PHYSIOLOGY AND REPRODUCTION

Effect of Strain and Age of the Broiler Breeder Female on Incubation Time and Chick Weight[1]

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ABSTRACT Two experiments were conducted to evaluate effects of strain [five in Experiment (Exp.) 1 and six in Exp. 2)] and age (29, 47, and 57 wk in Exp. 1 and 29, 41, and 52 wk in Exp. 2) of commercial broiler breeders on incubation time and chick weight. Highly significant differences in egg weight were found among strains in both Exp. After adjusting for effects of egg weight, significant effects of strain, age, and their interactions were found on incubation time, egg weight at transfer, and chick weight at hatch in Exp. 1, but not in Exp. 2. Mean incubation times varied among strains from 496.6 to 498.8 h in Exp. 1 and from 499.3 to 501.9 h in the second experiment. In Exp. 1, incubation time decreased from 498.6 h when breeders were 29 wk to 494.8 at 47 wk, whereas in Exp. 2, it decreased from 510.5 h at 29 wk to 495.1 h at 41 wk. This decrease also resulted in a negative correlation between egg weight and incubation time. Differences due to strain and age were found for yolk and albumen percentage and yolk: albumen ratio. Percentage yolk was 27.2 and 32.7% and percentage albumen was 60.1 and 55.9% in eggs from 29 to 52 wk breeders, respectively. Shell percentage was significantly affected by strain. Strain by age interactions were found for each response in Exp. 1 but only for set and chick weight in Exp. 2. Differences among incubators were found only for incubation time; interactions of incubation time and strain and age were also detected. Results indicate that genotype, age of the female breeder, and incubator should be considered along with their interactions to obtain optimum hatching performance.

(*Key words*: age, broiler breeder, genotype by environment interaction, chick weight, incubation time)

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INTRODUCTION

Weight of chicks at hatch is affected by several factors, including species, breed, egg nutrient levels, egg environment, egg size (Wilson, 1991 a,b), weight loss during the incubation period, weight of the shell and other residues at hatch (Tullett and Burton, 1982), shell quality, and incubator conditions (Peebles and Brake, 1987). At the time chicks are removed from the hatcher, their weight is determined by their weight at hatch and the amount of time they are held in the hatcher (Wyatt *et al*., 1985). The correlation coefficient between egg weight and embryo weight is near zero at the beginning of incubation (Hassan and Nordskog, 1971; Al-Murrani, 1978), but increases to a maximum (about 0.90) at hatch (Bray and Iton, 1962). Factors such as seasonal effects (because of changes in maternal metabolism), genotype, incubation period (Wilson, 1991b), body weight, and hen age (Benoff and Renden, 1983; Tserveni-Gousi, 1987), as well as correlated responses due to genetic selection (Rodda *et al*., 1977; Akbar *et al*., 1983; Fletcher *et al*., 1983), may alter egg weight-chick weight relationships.

The relationship between incubation time and egg weight is positive (Burton and Tullett, 1985), with some variation due to age of the hen (Crittenden and Bohren, 1961; Smith and Bohren, 1975), breed, line within breed (Smith and Bohren, 1975; Wilson, 1991b), and preincubation storage time (MacLaury and Insko, 1968; Bohren, 1978). Incubation time is heritable (Crittenden and Bohren, 1961; Siegel *et al*., 1968) and can be changed by selection (Smith and Bohren, 1974).

Little information is available concerning genotype by environment interaction effects on characteristics of incubation. Egg weight was not significantly affected by stock-location interactions in studies by Tindell *et al.* (1967), and this result was further indicated by Hartmann (1990), who reviewed genotype by environment interactions in poultry. Although egg weight may be the dominant factor affecting such characteristics as chick weight at hatch, it is possible that interpopulation genetics by macroenvironment interaction effects (McBride, 1958) during the breeder's life, or during incubation, could also be contributing factors.

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The objectives of the present study were to determine the influences of genotype and age of breeder on incubation time, chick weight, and mortality of broiler embryos, and the correlations between these characteristics. Further, the effects of breeder genotype and age and their interactions on egg components and yolk to albumen ratio were evaluated.

MATERIALS AND METHODS

Experiment 1

Three thousand and three hundred eggs from five broiler breeder strains (A, B, C, D, and E) at three different ages (29, 47, and 57 wk) were obtained from a broiler breeder company (Arbor Acres),[3] divided into replicate groups of 30 eggs each, individually identified, weighed to the nearest 0.1 g, and placed in setting trays to be incubated. Two Jamesway 252® incubators[4] were used and 11 replicates by strain were randomly distributed in each incubator. Average temperatures were 37.4 and 37.2 C dry bulb, and 28.5 and 28.4 C wet bulb in Incubators 1 and 2, respectively. The time the incubators were turned on was recorded as "Hour 0" of the experiment. To minimize cooling and possible effects on incubation time, the eggs were not removed from the incubator until after 456 h of incubation. At this time, the eggs were candled to identify infertile eggs and dead embryos, weighed individually, and those containing viable embryos were transferred to hatching baskets and returned to the incubator. At 480 h of incubation, and every 2 h thereafter, newly hatched chicks were weighed and hatch time recorded. The response variables considered in this experiment were egg weight at set (set weight) and transfer (transfer weight), chick weight at hatch (hatch weight), and incubation time to hatching. Embryonic mortality was not recorded nor was infertility verified, because unhatched eggs (candled infertile, early dead, and late dead) were inadvertently destroyed before macroscopic examination; thus, only hatchability of eggs set (total hatch) was calculated.

Experiment 2

Chick weight, incubation time, and the relative values of egg components as affected by age and genotype of the breeders were determined in this experiment. Two hundred eggs from each of 12 genetic crosses (6 females lines, each crossed with 2 different male lines and identified as 1A, 1B, 2A, 2B, 3A, 3C, 4A, 4D, 5A, 5E, 6A, and 6F) at three different ages (29, 41, and 52 wk) were obtained from the same broiler breeder company as in Experiment 1 and divided into two groups. A group of 150 eggs was randomly distributed in smaller groups of 15 eggs and allocated to each of 10 replicates per strain. Otherwise, the experimental procedure was the same as in Experiment 1, except that the chicks hatched in individual compartments of the baskets and were returned to the same compartment until process time (completion of the hatch). At process time (512 h incubation) each chick was removed from the incubator and weighed to obtain process weight. All unhatched eggs were examined macroscopically for embryonic development.

The response variables considered in this experiment were egg weight at set and transfer, chick weight at hatch and process, incubation time, and embryonic mortality. Process weight was the weight of the chick when the hatch was considered complete.

Another group of eggs (40) from each female line, and from each age (120 per line), was used to determine egg components. Eggs were individually weighed to the nearest 0.1 g, hard cooked in shell (Lee, 1985), and then cooled for 5 min in cold running water. The cooked egg was reweighed and the shell, yolk, and albumen were separated and weighed. Weight loss of eggs after cooking was about 1.5 to 2% for all strains, and thus, it is assumed, did not significantly change the relative amounts of the components.

Statistical Analysis

All effects were considered fixed in both experiments; therefore, residual variation was used as the error term in the analyses. Data from Experiment 1 were analyzed as a $5 \times 3 \times 2$ factorial with strain, age, and incubator as main effects. In preliminary analyses of the data, no significant effects of the three-factor interaction on any of the variables were detected; therefore, this interaction was not considered in the final model. Data from Experiment 2 were analyzed as a 6×3 factorial with strain, age, and their interactions in the mathematical model along with egg weight for the remaining dependent variables.

Eggs were not classified by weight; thus, to eliminate the variability due to egg weight, weight at setting was used as a covariable in all the ANOVA involving weight. Because of disproportionate subclass numbers, data were analyzed by the method of least squares ANOVA. Least squares means were compared by orthogonal contrasts. Comparisons among males indicated no significant effects on any variable; thus, the values for each female strain were pooled and males were deleted from the analyses. The number of strains was reduced to six. Egg components expressed as percentages of egg weight were transformed to natural logarithms prior to statistical analysis, but this did not alter interpretation of the results; therefore, estimates of effects and results of analyses from the original data (not transformed) are presented. The analyses were performed using the General Linear Models (GLM) and Correlation procedures of SAS® (SAS Institute, 1989). Partial correlations were estimated by multivariate analysis of variance (MANOVA). Data concerning total hatchability (Experiment 1) and mortality

[3]Arbor Acres Farm, Inc., Glastonbury, CT 06033.

[4]James Manufacturing Co., Fort Atkinson, WI; now Jamesway Incubator Co., Monroe, NC 28111.

TABLE 1. Probability values from least squares analyses of variance and orthogonal contrasts for characteristics of broiler breeder eggs affected by strain and age of female breeders, Experiment 1

Effect	df	Set weight[1]	Transfer weight	Hatch weight	Incubation time
Strain	4	0.001	0.034	0.001	0.001
Age	2	<0.001	0.001	<0.001	0.001
Strain × age	8	0.001	0.001	0.001	0.001
Incubator (INC)	1	0.367	0.221	0.107	0.001
Strain × INC	4	0.273	0.193	0.177	0.018
Age × INC	2	0.157	0.172	0.091	0.010
Set weight	1	. . .	0.000	0.001	0.018
Residual	7,594				
Orthogonal contrasts					
Age linear	1	0.001	0.001	0.000	0.082
Age quadratic	1	0.035	0.361	0.001	0.001

[1]Set weight included in the model for other responses.

(Experiment 2) were analyzed using the SAS® Categorical Model (CATMOD) procedure. Comparisons of least squares means for set weight and adjusted least squares means for the other variables were performed by orthogonal contrasts. When interaction effects were significant, comparisons of strain within age were performed.

RESULTS

Set Weight

Set weights differed among strains ($P < 0.001$), ranging from 60.66 to 62.92 g in Experiment 1 (Tables 1 and 2). Age effects were detected ($P < 0.001$) with increases as expected from 56.70 (29 wk) to 66.88 g (57 wk); the increase was curvilinear. Increases with age differed among strains (strain by age, $P < 0.001$). Differences among incubators could not be detected ($P = 0.36$), nor could interactions between incubator and either strain ($P = 0.27$) or age ($P = 0.15$).

Transfer Weight

Transfer weight adjusted for set weight was significantly affected by the strain ($P = 0.03$) and age ($P < 0.001$), similar to set weights in Experiment 1 (Tables 1 and 2) but not in Experiment 2 (Tables 3 and 4). Incubator effects and interactions between incubator and either strain or age were not significant.

Hatch Weight

Hatch weight, as set and transfer weights, was significantly affected by strain, age, and the interaction between strain and age in Experiment 1 (Tables 1 and 2), but not in Experiment 2 (Tables 3 and 4). It was lowest for Strain C, which differed significantly from all other strains. Age of hen in Experiment 1 (Tables 1 and 3) affected hatch weight in a curvilinear manner. Hatch weight and transfer weight were both closely correlated with set weight (Table 5), as would be expected.

TABLE 2. Least squares means for characteristics of broiler breeder eggs by strain and age of female breeders, Experiment 1

Effect	Set weight[1]	Transfer weight	Hatch weight	Incubation time
	(g)			(h)
Strain				
A	62.92	55.37	46.58	498.5
B	62.74	55.33	46.41	498.8
C	60.66	55.31	45.41	497.0
D	62.27	55.20	46.18	496.9
E	60.72	55.29	45.62	496.6
Age				
29 wk	56.70	55.00	42.85	498.6
47 wk	61.99	55.40	46.42	494.8
57 wk	66.88	55.49	48.84	499.4
Incubator				
1	61.82	55.34	46.19	498.8
2	61.90	55.26	45.89	496.3

[1]Set weight included in the model for other responses.

TABLE 3. Least squares analyses of variance and orthogonal contrasts for characteristics of broiler breeder eggs, Experiment 2

Effect	df	Egg weight		Chick weight		Incubation time
		Set[1]	Transfer	Hatch	Process	
Strain	5	0.001	0.343	0.617	0.817	0.133
Age	2	0.001	0.193	0.489	0.022	0.015
Strain × age	10	0.001	0.651	0.035	0.642	0.774
Set weight	1	. . .	<0.001	<0.001	0.001	0.094
Residual	2,670					
Orthogonal contrasts						
Age linear	1	0.000	0.010	0.532	0.027	0.001
Age quadratic	1	0.001	0.172	0.217	0.012	0.001

[1]Set weight included in the model for other responses.

Process Weight

Process weight (Experiment 2) was affected by age of the breeders (Table 3) with the largest chicks observed at the older breeder age (Table 4). Effects of age were significant and curvilinear. However, comparisons within age did not detect differences among strains (data not shown).

Incubation Time

Incubation time was significantly ($P < 0.001$) affected by strain, breeder age, interaction between strain and age, and incubator in Experiment 1 (Tables 1 and 2). In Experiment 2 (Tables 3 and 4), the only significant effect was age of the breeder. In both experiments, incubation time showed a significant curvilinear response, with the lowest value at the middle age of the breeder (47 and 41 wk for Experiments 1 and 2, respectively).

Simple correlations between incubation time and the other variables were significant and ranged from –0.144 to –0.228 (Table 5). Partial correlations were nonsignificant and positive, ranging from 0.015 to 0.140.

Total Hatchability and Embryonic Mortality

Significant effects of strain, age, and strain by age interactions were found on total hatchability in Experiment 1 (Table 6).

Embryonic mortality in Experiment 2 was affected by age, strain, and strain by age interaction when Strain 2 was involved (Tables 7 and 8). This strain had the highest percentage of mortality (14.42%) and was characterized by a higher incidence of malpositioned embryos (37% of the total malpositioned eggs across all strains, data not shown).

Egg Components

Analyses of variance for egg components detected significant effects of genotype and age of the female breeder and their interactions (Tables 9 and 10) on yolk to albumen ratio (Y:A). Yolk to albumen ratio increased linearly with age of breeder as a consequence of a linear decrease in the percentage of albumen. Comparisons of percentages of yolk within age showed differences between Strains 3 and 4 within 29- and 41-wk ages (data

TABLE 4. Least squares means for characteristics of broiler breeder eggs by strain and age of female breeders, Experiment 2

Effect	Egg weight		Chick weight		Incubation time
	Set[1]	Transfer	Hatch	Process	
	(g)				(h)
Strain					
1	64.95	58.68	48.34	45.83	501.7
2	67.01	58.44	48.26	45.87	501.9
3	63.40	58.84	48.65	45.96	499.5
4	65.01	58.68	48.57	45.92	499.3
5	64.16	58.61	48.14	45.99	500.8
6	63.25	58.94	48.80	45.93	501.2
Age					
29 wk	58.26	59.05	48.62	45.94	510.5
41 wk	66.04	58.39	48.28	45.58	495.1
52 wk	69.59	58.66	48.69	46.23	496.8

[1]Set weight included in the model for other responses.

TABLE 5. Simple and partial correlations between characteristics of broiler breeder eggs during incubation, Experiment 2[1]

Variable	Set weight	Transfer weight	Hatch weight	Process weight	Incubation time
Set weight		0.981	0.969	0.953	–0.226
Transfer weight	0.965		0.979	0.958	–0.213
Hatch weight	0.934	0.958		0.964	–0.228
Process weight	0.895	0.906	0.918		–0.144
Incubation time	0.038	0.036	0.015	0.140	

[1]Simple correlations above diagonal. Partial correlations below diagonal; see Table 4 for mathematical model.

not shown). These differences were consistent for albumen weight and Y:A within 41-wk age. Within 52-wk age, only Strains 5 vs 6 differed significantly in albumen weight and Y:A ratio. No significant effects were found for percentage shell, although data suggested that shell weight increased with age.

DISCUSSION

Egg Weight and Components

In both experiments, strains differed in initial egg weight. Differences in egg weight among various lines of chickens have been attributed to differences in yolk, albumen, and shell weight (Marion *et al*., 1964; Cherry *et al*., 1978; Benoff and Renden, 1983). Weight of the albumen component has the largest effect on egg weight (Rodda *et al*., 1977; Benoff and Renden, 1983). Results obtained in the present study in relation to differences in egg weights, egg components, and Y:A ratios agreed with these previous results only for Strains 2 and 4. Significant strain differences in egg components and yolk percentage have also been reported (Arafa *et al*., 1982; Carey, 1988).

Age of the breeder affects egg weight (Fletcher *et al*., 1981, 1983; Reinhart and Hurnik, 1984) and consequently egg components and their ratios (Cunningham *et al*., 1960; Anthony *et al*., 1989; O'Sullivan *et al*., 1991; Hussein *et al*., 1993). Results obtained in the present study were consistent with those reported in the literature. A significant curvilinear effect of age on yolk weight, but not for the other components, was observed in the present study and is consistent with results reported by Marion *et al*. (1964) related to yolk plus albumen. Although a highly significant strain by age interaction was observed for egg weight in Experiment 2, this effect was not significant for yolk and shell weight, and the probability values for albumen weight and Y:A ratio were 0.052 and 0.063 respectively. Comparison of strains within age indicated that Strains 5 and 6 performed differently at each age studied, which indicated a significant genotype by environment interaction effect that was not evident in the other strains.

Egg Weight Loss and Chick Weight

Initial egg weight is a temporary environmental influence that may mask the true genetic differences in embryonic growth among strains, principally if embryo growth is measured at hatching time when a high correlation (r = 0.90) exists between egg weight and chick weight (Bray and Iton, 1962). The simple and partial correlations obtained in this study are consistent with the high correlation between egg weight and chick weight reported in the literature (reviewed by Wilson, 1991b).

When initial egg weight was included in the model, no significant effects of strain and age on transfer and chick weight were detected in Experiment 2, although the strain by age interaction was significant for hatch and process weights. Similar results were reported by Sherman and Shultz (1989), who compared two strain

TABLE 6. Probability values from categorical analysis and orthogonal contrasts for total hatchability of broiler breeder eggs, Experiment 1

Source	df	Chi-square[1]	Probability
Intercept	1	3,116	<0.001
Strain	4	81	<0.001
Age	2	227	<0.001
Strain × age	8	32	<0.001
Incubator (INC)	1	20	<0.001
Strain × INC	4	4	0.391
Age × INC	2	<1	0.921
Residual	8	4	0.399
Orthogonal contrasts			
Age linear	1	174	<0.001
Age quadratic	1	75	<0.001

[1]CATMOD procedure.

TABLE 7. Probability values from categorical analysis and orthogonal contrasts for embryonic mortality of broiler breeder eggs, Experiment 2

Source	df	Chi-square[1]	Probability
Intercept	1	3,156	<0.001
Strain	5	14	0.014
Age	2	8	0.004
Strain × age	10	23	0.009
Orthogonal contrasts			
Age linear	1	<1	0.678
Age quadratic	1	4	0.061

[1]CATMOD procedure.

TABLE 8. Effects of strain and age on total hatchability and embryonic mortality of broiler breeder eggs, Experiments (Exp.) 1 and 2

Effect	Total hatchability	Total mortality
	(%)	
Strain, Exp. 1		
A	75.1	
B	77.2	
C	79.6	
D	70.4	
E	81.3	
Age		
29 wk	81.2	
47 wk	81.6	
57 wk	67.3	
Strain, Exp. 2		
1		8.0
2		14.4
3		6.2
4		6.3
5		7.6
6		7.9
Age		
29 wk		10.0
41 wk		5.8
52 wk		8.8

crosses of domestic turkeys after removing variation due to initial egg weight. The opposite was true in Experiment 1, in which strain, age, and the strain by age interaction were highly significant for all variables (Table 1). These results indicated that strains studied in Experiment 1 differed from each other (except Strains A and B), regardless of their egg size. Bray and Iton (1962) indicated that strains accounted for a significant amount of variation in embryo weights at different days of incubation but not at hatch when embryo weight was considered as percentage of initial egg weight. They suggested that differences occur within strains in egg weight and embryo weight relationship. On the contrary, results of Hassan and Nordskog (1971) indicated significant differences due to lines and crosses in hatch weight when data were adjusted for egg weight.

Incubation Time

Length of incubation time is affected by many factors (Wilson, 1991b) and can be changed through artificial selection as a direct or correlated response. Heritability of incubation time has been reported to be 0.49 (Crittenden and Bohren, 1961) or 0.50 (Siegel *et al.*, 1968); however, conflicting results are found in the literature relative to correlated response. Genetic correlations of 0.55 and 0.20 (from sire and dam components of variance) between incubation time and egg weight, respectively, were reported by Crittenden and Bohren (1961), whereas Siegel *et al.* (1968) found a genetic correlation of 0.11 and a negative phenotypic correlation between body weight and incubation time. On the contrary, Smith and Bohren (1974) found no genetic correlation between incubation time and egg weight and suggested that correlations reported by Crittenden and Bohren (1961) might be considered not significant because of their large standard errors (Smith and Bohren, 1974; Vasquez and Bohren, 1978). The former authors indicated that a fast-hatching line had significantly smaller egg weight than a slow-hatching line and the control, but these differences were attributed to random drift and were not a response correlated to selection for incubation time. A similar response related to egg weight and incubation time was observed in the present study (partial correlations, Table 5). The partial correlation between incubation time and egg weight was very low (0.038) and not significant. Simple correlation between these two variables was larger and negative (–0.226), but was not significant, which agrees with the results of Hager and Beane (1983).

In conclusion, results obtained in the current study indicate that, regardless of egg weight, some strains perform differently with regard to egg and chick characteristics during the incubation process, and that incubation time differs, possibly because of differences in egg components or physiological mechanisms. These differences may also be influenced by age of the hens, or incubator conditions. This finding indicates the presence of significant genotype by environment interactions. Commercial hatcheries, especially those setting eggs from multiple strains in multi-stage incubators, may benefit from observing strain characteristics in incubation time

TABLE 9. Probability values from least squares analyses of variance and orthogonal contrasts for egg weight and percentage of egg components, Experiment 2

Effect	df	Egg weight	Shell weight[1]	Yolk weight[1]	Albumen weight[1]	Yolk: albumen ratio
Strain	5	0.001	0.033	0.014	0.001	0.004
Age	2	0.001	0.612	0.001	0.001	0.001
Strain × age	10	0.017	0.177	0.132	0.052	0.063
Residual	674					
Orthogonal contrasts						
Age linear	1	0.001	0.498	0.001	0.001	0.001
Age quadratic	1	0.001	0.668	0.010	0.463	0.263

[1]As percentage of egg weight.

TABLE 10. Least squares means for egg weight and percentage of egg components by strain and age of female breeders, Experiment 2

Effect	No eggs	Egg weight	Shell weight[1]	Yolk weight[1]	Albumen weight[1]	Yolk:albumen ratio
		(g)	(%)			
Strain						
1	109	64.05	10.19	30.42	57.22	0.534
2	111	66.79	9.94	29.78	58.76	0.508
3	119	62.08	9.92	29.99	58.22	0.516
4	112	65.19	10.05	29.60	58.52	0.508
5	116	64.03	9.87	30.60	57.79	0.548
6	126	63.71	10.05	30.59	57.23	0.537
Age						
29 wk	120	57.73	9.97	27.22	60.14	0.458
41 wk	318	65.58	9.98	30.60	57.84	0.530
52 wk	255	69.62	10.05	32.71	55.93	0.587

[1]As percentage of egg weight.

and egg weight loss and adjusting setting times, humidity, and temperature accordingly to maximize chick quality and minimize delay in removal from the hatcher. Our results strongly suggest that because of these possible genotype by environment interactions, the genotype or strain of female breeders should be considered along with environmental conditions of incubation necessary to approach optimum hatching performance and obtain high quality chicks for each strain.

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