A STUDY OF FEATHER GROWTH IN EARLY AND LATE FEATHERING EMBRYOS AND CHICKS UP TO ELEVEN DAYS OF AGE

by

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INTRODUCTION

During recent years, commercial broiler growers have realized the necessity of having well developed and well feathered birds at market age. Well feathered birds, when dressed, possess more attractive and appealing carcasses, whereas "bare-backs" or poorly feathered broilers appear discolored and are discriminated against by the commercial buyers.

Poultry geneticists have felt that early feathering birds at market age have a more desirable carcass than the late feathering birds. It is, therefore, thought to be desirable in breeding to work toward early feathering in the broiler strains. However, there are some broiler producers who grow late feathering birds and contend that they are more desirable from a standpoint of plumage at market age.

It is known that early feathering is due to a sex-linked gene, (k) which is recessive to its allelemorph (K), late feathering. It is interesting to note that these two sex-linked genes produce one of the rare cases in animals in which a distinct modification of a physiological process depends upon a single pair of alleles.

Early feathering can be introduced into a flock, and, by simple genetic procedures, late feathering stock can be eliminated in a short time. Once the early feathering stock becomes homozygous, it will remain that way unless late feathering individuals are introduced.

The early feathering birds are more desirable from a commercial buyer's standpoint. Being more uniformly covered with feathers, they are less apt to suffer from extremes in temperature. They are also able to fly to the roosts at an earlier age, helping to prevent overcrowding in the brooder house.

In recent years during nationwide broiler growing contests, in which the leading broiler strain breeders were entered, it was observed that some pens

of birds, when killed and dressed, rated very high on size and conformation, but lost points on appearance. It was evident that several individuals in the pens were late feathering. It would appear that possibly some breeders mistakenly have retained late feathering stock, assuming they were early feathering.

Since the type of feathering can be determined at hatching, it would seem logical that one might determine early or late feathering before hatching. Therefore, the first portion of this study was undertaken to determine at what time during the embryonic stage of development early and late feathering could be recognized. Additional data also seemed desirable to critically compare the types of feathering up to eleven days of age. After eleven days, early and late feathering are easily distinguished by tail and wing development.

REVIEW OF LITERATURE

The outstanding discovery of Serebrovsky (1922) gave the first evidence of a sex-linked gene responsible for the rate of feather growth when breeding Barred Plymouth Rocks to Russian Orloffs.

Warren (1925) confirmed Serebrovsky's findings by mating Jersey Black Giants to White Leghorn females. All of the progeny were observed to be late feathering. When White Leghorn males were mated to Jersey Black Giant females, all of the pullet chicks showed early feathering, while all of the males showed late feathering. This was proof that early feathering was due to the sex-linked recessive factor (k).

Danforth (1929) concluded that there were probably two factors influencing feathering in chicks. He felt that one factor was local and restricted to the feather follicle. The other was general and indirect. In grafting

skin from one bird to another, he found that it was the genetic make-up of the donor and not that of the host which determined the rate of feathering in the transplanted tissue.

Rate of feathering is dependent also upon other inherited factors which are not affected by sex linkage. Warren (1933) found some chicks which were retarded in rate of feathering in a flock of White Leghorns, which are normally early feathering. He construed that "retarded" was a simple autosomal factor which was recessive and alters the expression of early feathering. The retarded gene was found to express itself in juvenile plumage only and to retard the growth of all the secondaries except the first three.

Jones and Hutt (1946) discovered a factor, called tardy ($\underline{t}$), which with retarded ($\underline{t}^s$) and the normal allele ($\underline{T}$) comprised a series of multiple alleles. The tardy chicks were totally absent of secondary feathers. The retarded and tardy mutations are identifiable in early feathering chicks only, as up to date it is not known how to recognize these mutations in the late feathering chicks.

Darrow and Warren (1944) reported finding an autosomal recessive modifying factor which somewhat inhibited feathering of birds homozygous for sex-linked early feathering. In studying early feathering Rhode Island Red, Barred Plymouth Rock, and White Plymouth Rock birds, they found the "modified early" birds to have primaries of length and type similar to White Leghorns, but at broiler age they were very seldom as well feathered. It was suggested that this might be due to the same factor previously reported as "retarded".

Radi and Warren (1938) found an autosomal dominant factor for improved feathering in late feathering strains. After selecting for several generations for both a well feathering strain of late feathering Rhode Island Reds

and a poor feathering strain of late feathering Rhode Island Reds, the two strains were crossed. It was observed that the offspring compared favorably with the well feathered parents.

Martin (1929) reported after studies on Barred Plymouth Rocks that chicks showed sex dimorphism, with the females feathering faster. Other workers have noted this difference, including Jaap and Morris (1937), Radi and Warren (1938), Hays and Sanborn (1942), and Darrow and Warren (1944).

Plumart (1952) found that throughout his studies of chicks to broiler age, early feathering males possessed a greater number of feathers on the dorsal feather tract than did late feathering males. Early feathering females exhibited more maturity of feathers up to eight weeks of age, but the difference decreased from 10 to 12 weeks of age. This was shown by actual count of feathers and classification of each one for degree of maturity.

Darrow (1941) found the number of well developed secondaries to be highly correlated with the degree of feathering over the back at six weeks of age. Darrow and Warren (1944) classified chicks at one day of age into three groups with regards to feathering--early, late, and intermediate. The "early" group had primaries longer than their coverts, the "late" group had primaries shorter than their coverts, and birds in the "intermediate" group had primaries and coverts of about the same length and diameter. The secondaries were classified in much the same manner. They found that intermediates were more like late feathering chicks with respect to feathering at broiler age. They concluded that "intermediate" was a type of late feathering and was the result of a dominant modifier.

Several workers have reported on feathering in relation to growth rate with varying results. Warren and Payne (1945) in comparing early and late feathering birds at market age, found that early feathering birds outweighed

the late feathering individuals in all eight groups studied. They felt it might be caused by genetic or physiological linkage between early feathering and rapid growth, or it might be that the presence of a well feathered body at an early age favors growth.

Martin (1929) showed the rate of development of feathers over the back of Barred Plymouth Rocks was closely related to rate of growth, the heavier chicks feathering more rapidly. Godfrey and Farnsworth (1952), however, found no relationship between the sex-linked early feathering gene and growth up to 10 weeks of age. They concluded that the action of the k gene occurs in the feather follicle and is not related to growth of body.

Hurry and Nordskog (1953) in working with Barred Plymouth Rocks and New Hampshires found that the sex-linked k appeared to improve feathering at broiler age without influencing its variation. However, the gene did not significantly increase body weights at eight weeks of age. The two sexes did not respond alike in regards to the influence of the k gene on variance in body weight. The sex-linked late feathering males were found to be more variable than the early feathering males. There appeared to be no effect of the sex-linked gene on body weight variance in the females.

Godfrey (1953) found evidence of a rapid growth gene Rg which was associated with late feathering. Males from a Rose Comb Black Bantam male-Barred Plymouth Rock female mating were back crossed to New Hampshire females. The results showed no difference in weight of early and late feathering males. However, there was definite difference in body weight of the two classes of females. The greatest difference occurred between six and nine weeks of age.

By crossing the F_1 generation of Rose Comb Black Bantam and Barred Plymouth Rocks, Godfrey noted that in all cases the late feathering males and females weighed more than the early feathering birds. He concluded that in

both cases the difference was due to the sex-linked rg gene which he suggests is located between the silver and late feathering loci on the sex chromosome. It was suggested that the gene is not peculiar and may be present at a low frequency in the normal sized breeds.

Dunn and Landauer (1930), in their studies of Silver Spangled Hamburg chickens, stated that the first true feathers of the wing appear at hatching or shortly thereafter. At three weeks of age, they found primaries and secondaries to be doubled in length from hatching. They noted that there were seven primaries and seven secondaries present at hatching. They found the first and second secondary to be absent, but that they made their appearance around the fifth week. The three remaining distal primaries made their appearance in 30 to 40 days.

Warren and Gordon (1935) identified the wing feathers by numbering the primaries distally and the secondaries proximally from the axial feather. They found in White Leghorns that about seven primaries were present at hatching and that primaries number 8, 9, and 10 emerged at regular intervals of from 10 to 14 days thereafter.

Secondaries numbers 2 to 7, inclusive, were present at hatching, with numbers 8 to 12 appearing later in proper sequence but at no regular interval. Secondary number 1 appeared in about two weeks. Since descriptions of secondaries number 1 and 2 at hatching in the work of Dunn and Landauer (1930), differ from those of Warren and Gordon (1935), it would seem probable that Dunn and Landauer included the axial feather as one of the secondaries.

The study of Warren and Gordon (1935) of the sequence of emergence of remiges in Rhode Island Reds provided results similar to those of the White Leghorns. However, there were fewer flight feathers at hatching, and the age at which the missing remiges first appeared differed considerably with the cor-

responding age for the White Leghorns. The females were found to have an average of five primaries with the males having an average of four. At hatching, the females had an average of three secondaries, while the males averaged only one. Secondaries number 1 and 2 were absent in both sexes. In the females, secondary number 2 made its appearance on the second day, while number 1 did not appear until the average age of 21 days. Secondary number 1 required an average of 26 days to emerge in the male, while the secondary number 2 appeared in about 5.5 days.

A great deal of work has been done and much has been written about the development and physiology of the feather. A good summary of the development of the flight feathers is given by Hamilton (1952).

According to him, each follicle gives rise to three phases of feathers which appear as down feathers, then juvenile feathers, followed by the adult feathers. Time of emergence of feathers varies according to which tract they belong. At seven and one-half days of incubation, flight feather germs are barely perceptible at optimal illumination or absent. At eight days the feather germs on the posterior edge of the wing are visible under good illumination.

From eight to nine days the epidermis begins to protrude outward as a shallow cap. There is rapid growth outwards of the newly formed feather germ, resulting in a tapering epidermal cylinder filled with a mesodermal core. The wing feathers are readily seen after ten days of incubation. Ridges begin to appear on the inner surface of the distal third of the feather germ on the eleventh day. More ridges appear rapidly on the right and left. These ridges are the primordia of the seperate barb vanes.

The down feathers grow at an increasingly rapid rate until the 13th day, at which time their growth ceases abruptly. Cornification of the formed ele-

ments begins. At 15 days, the juvenile feather starts to form. The blood within the vessels of the down becomes stagnant, and the large portion of the pulp with the innermost cylinder cells which bound it begin to shrink inward and eventually become reduced to dried cells. Near the base of the feather, the pulp constricts and begins forming a series of lumps which dry into the horny "pulp cap". The first pulp cap forms about 0.5 mm. above the calamus, or quill, and the others within the quill. Cornification of the base of the feather germ occurs where the barb ridges remain fused, forming the calamus.

By the time the chick hatches the main juvenile wing feathers have made their appearance and the down feathers are attached to their tips. At hatching the sheath of the down feathers splits, releasing the barbs, which extend outward about 13 mm. The exposed dried pulp then breaks up and is cast off, according to Hamilton (1952).

As shown by Warren (1944), early and late feathering chicks, can be distinguished by the relative length of the primaries and their coverts at hatching. However, the author was unable to find any report in the literature in which such comparative studies were made of the primaries and coverts before hatching.

EXPERIMENTAL PROCEDURE

Stock Used

All stock used in this study was obtained from the Kansas State College Experimental Poultry Farm. For the first part of the work, eggs to be incubated for embryological examinations were procured from matings of late feathering New Hampshire and Rhode Island Red females mated to White Leghorn males.

Thirty-six chicks were used in the second portion of the study, which was divided into two seperate experiments (A and B). They included pure bred

New Hampshires, pure bred White Plymouth Rocks, and three different types of crossbreds. Of the group, there were equal numbers of early and late feathering chicks.

Studies of Embryos

In the first phase of this study, it was hoped to determine whether early and late feathering could be distinquished before hatching, and if so, at what stage of development. White Leghorn males were mated to late feathering New Hampshire and Rhode Island Red females. It was known that they would produce late feathering males and early feathering females. The hens were trapnested since it was desirable to compare early and late feathering embryos from the same mating.

Fifty-two eggs were placed in the incubator on April 17, 1953. These eggs were removed from the incubator a few at a time, beginning with the twelfth day (April 29th), and continuing each day thereafter until the day of hatching. In order to identify which were early and which were late feathering, the embryos were examined with the aid of a dissecting microscope to determine sex. After critical examination, the sex was determined. On each day 2 or more eggs from the same female were broken and the embryos examined until both a male and a female were secured.

Beginning on the thirteenth day, the first two proximal primary wing feathers and their coverts were measured. The most distal two secondaries that could be observed and their coverts were also measured. These were recorded in millimeters.

This procedure was carried out throughout the remainder of the incubation period or until the 20th day. By using a male and a female, it was possible to compare the daily growth of the down feathers and the development of the

juvenile feathers for early and late feathering chicks up to the time of hatching.

Studies of Chicks After Hatching

Experiment A. For the purpose of gaining experience and learning the technique of measuring wing feathers, seven pairs of chicks were used. A pair in this study included one early and one late feathering chick having the same sire but not necessarily the same dam. The chicks were secured from matings of White Plymouth Rock males with White Leghorn and New Hampshire hens.

Primaries number 1, 2, and 3 were measured in this test, as were their corresponding coverts. Measurements were taken at hatching and were repeated daily through eight days of age. Although this test was run primarily to gain experience, there was such a surprisingly clear-cut difference between the early and late feathering chicks at eight days of age, that the results are shown in detail in Tables 5 and 6.

Experiment B. More extensive data were obtained from 22 chicks (11 pairs) used in the second study with hatched chicks. In this work a pair included one early and one late feathering chick having the same sire, and where possible the same dam also.

In order to produce the various pairs, it was necessary to progeny test males believed to be heterozygous for the late feathering gene. Early feathering White Leghorn and New Hampshire females were artificially inseminated with semen collected from these males. Six males proved to have the desired genotype and each was placed in a separate breeding pen. Three White Plymouth Rock males were mated to early feathering White Plymouth Rock females and one White Plymouth Rock male was mated to early feathering New Hampshire females. The fifth mating was between a New Hampshire male and early feathering New

Hampshire females. A crossbred male heterozygous for extension of black, barring, and late feathering (EeBbKk) was the sixth male used, and he was penned with early feathering White Plymouth Rock females. Table 1 shows the matings and offspring. It was possible to trapnest the birds in the pure White Plymouth Rock pens, which enabled full sibs to be compared.

Table 1. Origin of chicks used in Experiment B.

Pen Number	Breed of		Pairs of chicks used
	Sire	Dam	
1	White Plymouth Rock	White Plymouth Rocks	1
2	White Plymouth Rock	White Plymouth Rocks	2
3	White Plymouth Rock	White Plymouth Rocks	3
4	New Hampshire	New Hampshires	2
5	White Plymouth Rock	New Hampshires	1
6	Crossbred	White Plymouth Rocks	2

Eggs were collected for a period of two weeks and 200 placed in the incubator on April 3, 1953. They were transferred to the hatching trays on the 18th day. By the 20th day the chicks had begun hatching, so they were removed from the incubator and wingbanded in the morning and more were removed in the afternoon of that day. It was planned to measure the wing feathers shortly after the chicks emerged from the shell while the birds were still wet. Fifty one chicks hatched April 23 (the 20th day), but only three pairs of the desired sib chicks were hatched and measured. On April 24 (the 21st day), ten additional pairs of early and late feathering chicks were obtained and measurements were begun. Two pairs died shortly after the study began.

Although the axial wing feather was absent in the day-old chicks, the

space where it eventually would be was evident. The length of the first and second primaries distal to the axial space and of their corresponding covert was measured. Since the first secondary was also absent at hatching, the length of the second and third secondaries proximal to the axial space and that of their corresponding covert was measured. These lengths were recorded in millimeters.

In the technique of measuring, a chick was laid breast down in the palm of the hand. The feet and the legs were drawn together and held between the third and fourth fingers, with the base of the finger holding the legs near the body. The forefinger and thumb were used to hold the body and the left wing.

With the aid of an assistant, who stretched out the wing, the feathers were measured with a thin plastic ruler graduated in millimeters. The end of the ruler was placed at the base of the shaft and measurements were taken from the point at which the shaft emerged from the outer layer of the skin. Since the coverts are located slightly above and posterior to the primaries and secondaries, extreme care was taken not to measure the coverts from the same point as the main feathers. Measurements were recorded at two-day intervals through 11 days of age.

RESULTS

Studies of Embryos

Down feathers could be seen at 10 and 11 days of age, however, due to the difficulty in determining sex at that age, the taking of measurements of the feathers was not begun until the 12 day of incubation. Although measurements of the feathers from the time at which they emerged from the skin was sacri-

ficed, it was more important that the correct determination of sex be made, in order to identify which chicks possessed early feathering and which showed late feathering.

No consistent differences were found in the growth of the down feathers in the early and late feathering chicks. Tables 2 and 3 show the average daily length of feathers from the 12th through the 20th day of incubation. In both early and late feathering chicks, the covert down feathers tended to be about the same length as the corresponding primary down. However, the coverts in both cases tended to be slightly longer than their corresponding secondary down feathers. There was no appreciable growth after the 15th day of incubation. The small variation which did occur in the growth of the feathers was probably due to the use of entirely different embryos each day. Measurements of the down were recorded exclusive of the shaft of the juvenile feathers after the juveniles began making their appearance.

Evidence of beginning formation of the juvenile feathers could be seen on the 15th day. There appeared at that time a thickening at the base of the down feather and within the follicle. By the 17th day, the enlargement was quite noticeable. A constricted area of the skin on either side of each feath- had begun to form. This constricted ring proved to be the point of division between the base of the down feather and the tip of the underlying juvenile flight feather. By the 18th day, the juvenile feather within the follicle of primary number 1 of the female (early feathering) was 1 millimeter in length, compared to a length of 0.5 mm. for primary number 1 in the male (late feathering).

There was a distinct difference in the two groups on the 19th day. The primaries and their coverts had begun to emerge from the protruding follicle in the early feathering embryo. Primaries number 1 and 2 were 1.2 mm. and 2.0

Table 2. Length of primary and covert down feathers in early and late feathering embryos.*

Days of incubation	P_1**		PC_1		P_2		PC_2	
	Early	Late	Early	Late	Early	Late	Early	Late
12	2.5	4	2	2	2	3	1.5	2
13	7	6	7	6	6	6	5	5
14	8	7	9.5	7	8	8	9.5	8
15	10	10	10	10	10	11	10.5	10
16	10	9.5	10	9.5	10.5	9.5	11	9
17	12	10	10	10	11	10	10	10
18	13	11	12	12.5	12	11	13	13
19	12	13	11	13	13	13	11	13.5
20	12	12	13	12	13	12	12	13

*One pair of embryos from the same sire and dam were measured on each day. From the 18th to the 20th days the down was attached at its base to the tip of the juvenile feather. (See also Table 4.)

**Throughout the tables and figures in this thesis, primary feathers are indicated by P, primary coverts by PC, and secondaries and their coverts by S and SC, respectively. Subscript numbers are used to indicate which individual feather is under consideration, numbering distally from the axial feather (or axial space) in primaries and numbering proximally from the same point in the secondaries. All measurements are recorded in millimeters.

Table 3. Length of secondary and covert down feathers in early and late feathering embryos.*

Days of incubation	S_2		SC_2		S_3		SC_3	
	Early	Late	Early	Late	Early	Late	Early	Late
12	4	5	4	4	3	4	4.5	4
13	9	9	9	8	8	8	9	9
14	9	9	11	10	9	8.5	11	10
15	13	13	14	15	14	13	15	15
16	14	13	16	15	14	11	16	13
17	12	13	14	16	11	12	14	16
18	14	12	17	13.5	15	12	16	15.5
19	12	13	15	15.5	12	12.5	15	17
20	14	12	16	15	14	12	16	14

*Based on the same embryos described in Table 2. From the 18th to the 20th days the down was attached at its base to the tip of the juvenile feather. (See also Table 4).

mm. in length, respectively, compared to first and second covert lengths of 0.5 and 0.7 mm., respectively. The 4th primary was observed to be even longer (2.5 mm.) in length. The late feathering male on the 19th day showed no emergence of primaries number 1 and 2, but showed a small growth of their coverts. Coverts number 1 and 2 were 0.5 mm. and 1.0 mm. in length respectively.

In the early feathering embryo, the secondaries number 2 and 3 had emerged very little, measuring 0.2 mm. There was no evidence of the corresponding coverts. Secondaries number 2 and 3 of the late feathering chick showed no differentiation, but their coverts did show a trace of emergence. This did not appear to be in line since in later studies the corresponding coverts of early and late feathering chicks tended to average the same lengths. However, as stated previously, a different pair of embryos were studied daily. On the 19th day, the distal end of the juvenile feather shaft appeared quite red, as if filled with blood, whereas the base of the down feather was clear and appeared dried out and dead.

By the 20th day, all the juvenile feathers to be measured had appeared in both groups. The early feathering embryos resembled typical early feathering chicks. Both primaries and secondaries were longer than their corresponding coverts. In the late feathering embryos, however, the coverts were longer than their primaries and secondaries. Table 4 shows the time of emergence and daily length of the juvenile feathers.

The primaries and secondaries of the early feathering embryos averaged 2.3 mm. longer than those of the late feathering ones, but the difference bethe coverts in the two sections was only 1.0 mm.

From this phase of the study, it was found that early feathering and late feathering chicks could not be distinguished at any time by observing the down feathers. There was noted a difference in the follicles of the early and late

Table 4. A comparison of time of emergence and growth of juvenile primary, secondary, and covert feathers in early and late feathering chicks.

Feather	Length of feather after indicated days of incubation							
	17		18		19		20	
	Early*	Late	Early	Late	Early	Late	Early	Late
P_1	Trace	0	(1.0)**(0.5)		1.2	(0.7)	6.0	3.0
P_2	Trace	0	(1.0)	(0.5)	2.0	(0.7)	6.0	3.2
PC_1	0	0	0	0	0.5	0.5	4.0	3.3
PC_2	0	0	0	0	0.7	1.0	5.0	4.0
S_1	0	0	0	0	0.2	0	4.0	1.0
S_3	0	0	0	0	0.2	0	3.5	1.0
SC_2	0	0	0	0	0	Trace	3.0	2.0
SC_3	0	0	0	0	0	Trace	3.5	2.0

* "Early" denotes early feathering and "late" denotes late feathering.
**Numbers within the parenthesis indicate the length of protruding juvenile feather within the follicle prior to emergence.

feathering embryos at 17 days of age, but there was no clear-cut difference between early and late feathering chicks until the shafts of the juvenile feathers emerged from the follicle on the 19th day.

Studies of Chicks after Hatching

Experiment A. On the day of hatching, the average length of the primaries number 1, 2, and 3 of the early feathering chicks was 33.5 per cent greater than that of their corresponding coverts number 1, 2, and 3, since the primaries and coverts averaged 8.86 and 5.9 mm., respectively.

The average length of primaries number 1, 2, and 3 in the late feathering chicks was found to be 43.3 per cent less than that of their corresponding coverts. The primaries had an average length of 3.63 mm. compared to 6.4 mm. for the coverts. Primaries number 1, 2, and 3 of the early feathering chicks

averaged 5.23 mm. longer than those primaries of the late feathering chicks. The coverts of both early and late feathering chicks, however, had about the same average length. Coverts number 1, 2, and 3 of the late feathering individuals actually averaged 0.53 mm. longer than those of the early feathering chicks. Plates 1 and 2 show the appearance of the wing of representative early and late feathering chicks at hatching.

Measurements up to 8 days of age provided information which was not previously available. Tables 5 and 6 show the average daily lengths of primaries number 1, 2, and 3 and of their corresponding coverts. At the end of 8 days, the primaries of the early feathering chicks were practically twice as long as were their coverts. The primaries averaged 36.9 mm. in length compared to 19.1 mm. for coverts. The primaries at 8 days in the late feathering chicks were just beginning to attain the same length as their coverts. Primary number 1 was 0.6 mm. longer than its covert. However, covert number 2 was still 2.5 mm. longer than primary number 2 and covert number 3 was seen to be 4.4 mm. longer than primary number 3.

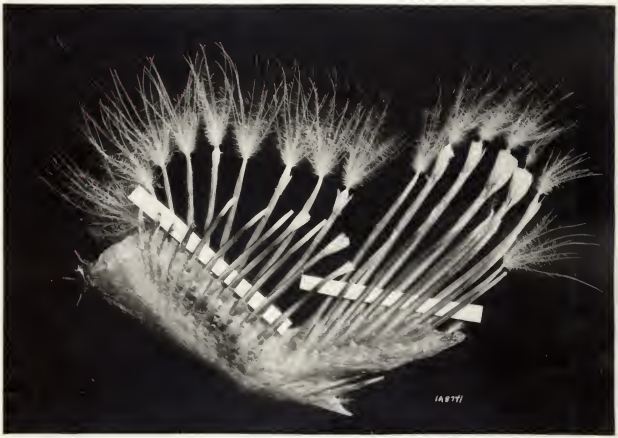
Table 5. Average length of primary and covert feathers in early feathering chicks (Experiment A).

Days after hatching	P_1	PC_1	P_2	PC_2	P_3	PC_3
1	8.1	5.5	8.8	6	9.7	6.2
2	11	7.5	12.6	8.6	13.5	9.1
3	16.1	9.7	17.2	11.2	18.2	12.4
4	20.4	12	21.5	14.2	23	15.5
5	25	14	26	17.1	28.4	18.4
6	28.4	14.8	30	18.5	32.8	19.9
7	32.5	16	33	19.1	35.5	21.2
8	35	16.1	36.7	19.5	39.1	21.7

EXPLANATION OF PLATE I

Top view of left wing of an early feathering chick with down removed to show more clearly the main wing feathers and their coverts. The primaries are beneath the white card on the right, and the secondaries are beneath the white card on the left. The coverts in each case are toward camera from the white cards. In order to aid in distinguishing the different groups of feathers, the down feathers have been removed from the tip of the juvenile coverts but not from the tip of juvenile primaries and secondaries. Note that the coverts are considerably shorter than the main wing feathers.

PLATE I



EXPLANATION OF PLATE II

Top view of left wing of a late feathering chick with down removed to show more clearly the main wing feathers and their coverts. The primaries are beneath the white card on the right, and the secondaries are beneath the white card on the left. The coverts in each case are toward camera from the white cards. In order to aid in distinguishing the different groups of feathers, the down feathers have been removed from the tip of the juvenile secondary coverts but not from the tip of juvenile secondaries. Note that the coverts are considerably longer than the main wing feathers.

PLATE II

Table 6. Average length of secondary and covert feathers in late feathering chicks (Experiment A).

Days after hatching	P_1	PC_1	P_2	PC_2	P_3	PC_3
1	3.1	5.5	3.7	6.7	4.1	7.1
2	4.8	7.7	5.4	9	5.7	9.7
3	6.8	10	6.8	11.1	7.7	12
4	9	12.2	8.8	14.5	9.7	15.2
5	11	14.6	10.7	17	11.3	18.1
6	12.4	15.5	12.4	18.2	13.5	19.3
7	15	16.4	15	19.8	15.7	20.9
8	17.5	16.9	17.3	19.8	17.5	21.9

The primaries in the early feathering birds at 8 days of age averaged twice the length for those of the late feathering chicks. However, the measurements of the coverts of both groups of chicks were almost identical throughout the 8-day period. Coverts in the early feathering chicks averaged 19.1 mm. compared to 19.5 mm. for coverts of the late feathering chicks.

The early feathering primaries averaged 36.9 mm. in length as compared to 17.4 mm. for the primaries of the late feathering chicks. The difference between early and late feathering chicks with respect to length of primaries number 1, 2, and 3 were all highly significant. Since the results of Experiment A showed such concrete differences between all 3 corresponding primaries according to type of feathering, measurements for Experiment B were confined to the first 2 primaries and additional data were taken for 2 secondaries and their coverts. Observations were continued until 11 days of age.

Experiment B. Tables 7 and 8 show the average lengths at 2-day intervals for primaries number 1 and 2, secondaries number 2 and 3 and the corresponding coverts in the early and late feathering chicks.

Table 7. Average length of primary and covert feathers in early and late feathering chicks (Experiment B).

Days after hatching	P_1		PC_1		P_2		PC_2	
	Early	Late	Early	Late	Early	Late	Early	Late
1	8.64	5.23	6.13	6.00	9.77	4.86	6.90	6.36
3	16.45	8.68	10.18	10.86	18.59	9.95	12.27	12.45
5	25.27	13.64	14.18	14.54	27.77	15.00	17.27	17.18
7	32.90	19.55	14.86	16.00	36.18	19.64	18.95	19.82
9	39.45	25.23	15.50	17.14	42.63	25.27	19.63	20.41
11	45.45	35.45	16.09	17.27	48.68	32.82	20.59	20.77

Table 8. Average length of secondary and covert feathers in early and late feathering chicks (Experiment B).

Days after hatching	S_2		SC_2		S_3		SC_3	
	Early	Late	Early	Late	Early	Late	Early	Late
1	7.54	2.09	4.68	3.73	7.09	1.91	5.36	4.04
3	13.68	4.54	9.36	6.86	12.86	4.45	10.68	8.00
5	22.18	7.91	17.09	12.40	20.90	7.54	16.40	11.73
7	28.73	10.91	22.45	17.18	27.18	10.68	21.49	17.05
9	35.54	14.50	25.68	21.95	34.18	14.73	24.77	21.45
11	42.27	22.09	27.45	27.55	41.68	20.09	26.68	26.75

Primaries and secondaries of the early feathering chicks were considerable longer than those of the late feathering chicks at one day of age. Corresponding coverts in early and late feathering chicks tended to average about the same in length, although the coverts of the secondaries in the late feathering chicks were slightly shorter than those of the early feathering chicks.

The graphs in Figs. 1 and 2 show that the primaries and secondaries of the early feathering chicks were considerably longer than their coverts through the first 11 days of age. In late feathering chicks, however, primary number 1 did not attain the same length as its covert until between the 5th and 6th day, and primary number 2 did not become longer than its covert until

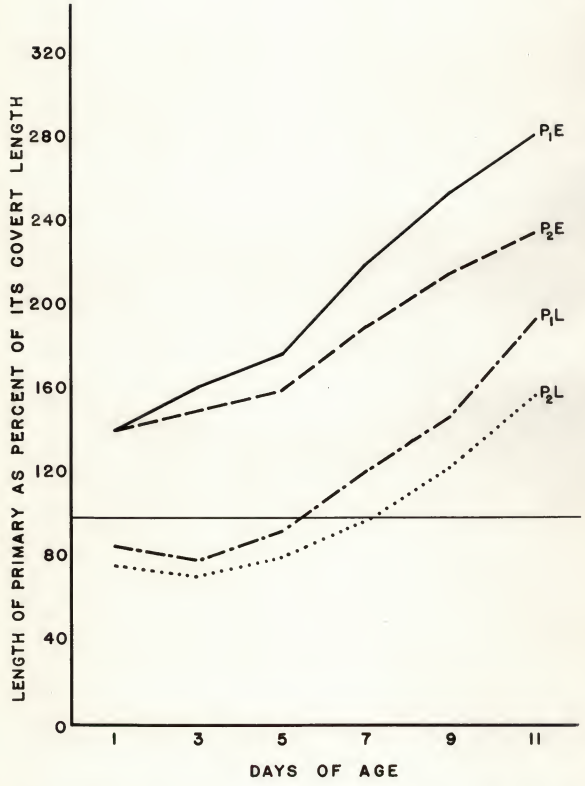


Fig. 1. A comparison of the relative length of coverts and primaries number 1 and 2 (P_1 and P_2) in early feathering chicks (E) and late feathering chicks (L).

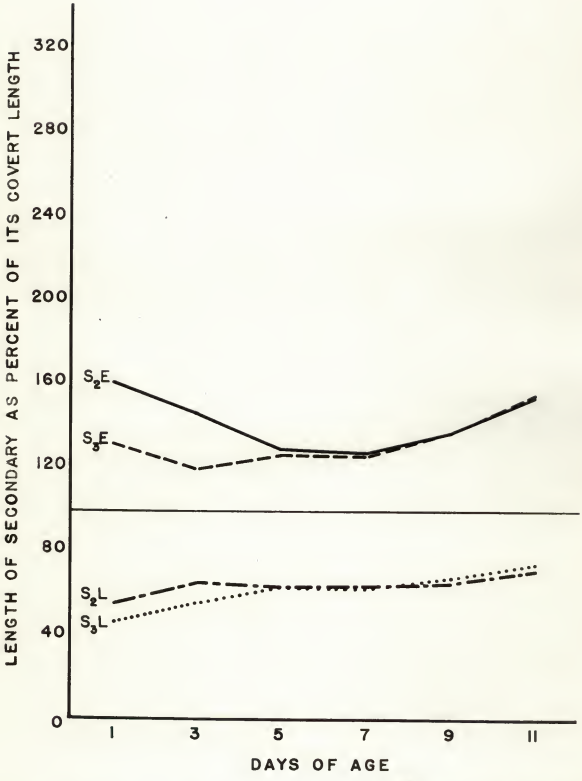


Fig. 2. A comparison of the relative length of coverts and secondaries number 2 and 3 (S_2 and S_3) in early feathering chicks (E) and late feathering chicks (L).

after the 7th day of age.

Secondaries number 2 and 3 of the late feathering birds never attained a length equal to that of their corresponding coverts up to 10 days of age. Table 9 shows the ratio of the length of primaries and secondaries in both groups of chicks to their corresponding coverts, from which the graphs in Figs. 1 and 2 were derived.

Table 9. Ratio of length of main wing feathers to that of corresponding covert.

Days after hatching	P_1/PC_1		P_2/PC_2		S_2/SC_2		S_3/SC_3	
	Early	Late	Early	Late	Early	Late	Early	Late
1	1.41	.87	1.41	.76	1.61	.56	1.32	.47
3	1.62	.80	1.51	.72	1.46	.66	1.20	.56
5	1.78	.94	1.61	.82	1.30	.64	1.27	.64
7	2.21	1.22	1.91	.99	1.29	.63	1.26	.63
9	2.55	1.49	2.17	1.24	1.38	.66	1.38	.69
11	2.82	1.94	2.36	1.58	1.54	.72	1.56	.75

The feathers of the males and females in the early feathering group averaged about the same length at 11 days of age. This was true also with respect to coverts in late feathering chicks. However, the other feathers measured in the late feathering female chicks were found to average 3 mm. more in length than the corresponding feathers of late feathering males. Tables 10 and 11 give a detailed comparison of males and females in both the groups of chicks studied.

As pointed out in the description of methods used, three pairs of chicks among the group of 11 pairs studied, had hatched and were removed from the incubator and feather measurements were recorded on the 20th day. The remaining 8 pairs of chicks hatched during the 21st day of incubation. Measurements were taken of all 11 pairs on the 21st day. The length of primary number 1 of the three early feathering chicks (which were more than 24 hours old) ranged

Table 10. Average length of primary and covert feathers in early and late feathering chicks by sex.

Days after hatching	Sex	P_1		PC_1		P_2		PC_2	
		Early	Late	Early	Late	Early	Late	Early	Late
1	M	8.7	4.0	5.7	5.3	9.2	4.0	6.4	6.0
	F	9.3	6.7	6.6	6.8	10.4	5.9	7.5	6.8
3	M	15.8	8.0	9.6	10.0	18.2	8.1	11.8	11.8
	F	17.2	9.5	10.3	11.8	19.0	9.9	12.8	13.2
5	M	24.6	12.8	14.0	14.1	27.1	13.0	17.1	16.5
	F	26	14.6	14.4	15.0	28.5	15.4	17.4	18.0
7	M	32.1	18.3	15.1	15.8	35.3	18.6	19.1	19.5
	F	35.8	21.0	14.6	16.4	37.2	20.8	18.7	20.2
9	M	39	24.3	15.7	16.6	42.0	24.4	20.9	20.3
	F	40	27.1	15.2	17.5	43.4	26.3	19.0	20.5
11	M	45.0	31.8	16.8	17.0	48.4	31.6	21.7	20.6
	F	46.0	35.4	15.2	17.6	49	34.2	19.2	20.9

Table 11. Average length of secondary and covert feathers in early and late feathering chicks by sex.

Days after hatching	Sex	S_2		SC_2		S_3		SC_3	
		Early	Late	Early	Late	Early	Late	Early	Late
1	M	7.0	1.1	4.2	3.0	6.8	1.1	5.1	3.3
	F	8.2	3.2	5.2	4.6	7.4	2.8	5.6	4.9
3	M	12.6	3.6	8.8	6.3	12.4	3.5	10.3	7.0
	F	14.6	5.6	10.0	7.5	13.6	5.6	11.1	8.8
5	M	20.6	7.0	19.0	11.5	20.1	6.8	16.1	11.0
	F	24.0	9.0	17.2	13.4	21.8	8.7	16.8	12.6
7	M	27.3	9.8	22.1	16.6	26.0	9.8	20.9	16.1
	F	30.4	12.2	24.4	17.8	28.6	11.7	22.2	18.2
9	M	32.6	13.4	25.4	21.2	33.5	13.5	24.6	20.7
	F	37.0	15.8	26.0	22.8	35.0	16.2	24.7	22.3
11	M	42.0	18.5	27.3	26.3	41.2	18.8	26.4	25.6
	F	42.6	21.4	27.6	29.0	42.2	21.6	27	28

from 9 to 12 mm., compared to a range of 5 to 11 mm. for the 8 early feathering chicks which hatched on the 21st day. The primary number 1 of the 3 late feathering chicks had a range of 3 to 10 mm. in length when 24 hours old, compared to a range of 3 to 8 mm. for the 8 newly hatched late feathering chicks at the same time.

These data suggest that some of the variation present in chicks removed from the incubator on the 21st and 22nd day under normal procedure, is due to the fact that some of the chicks actually may have hatched as long as 30 hours or more previously. However, 25 hours elapse after hatching did not account for all the variation among chicks measured 21 days after incubation commenced since some chicks known to be less than 19 hours old had feathers longer than did some other chicks known to be more than 24 hours old.

In order to determine whether the early feathering chicks showed an increase or decrease in their advantage over the late feathering chicks during the period studied, the growth increment of each feather (primary and secondary) during each 2-day period was calculated. These results are shown in Table 12.

It was apparent that the primaries and secondaries of early feathering chicks studied continued to increase their advantage over those of the late feathering chicks with respect to actual increase in length of main wing feathers up to 9 days of age.

The proportionate advantage for early feathering chicks, however, began to decrease in the primaries after the 3rd day. The proportionate advantage in the secondaries decreased after the second day.

Table 12. Average growth of feathers during 2-day periods in early and late feathering chicks.

Days	Primaries: Growth in mm. Early	Late	Ratio of Early/Late	Secondaries: Growth in mm. Early	Late	Ratio of Early/Late
	P_1			S_2		
1-3	7.31	3.45	2.27	6.09	2.45	2.49
3-5	8.82	4.96	1.78	8.55	3.37	2.54
5-7	7.63	5.91	1.29	6.55	3.00	2.18
7-9	6.55	5.68	1.15	6.81	3.59	1.89
9-11	6.00	8.22	.73	6.73	7.59	.89
	P_2			S_3		
1-3	8.82	4.09	2.16	5.77	2.54	2.27
3-5	9.18	6.05	1.52	8.04	3.09	2.60
5-7	8.41	4.64	1.82	6.28	3.14	2.00
7-9	6.45	5.63	1.15	7.00	4.05	1.73
9-11	4.05	7.55	.80	7.50	5.36	1.40

DISCUSSION

The results have shown that there was no difference in the down length of early and late feathering chicks from the 13th through the 20th day of incubation. The down feathers had ceased growing before the final day. However, by the 19th day, it was obvious that the developing primary and secondary juveniles of the early feathering chicks were longer than those of the late feathering ones. It seems strange that the factor which causes early feathering in chicks does not express itself until the juvenile plumage begins growth, particularly since both the down and juvenile feathers originate from the same follicle.

In reference to feathering, it will be noted that the terms "early" and "late" were used instead of "rapid" and "slow" throughout this thesis. The latter terms and other terms are found in various reports in the literature. It would seem more appropriate to use the terms "early and "late" for the fol-

lowing reasons:

1. The present data reveal that the juvenile wing feathers in the early feathering chicks actually make their appearance earlier than corresponding ones do in the late feathering chicks.

2. Actual growth rate of the feathers was found to be reversed after 9 days of age. (Table 12.)

3. The time of molt throughout early life is different. The juvenile feathers of the late feathering chicks not only appear later, but they are also molted at a later time.

These data show that the terms "rapid" and "slow" would have to be qualified according to age, due to different proportionate rates demonstrated after 9 days of age.

This study has shown that early and late feathering chicks can be distinguished with little difficulty from time of hatching through 11 days of age. This is of considerable value to producers and breeders who wish to sort through their chicks upon arrival and separate the early and late feathering chicks. Because of the time chicks are held in the incubator and time in transit before arrival, some producers may have had some doubts about distinguishing the two groups.

It can also be stated that most breeders and growers have placed more emphasis on the primaries as an index to feathering and have given little attention to the secondaries and the relative length of the coverts. In the present experiment the length of primaries in relation to the length of their coverts was a good gauge in determining the types of feathering in chicks up to about 5 days of age. From 5 days through 11 days of age, however, the early and late feathering chicks were more readily distinguished from obser-

vations of the secondaries and their coverts. The secondaries of the early feathering chicks were 35 to 40% longer than their coverts at 11 days of age. In comparison, the secondaries of the late feathering chicks were never found to be as long as their coverts up to 11 days of age.

Much has been written in the literature describing the primaries and coverts of early and late feathering chicks at one day of age. It has been known that the primaries are longer than their coverts in the early feathering chicks. In late feathering chicks, the chief characteristic described has been the very short feathers or the equal length of primaries and coverts. However, the author was unable to find in the literature any comment as to whether the coverts are actually longer or shorter in late feathering chicks than in early feathering ones. Studies reported here showed definitely that there is no appreciable difference in the length of the coverts of early and late feathering chicks. All corresponding coverts studied in the two groups averaged almost the same length throughout the 11 days of the study. The main difference appears to be in the length of primaries and secondaries. They are either longer or shorter than their coverts.

In sorting chicks up to 11 days of age, poultrymen should face no difficulty in determining early and late feathering in their chicks. It is advised that more attention be given to the secondaries, particularly after the chicks are 4 to 5 days of age.

SUMMARY

From studies of early and late feathering chicks before hatching and after hatching through 11 days of age, the following observations were made:

1. The gene which causes early feathering in chicks showed no effect on

the down feathers as there was no difference in length and growth of down feathers in early and late feathering chicks from 13 to 20 days of incubation between the groups of embryos with contrasting inheritance for feathering.

2. The primaries and secondaries of early feathering chicks were readily distinguished from those of the late feathering chicks after 19 days of incubation. There appeared to be a difference of the primary juvenile feathers within the follicle as early as the 17th day.

3. From hatching through 11 days of age, primaries and secondaries were longer than their corresponding coverts in early feathering chicks. Primaries number 1 and 2 in the late feathering chicks did not reach the same length as their coverts until 5 to 7 days of age. Secondaries in late feathering chicks never reached lengths as great as that of their coverts throughout the 11 days they were studied.

4. Corresponding coverts studied in early and late feathering chicks averaged practically the same length from 1 to 11 days of age.

5. Wing feathers of the late feathering females tended to be longer than those of the late feathering males at hatching and also at 11 days of age.

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A STUDY OF FEATHER GROWTH IN EARLY AND LATE FEATHERING EMBRYOS AND CHICKS UP TO ELEVEN DAYS OF AGE

by

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ABSTRACT OF THESIS

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ABSTRACT

The purpose of this study was to compare the main wing feathers of early and late feathering chicks during the embryonic stage of development and from day of hatching through 11 days of age. The primary and secondary feathers and their covert feathers were measured and recorded in millimeters. From these comparisons, the following observations were made:

1. The gene which causes early feathering in chicks showed no effect on the down feathers. There was no difference in length and growth of down feathers of the early and late feathering chicks from 13 to 20 days of incubation between the groups of embryos with contrasting inheritance for feathering. A pair of embryos which included a full brother and sister was studied each day. It was known that the females were early feathering and the males late feathering.

2. The primaries and secondaries of early feathering chicks were readily distinguished from those of the late feathering chicks after 19 days of incubation. There was a marked difference in the length of the primaries of the two groups. As early as the 17th day, there appeared to be a difference of the primary juvenile feather within the follicle. A thickening within the follicle was observed on this day in the early feathering chicks, with practically none seen in the late feathering chicks.

3. From hatching through 11 days of age, primaries and secondaries were longer than their corresponding coverts in early feathering chicks. There was never any question as to which were the longer through the study. Primaries number 1 and 2 in the late feathering chicks did not reach the same length as their coverts until 5 to 7 days of age. Secondaries in late feathering chicks never reached a length as great as those of their coverts throughout the 11

days they were studied. These results showed that after 4-5 days of age, the determination of early and late feathering chicks could more easily be accomplished by comparing the length of secondary feathers to that of their coverts.

4. All coverts studied in early and late feathering chicks averaged practically the same length from 1 to 11 days of age. This study proved that at day of hatching until 4 to 5 days of age, the difference in early and late feathering chicks was due to the primaries and secondaries. They were either longer or shorter than the coverts during that period of time.

5. Wing feathers of the late feathering females tended to be longer than those of late feathering males at hatching and also at 11 days after hatching. This result seems to coincide with results in other studies in which the late feathering females were more fully clothed with plumage than were the late feathering males of the same age.