range of variation of chi-square values for 2 degrees of freedom at the 5-percent level of significance is between .000 and 5.991 and for 3 degrees of freedom is between .003 and 7.816. Since four classes or scores were used, three degrees of freedom are available for each feather tract where the progeny falls in all four classes and two degrees of freedom are available where the progeny fall in only three classes. By also referring to the tables of Snedecors (84) it can safely be concluded that the chi-square values in Table XII that exceed 7.815 are significant and those that exceed 11.241 are highly significant.

In the progeny from mating $(E \times L) \times L$ the slow-feathering (Kk) and the fast-feathering (kk) males differed significantly in degree of feathering at 8 weeks of age over the neck, back, tail, and shoulder. The fast-feathering (k-) and slow-feathering (K-) females differed significantly over the same

TABLE X

Percentage Distributions of the Male Progeny
Grouped on the Basis of Feather Score for Each
of the Tracts Observed

Tract	Feather Score	(E x L) x (E x L) (KK Kk)	(Kk)	(kk)	B x (E x L) KK	B x (L x R) Kk	L x (L x R) kk	(E x L) x L (Kk)	(kk)
Neck	0	4.1	0.0	0.0	2.0	1.7	0.0	2.5	0.0
	1	28.6	36.7	7.1	54.9	25.3	4.3	27.8	10.3
	2	61.2	56.7	71.4	43.1	67.5	66.0	84.6	66.4
	3	6.1	6.7	21.4	0.0	7.5	29.8	5.1	23.4
Back	0	12.2	10.0	0.0	7.8	5.0	0.0	1.3	0.0
	1	44.9	50.0	25.0	80.4	47.5	17.0	41.8	14.0
	2	40.8	26.7	50.0	11.8	45.0	63.8	51.9	73.8
	3	2.0	13.3	25.0	0.0	2.5	19.1	5.1	12.1
Tail	0	4.1	0.0	0.0	0.0	1.7	2.1	0.0	0.0
	1	42.9	33.3	0.0	78.4	31.7	0.0	17.7	3.7
	2	36.7	50.0	46.4	17.6	56.7	31.9	51.9	55.1
	3	14.3	16.7	53.6	3.9	10.0	66.0	30.4	41.1
Shoulder	0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	12.2	3.3	0.0	3.9	4.2	0.0	19.0	4.7
	2	44.9	43.3	32.1	78.4	47.5	29.8	54.4	58.9
	3	40.8	53.3	67.9	17.6	48.3	70.2	26.6	36.4
Web	0	20.4	10.0	14.3	7.8	10.8	4.3	7.6	5.6
	1	73.5	86.7	78.6	88.2	80.8	89.4	73.4	66.4
	2	4.1	3.3	7.1	3.9	8.3	6.4	15.2	26.2
	3	2.0	0.0	0.0	0.0	0.0	0.0	3.7	1.9
Thigh	0	55.1	66.7	50.0	41.2	57.5	57.4	25.3	23.4
	1	40.8	30.0	35.7	58.8	38.3	38.3	40.5	32.7
	2	2.0	3.3	7.1	0.0	4.2	4.3	30.4	39.3
	3	0.0	0.0	0.0	0.0	0.0	0.0	3.7	4.7
Leg	0	4.1	6.7	3.6	0.0	1.7	4.3	5.1	4.7
	1	42.9	56.7	35.7	21.6	33.3	44.7	43.0	50.5
	2	34.7	26.7	53.6	52.9	46.7	48.9	46.8	38.3
	3	18.4	10.0	7.1	25.5	18.3	2.1	5.1	6.5
Breast	0	26.5	30.0	17.9	27.5	24.2	25.5	7.6	6.5
	1	69.4	63.3	67.9	70.6	70.8	70.2	67.0	62.6
	2	4.1	6.7	10.7	2.0	2.5	4.3	24.1	29.0
	3	0.0	0.0	3.6	0.0	2.5	0.0	1.3	1.9
Abdomen	0	2.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0
	1	28.5	26.7	17.9	13.7	20.0	6.4	8.9	11.2
	2	16.3	30.0	25.0	31.4	28.3	29.8	55.7	49.5
	3	53.1	43.3	57.1	54.9	50.0	63.8	35.5	39.3
NO. OF PROGENY		49	30	28	51	119	47	79	107

TABLE XI

Percentage Distribution of the Female Progeny Grouped on the Basis of Feather Score for Each of the Tracts Observed

Tract	Feather Score	(E x L) x (E x L) (K-)	(E x L) x (E x L) (k-)	(E x L) x (L x R) (K-)	(E x L) x (L x R) (k-)	B x (E x L) (K-)	B x (L x R) (K-)	L x (L x R) (k-)	(E x L) x L (K-)	(E x L) x L (k-)
Neck	0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
	1	20.0	3.7	20.8	6.1	2.6	13.0	6.4	8.6	1.4
	2	76.0	51.9	66.7	39.4	89.7	74.0	51.3	88.9	68.1
	3	4.0	44.4	12.5	54.5	7.7	12.2	42.3	2.5	30.6
Back	0	0.0	0.0	0.0	0.0	2.6	0.8	0.0	0.0	0.0
	1	0.0	0.0	29.2	9.1	0.0	25.2	5.1	29.6	5.6
	2	66.7	66.7	62.5	36.4	87.2	61.8	51.3	63.0	52.8
	3	33.3	33.3	8.3	54.5	10.3	12.2	43.6	7.4	41.7
Tail	0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0
	1	0.0	0.0	20.8	0.0	5.1	19.8	1.3	7.4	0.0
	2	22.2	22.2	41.7	21.2	64.1	58.0	16.7	70.4	33.3
	3	77.8	77.8	37.5	78.8	30.8	21.4	82.0	22.2	86.7
Shoulder	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	0.0	0.0	0.0	0.0	0.0	0.8	0.0	22.2	8.3
	2	40.0	11.1	41.7	9.1	17.9	36.6	16.7	45.7	33.3
	3	60.0	88.9	58.3	90.9	82.1	62.6	83.3	32.1	58.3
Web	0	8.0	3.7	4.2	12.1	2.6	1.5	2.6	1.2	1.4
	1	88.0	66.7	95.8	72.7	89.7	84.7	78.2	63.0	44.4
	2	0.0	22.2	0.0	12.1	7.7	13.7	16.7	35.8	47.2
	3	4.0	7.4	0.0	3.0	0.0	0.0	2.6	0.0	6.9
Thigh	0	40.0	3.7	54.2	33.3	15.4	32.8	43.6	13.6	6.9
	1	56.0	66.7	33.3	51.5	66.7	53.4	47.4	48.1	31.9
	2	4.0	22.2	8.3	15.2	12.8	9.2	6.4	35.8	52.8
	3	0.0	7.4	4.2	0.0	5.1	4.6	2.6	2.5	8.3
Leg	0	0.0	0.0	0.0	6.1	0.0	0.0	5.1	4.9	1.4
	1	40.0	22.2	25.0	30.3	2.6	14.5	33.7	35.8	31.9
	2	48.0	59.3	58.3	45.5	43.6	55.0	44.9	55.6	54.2
	3	12.0	18.5	16.7	18.2	53.8	30.5	10.3	3.7	12.5
Breast	0	12.0	11.1	8.3	6.1	5.1	8.4	11.5	1.2	2.8
	1	80.0	63.0	87.5	72.7	89.7	83.2	82.0	46.9	61.1
	2	4.0	18.5	4.2	21.2	5.1	6.9	5.1	44.4	34.7
	3	4.0	7.4	0.0	0.0	0.0	1.5	1.3	7.4	1.4
Abdomen	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	8.0	14.8	4.2	6.1	2.6	5.3	3.8	13.6	1.4
	2	24.0	18.5	29.2	24.2	10.3	19.8	23.1	53.1	43.1
	3	68.0	66.7	66.7	63.7	87.2	74.8	73.1	33.3	55.6
NO. OF PROGENY		25	27	24	33	39	130	78	81	72

TABLE XII

Chi-Square Values Obtained in Comparing the Feather
Score of Progeny Groups for Each Tract

Comparison	Tracts								
	Neck	Back	Tail	Shoulder	Web	Thigh	Leg	Breast	Abdomen
Slow (Kk) and fast (kk) males from (E x L) x L mating	20.27	20.92	10.71	10.16	3.71	1.87	1.48	0.72	0.74
Slow (K-) and fast (k-) female from (F x L) x L mating	25.05	41.46	32.73	12.05	9.25	7.60	5.37	4.40	11.56
Fast (kk) males and slow (K-) females from (F x L) x L mating	17.29	1.63	7.93	13.35	5.45	5.84	7.88	11.43	0.80
Slow (K-) and fast (k-) females from (F x L) x (E x L) mating	12.65	11.50	14.16	5.76	6.99	13.37	1.98	2.72	0.71
Slow (Kk) and fast (kk) males from (E x L) x (L x R) mating	8.42	8.30	15.07	1.91	2.74	1.83	4.42	2.28	1.18
Slow (K-) and fast (k-) females from (E x L) x (L x R) mating	11.13	13.65	12.67	8.39	5.50	4.43	2.11	3.34	0.25
Slow (KK) males from B x (F x L) mating and slow (Kk) males from B x (L x R) mating	16.65	19.76	31.77	14.64	1.64	7.35	3.70	1.47	1.95
Slow (K-) females from B x (E x L) mating and slow (K-) females from B x (L x R) mating	9.79	13.62	17.51	5.28	1.13	9.82	10.82	1.30	1.65
Slow (Kk) males from B x (L x R) mating and slow (K-) females from B x (L x R) mating	6.27	23.71	9.03	7.10	10.82	13.93	4.80	13.91	19.10

four tracts, and also the web and abdomen. The fast-feathering (kk) males from this mating had a significantly higher degree of feathering over the neck, tail, and shoulder but a significantly lower degree over the breast than the slow-feathering (K-) females. The fast-feathering (k-) females were significantly better feathered than the slow feathering (K-) females from mating (E x L) x (E x L) only over the neck, back, tail, and thigh. The fast-feathering progeny (kk and k-) were significantly better feathered than the slow-feathered (Kk and K-) progeny from mating (E x L) x (L x R) only over the neck, back, and tail. It is also interesting to note that the slow-feathering heterozygous (Kk) males from mating R x (L x R) were significantly better feathered over the neck, back, tail, and shoulders than the slow-feathering homozygous (KK) males from the mating R x (E x L). On the other hand, the slow-feathering females (K-) from mating R x (E x L) are significantly better feathered over the neck, back, tail, thigh, and leg than the slow-feathering females (K-) from the mating R x (L x R). The slow-feathering (K-) females from mating R x (L x R) are significantly better feathered over the back, tail, web, thigh, breast, and abdomen than the slow-feathering (Kk) males.

These chi-square values show in general that significant differences in degree of feathering are most likely to occur over the neck, back, tail, and shoulder at 8 weeks of age. It is also obvious from this study that, although the birds carrying the genes kk or k- have a higher feather score at 8 weeks of age than those carrying the genes Kk and K-, they are not more completely feathered over all parts of the body. Referring again to Tables X and XI, it is noticed in the mating (E x L) x L that, ahtough the first four tracts are significantly different in degree of feathering in the males and females, this difference is not of material economic importance. For example, 41.8 and 51.9 percent of the slow-feathering (Kk) males at 10 days had a score

of 1 and 2, respectively, for the feather tract over the back as contrasted with 14.0 and 73.8 percent, respectively, for the fast-feathering (kk) males at 10 days. However, only 12.1 percent of the fast-feathering males were completely feathered over the back whereas 5.1 percent of the slow-feathering males were also completely feathered. In the females the differences between the two groups are much greater than in the males. It is also significant to note that, while 29.6 percent of the slow-feathering (K-) females had a score of 1 for the feather tract over the back, 5.6 percent of the fast-feathering (k-) females also had a score of 1. This means that 4 females out of 72 were observed to be bare over the back except for pin feathers.

Since the sex-linked gene, K was found to have a significant effect on rate of feathering over some parts of the body at 8 weeks of age, consideration was also given to the possible relationship of the sex-linked barred gene, B. Table XIII gives the percentage distributions of the progeny from the mating (K x L) x L on the basis of feather score and genetic composition in regard to these two sex-linked genes. A close inspection of this table shows that no consistent differences exist between either the barred and non-barred fast-feathering progeny or the barred and non-barred slow-feathering progeny.

Relationship of Rate of Growth to Rate of Feathering. In order to determine the inter-relationship of body weight and feather score for each of the tracts at 8 weeks, the mean body weight and mean feather score of each of the remaining tracts was obtained for all the progeny classified according to the feather score of each tract in consecutive order. These means and the number of progeny involved for each feather score are given for all tracts in Tables XIV and XV for the males and females, respectively. These tables show a rather consistent inter-relationship between body weight and each feather tract when the progeny of all the matings are considered as a group. A general conclusion can be made that

TABLE XIII

Percentage Distribution of the Progeny of the (E x L) x L Mating on the Basis of Feather Score and Genetic Composition

Tract	Feather Score	Males Genetic Composition				Females Genetic Composition			
		BbKk	bbKk	BbKK	bbKK	B-k-	b-k-	B-K-	b-K-
Neck	0	0.0	0.0	3.8	3.1	0.0	0.0	0.0	0.0
	1	12.2	5.3	30.8	31.3	0.0	3.1	13.3	5.1
	2	63.4	76.3	61.5	62.5	77.3	78.1	83.3	92.3
	3	24.4	18.4	3.8	3.1	22.7	18.8	3.3	2.6
Back	0	0.0	0.0	0.0	3.1	0.0	0.0	0.0	0.0
	1	14.6	7.9	34.6	50.0	9.1	6.3	26.7	17.9
	2	68.3	89.5	61.5	43.8	63.6	68.8	66.7	76.9
	3	17.1	2.6	3.8	3.1	27.3	25.0	6.7	5.1
Tail	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	2.4	0.0	15.4	15.6	0.0	0.0	3.3	7.7
	2	63.4	57.9	46.2	68.8	40.9	46.9	73.3	76.9
	3	34.1	42.1	38.5	15.6	59.1	53.1	23.3	15.4
Shoulder	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	7.3	2.6	19.2	31.3	4.5	12.5	26.7	25.6
	2	63.4	63.2	61.5	53.1	50.0	40.6	50.0	46.2
	3	29.3	34.2	19.2	15.6	45.5	46.9	23.3	28.2
Web	0	0.0	2.6	7.7	9.4	0.0	0.0	0.0	0.0
	1	7.3	71.1	65.4	71.9	4.5	59.4	53.3	64.1
	2	58.5	23.7	19.2	18.8	77.3	40.6	46.7	35.9
	3	24.1	2.6	7.7	0.0	18.2	0.0	0.0	0.0
Thigh	0	14.6	18.4	15.4	25.0	9.1	0.0	13.3	7.7
	1	29.3	28.9	42.3	37.5	22.7	31.3	40.0	53.8
	2	46.3	52.6	42.3	31.3	59.1	65.6	43.3	38.5
	3	10.0	0.0	0.0	6.3	9.1	3.1	3.3	0.0
Leg	0	7.3	0.0	3.8	9.4	4.5	0.0	3.3	5.1
	1	46.3	63.2	46.2	56.3	31.3	40.6	33.3	38.5
	2	39.0	36.8	46.2	34.4	59.1	50.0	63.3	56.4
	3	7.3	0.0	3.8	0.0	4.5	9.4	0.0	0.0
Breast	0	2.4	5.3	3.8	12.5	4.5	0.0	0.0	0.0
	1	63.4	63.2	65.4	56.3	63.6	59.4	0.0	71.8
	2	34.1	31.6	26.9	31.3	31.8	40.6	80.0	28.2
	3	0.0	0.0	3.8	0.0	0.0	0.0	20.0	0.0
Abdomen	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	1	14.6	5.3	11.5	6.3	4.5	0.0	10.0	12.8
	2	56.1	57.9	61.5	78.1	45.5	56.3	63.3	56.4
	3	29.3	36.8	26.9	15.6	50.0	43.8	26.7	30.8

TABLE XIV

The Inter-relationship of Body Weight and Feather
Score for Each of the Tracts at 8 Weeks When the
Male Progeny Were Classified According to the
Feather Score of Each Tract in Consecutive Order

Tract	Feather Score	No. of Progeny	Body Weight	Back	Tail	Shoulder	Web	Thigh	Leg	Breast	Abdomen
Neck	0	7	254.9	.01	.71	1.00	.00	.01	.43	.01	.86
	1	128	426.4	1.22	1.87	2.10	.81	.45	1.49	.66	2.02
	2	535	502.1	1.72	2.13	2.40	1.10	.80	1.75	1.02	2.42
	3	68	538.7	2.41	2.72	2.85	1.35	1.15	1.68	1.21	2.53
Back	0	20	322.0		.95	1.55	.35	.05	.85	.20	1.05
	1	205	461.7		1.47	2.13	.87	.45	1.52	.73	2.09
	2	260	508.8		2.37	2.52	1.19	.96	1.79	1.14	2.53
	3	48	534.6		2.89	2.94	1.56	1.21	1.94	1.19	2.68
Tail	0	5	292.6			1.40	.20	.00	.60	.00	.80
	1	133	443.1			2.02	.76	.37	1.53	.62	2.01
	2	244	486.6			2.30	1.11	.81	1.61	1.05	2.31
	3	151	529.4			2.81	1.24	1.03	1.91	1.11	2.66
Shoulder	0	1	251.0				.00	.00	.00	.00	1.00
	1	35	564.6				.77	.74	.83	.83	1.51
	2	263	462.7				.99	.69	1.51	.90	2.10
	3	234	531.5				1.16	.82	1.97	1.03	2.70
Web	0	51	357.1					.18	.88	.33	1.39
	1	412	497.5					.71	1.76	.94	2.45
	2	62	504.7					1.40	1.65	1.52	2.23
	3	8	574.6					1.50	1.75	1.25	2.58
Thigh	0	231	436.9						1.38	.65	2.06
	1	215	526.7						1.98	1.07	2.57
	2	75	511.0						1.57	1.48	2.36
	3	12	549.7						2.08	1.33	2.58
Leg	0	20	331.8							.45	1.40
	1	208	428.7							.80	1.88
	2	236	518.1							1.09	2.62
	3	69	594.2							1.09	2.88
Breast	0	101	405.5								1.65
	1	362	506.4								2.51
	2	65	498.4								2.23
	3	5	481.6								2.80
Abdomen	0	3	261.3								
	1	83	382.0								
	2	188	474.1								
	3	259	530.6								

TABLE XV

The Inter-relationship of Body Weight and Feather
Score for Each of the Tracts at 8 Weeks When the
Female Progeny Were Classified According to the
Feather Score of Each Tract in Consecutive Order

Tract	Feather Score	No. of Progeny	Tracts								
			Body Weight	Back	Tail	Shoulder	Web	Thigh	Leg	Breast	Abdomen
Neck	1	45	591.6	1.20	1.53	2.07	.98	.63	1.47	.67	2.07
	2	378	458.2	2.01	2.53	2.67	1.12	1.02	1.94	1.07	2.64
	3	127	486.3	2.73	2.83	2.97	1.46	1.22	2.00	1.22	2.71
Back	0	2	341.0	2.00	2.00	2.00	0.50	0.50	2.00	0.50	2.00
	1	79	599.2		1.58	2.00	.96	.63	1.44	.80	1.97
	2	524	464.9		2.56	2.63	1.18	1.01	1.94	1.10	2.67
	3	145	480.9		2.95	2.95	1.35	1.29	2.11	1.24	2.83
Tail	1	44	576.9			2.05	.89	.54	1.57	.73	1.83
	2	240	462.0			2.42	1.15	1.04	1.88	1.08	2.66
	3	266	469.5			2.90	1.28	1.12	2.01	1.17	2.76
Shoulder	1	26	590.2				1.16	1.28	1.04	1.08	1.80
	2	159	425.7				1.14	.97	1.61	1.08	2.87
	3	586	478.5				1.21	1.05	2.10	1.10	2.81
Web	0	17	549.1					.71	1.12	.65	1.88
	1	423	458.5					.89	1.93	1.00	2.69
	2	89	470.8					1.58	1.99	1.45	2.39
	3	11	565.1					1.58	1.75	1.93	2.68
Thigh	0	141	419.8						1.92	.81	2.51
	1	276	471.2						2.07	1.06	2.70
	2	110	466.3						1.89	1.44	2.45
	3	13	522.8						2.61	1.57	2.91
Leg	0	10	393.8							.80	1.70
	1	138	385.6							.97	2.14
	2	234	460.1							1.16	2.72
	3	1110	517.3							1.14	2.86
Breast	0	40	460.2								2.23
	1	426	452.5								2.69
	2	74	457.9								2.38
	3	8	509.4								2.25
Abdomen	1	34	403.4								
	2	147	418.1								
	3	362	480.7								

over all parts of the body are correlated.

It will be recalled that the data obtained on the F_1 progeny tend to show a negative relationship between rate of feathering and rate of growth. The results from previous investigations also were not in complete agreement. The coefficient of correlation obtained by Radi and Warren (75) ranged from 0.055 to 0.383 and 0.194 to 0.240 for females and males, respectively. Gericke and Platt (19) in their Barred Plymouth Rock investigation obtained a coefficient of correlation of 0.812. Jaap and Morris (40), working with a number of different breeds, obtained a correlation coefficient of only 0.23. Radi and Warren (75) were led to conclude that body weight and feathering as determined at 8 weeks of age bear no close relationship.

Since a high degree of relationship is apparent in the F_2 and backcross data obtained in this investigation, it would be of importance to determine conclusively if genes for the expression of these two characters are borne on the same chromosome or whether the relationship is of a physiological nature. In an effort to obtain more information regarding this subject, correlation coefficients were obtained for each of the progeny groups and a covariance analysis was made of the relationship of total feather score to body weight and shank length. The coefficients obtained and the results of the covariance analysis are given for the males and females in Table XVI. Snedecor's (84) tables were referred to again in order to determine the 5-percent and 1-percent level of significance for the degrees of freedom available for each coefficient.

The coefficients obtained between feather score and body weight are highly significant for all male progeny groups except for mating L x (L x R) which is hardly significant. The coefficients are also highly significant for all the female progeny groups except those from mating (E x L) x (E x L) and the fast-feathering group from mating (E x L) x L. The three exceptional coefficients are also below the 5-percent level of significance. The

TABLE XVI

Correlation Coefficients Obtained in the Analysis
of the Relationship of Total Feather Score to Body
Weight and Shank Length at 8 Weeks of Age

Mating or Groups	Rate of Feathering at 10 Days of Age	Feather Score and Body Weight				Feather Score and Shank Length			
		Males		Females		Males		Females	
		Degrees of Freedom	Correlation Coefficients	Degrees of Freedom	Correlation Coefficients	Degrees of Freedom	Correlation Coefficients	Degrees of Freedom	Correlation Coefficients
(E x L) x (F x L)	Slow	47	.537	25	.260	47	.587	23	.417
(E x L) x (F x L)	Fast	--	--	25	.324	--	--	20	.484
(F x L) x (L x R)	Slow	28	.659	22	.664	28	.677	22	.688
(E x L) x (L x R)	Fast	26	.618	31	.520	24	.639	31	.549
R x (E x L)	Slow	49	.617	37	.527	49	.537	37	.558
R x (L x R)	Slow	117	.717	128	.684	114	.699	127	.647
L x (L x R)	Fast	45	.830	76	.474	45	.559	73	.525
(E x L) x L	Slow	77	.605	79	.598	77	.591	79	.632
(E x L) x L	Fast	105	.640	70	.116	105	.654	70	.349
Between Matings or Groups		7	-.305	8	.047	7	-.457	8	.109
Within Matings or Groups		500	.625	500	.496	495	.625	491	.554
TOTAL		507	.565	508	.449	502	.540	499	.502

correlation coefficients obtained between total feather scores and shank length are highly significant for all the female progeny groups except those from the mating (B x L) x (B x L). These two exceptional coefficients are of a high value and are above the 5-percent level of significance, but the degrees of freedom available are too small for the coefficients to be highly significant.

The correlation coefficients obtained in the covariance analysis are highly significant in each case within matings or groups and for total variance but not significant between matings or groups.

This covariance analysis shows that the significant relationship between rate of feathering and rate of growth is due to the high relationship existing between these two factors in the progeny of the same general genetic composition. This would suggest that either the genes for the expression of these two characters are borne on the same chromosome or some of the genes for the expression of one of the characters also influence the other character, rather than the relationship is due to the expression of a physiological function. If the relationship was solely of a physiological nature the correlation coefficients should be positive also between matings or groups.

It is impossible from a study of these data to determine the number of genes that affect rate of growth as well as rate of feathering. It is apparent, however, that in the case of each character, multiple genes are involved.

SUMMARY AND CONCLUSIONS

An analysis of the data obtained in this investigation appeared to warrant the conclusions that follow.

1. In general the Barred Plymouth Rock parental stock transmitted genes to the F_1, F_2, and backcross progeny that contributed to a more rapid rate of growth and a less rapid rate of feathering at 8 weeks of age than those contributed by the Brown Leghorn parental stock.

2. No consistent differences were obtained in rate of growth or rate of feathering between the descendants from the exhibition-bred Barred Plymouth Rock male and the production-bred Barred Plymouth Rock females.

3. The male progeny of all F_1, F_2, and backcross matings had significantly greater body weight and shank length, but a significantly lower rate of feathering than the female progeny at 8 weeks of age.

4. The conformation or shape as determined by the ratio of mean shank length to the cube root of the mean body weight for the progeny from each of the P_1, F_1, and backcross matings was found to vary only slightly at 8 weeks of age.

5. The male and female progeny from each mating also were very similar in conformation.

6. Neither the sex-linked gene (B) for barred plumage nor the sex-linked gene (K) for slow rate of feathering had a significant influence on rate of growth. However, in all matings but one the non-barred fast-feathering males (bbkk) and females (bk-) grew at a comparatively faster rate than either the barred fast-feathering, barred slow-feathering, or non-barred slow-feathering males and females.

7. The sex-linked gene for early sexual maturity is responsible perhaps for the indication that a sex-linked gene exists for rate of growth.

8. Birds homozygous or heterozygous for the sex-linked gene K had a significantly lower feather score at 8 weeks of age than birds carrying the recessive gene only. The significant differences in total feather score were found to be due largely to the significant differences in degree of feathering over the neck, back, tail, and shoulder tracts.

9. Since considerable variation existed in the degree of feathering of each tract among birds recessive for the sex-linked gene K, a number of other genes must be involved, some of which act upon the sex-linked gene.

10. The sex-linked gene for rate of feathering has very little influence upon the rate of feathering of tracts other than those over neck, back, tail, and shoulders.

11. The sex-linked gene (B) for barred plumage was found to be loosely linked with the sex-linked gene (K) for rate of feathering but had no significant affect on degree of feathering at 8 weeks of age.

12. The correlation coefficients obtained between rate of growth and rate of feathering were positive and highly significant for the total population and for the progeny groups within matings. However, the coefficients obtained between the means for the different progeny groups were not only non-significant but also negative for the males, suggesting that the correlation existing in the total population could not be due to a relationship solely physiological in nature. Genes for the expression of these factors are borne on the same chromosome, or one or more genes influence both factors.

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Publications:

1931:
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