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THE INFLUENCE OF SOME FACTORS ON THE HATCHABILITY OF THE HEN'S EGG

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SUMMARY

1. There is a tendency for hatching quality of eggs to decrease as the age of the female producing them increases. No evidence was found for any influence of the age of the male upon hatchability of the eggs which he fertilizes.

2. Heavy egg production was not found to impair the hatching quality of the eggs produced.

3. Pullets pausing during the period previous to the hatching season produced eggs with better hatchability than did those laying continuously throughout this period.

4. Close inbreeding impairs the hatching quality, while outcrossing improves it.

5. Hatchability percentages vary inversely with the size of the egg.

6. Under the experimental conditions provided, holding eggs longer than six days appeared to be detrimental.

7. There was some indication that under certain conditions hatching quality of eggs was interfered with by low temperatures encountered before the eggs were placed in the incubator.

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THE INFLUENCE OF SOME FACTORS ON THE HATCHABILITY OF THE HEN'S EGG[1]

D. C. WARREN

GENERAL PROBLEM

The problem of hatchability of eggs is one of many complications. The more usual conception of the term does not take this fact into consideration. In studies on hatchability, instead of considering the single incident — the emergence of the chick from the shell — it should be kept in mind that a large number of physiological processes are concerned. During the incubation period the contents of the egg are transformed into an organism fully equipped for most of the processes of life. The term hatchability focuses our attention on the final step, the escape of the chick from the shell. However, in so complicated an organism as the fowl, it is easy to conceive that during development many irregularities might occur which would be fatal to the embryo. According to Payne (1919) 48.7 per cent of the total embryonic mortality occurs between the eighteenth and twenty-first days of development. This leaves over half of the occurring mortality which must be due to defects in development previous to the stage at which the chick would be equipped to escape from the shell.

In reality the problem of hatchability includes the life span of the bird from fertilization to the emergence of the chick from the egg. The hatchability percentage is a measure of embryonic viability. If we should direct our attention to any equal period in the bird's life and consider all causes of mortality as a unit, it is readily seen that the problem would be a complicated one and that a large number of causal agents would be involved. At no equal period in the post-hatching existence is the mortality so high, nor do such extreme changes take place in the body of the bird, as during the embryonic period.

When dealing with so complicated a period in the bird's life history definite results are difficult to obtain. The end results, the percentage of the chicks which have survived the combined action of all deleterious factors, constitute the available evidence, and thus it is difficult to show the independent effect of any one. Frequent statements have been incorporated in the literature on poultry as to the influence of certain factors on hatchability. Some of these are well supported by experimental evidence, while in many other instances the evidence is very inadequate.

It is attempted in this publication to summarize a large volume of data accumulated over a period of years in the light of their bearing on the factors affecting the hatchability of the egg. The factors considered are largely environmental, either internal or external, although a few may be classified as inherent.

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1. Contribution No. 75 from the Department of Poultry Husbandry.

STOCK AND MANAGEMENT

The data here presented are those accumulated from the regular breeding operations at the poultry plant of the Kansas Agricultural Experiment Station for the period 1921 to 1929. The two breeds for which data are summarized are the Single-Comb White Leghorn and the Single-Comb Rhode Island Red.

The genetic constitution of the two breeds used was also fairly uniform, since little new blood was introduced during the period involved. Criticism may always be made of conclusions drawn from data of this kind, because they are not derived from a set-up which is for the specific purpose of testing the influence of the particular factor under consideration, However, in any study on hatchability there are a number of uncontrollable factors, and the fact that these results cover a long period in which conditions may be somewhat variable may tend to make the deductions more dependable. The individual females come from a large number of matings. This condition, combined with the long period over which the data were spread, might tend to prevent the vitiation of results by some one external factor which might have weight in an experiment covering a very limited period and involving more homogeneous stock.

METHOD OF INCUBATION

Still air, hot-water types of incubators (Candee, 1921-'22; Newtown, 1923-'29) were used throughout the period of the experiment. During the early years the capacity was 3,600 eggs, but, later an extra deck was added to the Newtown, doubling the capacity. The incubators were equipped with an alarm system which gave warning to the operator when the temperature varied more than two degrees from the optimum. The recommendations of the manufacturers were followed in the operation of the incubators. The temperatures maintained at the top of the eggs were 102° F. for the first week, 103°F. for the second week, and 104° F. for the third week.

Since all of the records were from pedigree breeding in which net bags were used for segregating the eggs, it was found necessary to raise the temperature to 105° F. during the period when the eggs were bagged for hatching (19-21 days of incubation).

Most of the results were obtained during the months of February, March, and April, although a very limited number of chicks were hatched in January and May. It was a usual practice to produce most of the Rhode Island Reds during the early part of this period, while the White Leghorns were largely produced during March and April.

The eggs were set each Tuesday, and between sets they were held in a basement room where the range of temperature was from 45° to 70° F. Each Saturday the temperature in the holding room was brought to about 75° F. for a few hours while the eggs to hatch the following week were bagged. The period of heating was probably not long enough to greatly change the temperature of the interior of the eggs being held for incubation. The eggs were held in individual hen filing trays so arranged that each egg was turned occasionally during the holding period.

The percentage of hatchability calculated for each female was based upon fertile eggs. Only those females having 10 or more fertile eggs were included. The writer's data were secured from individual female hatchability records based upon the eggs produced during one hatching season of six to twelve weeks. All averages given are of the individual percentages of hatchability and the percentages were based upon fertile eggs only. For recording the hatchability results the eggs were examined on the tenth and eighteenth days of incubation. In the examination an ordinary candling device was used, and those eggs showing no evidence of development on the tenth day were classed as infertiles, while those having started to develop but which then showed signs of disintegration were taken out as dead embryos. It is realized that since the eggs were not individually broken some error will result from classifying with the infertiles some of those embryos dying in the earliest stages of development. Those embryos which died between the tenth and the eighteenth days of incubation were removed during the second examination, which was made on the eighteenth day. The dead-in-shell were recorded on the day of hatching.

FACTORS CONSIDERED

AGE OF BREEDING STOCK

There exists among practical poultrymen a prejudice against the use of young breeding stock. This attitude has been fostered to a degree by some recommendations found in literature dealing with poultry. The belief held by many poultrymen is that both pullets and cockerels should be avoided as breeders, and that if one or the other is utilized they always should be used with older mates. The results from breeding young stock are held to be poorer hatchability and less vigorous chicks. Some have also held that since pullets were usually in heavy egg production during the hatching season they could not be expected to give vigorous offspring.

We have in this study brought together the more important results on the subject in addition to a considerable body of new data secured from our own experimental flock.

Hays (1928) considered the influence of the factor, age of stock, upon hatchability in Single-Comb Rhode Island Reds. His work shows that the same males used as cockerels and as yearlings with different females on succeeding years gave a hatchability percentage of 63.8 and 79.5, respectively. A second series gave a hatchability of 65.2 per cent as cockerels and 79 per cent as yearlings. In neither case was the difference found to be statistically significant. Results from a limited number of females being compared for hatchability during their first and second laying years failed to show any significant effect of age. Hays and Sanborn (1924), in an earlier publication, reported a significant difference in favor of pullets when comparing the hatchability from the same females as pullets and as yearlings. The pullet-year hatchability percentage for 253 birds was 56.7 and the first hen year 47.9.

Data involving a much larger number of Single-Comb White Leghorns were published by Hyre and Hall (1932). They reported upon 633 females in which they were able to compare the second- and third-year records, 219 birds for second- to fourth-year records, 85 birds for second- to fifth-year records, and 34 birds for the second through the sixth year. Table I is taken from the publication by Hyre and Hall. Statistical treatment was not applied to these differences, but the rather consistent and large decrease in hatchability percentage obtained in succeeding years is probably in most instances significant. The same authors reporting the hatchability results from 202 birds used as pullets and yearling hens, found the pullet year giving a 54.3 per cent hatch and the next year a 52.4 per cent hatch. The difference here was not statistically significant.

TABLE I.—HATCHABILITY RESULTS FROM THE EGGS OF THE SAME S. C. WHITE LEGHORN HENS ON SUCCEEDING YEARS WHEN MATED TO DIFFERENT MALES

From Hyre and Hall, 1932.

Second year.	Third year.	Fourth year.	Fifth year.	Sixth year.
62.38	53.17	....	....	....
61.86	55.04	46.35	....	....
63.06	58.60	57.33	47.31	....
64.80	57.48	57.64	56.36	47.82

Pearl and Surface (1909) reported on a comparison of the hatchability during the first and second laying years for a group of 52 Barred Plymouth Rock females. The mean percentage of hatchability for the pullet year was 49.8 and for the next year was 51.6. These authors considered the small difference found here of no consequence.

Data obtained in this investigation were upon both Single-Comb White Leghorns and Single-Comb Rhode Island Reds. The influence of age is considered in both sexes. The results are summarized from three points of view. First, on the basis of the age of the female, disregarding the age of her mates; second, pullets and hens mated to the same males; and third, on the basis of combinations of parents of varying ages.

In drawing conclusions the effect of selection, which frequently is a factor, has been kept in mind. In the stock used there has been some attempt to maintain fair utility qualities. Thus, there has been selection for improvement in both egg production and hatchability. The poorest hatchers were, therefore, not carried over into succeeding years when once their unsatisfactory performance was proved. This practice should have had the effect of improving the later year's hatchability over that of earlier years. Since the stock was carried primarily for experiments in other lines, it is not believed that selection has any very important bearing in the data here presented, but its possible influence has been kept in mind in segregating data and interpreting the results.

In Table II are presented the results of hatching from the same females at varying ages. In this summary no cognizance is taken of the age of the male, so that any differences obtained appear in spite of the influence of the varying age of their male mates. If age is a factor influencing hatching quality, it seems more probable that it would be expressed in the female. The female, in addition to contributing her half of the inherent qualities of the embryo, also supplies the nutrients which sustain the embryo during development.

The range of age in the females considered in Table II is from one to four years. All individuals, however, did not cover the entire range. The largest groups were those for which comparisons could be made of the first and second, and second and third years. It is to be remembered that all comparisons, except those given in the last line of each section of the table, are of the same female's hatching record for succeeding years. The exceptions mentioned were comparisons of birds upon which only one year's results were recorded. The first- and second-year records of different birds have not been compared where the second-year individuals were also hatched from during their pullet year. Because of selection, the second-year birds would not be exactly comparable with the first-year group since from among the latter the poorer hatchers might have been eliminated. There was a large group upon which only one year's record was taken, and in these, selection could not have been practiced. In the six comparisons of first- and second-year hatching records the pullet-year results were equal to or better than those of the second year. In no case was the difference in favor of the pullets statistically significant.

Regarding the comparisons of first and second years with succeeding ones up to the fourth laying year, the results are somewhat variable. The general trend, however, is toward a decreasing percentage of hatch in succeeding years. In most cases the difference was not statistically significant, but in the large number of comparisons the general trend is fairly evident.

In Table III are the results of mating groups of pullets and yearlings to the same males. These data were obtained from a nutrition experiment which carried both hens and pullets in each pen. The purpose of the experiment was to determine the optimum amount of alfalfa leaf meal to use as a supplement when white corn comprised 65 per cent of the ration. The ration of the pens (78, 79, and 80) carried alfalfa leaf meal in 15, 10, and 5 per cents, respectively. These three groups may be considered as having fairly adequate rations. It may be noted that in each of the three pens the hatch-

TABLE II.—HATCHABILITY OF EGGS IN RELATION TO AGE OF THE FEMALE

AGE OF FEMALE.	Number of birds.	Mean percentage of hatchability.				Differences in percentage of hatchability for various years.				
		First year.	Second year.	Third year.	Fourth year.	First and second.	First and third.	Second and third.	Second and fourth.	Third and fourth.
S. C. White Leghorn.										
Females used during 1st and 2d laying years................	35	70.1±1.9	62.7±2.4	....	....	7.4±3.0	....	....	....	....
Females used during 2d and 3d laying years................	54	....	76.7±1.3	65.6±2.3	....	....	....	11.1±2.6	....	....
Females used during 1st, 2d and 3d laying years............	12	75.0±3.3	65.8±3.4	70.0±3.9	....	9.2±4.7	5.0±5.1	4.2±5.2	....	....
Females used during 2d, 3d and and 4th laying years........	23	....	78.0±1.6	72.4±2.1	60.7±2.7	....	....	5.6±2.6	17.3±3.1	11.7±3.4
Females used for one year only: First laying year............	283	68.7±0.7	....	....	....	1.1±1.5	....	....	....	....
Second laying year..........	112	....	67.6±1.3	....	....	....	....	....	....	....
S. C. Rhode Island Red.										
Females used during 1st and 2d laying years................	18	55.0±2.8	43.9±3.9	....	....	11.1±4.8	....	....	....	....
Females used during 2d and 3d laying years................	32	....	64.1±2.4	62.5±2.3	....	....	....	1.6±3.3	....	....
Females used during 1st, 2d and 3d laying years............	12	60.0±3.5	53.3±4.8	49.2±3.9	....	6.7±5.9	10.8±5.2	4.1±6.1	....	....
Females used during 2d, 3d and 4th laying years............	12	....	69.2±4.5	65.8±2.8	54.2±5.1	....	....	3.4±5.3	15.0±6.7	11.6±5.8
Females used for one year only: First laying year............	151	58.1±1.1	....	....	....	0.6±2.1	....	....	....	....
Second laying year..........	75	....	58.7±1.7	....	....	....	....	....	....	....

ing quality of the pullet eggs was equal to or superior to that of the hens. In pens 79 and 80 the difference in favor of the pullets was statistically significant.

TABLE III.—COMPARISON OF S. C. WHITE LEGHORN PULLET AND HEN HATCHABILITY WHEN MATED TO THE SAME MALES

PEN NO.	Pullets.			Hens in second laying year.			Difference.
	No. of birds.	No. of fertile eggs.	Mean percentage of hatchability.	No. of birds.	No. of fertile eggs.	Mean percentage of hatchability.	
78...........	32	500	66.8±1.4	20	322	62.4±1.8	4.4±2.3
79...........	35	562	69.2±1.3	18	306	56.5±1.9	12.7±2.3
80...........	29	414	67.4±1.6	17	285	54.0±2.0	13.4±2.5

In Table IV are listed combinations of individuals of varying ages, cockerels by pullets, cockerels by hens in second year of production, cockerels by hens beyond the second year of production, and males in the second year of sexual maturity by hens in their second laying year. The only significant difference in hatchability was that found between the third and last groups. The data here are not sufficient to draw definite conclusions, but there is little evidence to support the view that hatchability of eggs is materially influenced by the age of the sire fertilizing them. In the foregoing statement we are eliminating the factor infertility and considering the hatchability of fertile eggs only. It is an accepted fact that a higher percentage of infertility occurs when older males are used. Hays (1928) considers the influence of the age of sires on hatchability, and concludes that his data do not justify the view that hatching quality is influenced by the age of the male that fertilizes the eggs.

To summarize the results of this and previously conducted experiments along this line, it can be stated that there is but little evidence supporting the view that pullets do not give so good hatchability of eggs as do older hens. In fact, more frequently the evidence is in favor of the pullets. Hays (1928) cites two experiments, one showing no difference and the other giving a significant difference in favor of the pullets. Hyre and Hall (1932) found no difference between a group of pullets and yearlings. Pearl and Surface (1909) also found no significant difference between pullets and yearlings. The additional results herein reported include nine comparisons of hatchability of the eggs of pullets and yearlings. In eight of the nine comparisons the pullets gave a better hatchability than the hens, but in only three cases were the differences statistically significant. In the one case where the pullets were not superior to the yearlings in hatching quality of their eggs the hatchability percentages were practically identical. Therefore, it seems that a consideration of all experiments listed here would indicate rather con-

TABLE IV.—HATCHABILITY OF EGGS IN RELATION TO AGE OF BREEDING STOCK

Group No.	No. of birds.	Type of mating.	Mean percentage of hatchability.	Differences between various types of matings.			
				Group No.	2	3	4
S. C. White Leghorn.							
1	279	Cockerels by pullets..	68.3±0.7	1	1.3±1.2	4.1±1.7	6.2±1.8
2	169	Cockerels by hens in second laying year,	69.6±1.0	2	....	5.4±1.9	4.9±2.0
3	84	Cockerels by hens beyond second laying year..........	64.2±1.6	3	....	....	10.3±2.3
4	42	Second-year males by hens in second laying year..........	74.5±1.7	4	....	....	....
S. C. Rhode Island Red.							
1	162	Cockerels by pullets..	58.5±1.1	1	1.1±1.9	0.7±2.3	....
2	92	Cockerels by hens in second laying year,	57.4±1.6	2	....	1.8±2.7	....
3	43	Cockerels by hens beyond second laying year.............	59.2±2.1	3	....	....	....

clusively that eggs from pullets give as good, if not better, hatchability than eggs from yearlings.

The data of Hyre and Hall and those presented in Table II are the only ones which permit a comparison of the hatchability from hens in their third or later laying years. The results, probably due to the smallness of numbers, are somewhat variable, but there appears to be a rather evident trend toward poorer hatchability in the later years of life. This fact, combined with the evidence that pullet eggs are equal in hatching quality, if not superior, to those of birds in their second laying year, certainly would not support the opinion that pullets are inferior to hens in hatchability of eggs.

PREVIOUS PRODUCTION

The question of current or previous egg production as a factor influencing the hatching quality of eggs was given attention. The strain of heavy egg production has been held by some workers to be detrimental to the vigor of the embryo and thus to reduce the hatchability of the egg.

Jull (1928, 1931) has considered both antecedent and current egg production in their effect upon hatchability of eggs. He investigated the effects of antecedent production on embryonic mortality in 65 Barred Plymouth Rocks, 197 Rhode Island Reds, and 281 White Leghorns. In practically all instances the differences were nonsignificant, and the author concluded that heavy egg production during the breeding season was not detrimental to high hatchability.

Lamson and Card (1920) have also studied the effect of previous production upon hatchability. Their work was on White Leghorn hens. They calculated the coefficient of correlation between winter egg production and hatchability, between the previous year's production and hatchability, and the rate of production during the 90-day period preceding the date of hatching. In no case did they find any statistically significant value. Pearl and Surface (1909) state that there is a significant negative correlation between winter period of production and hatchability, indicating that the higher the winter egg production the lower the hatchability of the eggs produced. However, the very low value of the coefficients of correlation —0.25, —0.13, —0.01, and —0.22 would by many be considered insignificant. They certainly would have little practical significance.

Knox (1927) reported on the relationship of hatchability to rate of production and annual production in 92 White Plymouth Rocks. He concludes that the rate of production has a slight influence on hatchability, the coefficient of correlation value being 0.16 ± 0.08. He also found that production has a slight but insignificant correlation with hatchability, the value here being 0.13 ± 0.08.

In the present study the influence of egg production upon hatchability has been considered from several viewpoints. Some of the factors studied in their relation to hatchability were: Number of eggs laid previous to the beginning of the hatching season (March 1) in both pullets and hens, the length of the period of production at the beginning of the hatching season in both hens and pullets, the first year's production in birds used first as yearlings, and the length of the pause or rest period.

NUMBER OF EGGS PRODUCED PREVIOUS TO HATCHING SEASON

The effect of the number of eggs produced previous to the beginning of the hatching season (March 1) was measured both in pullets and hens. In the case of the pullets it was the total egg production from the beginning of the laying year to March 1. In the older females it included only those eggs laid after the beginning of the current laying year (to March 1), or those eggs laid after the pause in production resulting from the molt of the plumage. The few birds which did not cease to produce during the molting period or, in other words, those which had no pause between their first and second laying years, were eliminated from consideration. The data are presented in two forms, the coefficient of correlation between each of these factors and percentage of hatchability; and a comparison of the hatchability of birds segregated in a high and low group for each factor considered. In Table V is given the coefficient of correlation between each factor considered and the hatchability percentage. Table VI includes the hatchability results from grouping the birds in low, medium, and high groups for the factors considered. The differences between the means of the high and low groups are given together with their probable errors. The grouping was entirely arbitrary, the divisions being made so that there was a fairly representative number in the low and high groups.

TABLE V.—COEFFICIENT OF CORRELATION BETWEEN HATCHABILITY PERCENTAGE AND VARIOUS PRODUCTION FACTORS

PRODUCTION FACTOR.	Breed.	Number of birds.	Production factor.		Percentage of hatchability.		Correlation coefficient.
			Mean.	Standard deviation.	Mean.	Standard deviation.	
Number of eggs laid to March 1 (pullets)	W. Leg.	258	82.17	30.51	69.77	18.17	—0.077±0.042
	R. I. Red	173	64.10	30.69	57.77	19.87	0.332±0.046
Number of eggs laid to March 1 (hens)	W. Leg.	171	24.42	14.93	71.08	18.81	—0.052±0.052
	R. I. Red	62	30.16	16.52	60.65	20.90	0.121±0.086
Period of production to March 1 in days (nonpausing pullets)	W. Leg.	117	110.68	37.96	66.37	20.52	—0.229±0.059
	R. I. Red	122	79.84	36.84	54.34	20.62	0.248±0.058
Period of production to March 1 in days (hens)	W. Leg.	226	44.69	33.59	69.65	19.42	—0.209±0.043
	R. I. Red	114	45.70	31.11	61.40	20.20	0.031±0.064
Intensity of production in per cent (pullets)	W. Leg.	254	62.91	9.54	70.35	19.77	0.013±0.043
	R. I. Red	188	67.29	9.64	56.65	21.26	0.171±0.047
Length of pause in days	W. Leg.	139	35.79	21.54	72.48	15.43	0.038±0.057
	R. I. Red	52	34.04	20.40	66.15	15.00	0.136±0.094
First year's production to second year's hatchability (hens)	W. Leg.	227	246.30	24.52	69.32	19.52	—0.195±0.043
	R. I. Red	134	220.30	24.00	58.21	22.36	—0.103±0.059

TABLE VI.—HATCHABILITY OF EGGS IN RELATION TO VARIOUS PRODUCTION FACTORS

PRODUCTION FACTOR.	Breed.	High group.		Medium group.		Low group.		Difference between high and low groups.
		Limits.	Mean percentage of hatchability.	Limits.	Mean percentage of hatchability.	Limits.	Mean percentage of hatchability.	
Number of eggs laid to March 1 (pullets)	W. Leg.	101–160	68.5±1.5	41–100	70.2	1– 40	70.8±2.5	2.3±2.9
	R. I. Red	81–160	66.4±1.6	41– 80	57.3	1– 40	47.4±2.1	19.0±2.6
Number of eggs laid to March 1 (hens)	W. Leg.	41– 60	68.2±2.3	21– 40	71.8	1– 20	71.6±1.3	3.4±2.6
	R. I. Red	41– 60	63.9±3.3	21– 40	58.5	1– 20	60.2±3.9	3.7±5.1
Period of production to Mar. 1 in days (nonpausing pullets)	W. Leg.	121–160	63.0±1.8	81–120	67.3	1– 80	74.5±2.8	11.5±3.3
	R. I. Red	101–140	58.8±2.3	61–100	57.2	1– 60	45.9±2.0	12.9±3.1
Period of production to March 1 in days (hens)	W. Leg.	101–140	59.0±3.3	41–100	68.6	1– 40	72.2±1.0	13.2±3.3
	R. I. Red	81–120	60.0±3.2	41– 80	63.6	1– 40	60.4±1.9	0.4±3.7
Intensity of production in per cent (pullets)	W. Leg.	61– 70	69.9±1.0	51– 60	73.8	1– 50	61.1±3.0	8.8±3.1
	R. I. Red	71–100	59.0±1.7	61– 70	57.2	1– 60	51.2±2.3	7.8±2.8
Length of pause in days	W. Leg.	61–100	73.3±1.8	31– 60	73.7	1– 30	71.3±1.4	2.0±2.3
	R. I. Red	41–100	67.1±2.5	21– 40	63.9	1– 20	67.7±2.3	0.6±3.4
First year's production to second year's hatchability	W. Leg.	261–300	71.3±1.5	221–260	67.3	200–220	73.1±2.0	1.8±2.5
	R. I. Red	241–300	55.7±2.4	201–240	58.2	180–200	60.9±2.6	5.2±3.5

For the pullets the mean number of eggs produced to March 1 was 82.17 in White Leghorns and 64.1 in Rhode Island Reds. The coefficient of correlation for number of eggs laid and hatchability was -0.077 for White Leghorns and 0.332 for Rhode Island Reds. The results on the two breeds are very different, the correlation value in the White Leghorn pullets being too small to have any significance, while that for the Rhode Island Red pullets is a positive value of sufficient magnitude to suggest a slight relationship. The relationship would suggest that the more eggs produced before the hatching season the better the hatchability. This result is directly opposed to the view held by many poultrymen. In Table VI, where the mean hatchability percentage of those having the the greatest number of eggs to March 1 is compared with the mean of those having the smallest number of eggs, no significant difference was found in the White Leghorns, but the Rhode Island Reds showed a highly significant difference in favor of the high producers.

The results from females beyond their first year of production show no evidence for any influence of the number of eggs produced previous to the hatching season upon hatchability of eggs. In neither the White Leghorns nor Rhode Island Reds was the correlation coefficient (-0.05 ± 0.052 and 0.121 ± 0.086) large enough to have any significance. The differences in hatchability between the two extreme groups of hens for number of eggs produced before the hatching season were also nonsignificant. Thus, it would seem that there is no evidence from these experiments that high production for the period preceding the hatching season in any way impairs hatchability of eggs of either pullets or hens.

LENGTH OF PERIOD OF PRODUCTION

The consideration of the number of eggs produced to March 1, as discussed in the preceding section, takes into account both intensity and period of production. It was thought that to study these two factors independently might reveal some relationship which the foregoing study had failed to disclose. Period of production as here considered is the number of days from the laying of the first pullet egg to March 1. For females beyond the first year of production it is the period from the laying of the first egg following the molt to March 1. Pullets commonly exhibit what is called winter pause, or a period of partial molt. The occurrence of such pauses might tend to vitiate the results of this study, since intervening rest periods might permit the bird to recuperate from the strain of long continued production. In order to avoid the possible influence of pauses in production, those birds having pauses of one week or more were eliminated from consideration. So the data on pullets are only for nonpausing individuals. This selection was not followed in the hens, since pausing is much less frequently found in their records. As in the preceding study the few hens which continued to lay throughout the molt were eliminated from consideration.

The coefficient-of-correlation values found in Table V for the relationship between hatchability and the period over which a female had produced previous to the hatching season, were relatively low. Some workers might accept them as evidence for a degree of association between these two factors. The r-value was -0.229 for White Leghorn pullets and 0.248 for Rhode Island Red pullets. In hens it was -0.209 for White Leghorns and 0.031 for Rhode Island Reds. This rather consistent difference between the two breeds, Leghorns showing a negative correlation value and Reds showing a positive one, although low, is rather interesting. If this difference in behavior in the two breeds has any significance the writer is at a loss to offer any explanation. In Table VI the probable error of the difference indicates that the difference in hatchability between the birds having produced for long and short periods is approaching a value having significance in the White Leghorn hens and pullets. The mean hatchability percentage for Rhode Island Red pullets having been in production for a long period was significantly higher than that of birds having laid only for a short period. In other words, the early-maturing Rhode Island Red pullets gave better hatchability than the late-maturing ones. This is not in agreement with results from White Leghorns and is difficult to explain.

INTENSITY OF PRODUCTION

In this study an attempt has been made to measure the independent action of intensity, or rate of production, upon hatchability of pullets' eggs. Intensity as considered here is expressed in percentage, obtained by dividing the total period of production into the number of eggs produced. Any pauses of seven days or more were deducted from the period of production before making the calculation. The period utilized was from the first egg to April 1. Most other records covered only the period to March 1, but here it was desired to include some of the hatching season. The values of the coefficients of correlation between intensity and hatchability for White Leghorns and Rhode Island Reds were 0.013 and 0.171, respectively, both being of too low magnitude to have any significance. The differences in hatchability (Table VI) between the groups of highest and lowest intensity in both White Leghorns and Rhode Island Reds were too small to be statistically significant.

LENGTH OF PAUSE IN PRODUCTION

It has sometimes been suggested that pullets will give better hatchability if they are caused to molt just before the hatching season. This has been the practice particularly where eggs from pullets were to be used for hatching. Pauses normally appear in the records of many pullets and most commonly occur with the onset of severe winter conditions. It also has been shown that pausing is most evident in the records of pullets having started to lay at a season earlier than the average. The pause is usually accompanied by a molt of varying degrees, and the length of the pause is approximately in agreement with the extent of the molt.

In order to determine whether birds showing pauses previous to the hatching season lay eggs of superior hatching quality, a comparison was made of the pausing and nonpausing females. The mean hatchability percentage of eggs produced by the 117 nonpausing pullets was 66.37 ± 1.28, while the pausing White Leghorns had a hatchability percentage of 72.48 ±0.88. The difference, 6.11 ± 1.55, is statistically significant. In the Rhode Island Red pullets the results are very similar, since the nonpausing pullets gave a hatchability of 54.34 ± 1.26 per cent, while the pausing ones gave a value of 66.15 ±1.4. The difference here of 11.81 ±1.88 is highly significant. These results would thus indicate that birds having a pause during the period previous to the hatching season produce eggs of higher hatching quality than do those laying continuously.

The exact cause of pausing is not known, although it has been suggested that it represents the end of the fall production period, which has been added to the normal reproductive period of the wild fowl. One source of error in this study is the inclusion in the pausing classification of those birds which cease production because of sickness. The records did not make it possible to distinguish between these two types. In their effect on hatchability of eggs it seems that pauses of the two kinds might be expected to have opposing influences. Pausing because of partial molt might be expected to improve the hatchability because of the rest imposed, while pausing because of sickness might impair the hatchability because of effect of the disorder on the metabolism of the female producing the egg.

The data were summarized so as to determine whether there was any influence of the length of the pause upon hatchability. The coefficient of correlation (Table V) for the relationship of these two factors was 0.038 ± 0.057 in the White Leghorns and 0.136 ± 0.094 in Rhode Island Reds. Neither value may be considered statistically significant. In Table VI where the two groups, one with long pauses and one with short pauses, were compared it was found that the mean percentages of hatchability in the two groups differed to a nonsignificant degree.

The general results from this study indicate that those birds which have pauses in their records give slightly better hatchability than do those laying continuously from the beginning. There seems to be no evidence for any association between the degree of improvement of the hatchability and the extent of the pause.

It is somewhat difficult to bring these conclusions in accord with results on period of production and number of eggs produced previous to the hatching. They failed to indicate that heavy production in any way interferes with the hatching power of eggs. It would then seem that the beneficial effects of the pause are due to factors other than the rest afforded by the cessation of production.

RELATIONSHIP OF BREEDING STOCK

INBREEDING

The fact that too close inbreeding may impair the vigor of animals is a matter of common knowledge among those engaged in breeding operations. This fact is so well impressed upon the animal breeder that he frequently handicaps his operations by too strictly avoiding even slight degrees of inbreeding. The fowl appears to be rather outstanding in its susceptibility to the deleterious effects of inbreeding. Hatching quality of eggs is one of the first characteristics to reflect the influence of intensive inbreeding. Strains of the fowl when subjected to successive generations of brother-sister or parent-offspring matings usually become extinct, and it is often found that failure to hatch has been one of the major contributing factors.

The work of Cole and Halpin (1922) showed that the hatching quality of eggs was injured by inbreeding. Hays (1924) also noted a rapid decline in hatchability following close inbreeding. Probably the best evidence regarding the influence of inbreeding is found (Table VII) in the work of Dunn (1928).

In Table VII there is a comparison of continued brother-sister matings with matings of the same stock carried in a manner by which inbreeding was avoided. It is seen that there was a very rapid decline in hatchability of the eggs, and that most of the families failed to survive very many generations of inbreeding.

TABLE VII.—HATCHABILITY RESULTS FROM SUCCESSIVE GENERATIONS OF BROTHER-SISTER MATINGS

From Dunn, 1928

Generation of Inbreeding.	Inbred stock.			Outbred stock.	
	Number of families.	Number of eggs.	Percentage of hatchability.	Number of eggs.	Percentage of hatchability.
Before inbreeding........	8	204	75.0	....	....
First..................	8	1,304	50.5	520	49.8
Second.................	7	2,269	46.7	492	67.5
Third..................	5	932	34.3	768	60.8
Fourth.................	2	141	46.8	531	60.1
Fifth..................	1	65	41.5	742	59.2

In Table VIII are given the results of Dunkerly (1930). He studied in three different breeds the influence of one generation of father-daughter matings. The generation of inbreeding was in all cases preceded by a generation of outbreeding. The comparison was between father-daughter matings and those of similar breeding but without any inbreeding. The general tendency over the four-year period considered is for the father-daughter matings to give poorer hatching results than the outbred matings.

TABLE VIII.—HATCHABILITY RESULTS OF FATHER-DAUGHTER AND OUTBRED MATINGS

From Dunkerly, 1930.

YEAR.	Percentage of hatchability of fertile eggs.					
	White Wyandotte.		S. C. Rhode Island Red.		S. C. White Leghorn.	
	Father-daughter matings.	Outbred matings.	Father-daughter matings.	Outbred matings.	Father-daughter matings.	Outbred matings.
1926.......	55.38	....	59.64	....	62.92	....
1927.......	45.77	47.42	51.36	49.46	50.24	88.89
1928.......	56.97	56.18	33.54	56.38	47.58	77.16
1929.......	62.10	72.61	....	....	....	....

Jull (1929) reported on the relationship of consanguinity to hatching quality of eggs. Successive generations of inbred Barred Plymouth Rocks gave hatchability percentages of 76, 43, 44, and 23, respectively. White Leghorns in successive years of inbreeding gave the following percentages: 83, 62, 52, and 49. Jull compared the effects of half-brother-sister and full-brother-sister matings on the hatching quality of eggs. Here he found the half-brother-sister matings to give slightly better hatching results than the full-brother sister matings. In Barred Plymouth Rocks the full-brother-sister matings gave 34.0 ± 2.3 per cent hatchability and the half-brother-sister matings 45.5 ± 1.6 per cent,. For the same type of matings in the White Leghorns the results were 52.5 ± 2.0 and 56.4 ± 1.3 per cent, respectively. In both breeds the two types of inbred matings reduced the hatching quality materially when compared with that of noninbred stock.

The foregoing results are upon carefully controlled experiments. Our own data are from less controlled material, but the numbers are probably large enough to avoid any serious discrepancies from this source. In attempting to measure the influence of inbreeding on hatching quality of eggs in ordinary breeding practices, the coefficient of inbreeding was calculated for each mating used. The formula for calculation of the coefficient of inbreeding was that worked out by Wright (1923). This value attempts to express in a single figure the degree of inbreeding found in the pedigree of any individual. The coefficient of inbreeding as used was for the chicks produced by a mating, and in the studies this value was checked against the hatchability percentage resulting from the mating. The coefficient value is in percentage and for a half-brother-sister mating is 12.5; for a full-brother-sister mating, 25; and for three successive generations of brother-sister matings, 50.

In measuring the effect of inbreeding the coefficient of correlation between the percentage of hatchability and the coefficient of inbreeding was calculated. Table IX shows the relationship be-

TABLE IX.—COEFFICIENT OF CORRELATION BETWEEN HATCHABILITY PERCENTAGE AND COEFFICIENT OF INBREEDING

BREED.	Number of birds.	Degree of inbreeding.	Coefficient of inbreeding.		Percentage of hatchability.		Correlation coefficient.
			Mean.	Standard deviation.	Mean.	Standard deviation.	
S. C. White Leghorn	103	0.6–10.5	4.68	2.45	69.76	19.87	—0.399±0.057
S. C. White Leghorn	281	0.0–50.0	9.09	11.29	69.91	19.99	—0.188±0.039
S. C. Rhode Island Red	137	0.0–50.0	10.63	8.62	56.16	19.78	—0.163±0.056

TABLE X.—HATCHABILITY OF EGGS IN RELATION TO COEFFICIENT OF INBREEDING

BREED.	Number of birds.	Degree of inbreeding.						Difference between high and low groups.
		High.		Medium.		Low.		
		Limits.	Mean percentage of hatchability.	Limits.	Mean percentage of hatchability.	Limits.	Mean percentage of hatchability.	
S. C. White Leghorn	281	21–50	61.6±2.0	11–20	66.1	0–10	71.9±1.0	10.3±2.3
S. C. Rhode Island Red	137	11–40	54.0±1.3	1–10	56.0	0	67.9±3.0	13.9±3.3

tween the percentage of hatchability and the coefficient of inbreeding for both White Leghorns and Rhode Island Reds. The range for the coefficient value for inbreeding was 0 to 50 per cent. Inasmuch as approximately half of the White Leghorns fell in the 0 to 10 per cent classes, a separate calculation was also made from those falling within these narrow limits. The group of Rhode Island Reds was considered as a whole only. The only coefficient of correlation value that may be considered at all significant was for the entire group of White Leghorns. The correlation value here was 0.399.

In Table X are given the same results in a slightly different form. Here the birds were divided into three groups ranging from high to low coefficients of inbreeding, and a comparison was made of the hatchability means for the two extreme classes. The data show that there is a statistically significant difference between the groups of high and low degrees of inbreeding. The results as a whole indicate that hatching quality of eggs is influenced by the variations in degree of inbreeding encountered in this study.

Jull (1929) also made a study of the relationship of the coefficient of inbreeding to hatching quality. His results were drawn largely from inbreeding experiments instead of being taken from more or less promiscuous matings as was true of the foregoing results. Since his matings were either full-brother-sister or half-brother-sister in successive generations, the coefficient values fell into definite classes with no intermediate ones. Jull reported upon both Barred Plymouth Rocks and White Leghorns. In Table XI, adapted from Jull's data, it is shown that he found a fairly close agreement between the degree of inbreeding and the percentage of hatch.

TABLE XI.—HATCHABILITY OF EGGS IN RELATION TO COEFFICIENT OF INBREEDING

From Jull, 1929.

Barred Plymouth Rock.			S. C. White Leghorn.		
Number of families.	Coefficient of inbreeding.	Percentage of hatchability.	Number of families.	Coefficient of inbreeding.	Percentage of hatchability.
17	12.5	47.3±2.9	20	12.5	58.4±3.5
12	25.0	40.1±4.0	17	25.0	56.6±1.9
10	37.5	21.0±5.3	12	37.5	52.0±4.2
....	....	....	5	50.0	43.4±4.8

OUTBREEDING

There is a considerable body of data to indicate that outbreeding of varying degrees stimulates the hatching quality of eggs. This is particularly evident from the outcrossing of strains of which the hatchability of eggs has been reduced by inbreeding. The term outbreeding is here used to include the mating of distantly related individuals of the same breed and variety as well as hybrids resulting from crossing of different breeds.

The results of Dunn (1928) have shown rather definite and immediate improvement of hatchability from the crossing of strains previously inbred. He crossed two inbred strains which had given hatchability percentages of 53 and 47 and improved the percentage of hatchability to 85. The mating of two inbred strains which previously gave 47 and 42 per cent hatchability produced eggs which had a 73 per cent hatch. The writer's own results (1930) from crossing two production-bred strains of White Leghorns gave no very pronounced improvement in the hatching quality of the eggs. The average hatchability percentages for the two strains were 75 and 72 while the reciprocal crosses of the two gave hatchability percentages of 75 and 84.

A second experiment conducted at the Kansas station gave similar results. In this case the two pure strains had a hatchability of 61 and 71 per cent, while the cross strain results from reciprocal crosses of the two were 72 and 59 per cent hatchability.

The most striking results are from outcrosses of a more extreme degree, that is, the mating of different breeds. Here considerable stimulation of hatching quality of eggs is obtained.

The writer (1927) published upon the general stimulation obtained from crossing Single-Comb White Leghorns and Jersey Black Giants. In this study the hatchability percentage for Jersey Black Giants was 57, for White Leghorns 73, and for eggs resulting from the mating of these two breeds, 78.

A more extensive experiment carried out by the writer showed improvement in hatchability of eggs of White Leghorn females when used in crossbred matings over purebred matings of the same females. Females from three strains of White Leghorns were first mated to Barred Plymouth Rock males and later to males of their own strain. When crossbred the eggs gave a hatchability of 80, 80, and 86 per cent, respectively, while the hatchability percentages for the same three groups of females in purebred matings during the same season were 61, 71, and 84.

Thus the results are fairly consistent in indicating that the hatching quality of eggs is impaired by inbreeding and stimulated by crossbreeding.

EGG SIZE

It is known that there is a gradual increase in the size of a pullet's eggs from the initial one to those produced in early February. There is considerable variability in egg size among birds, but when the maximum is reached in February the size remains relatively constant.

Other workers have considered the relationship of egg size to hatchability. Dunn (1922) incubated the eggs of 47 Single-Comb White Leghorn pullets and found a significant superiority in hatchability of medium-sized eggs over large ones. Jull and Haynes (1925), working with the eggs of 24 Barred Plymouth Rocks, found that the hatchability decreased as the size increased. Their numbers were not large enough to give significant results. The results of these workers are summarized in Table XIV.

In a study by Don McClelland (unpublished) on the Kansas Agricultural Experiment Station flock, a comparison was made of the hatching quality of pullet eggs when grouped into classes according to egg size. This work was done during the 1931 hatching season and included Single-Comb White Leghorns and Single-Comb Rhode Island Reds. These results are summarized in Table XII. McClelland fails to state the number of pullets considered in each breed, but the number of eggs used is fairly large except for the large-size group. It is noted that in each breed the percentage of hatchability decreased as the egg size increased.

TABLE XII.—HATCHABILITY IN RELATION TO EGG SIZE FOR THE KANSAS AGRICULTURAL EXPERIMENT STATION FLOCK (1931)

Mean egg weight in grams.	S. C. Rhode Island Red.			S. C. White Leghorn.		
	Total eggs set.	Number of fertile eggs.	Percentage of hatchability of fertile eggs.	Total eggs set.	Number of fertile eggs.	Percentage of hatchability of fertile eggs.
44–51.9	265	230	79.6	339	318	73.9
52–59.9	633	499	64.5	1,713	1,573	64.4
60–73.9	62	54	55.6	128	122	62.3

Our own studies on the influence of egg size on hatchability include data for 222 White Leghorns and 161 Rhode Island Reds. In both breeds the results are for the first laying year.

The first treatment (Table XIII) of these data was to calculate the coefficient of correlation between the female's average egg size and her percentage of hatchability. The mean egg size was determined by taking the mean weight of ten eggs produced in March, this being the mid-hatching season. In both breeds the coefficient value was a negative one, being —0.171 for White Leghorns and —0.264 for Rhode Island Reds. The values are considered too low to be statistically significant.

In the second treatment of the data (Table XIII) the birds were divided into three groups, one having a large egg size, one with a medium egg size, and one producing small eggs. These three groups were compared for hatching quality of their eggs. For the three groups of White Leghorns the hatchability percentages were 68.3, 72.1, and 73.9, respectively. The smallest- and medium-sized eggs hatched better than the large ones, but the difference was not statistically significant. The large Rhode Island Red eggs hatched 51.8 per cent; the medium size, 59.4 per cent; and the small eggs, 69.1 per cent. Here again the poorest hatching group was the one laying the largest eggs. There was a highly significant difference in hatching power between the two extreme groups, and the medium-egg-size group was intermediate in hatchability.

TABLE XIII.—HATCHABILITY OF EGGS IN RELATION TO EGG SIZE

CORRELATION OF EGG SIZE AND PERCENTAGE HATCH

BREED.	Number of birds.	Egg size.		Percentage of hatchability.		Coefficient of correlation.
		Mean.	Standard deviation.	Mean.	Standard deviation.	
		gm.	*gm.*			
S. C. White Leghorn	222	53.7	3.7	71.5	17.2	—0.171±0.044
S. C. Rhode Island Red	161	56.5	4.6	58.0	19.4	—0.264±0.050

MEAN PERCENTAGE HATCH OF FEMALES GROUPED ACCORDING TO EGG SIZE

BREED.	Small-egg group.		Medium-egg group.		Large-egg group.		Difference between large- and small-egg groups.
	Limits.	Percentage of hatchability.	Limits.	Percentage of hatchability.	Limits.	Percentage of hatchability.	
	gm.		*gm.*		*gm.*		
S. C. White Leghorn	46–51.9	73.9±1.4	52–55.9	72.1	56–67	68.3±1.5	5.6±2.1
S. C. Rhode Island Red	44–51.9	69.1±2.0	52–57.9	59.4	58–67	51.8±1.6	17.3±2.6

There is a somewhat general agreement in the results of all workers studying the influence of egg size on hatching quality of eggs of pullets, although many of the findings were not statistically significant. The results of all workers on the subject have been brought together in Table XIV. There is a little difference among the workers in the method of segregation of data, but in general the classes are fairly comparable. Dunn (1922) obtained the best hatchability from his medium-egg-size group of females and poorest results from the large-egg group. The results of Jull and Haynes (1925) on Barred Plymouth Rocks, McClelland *(op. cit.)* on White Leghorns and Rhode Island Reds, and the writer on White Leghorns and Rhode Island Reds are in agreement in showing an inverse relationship between hatching quality and egg size. The above results were obtained from placing the pullets in three arbitrary classes — small, medium, and large egg sizes. All results were in close agreement in placing the large-egg pullets in the poorest group of hatchers.

TABLE XIV.—COMPARISON OF THE RESULTS OF VARIOUS WORKERS RELATING TO THE INFLUENCE OF EGG SIZE ON HATCHING QUALITY

WORKER.	Small size.		Medium size.		Large size.	
	Range in grams.	Percentage of hatchability.	Range in grams.	Percentage of hatchability.	Range in grams.	Percentage of hatchability.
Dunn (1922):						
White Leghorn	44–51.9	58	52–59.9	62	60–73.9	44
Jull and Haynes (1925):						
Barred Plymouth Rock	46–52.9	68	53–59.9	65	60–67.0	52
McClelland (1931):						
Rhode Island Red	44–51.9	79.6	52–59.9	64.5	60–73.9	55.6
White Leghorn	44–51.9	73.9	52–59.9	64.4	60–73.9	62.3
Warren (this publication):						
Rhode Island Red	44–51.9	69.9	52–57.9	59.4	58–67.9	51.8
White Leghorn	46–51.9	73.9	52–55.9	72.1	56–67.0	68.3

It should be noted that these results were upon pullets, and that no adequate data are available on hens. It may be that we are here measuring the effect of factors other than egg size, since egg size is known to be closely associated with other factors, such as age at sexual maturity and body size. To the writer's knowledge there is, however, no evidence that either of the above-mentioned factors influence hatching quality of eggs. No explanation is here offered for the apparent association between egg size and hatchability.

PERIOD OF HOLDING EGGS

The opinion appears to be very generally held that the hen's eggs may be held satisfactorily for a week before starting incubation, but that longer periods of holding will result in impairment of their hatching quality. No recent work has been carried out along this line, and perhaps the best results were published several years ago by Waite (1919). He compared the hatchability of eggs held for periods from 1 to 28 days. Since his data covered a period of several years, each day's eggs are not strictly comparable with those of each other day, but the numbers are large enough to make the general trends dependable.

The first evidence that Waite found for any decline in hatching quality appeared on the sixth day of holding, and unquestionable reductions occurred beginning with the eighth day. The decline continued as the period of holding increased, and the hatchability reached 7.89 per cent on the twenty-eighth day. The percentage of infertility also increased as the period of holding was prolonged. Scott (1933) suggested that this apparent increase in infertility might be due to the inclusion in the infertile class of embryos dying very early in development. This would be probable when ordinary candling methods are followed, since embryonic mortality due to holding of eggs would probably occur in the early stages of development. If Scott's suggestion be correct Waite's hatching percentages are too high for the later periods, since some of those eggs classed as infertiles should have been added to the unhatched fertile group.

An important factor in any study of the effect of the period of holding on hatching qualtiy is the environmental conditions under which the eggs are held. Waite supplied no information as to the holding conditions other than the fact that the eggs were kept at cellar temperatures.

Recent work of H. M. Scott (1933) of Kansas Agricultural Experiment Station has indicated that the deleterious effects of holding eggs may be greatly reduced if proper temperature and moisture conditions are provided. Scott's numbers are not large, but his data do indicate that good hatchability may be obtained after a considerable longer period of holding than is usually recommended. Table XV gives Scott's results from holding eggs for periods of 1 to 84 days.

TABLE XV.—EFFECT OF HOLDING S. C. WHITE LEGHORN EGGS AT 54° F.

From Scott, 1933.

PERIOD HELD IN DAYS.	Number of fertile eggs.	Percentage of hatchability.
0–6	62	69.4
7–13	66	66.7
14–20	78	68.0
21–27	79	44.3
28–34	78	32.1

The temperatures under which Scott held the eggs were very uniform, the fluctuations being less than 1° Fahrenheit. The humidity was also very uniform, the wet-bulb reading being 52.5° F. It is seen from Table XV that no decline in hatchability percentage was observed until after the twentieth day. These results emphasize the need of more experimentation on the effects of holding eggs under conditions of carefully controlled temperature and humidity.

The writer's results on the effect of period of holding on hatching quality were for the regular hatching season of 1928. The conditions under which the eggs were held were far from optimum but perhaps approach those under which eggs are frequently held. The usual range of temperatures in the holding room was 55 to 65° F. except on each Saturday when the temperature was raised to 75° for about four hours while the forthcoming hatch was being prepared for pedigreeing. Eggs were set each Tuesday, so that the period of holding ranged from one to seven days. The eggs were placed in the incubator at about 10 a. m., making the one-day eggs held approximately 24 hours, but the period would vary depending upon the hour of laying. The same error was encountered in succeeding periods of holding, but it did not represent so large a proportion of the period. Our results include the eggs of both Single-Comb White Leghorns and Single-Comb Rhode Island Reds.

In Table XVI are summarized the results from the two breeds for periods of holding from one to seven days. Our results agree fairly closely with those of Waite (1919), except that the decline in percentage hatch started on the sixth day in his work and on the seventh day in our data. The decline in hatchability was very evident in both White Leghorns and Rhode Island Reds. The difference here can hardly be attributed to anything other than the period of holding, since the results included 3,666 White Leghorn eggs and 3,316 Rhode Island Red eggs distributed over 10 seven-day holdings. The incubation work was done in a large sectional type of incubator where some variability of conditions was encountered, but since all of one hen's eggs for each seven-day period were placed together on a tray this practice tended to distribute the environmental influences so as not to vitiate the results.

TABLE XVI.—EFFECT OF HOLDING EGGS FOR PERIODS OF ONE TO SEVEN DAYS

Period held in days.	S. C. White Leghorn.			S. C. Rhode Island Red.		
	Number of eggs.	Percentage of fertility.	Percentage of hatchability of fertile eggs.	Number of eggs.	Percentage of fertility.	Percentage of hatchability of fertile eggs.
1	542	88.6	59.8	484	94.0	60.4
2	543	89.0	57.3	484	90.7	63.3
3	503	87.3	60.1	475	93.1	61.8
4	521	90.6	58.1	478	93.7	62.7
5	513	86.7	58.2	477	91.8	60.7
6	533	88.7	59.8	448	93.3	61.5
7	511	86.9	52.7	465	89.0	53.9

The data given in Table XVI have been rearranged in Tables XVII and XVIII. The first 10 horizontal lines of figures give the results of each of the 10 hatches divided into the periods of holding from one to seven days. The means in the horizontal line at the bottom of the table are for all of the eggs of each seven-day period and the vertical row of figures at the right is for the different hatches. These data represent all of the eggs laid by the group of hens for the 10-week period. The 70 values given in the body of the table are the daily percentages of hatchability of fertile eggs for the 10-week period. The successive day's results may be followed by reading horizontally from right to left.

TABLE XVII.—THE RESULTS OF TEN HATCHES OF S. C. WHITE LEGHORN EGGS HELD FOR PERIODS OF ONE TO SEVEN DAYS

Percentage of hatchability.

WEEKLY SETS.	Period of holding in days.							Mean percentage of hatchability.
	1	2	3	4	5	6	7	
1...........	57.1	34.3	41.4	42.9	54.3	50.5	43.5	46.2
2...........	56.8	48.9	77.1	64.1	48.5	72.7	63.6	61.2
3...........	57.9	62.9	40.0	62.5	51.4	83.7	59.4	60.9
4...........	83.0	64.2	82.4	74.5	75.6	61.0	67.4	72.4
5...........	52.8	48.9	50.0	36.2	50.0	42.0	43.4	46.2
6...........	36.4	59.6	56.5	58.3	51.0	38.3	38.6	48.4
7...........	75.0	68.3	75.9	76.4	67.3	78.9	63.5	72.2
8...........	67.3	59.2	67.9	69.4	61.5	66.7	58.0	64.4
9...........	55.8	48.0	50.0	44.0	60.9	53.0	40.5	50.4
10...........	53.1	69.2	43.8	46.3	55.6	71.4	52.0	55.9
Mean........	59.8	57.3	60.1	58.1	58.2	59.8	52.7	58.0

A surprising result shown in these tables is the great amount of variability recorded from day to day. The frequent differences of 30 and 40 per cent in the same week's eggs are difficult to account for by chance. It is true that the daily production for the group represented in either table was small (ranging from 20 to 63 eggs) but with the uniform distribution of the eggs in the incubator (described above) such differences would hardly be expected. The possibility that the daily variability might be due to unfavorable conditions encountered while the eggs were in the trapnests or being collected suggests itself. A fact which fails to support this view is that the hatching results from the two breeds fail to concur in their daily fluctuations. Since the eggs of the two breeds were subjected to the same treatment before being placed in the holding room: some agreement would be expected if the responsible factor were encountered during this period. Unfavorable conditions within the incubator should affect all eggs of a set alike. Since the daily

TABLE XVIII.—THE RESULTS OF TEN HATCHES OF S. C. RHODE ISLAND RED EGGS HELD FOR PERIODS OF ONE TO SEVEN DAYS

Percentage of hatchability.

WEEKLY SETS.	Period of holding in days.							Mean percentage of hatchability.
	1	2	3	4	5	6	7	
1	53.5	77.5	61.3	58.1	61.1	56.3	61.1	61.3
2	61.9	52.5	52.5	74.4	72.1	57.1	54.5	61.1
3	60.4	53.1	64.7	66.7	57.8	64.3	54.8	60.5
4	67.9	79.2	72.4	69.4	79.6	68.0	59.6	71.0
5	57.1	53.1	53.3	65.2	36.9	62.5	59.1	55.0
6	52.5	69.2	52.6	61.1	67.9	58.8	58.2	59.8
7	68.0	72.2	74.1	64.3	65.6	66.2	54.2	66.6
8	55.6	57.1	60.0	57.1	50.0	60.6	54.4	56.5
9	65.5	61.5	60.7	46.4	50.0	57.1	28.6	53.7
10	75.0	50.0	58.3	55.0	52.9	52.4	25.0	52.2
Mean	60.4	63.3	61.8	62.7	60.7	61.5	53.9	60.7

variability in hatching quality cannot be accounted for by factors met during the period between laying and being placed in the holding room, during the period of holding, nor during the incubation period, it may be true that the fluctuations are chance ones.

When the results are summarized, as shown at the bottom of Tables XVII and XVIII, there is little evidence of any detrimental effects of holding eggs until after the sixth day. The eggs held for seven days showed a definite decline in hatchability in both breeds.

AGE OF SPERM

Warren and Kilpatrick (1929) considered the effect of age (staleness) of sperm on hatching quality of eggs. The experiment was carried out with a group of White Leghorn pullets which had been isolated from males long enough to insure that their eggs were infertile. Males were placed with the females and the incubation work was started two days later. The eggs were collected from the nests five times daily and placed immediately in an incubator. After placing seven days' eggs in the incubator (eighth day of mated period) the males were removed and the incubation work was continued until fertility practically ceased on the seventeenth day after the isolation of the females.

Table XIX includes a summary of data from the two experiments carried out as described in the preceding paragraph. It is seen that the hatching quality of eggs was not impaired even in the later period of fertility. The low percentage of hatch for the last two days may be attributed to chance as a consequence of the small number of fertile eggs. It, therefore, appears that any sperm which

TABLE XIX.—EFFECT OF AGE OF SPERM ON HATCHING QUALITY

From Warren and Kilpatrick, 1929.

	Mated period in days.							Unmated period in days.																	Total.
	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Number of eggs set	53	58	55	61	49	54	47	47	49	41	52	57	46	62	53	55	60	57	53	61	51	44	35	36	1,236
Number of fertile eggs	5	25	37	42	40	45	39	43	44	35	41	46	31	45	37	35	27	23	15	17	6	2	4	2	686
Number of chicks	4	15	27	31	30	29	30	34	24	27	26	34	23	33	27	28	21	16	10	11	4	2	1	1	488
Percentage of hatchability	80	60	73	74	75	65	77	79	55	77	63	76	74	73	73	80	78	70	67	65	67	100	25	50	71.1

is sufficiently fresh to stimulate development of the egg will produce a normal embryo.

In view of the prevalent opinion that eggs should be held for at least a short period between laying and being placed in the incubators, it is of interest to note that these eggs were placed in the incubator immediately after being laid. It cannot be said how much better they might have hatched had they been held for a period, but it is at least recorded that good hatchability may be obtained from eggs handled in this manner.

SEASONS AND TEMPERATURE

The period over which hatching results were available during each season from the Kansas Agricultural Experiment Station flock was not long enough to secure a satisfactory measure of the influence of season. Since temperature is the one feature of the environment which fluctuates most during the hatching season, it has been the factor which was considered in this study.

In order to obtain results over a longer season and to include larger numbers of eggs, data from three commercial hatcheries in Kansas were used in this study. The three hatcheries from which records were taken were located in the eastern half of Kansas and were operated by hatcherymen in whose records we had confidence.

It is realized that data obtained from commercial sources are subject to criticism, since those making the records do not always fully appreciate the necessity of accuracy such as is essential for scientific study. There is, however, the advantage of large numbers with which they deal and which tend to counteract the effect of errors in such records. In these records we also have no distinction made between loss due to infertility and to embryonic mortality, since in commercial hatching one test only is made during incubation. It also should be kept in mind that the stock from which commercial hatching is done does not represent average but selected material. In fact, most progressive hatcherymen refuse to buy eggs from flocks which fall below a certain minimum in hatchability. If the same stock is used throughout the season by the hatcherymen, the fact that it is selected should not influence the results on the effect of season. Care was taken to include in the study only those flocks which were used for the entire season. Each of the three hatcheries carried six or seven of the more pouplar breeds.

In determining the association between fluctuations in temperature and the variation in hatching quality in eggs the means of the daily minimum temperatures for a period of a week were checked against the mean hatchability percentages for eggs placed in the incubator during the same period. The temperatures used were those recorded at Manhattan, Kan., by the services of the United States Weather Bureau. The one hatchery most widely separated from the point of recording temperatures was a distance of 200 miles south. It is realized that there would be some differences in temperatures recorded at these two points, but the measurements are relative and the forms of the temperature curves recorded at the two locations would be very similar. There was also some question whether to make use of the means of maximum or minimum temperatures. For one year both were graphed, and it was found the forms of the graphs of the two were practically identical.

In Table XX are given the weekly mean minimum temperatures from January 1 to May 2, 1928, together with the mean weekly hatchability percentages for the commercial hatcheries A and B. There is also given the hatchability percentages for the Single-Comb Rhode Island Red and Single-Comb White Leghorn flocks of the Kansas Agricultural Experiment Station for the portion of the period for which data were available. The results for the last two groups were from eggs that were pedigree hatched, some steps of which probably handicap the chick's escape from the shell. In these groups the matings were made for special studies, and no selection for hatchability was practiced as was the case in the commercial hatchery results. The hatching of the Kansas Agricultural Experiment Station flocks was done in a still-air Newtown Giant Incubator, while the results from hatcheries A, B, and C were from Smith Incubators (forced draft).

During part of the time the commercial hatcheries placed eggs in the incubators twice a week. The dates given are for seven-day periods, and the hatchability results are for the eggs set during that week. The mean weekly minimums are for the seven-day periods indicated in the first column. As is shown in Table XX the weekly egg totals for the commercial hatcheries were many times larger than those used in the two breeds of the Agricultural Experiment Station flock. However, the numbers in all cases were large enough to give dependable results. The experiment station results covered a much shorter hatching season than those of the commercial hatcheries.

It is seen that the temperature fluctuations for the 1928 season were rather extreme. It should also be kept in mind that the minimum temperatures are weekly means and that the actual minimum for some days probably was considerably below the figure given. For the early part of the season the close association of the curves for temperature and hatchability at hatchery B is rather pronounced as is well brought out by figure 1. The fluctuations in hatching quality of the two experiment station breeds are, for the period included, somewhat in agreement with those of hatchery B.

The most interesting feature of figure 1 is the extreme uniformity of the results from hatchery A. Whatever were the factors responsible for the wide fluctuations in the other curves, they must have been under control in the case of hatchery A.

It should be kept in mind that the percentages presented in Table XX and figure 1 were calculated from total eggs set and not fertile eggs only. It is known that infertility is sometimes much higher in the early-season hatches and that extremely cold periods affect the sexual activity of the males. The possibility that fluctuations in fertility might be the major factor responsible for the variations in

TABLE XX.—HATCHABILITY IN RELATION TO TEMPERATURE FLUCTUATIONS AS SHOWN BY RESULTS FROM TWO COMMERCIAL HATCHERIES AND THE EXPERIMENT STATION FLOCK

DATE.	Weekly mean minimum temperature.	Hatchery A.		Hatchery B.		Experiment station White Leghorn.		Experiment station Rhode Island Red.	
		Total eggs set.	Percentage of hatchability.	Total eggs set.	Percentage of hatchability.	Total eggs set.	Percentage of hatchability.	Total eggs set.	Percentage of hatchability.
Jan. 4–10	25.7	2,928	71.1	3,499	56.0	......	......	......	......
Jan. 11–17	33.4	4,055	77.0	1,411	64.1	......	......	......	......
Jan. 18–24	23.4	7,002	78.9	3,178	49.6	......	......	......	......
Jan. 25–31	17.3	8,645	78.3	3,726	55.0	258	41.9	296	54.1
Feb. 1– 7	32.9	5,745	79.4	4,963	63.4	278	56.1	297	54.5
Feb. 8–14	30.9	10,204	80.2	5,194	58.0	287	54.7	350	57.7
Feb. 15–21	20.6	9,996	79.7	2,906	55.2	383	67.9	389	66.1
Feb. 22–28	17.1	9,699	78.2	4,587	53.3	379	41.7	340	50.3
Mar. 29– 7	27.4	12,177	78.8	6,487	53.7	409	41.3	418	54.5
Mar. 8–14	40.0	8,957	78.1	8,152	55.9	457	61.5	428	61.9
Mar. 15–21	29.3	12,568	80.2	6,710	50.2	450	52.7	447	52.6
Mar. 22–28	44.1	12,785	79.0	6,598	49.3	380	44.5	197	51.8
Mar. 29– 4	45.1	12,482	80.2	6,801	46.0	385	50.4	149	47.7
Apr. 5–11	32.7	8,816	79.2	6,511	50.2	......	......	......	......
Apr. 12–18	34.0	10,887	79.8	4,295	48.8	......	......	......	......
Apr. 19–25	39.7	6,641	78.7	6,039	46.2	......	......	......	......
Apr. 26– 2	45.3	2,820	79.6	......	......	......	......	......	......

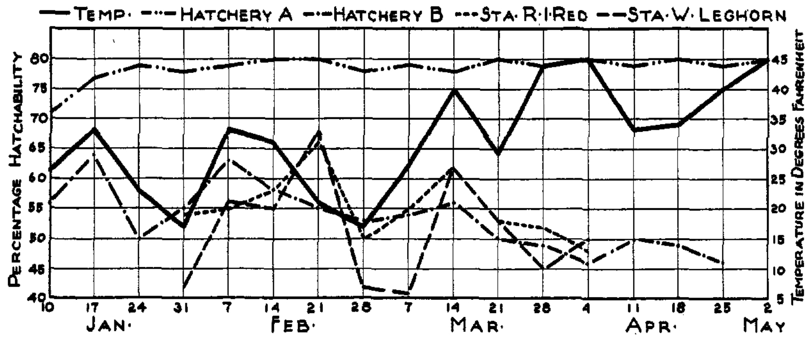

FIG. 1.—The influence of outdoor temperatures upon the hatching results of two commercial hatcheries and two experiment station flocks in 1928.

percentage hatch was considered. From the commercial hatcheries the percentages of hatchability from total eggs only were available. In the case of the experiment station flock the tests were arranged and the records so kept that it was possible to calculate the percentages on fertile eggs set. In figure 2 are graphed the data on percentage hatchability of both total and fertile eggs set for White Leghorns and Rhode Island Reds. The very close agreement in form of curve for the two calculations in each breed indicates that infertility did not greatly affect the form of the curves presented in Table XX.

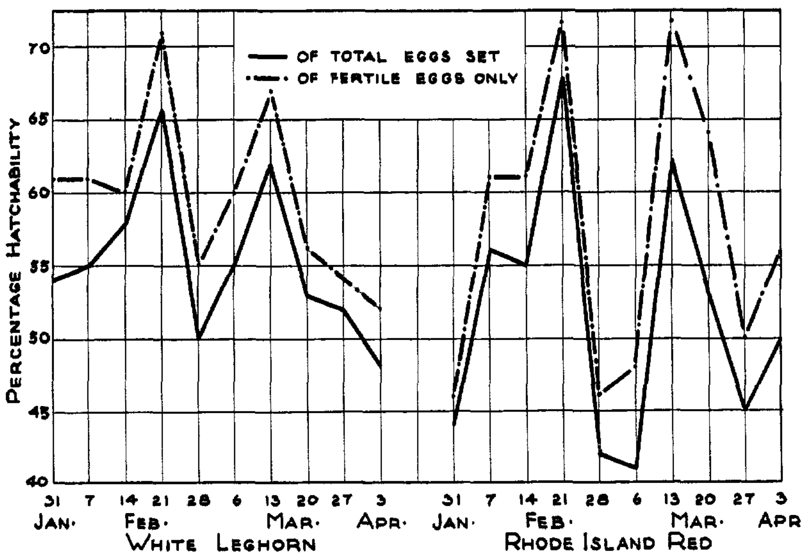

FIG. 2.—A comparison of curves for seasonal hatchability calculated upon total eggs set and upon fertile eggs only.

During the three years, 1925 to 1927, inclusive, data were obtained from a third hatchery in Kansas designated as hatchery C. In figure 3 are shown the curves for weekly minimum mean temperatures together with the weekly mean hatchability percentages. There is not in this figure the agreement in form of curves of temperature and hatchability that was previously found. The curve of hatchability here shows less fluctuations than that of hatchery B but more than hatchery A, as shown in figure 1. The curves of temperature for the years included in figure 3 show less fluctuation than

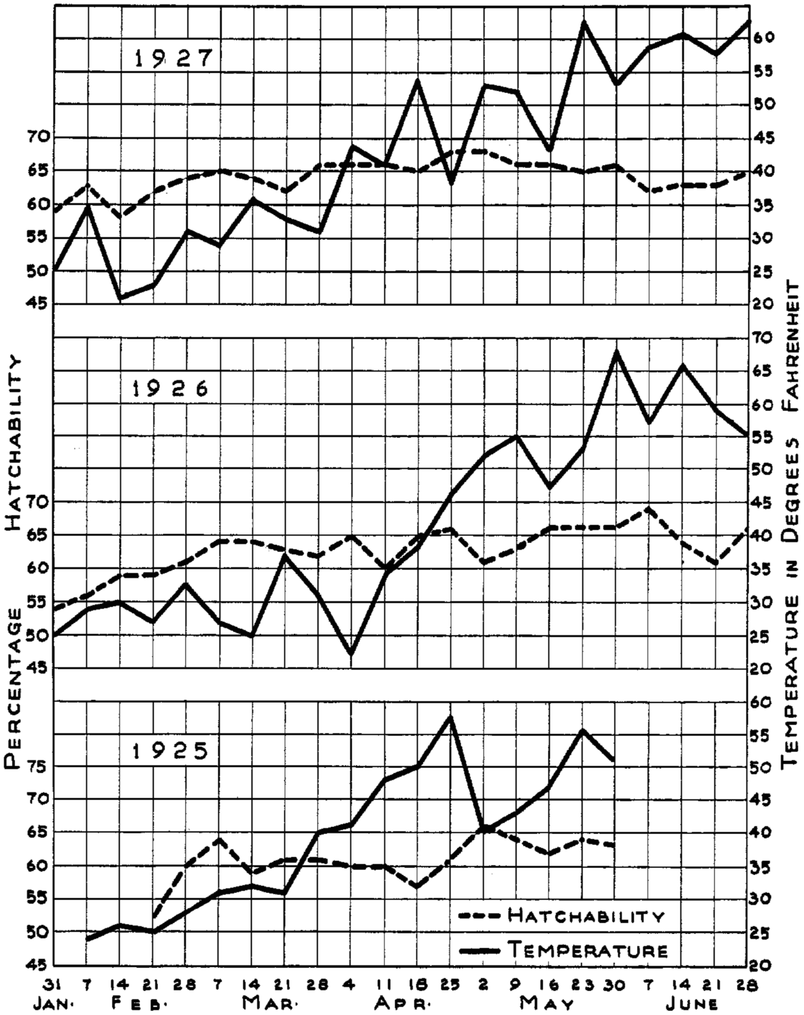

FIG. 3.—The influence of outdoor temperatures upon the hatching results of a commercial hatchery for three successive seasons.

those for 1928. (Fig. 1.) It will be noted that at the beginning of 1927 there is a slight tendency for agreement between the curves of temperature and hatchability.

In view of the results in both figures 1 and 3 there remains a question as to whether there is any real influence of temperature fluctuations on hatching quality. The data from hatcheries A and C would indicate that there are circumstances under which the hatching results are independent of extreme temperature fluctuations. The very close association between fluctuations in temperature and hatching power in the case of hatchery B can hardly be attributed to chance. This opinion is further supported by the agreement of the results from the experiment station flock for the same year. It is seen from figure 1 that close association of the curves of temperature and hatchability is most evident during the early season. This is to be expected since, if temperatures are effective, their influence would be most evident at the season when they fall to lowest extremes.

If it be admitted that there is evidence for the influence of temperature fluctuations in early season on hatching quality of eggs, it is of interest to consider how the influence is exerted. Unfavorable temperatures might react on the female herself and so affect her metabolism as to cause her to produce eggs with reduced hatching power. Low temperatures might act directly on the eggs while they are being collected or during the holding period and kill the embryo or weaken it to the extent that it dies in the early stages of development. The low temperatures might affect the regulation of the incubators and in this way reduce the hatchability of the eggs. Finally, the sexual activity of males might be reduced in extremely cold periods and thus reduce the hatchability by increasing the infertility.

Since the females producing eggs for the three hatcheries were subjected to approximately the same temperature fluctuations, the disagreement in hatching results would seem to indicate that the effects were not on the females themselves. It is true, however, that the existing evidence for the influence of temperature on hatching quality points to its action during the period immediately prior to placing the eggs in the incubator. The points on the hatchability curves in figures 1, 2, and 3 are for this period. Thus, action at this time might be on the female producing the egg or directly on the egg during the holding period.

It seems improbable that outside fluctuation in temperature would greatly affect the operation of the incubators, especially those of the force-draft type which were used in the commerical hatcheries. The evidence found in figure 2 fails to support the suggestion that infertility was a factor in causing the fluctuation in hatching results.

Thus it seems that whatever evidence there is available points to the action of unfavorable temperatures on the female producing the egg or on the egg before it goes into the incubator. The results on this phase of the study, although inconclusive, are sufficiently suggestive to emphasize the need of further studies along this line.

It should be kept in mind that on the results presented in figures 1 and 3 seasonal factors other than temperature are acting. In these figures there is, however, no very consistent seasonal trend. Upp and Tompson (1927), who studied the effect of season on hatchability, concluded that the best results were obtained during January 1 to April 7. They found that summer and fall hatching gave very poor results. Since the period of study here was limited to the spring season the findings of Upp and Thompson do not apply.

GENERAL DISCUSSION

As was anticipated when this study was first considered, it has not been possible to demonstrate many factors which have a definite effect upon hatching quality of eggs. Since the ability of the chick to escape from the shell is dependent upon a long series of developmental processes, it may readily be seen how complications arising might make it difficult to segregate sufficiently any one influence to demonstrate its effect.

There seems to be no experimental support for the prevalent opinion among practical poultrymen that pullets are inferior to hens in producing hatchable eggs. If the results of the writer, together with those of other workers, are considered, the balance of the evidence is in favor of the pullets. There is a rather general tendency, as shown by the results of various workers, for percentage of hatchability to decrease as age increases. Although the data are somewhat limited there is no evidence to support the view that the age of the male influences the hatching quality of fertilized eggs.

The influence of both current and previous production upon hatchability of eggs was considered. The results from White Leghorns and Rhode Island Reds failed to show any influence of the number of eggs produced previous to the hatching season upon hatchability of eggs. The results on effect of length of period of production previous to the hatching season are somewhat inconsistent. In the White Leghorns there is slight evidence that both pullets and hens in production for a long period, or, in other words, the early starters, had the hatching quality of their eggs impaired.

In the Rhode Island Red hens there was no evidence of any effect of length of period of production upon hatchability, while in the case of the pullets there was a significant difference in hatchability favoring the females in production for the longest period. It is difficult to account for the last result and also the lack of agreement between the two breeds.

There were no significant differences in hatchability to indicate any influence of intensity of production upon hatchability of eggs. This would indicate that high rate of laying does not handicap the hatchability of pullet eggs; in fact the slight difference occurring in hatchability was in favor of those birds of high intensity.

In both Rhode Island Reds and White Leghorns there was evidence that pullets which have a pause in their records during the period previous to the hatching season have a tendency to produce eggs which hatch somewhat better than do those of pullets laying continuously. It is known that those pullets starting to lay exceptionally early have more of a tendency to pause, so the pausing group probably included those females which had been in production longest. It was not found, however, that there was any very definite evidence indicating that the period of production influenced hatchability. It was not found that the length of pause in any way affected the hatching quality of eggs from pausing birds.

The last production factor considered was the previous year's egg production. The influence of the first year's egg production upon the second year's hatching quality was measured. No evidence was found indicating that the first year's laying record in any way influenced the hatching quality of eggs produced during the succeeding season.

Thus in general it may be said that there is little evidence supporting the view that heavy egg production reduces the hatching power of the eggs produced. In the Rhode Island Reds the three production factors (number of eggs, period of production, and intensity of laying) considered, showed that the best producing pullets have the best hatching records. Pullets showing a pause in the period previous to the hatching season had a slightly better hatching record than those females laying continuously.

The coefficient of inbreeding used as a measure of consanguinity was found to influence the hatching quality of eggs produced. The writer's data, taken from general flock matings, substantiated the results from inbreeding experiments indicating that inbreeding has a deleterious effect upon hatching quality. It was also shown that outbreeding improved the hatchability of eggs.

The results of this study are in agreement with those of earlier workers by indicating that hens producing large eggs (56 grams and above) do not give so good hatchability as do those producing smaller eggs. These results and those of some others workers show that the best hatching results were obtained from the females producing eggs smaller than the average. This association of high hatchability and small-egg size presents a problem of somewhat serious consequence to the poultry breeder. It does not mean that with proper breeding methods high hatchability cannot be separated from small size, but these results do present a tendency which should be kept in mind in breeding for improvement of egg size.

The results on holding of eggs show that under the conditions provided in this study, holding eggs longer than six days impairs their hatching quality. Attention is directed to work of Scott (1933) which shows that if proper temperatures sufficiently regulated are provided, the holding period may be considerably extended.

The results of Warren and Kilpatrick (1929) show that the hatching quality of eggs is not affected by staleness of the sperm fertilizing the egg. Sperm will live in the oviduct of the female for an average period of about 15 days, and as long as the sperm are capable of fertilizing eggs the development which follows will be normal.

The study of results of the Kansas Agricultural Experiment Station flock and those obtained from commercial hatcheries indicated that under some conditions hatchability of eggs may be influenced by outside temperatures. It appeared that the effect of fertility upon hatching quality was not the major one being measured. There were some inconsistencies in this phase of the work, but, the results are sufficiently suggestive to justify further investigation.

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