CORRELATED PHYSIOLOGICAL RESPONSES IN A BIDIRECTIONAL SELECTION EXPERIMENT FOR BODY WEIGHT IN CHICKENS

by

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INTRODUCTION

Artificial selection for body weight is expressed phenotypically through changes in physiological mechanisms. Physiologically, variations in body weight may be due to several factors such as hormones, behaviors, and enzymes. Two traits of particular interest in this dissertation, which involves lines differing in body weight, are metabolic rates and blood glutathione levels.

At Virginia Polytechnic Institute, a long-term bidirectional selection experiment for body weight at 8 weeks of age has been in progress since 1957. Artificial selection has resulted in a high weight line and a low weight line of chickens which are now extremely diverse for the selected trait. The purpose of this dissertation was two-fold. We wished first to compare the metabolic rates and the blood glutathione levels of chickens from these selected lines, and second to determine the influence of environment on the metabolism and growth of these lines. Such information can provide evidence on the correlated responses of the physiological mechanism when selection is for body weight *per se*.

REVIEW OF LITERATURE

Properties of Glutathione

γ-L-glutamyl-L-cysteinylglycine (glutathione) is a tripeptide of glutamic acid, cysteine, and glycine that differs from other peptides in the α-peptide bond of the second linkage (White et al., 1968). Glutathione was isolated from yeast and mammilian muscle and liver by Hopkins (1921) who felt the compound was the same as the philothion of de Rey-Pailhade (1888). Hopkins believed that it was a dipeptide of glutamic acid and cysteine; however, later hunter and Eagles (1927a) suggested that it was a tripeptide. The exact structure proposed by Pirie and Pinhey (1929) was confirmed by Harington and Mead (1935).

Glutathione is colorless, melts at 195°C, and is readily soluble in water, liquid ammonia, and dimethylformamide. It has the properties of an acid, of an α-aminocarboxylic acid, and of a peptide. Reactivity is due to its α-glutamyl linkage, its sulfhydryl group, and its mercaptan nature. Glutathione exists in both the reduced (GSH) and oxidized (GSSG) states. Higher levels of the reduced form are found in most tissues (Bhattacharya et al., 1955).

Biosynthesis of GSH is accompolished in 3 steps with the aid of two non-specific enzymes. First, glutamic acid and cysteine are coupled to form glutamylcysteine; then the latter compound is coupled with glycine to form the tripeptide. ATP plus ions of magnesium and potassium are necessary for the reactions to flow (White et al., 1968). Methods for synthesis were presented at the 1953 Symposium on Glutathione (Colowick et al., 1954).

Physiological Functions of Glutathione

Glutathione has been credited with numerous physiological functions and for being involved in several biochemical pathways. Examples are a radioprotective effect, an involvement in hemolytic disorders, a relation to methionine levels in the blood, an effect on the dissociation curve of hemoglobin, an influence on lactation, an influence on pigmentation, an increase in oxygen consumption, a pituitary influence on tissue levels, a stress influence on tissue levels, and an alloxan protective effect.

Patt et al. (1949) demonstrated that the sufhydryl compound cysteine offered radiation protection to mammals if given shortly before irradiation. Mouse fibroblasts x-rayed with dosages ranging from 0-1,000 r were protected if they were treated with cysteamine prior to irradiation (Gaines et al., 1964). Revesz and Modiz (1965) observed an increase in GSH following cysteamine treatments of mouse ascites cells and hypothesized that GSH was the radioprotective agent. They further hypothesized that GSH functioned to remove radiation induced free radicals and to remove generated hydrogen peroxide by the GSH peroxidase pathway, since GSH is involved in the conversion of hydrogen peroxide to water and oxygen.

GSH has been shown to play a role in maintaining the integrity of the erythrocyte and in protecting hemoglobin from oxidative breakdown (Miles, 1957). Fegler (1952) studied the relationship between erythrocyte hemolysis and blood GSH levels of horses. There was a marked increase in the rate of hemolysis when the GSH concentration

dropped to 40% of its initial value. He concluded that GSH must be important in maintaining the structural integrity of the erythrocyte. A hypothesis that GSH plays its role in erythrocyte function by retarding the aging process was offered by Harley (1965). This could be due to its enhancing the activity of sulfhydryl enzymes. Primaquime sensitivity, a hemolytic condition, seems to be due to a low concentration of GSH (White et al., 1968).

Smith and Osburn (1967) studied ewes with abnormally low levels of blood GSH. The sheep were studied for two months during which no apparent hemolytic disorders were noted. Prins et al. (1964) reported a hereditary absence of blood GSH. Such individuals exhibit a hemolytic disorder with a borderline anemia and reticulocytosis.

Kano et al. (1968) studied the effects of methionine on GSH levels in hypothyroid chicks. Thiouracil (which promoted the hypothyroid state) and methionine supplementation of a basal diet gave higher liver and muscle GSH levels than either treatment singly. Higher blood GSH levels with a methionine supplementation were also noted by Gazo et al. (1968).

A high concentration of blood GSH shifts the dissociation curve of oxygemoglobin to the right, enabling oxygen to be more readily available to tissues (Horejsi, 1967). Addition of GSH to either preserved blood or plasma extenders increased the survival of rats subjected to laboratory induced hemorrhagic shock.

Evidence that GSH was related to lactation in rats was provided by Scharfschwerdt et al. (1965) who found nearly twice as much tissue

concentration in the mammae during lactation than during the involution period. The blood GSH from the jugular and mammary veins of non-lactating and lactating cows was measured by Harding and Cary (1926). Although values from both sources were identical for non-lactating cows, samples from the mammary vein of lactating ones were 25% less that those from the jugular. In this case the GSH could have been supplying the sulfhydryl that was going into the milk.

Halprin (1966) presented evidence that the sulfhydryl compound that Rothman et al. (1946) proposed to inhibit melanin formation was GSH. He found Caucausian epidermis to contain sufficient GSH to inhibit melanin formation. Lesser amounts of GSH were evident in the epidermis of Negroes.

Fried et al. (1964) studied the effects on oxygen consumption of injecting obese mice and their thin siblings with GSH. In the obese mice, injections of 33, 66, and 180 mg of GSH caused 36%, 28%, and 28% increases in oxygen consumption, respectively. The average increase for saline injected controls was 8%. GSH had no effect on the thin siblings. The increased oxygen consumption of obese mice was not sustained, and long term treatment with GSH was not effective in sustaining it. They did find, however, that GSH injection of salamanders caused sustained increases in oxygen consumption.

Hypophysectomy of rats significantly decreased GSH levels of the spleen and heart (Binkley et al., 1951). Although there was a decrease in blood GSH levels, the decline was not significant.

Administration of GSH restored the levels to normal. Liver and muscle GSH in rabbits after injection of potent hypophyseal hormones and after injection of inactive hormones were measured by Gregory and Goss (1939). The active hormones lowered both the muscle and the liver GSH concentrations. The authors attributed the lowered concentrations of GSH to increased protein anabolism.

ACTH injections caused no appreciable changes in adrenal GSH levels (Harding and Nelson, 1963). Grunert and Phillips (1951a) measured blood, kidney, and liver GSH levels of rats after ACTH injection and after stress. Stresses were cold, histamine, epinephrine and deoxycorticosteroneacetate (DCA). None of these had any influence on the GSH levels and led to a questioning of the influence, if any, of the pituitary-adrenal axis on blood GSH levels. Persky (1954), however, reported that in humans psychological stress was effective in reducing blood GSH levels. The stresses consisted of jumping from a thirty-four foot tower, parachute jumping, and participation in night infiltration exercises. He felt that the reduction in GSH was due to the stress and not to the extreme physical activity.

GSH appears to provide a protective effect against the diabetogenic effect of alloxan in rats (Lazarow, 1946). Complete protection was obtained from injections of 2.0 to 7.5 mm of GSH or cysteine per kg of body weight one to two minnutes prior to alloxan injection.

Relation of Glutathione to Growth

Studies of the relationship between GSH and growth have been conducted with cattle, sheep, rats, rabbits, and chickens. Results are inconsistent, with some evidence to suggest a correlation between GSH and body weight and other evidence showing no correlation between the two traits. Body weight appears to be associated with blood GSH levels in sheep and cattle (Patruskev, 1940). In contrast, Kidwell et al. (1955) measured blood GSH in 47 Hereford steers which ranged from 15 to 21 months of age and found no relationship between GSH and either weight or rate of gain. Theyconcluded that whole blood GSH was not a useful criterion in selecting for growth rate and body size in cattle.

Gregory et al. (1933) measured the total carcass GSH of newborn rabbits from six populations that differed genetically for adult body size. Although GSH content was positively associated with the adult body weights of the respective populations, within a population GSH content was not correlated with body size. Sherrod and Struck (1943) attempted to induce growth in rats by daily injections of 25 mg GSH from 21 days of age through pregnancy and lactation. The process was carried out for four generations with no observed increase in growth rate. Sample sizes, however, were very small (n=3 to 11). Telupilova (1959) investigated postnatal and adult GSH levels in rats and rabbits. Blood and liver GSH levels were lower in the postnatal period than in adults. The former is a period of rapid growth.

Muscle and spleen GSH were, however, greater in the postnatal period than in adults. There were no differences between the two periods for brain, lung, and kidney GSH.

Comparisons of total carcass GSH were made for White Leghorn and Barred Plymouth Rock embryos incubated from 5 to 19 days (Gregory et al., 1936). GSH content was low early, peaked at day 14, declined and then peaked again on day 17 or 18 with a subsequent decline. Barred Rocks had consistently higher GSH levels than Leghorns on all days except day 13. Whole carcass GSH levels were also measured in White Leghorns and Barred Plymouth Rocks during the period of 2 to 14 days posthatching (Gregory et al., 1937). GSH was greater in the Barred Rocks than in the Leghorns throughout the period and was significantly greater at 8 and 12 days of age. The concentration of GSH was low immediately after hatching, increased from 2 to 4 days, dropped slightly on day 6 and was rising from day 8 to the end of the period. Although Leghorns were slightly heavier at 2 and 4 days of age, the Barred Rocks quickly gained a weight advantage and were significantly heavier than the Leghorns at 14 days of age. Stutts and Kunkel (1958) compared whole carcass GSH contents of the White Leghorn and New Hampshire embryos and obtained information that was inconsistent with that of Gregory. In one experiment the GSH of the Leghorns was significantly greater on days 12, 13 and 14 of incubation whereas in a second experiment the New Hampshires were greater on day 13. They also compared whole carcass GSH of embryos in three inbred lines of Leghorns to a non-inbred and found no differences. Charkey

et al. (1965) compared the blood and liver GSH concentrations between fast growers and slow growers of the same line of chickens. Over the test period (5 to 28 days) more rapid growth was associated with higher maintained levels of liver and blood GSH.

Seasonal and Diurnal Variations in Glutathione Levels

There are some indications of diurnal and seasonal variations in the concentration of tissue GSH. Liver GSH concentrations of mice were the highest from 8:00 A.M. to 12:00 noon and were the lowest at 8:00 P.M. (Beck, 1958). Although Preininger et al. (1961) observed a diurnal variation in liver GSH of rats, the times of maximum and minimum concentrations differed from those of mice. Minimal values for rats were from 7:00 to 11:00 A.M. and maximal values were from 3:00 to 11:00 P.M. The different times of maximal and minimal concentrations between mice and rats could be indicative of different feeding habits between the species. Preininger found no diurnal rhythm in brain levels of GSH.

Gazatto (1939) measured blood levels of GSH and noted a small seasonal variation. The rabbits tended to have their greatest levels of GSH during the winter.

Inheritance of Glutathione Levels

There are reports indicating a hereditary influence on levels of GSH in tissues. Gregory et al. (1933, 1936 and 1937) presented data showing hereditary differences in whole carcass GSH values of rabbits, chick embryos, and young chickens. They presented further evidence that tissue GSH levels are heritable by determination of

the whole carcass GSH of homozygous Cornish lethal, heterozygous Creeper, and normal embryos (Gregory et al., 1939). The GSH content of 14 to 19 day embryos with the Cornish lethal were consistently lower than those of the heterozygous Creeper and normal embryos.

Blood GSH values of three inbred lines of mature White Leghorn chickens were measured by Stutts et al. (1956). They felt if GSH values were genetically controlled they should become fixed by inbreeding. One line had significantly lower values than the others, and with this information they concluded that the blood GSH concentration of mature chickens is genetically controlled.

Using two inbred strains of mice and their reciprocal crosses, Swenson et al. (1959) measured blood GSH concentrations. One strain was alloxan resistant, and the other was alloxan sensitive. As was discussed earlier, GSH can protect against the diabetogenic effect of alloxan if given prior to alloxan injection. The resistant strain had significantly greater GSH values than the sensitive strain, and the crosses were significantly different from the sensitive strain but not the resistant strain or between themselves. A genetic basis was suggested to control GSH levels.

Kunkel et al. (1954) compared blood GSH values among Hereford, Brahman, and Angus cattle ranging from 9 to 13 months of age. The Herefords had significantly lower GSH values that the other two breeds. A heritability estimate based on half-sib correlations was 0.86 for blood GSH of Hereford calves.

Determination of Glutathione

Several methods have been developed for the assay of GSH. Hopkins (1921) used its reaction with sodium nitroprusside to identify the compound during the isolation processes. The reaction produces a violet red color which is due to the concentration of the sulfhydryl group of GSH. The production of color enables one to colorimetrically measure the GSH. Methods based on the sodium nitroprusside reaction are those of Fujita and Numata (1938b), Bruckman and Werthermer (1947), and Grunert and Phillips (1951b). Although the literature indicates that the method of Grunert and Phillips is the most popular, the procedure is not specific for GSH because other sulfhydryl compounds will react with nitroprusside. It does not measure ascorbic acid.

Iodometric titration is another method for the assay of GSH. The procedure depends on the quantitative oxidation of the sulfhydryl group by iodine, and the end point of the determination may be followed by either sodium nitroprusside or starch. Iodometric titrations are also non-specific, and they also measure ascorbic acid. The ascorbic acid, however, can be destroyed or corrected for by measurement. Iodometric methods have been described by Tunnicliffe (1925), Woodward and Fry (1932) and Fujita and Numata (1938a).

Another assay method is based on GSH's coenzyme activity in the glyoxalase system (Woodward, 1935). Glyoxalase catalyzes the conversion of methylglyoxal to lactic acid, and when GSH is the limiting factor the rate of the conversion can be used to analyze for GSH. The reaction can be measured manometrically either by adding

bicarbonate to the system and determining the amount of carbon dioxide released by the lactic acid, or by measuring the decrease of methylglyoxal. This is a specific measure of the tripeptide. Other procedures for measuring GSH include the amperometric titration method, phosphotungstate method, the naphthoquinone sulfonate method, the ferricyanide method, microbiological assay, and paper chromatography.

Recently developed procedures for determination of GSH include the alloxan 305 method (Kay and Murfitt, 1960) and the one by Beutler et al. (1963) that utilizes the reaction of GSH with DTNB [5,5' dithiobis-(2-nitrobenzoic acid)]. The alloxan method utilized the reaction of GSH and alloxan to form a compound which has an absorption peak at 305 mμ. Although other sulfhydryl compounds react with alloxan, they form dialuric acid which has an absorption peak at 275 mμ. The DTNB method was developed from the procedure of Stevenson et al. (1960) in which GSH reacted with bis-(p-nitrophenyl) disulfide to form a stable yellow color that could be followed colorimetrically. A derivative (DTNB) of this compound provided a very accurate method of GSH determination which can be followed colorimetrically at 412 mμ. A drawback to the method is that it also measures ergothione. There are, however, only very small quantities of ergothione in erythrocytes.

Since the GSH of blood is contained in the erythrocytes (Hunter and Eagles, 1927b), measures of blood GSH should be accompanied by a determination of the packed cell volume. This permits the expression of GSH concentration in terms of blood cell volume.

Metabolism

The metabolic rates of animals can be determined by the utilization of either one or both of the principles of calorimetry, namely, direct and indirect calorimetry. Methods of direct calorimetry measure the actual heat production of an animal. The individual is confined in a closed chamber (the calorimeter) which has been engineered to measure the animal's heat production. The first calorimeter consisted of a chamber that contained a known amount of ice. Heat production was thusly estimated from the amount of melted ice (Lavoisier and Laplace, 1780). The same workers determined the heat production by measuring the increased temperature of a volume of water inside the calorimeter.

The modern direct calorimeter is the water calorimeter. It is a well insulated box, lined inside with copper and outside with zinc. Resistance thermometers connect the linings to keep the outside temperature the same as the inside and thus avoid the loss of heat from the calorimeter. Water flowing through pipes inside the chamber is warmed by the animal's heat production, and the increase in temperature of the output water over the input measures the heat production. Water absorbers in the calorimeter determine the heat loss due to evaporization.

Indirect calorimetry is based on the fact that the caloric values of oxygen are known for given RQ's (respiratory quotients). Therefore, heat production can be determined from data on oxygen comsumption. Because this correlation exists oxygen comsumption values, without transformation to caloric values, give metabolic rates.

Indirect methods of calorimetry have been divised according to the size of the species to be measured. Spirometeric methods and gas analyzers have been used for large animals and man. Gravimetric methods have normally been used for smaller animals. Charkey and Thornton (1959) presented a method for small animals in which an individual was placed in a darkened chamber, which calmed diurnal species. The amount of oxygen used over a period of time was recorded.

The collection of data is less laborious and less expensive for indirect than for direct calorimetry. These reasons explain why most of the data on metabolic rates of animals have been obtained by indirect methods.

Metabolic Rates in Chickens

The metabolic rate of growing and adult chickens has been measured by several investigators. Metabolism per unit of surface area in White Leghorns was lower at hatching than for adults. They (Mitchell et al., 1927) observed further that there was a rise from hatching to a maximum point at 30 to 40 days of age, and then a decline to the adult level which was reached at 80 days of age. In Rhode Island Reds, however, the peak rate occurred at about 28 to 35 days of age (Kibler and Brody, 1944). This was consistent with the finding of Barott et al. (1938). They observed that oxygen consumption per unit weight was highest (1.20) at 28 days of age and had declined to 0.97 by day 56. Barott et al. also reported a diurnal variation in oxygen consumption with the maximum at 8:00 A.M. and the minimum at 8:00 P.M.

Oxygen consumption per unit weight of commercial broilers measured to 100 g of body weight increased to a peak at 60 g in one group and 70 g in another and remained constant through the test period (Beattie and Freeman, 1962). Allometric growth of a particular tissue was cited as a possible explanation for the increase. In a Rhode Island Red by a Light Sussex cross, oxygen consumption rose to 14 days and then held constant through 28 days (Freeman, 1963). The pattern of oxygen consumption in quail is similar but on a correspondingly diminished scale (Freeman, 1967). The maximal oxygen consumption values were at one week and then declined to adult levels.

Thus metabolic rates in chickens appear to be low at hatching, rise to peak values at 4 to 6 weeks and then decline to adult levels at 11 to 12 weeks. The same sequence is also evident in quail, but the maximal and minimal levels occur at earlier ages. There is evidence of a diurnal variation in oxygen consumption of chickens, with maximal values in the morning and minimal values in the evening.

EXPERIMENTAL

This dissertation consisted of two experiments that utilized the high weight line (HWL) and the low weight line (LWL) of chickens developed by Siegel (1962). These lines originated in 1957 from crosses of 7 inbred lines of White Plymouth Rocks developed at the Virginia Polytechnic Institute. Individual phenotypic selection in both sexes has been practiced in each line starting from the common base population. Inbreeding has been minimized by restriction of sib matings. Presently these lines are sufficiently divergent so that at 8 weeks of age HWL females weigh approximately 100 g more than LWL males. The purpose of the experiments conducted here was to study the metabolism of these lines at the intracellular and the organism levels. Experiment 1 was designed to compare blood reduced glutathione (GSH) levels of these lines. Experiment 2 was designed to measure the metabolic rates of the lines and to determine the effect of light environments on their growth and metabolic rates.

Experiment 1: Blood Glutathione

Stocks and Management

Blood GSH was determined for twelfth (S_{12}) generation male chicks from the high weight (HWL) and the low weight (LWL) lines developed by Siegel (1962). Two trials (1 and 2), separated by an interval of 2 weeks, were conducted in the spring of 1969. Chicks used in Trial 1 were reared on litter with feed and water provided *ad libitum*. Lines were intermingled. Chicks used in Trial 2 were maintained in wire-floor batteries with feed and water provided

ad libitum, and the lines were not intermingled. The same ration was fed in both trials, and the formulation (Siegel, 1962) was that used throughout all generations of selection.

Glutathione Determination

Twelve chickens from each line were assayed for blood GSH by the method of Beutler et al. (1963) at 1, 4, 7, 10, 13, 16, 19, 28, 56, 112, and 168 days of age. The assay method is a colorimetric procedure requiring an initial spectrophotometric standardization of known GSH concentrations. Reagents consist of a protein precipitating solution (a mixture of glacial metaphosphoric acid, sodium chloride and EDTA), a phosphate (Na_2HPO_4) solution and a DTNB [(5, 5' dithiobis-(2-nitrobenzoic acid)] solution in a phosphate buffer of pH 7.2.

The procedure involves hemolysing 0.2 ml of whole blood in 1.8 ml of distilled water. To the hemolysate 3 ml of the precipitating solution is added. After standing for 5 to 10 minutes, the mixture is filtered, and 2 ml of the filtrate is added to 4 ml of the phosphate solution. To this 0.5 ml of DTNB solution is added for the development of color. The blank consists of 4 ml of phosphate solution, 1 ml of diluted precipitating solution (3 parts to 2 parts of distilled water) and 0.5 ml of DTNB solution. Optical density readings are at 412 mμ. GSH concentrations were determined in duplicate for each sample of blood, and the mean was considered the actual value.

Blood was obtained by cardiac puncture. During the period when measurements were obtained every third day, at least one week elapsed before blood was taken a second time. Body weights in g and

duplicate packed cell volumes were obtained for each chick, each time blood was obtained for GSH. Cardiac blood was collected in oxalated microhematocrit tubes, spun for 3 minutes in a Drummond centrifuge, and percentage packed cell volume read on a Drummond reader. The mean of the 2 samples was considered the actual value for each bird.

Body weight, percentage packed cell volumes, mg GSH per 100 ml of whole blood and mg GSH per 100 ml of red blood cells were analyzed within trials using a completely randomized design. The statistical model was:

$$X_{ij} = \mu + L_i + e_{ij}$$

where:

$i = 1, 2$ lines

$j = 2, 2, \ldots r$ individuals per line.

Analyses were also made between trials within ages. The statistical model with main effects considered fixed was:

$$X_{ijk} = \mu + T_i + L_j + TL_{ij} + e_{ijk}$$

where:

$i = 1, 2$ trials

$j = 1, 2$ lines

$k = 1, 2, \ldots r$ individuals per line per trial.

Mg GSH per 100 ml of red blood cells was also analyzed between trials, among ages from 1 to 19 days of age. The statistical model with main effects considered fixed was:

$$X_{ijkl} = \mu + T_i + A_j + L_k + TA_{ij} + TL_{ijk} + AL_{jk} + e_{ijkl}$$

where:

i = 1, 2 trials

j = 1, 2 ...7 ages

k = 1, 2 lines

l = 1, 2 ...r individuals per line per trial per age.

Results and Discussion

Body Weight

There was a highly significant difference between lines for body weight at one day of age and at all ages thereafter (Table I). HWL chicks were heavier than LWL chicks in all comparisons and the difference between lines increased with age (Table II). Differences between lines for body weight were expected since there had been 12 generations of divergent selection for this trait. Differences between trials for body weight were inconsistent, being highly significant at 4, 7, 16, and 28 days of age and not significant at 1, 10, 13, 19, 56, 112, and 168 days (Table I). The trial x line interaction for body weight was significant at 4, 28, and 56 days of age, highly significant at 16 days of age, and not significant at the other ages. Although trial effects and trial x line interactions were present at some ages, they did not follow a consistent pattern. Possible reasons for the lack of consistency may have been somewhat different growth rates between the trials and sampling.

Table I. - Analyses of variance for body weight

Source of variation	DF	Ages (days) 1 MS	4 MS	7 MS	10 MS	13 MS	16 MS
Trials (T)	1	7	1027**	462**	<1	397	16,913**
Lines (L)	1	1190**	4332**	7375**	20,050**	41,890**	53,801**
T X L	1	6	169*	118	179	184	3519**
Error	44	5	33	60	78	226	245

Source of variation	DF	Ages (days) 19 MS	28 MS x 10^2	56 MS x 10^2	112 MS x 10^3	168 MS x 10^3
Trials (T)	1	54	83**	47	154	192
Lines (L)	1	203,972**	7998**	65,712**	33,275**	26,288**
T X L	1	1938	54*	391*	36	143
Error	44	636	11	69	55	71

*P $\leq$ .05

**P $\leq$ .01

Table II. - Means and standard deviations for body weight (g) by lines and ages

Ages (days)	Lines		Diff
	HWL	LWL	
1	42 ± 2	33 ± 2	9**
4	65 ± 8	45 ± 3	20**
7	76 ± 8	51 ± 7	25**
10	104 ± 10	63 ± 7	41**
13	141 ± 18	82 ± 12	59**
16	175 ± 19	108 ± 11	67**
19	265 ± 26	134 ± 24	131**
28	456 ± 34	191 ± 33	265**
56	1221 ± 87	481 ± 79	740**
112	2795 ± 262	1079 ± 201	1716**
168	3625 ± 246	2145 ± 285	1480**

**$P \leq .01$

Packed Cell Volume

Analyses of variance and means and standard deviations for packed cell volumes are presented by lines and ages in Tables III and IV, respectively. There was no significant difference between lines for packed cell volumes until 28 days of age. At this age and all ages thereafter percentage packed cell volumes were either significantly or highly significantly greater in the HWL than in the LWL. Differences between trials were significant at 4, 7, 10 and 168 days of age and highly significant at 13 and 56 days. The trial x line interaction was not significant at any age except at 19 days, and this was probably due to chance.

The results found here are consistent with those of Newell and Shaffner (1950), Washburn and Siegel (1963), Best (1966), and Gilbert (1969). Best (1966) observed higher than normal juvenile packed cell volumes during the early posthatching period. It will be noted in Table IV that the same pattern was observed in both of the lines studied in this dissertation. Gilbert (1969) noted a random variation in packed cell volumes up to sexual maturity in males, while Newell and Shaffner (1950) found the increase at later ages to be concomitant with the occurrence of sexual maturity. They found the rise was due to increased levels of androgen. Washburn (1962) found significant differences between the HWL and LWL in the S_3 generation, with packed cell volumes being greater in the HWL than in the LWL at 43, 106, and 140 days of age. He suggested the difference might be because HWL males attain sexual maturity at earlier ages than LWL males.

Table III. - Analyses of variance for packed cell volumes

Source of variation	DF	Ages (days) 1 MS	4 MS	7 MS	10 MS	13 MS	16 MS
Trials (T)	1	<1	17.3*	36.2*	45.6*	65.3**	<1
Lines (L)	1	<1	1.5	<1	<1	12.0	<1
T X L	1	6.1	1.3	17.2	4.2	5.1	4.1
Error	44	7.8	3.1	7.4	7.8	4.7	4.2

Source of variation	DF	Ages (days) 19 MS	28 MS	56 MS	112 MS	168 MS
Trials (T)	1	11.4	1.9	97.7**	<1	79.8*
Lines (L)	1	<1	23.9*	22.8*	148.7**	97.7*
T X L	1	27.9*	1.6	3.3	6.1	<1
Error	44	6.0	4.6	3.4	9.0	15.1

*$P \leq .05$

**$P \leq .01$

Table IV. - Means and standard deviations for percentage packed cell volumes by lines and ages

Ages (days)	Lines HWL	LWL	Diff
1	33.5 ± 3.5	33.0 ± 2.5	0.5
4	30.3 ± 1.4	30.7 ± 2.1	-0.4
7	26.8 ± 1.8	26.9 ± 2.5	-0.1
10	27.9 ± 2.8	27.9 ± 2.8	0.0
13	27.7 ± 2.1	26.7 ± 2.3	1.0
16	27.7 ± 1.9	27.7 ± 2.1	0.0
19	26.3 ± 2.6	26.5 ± 2.2	-0.2
28	27.9 ± 1.6	26.5 ± 2.6	1.4*
56	29.4 ± 1.6	28.1 ± 2.1	1.3*
112	31.3 ± 3.3	27.7 ± 2.7	3.6**
168	38.1 ± 3.2	35.3 ± 4.5	2.8*

*$P \leq .05$

**$P \leq .01$

Blood Glutathione

Mg GSH per 100 ml of Whole Blood: The line effect for GSH was highly significant at 1, 4, 13, 28, and 56 days of age. In 18 of 22 within age-trial comparisons the concentration of GSH was greater in the HWL than in the LWL. Trial effects for GSH were either significant or highly significant at most ages (1, 4, 7, 10, 13, 16, 19, and 56 days); whereas, the trial x line interaction was present only at 7 days of age (Table V). Due to heterogenous variances analyses were not made at 112 and 168 days of age.

MG GSH per 100 ml of Erythrocytes: Means and standard deviations for mg GSH per 100 ml of erythrocytes are presented in Table VIII. Differences between lines were significant at 1, 7, 13, and 19 days of age and highly significant at 4 days (Table VII and VIII). In all cases values were greater in the HWL than in the LWL. Trial effects were highly significant at 1, 10, 16 and 19 days. Significant trial x line interactions were present at 7, 10, and 19 days of age. Again, because of heterogenous variances the analyses were not made at 112 and 168 days of age.

An overall analysis of variance was made across trials and ages from 1 to 19 days of age (Table IX). Trial effects were not significant and GSH concentrations have been presented graphically (Figure 1) for each line during the first 19 days posthatching. GSH concentration per 100 ml of erythrocytes was greater in the HWL than in the LWL throughout, and the difference between lines was highly significant. Age effects were also highly significant, a

Table V. - Analyses of variance for blood GSH (mg GSH per 100 ml of whole blood)

Source of variation	DF	Ages (days) 1 MS	4 MS	7 MS	10 MS	13 MS	16 MS
Trials (T)	1	1620**	701**	777*	5916**	1407**	954**
Lines (L)	1	1429**	2468**	369	93	1069**	67
T X L	1	22	19	1260**	197	15	38
Error	44	163	95	165	174	73	97

Source of variation	DF	Ages (days) 19 MS	28 MS	56 MS
Trials (T)	1	1520**	31	1808**
Lines (L)	1	145	877**	921**
T X L	1	1086	9	156
Error	44	77	104	104

*P $\leq$ .05

**P $\leq$ .01

Table VI. - Means and standard deviations for blood GSH (mg per 100 ml of whole blood) by lines and ages

Ages (days)	Lines HWL	LWL	Diff
1	54.5 ± 14.8	43.7 ± 10.4	10.8**
4	86.6 ± 9.2	72.3 ± 10.2	14.3**
7	85.0 ± 10.2	79.5 ± 15.1	5.5
10	81.1 ± 14.7	78.3 ± 11.4	2.8
13	80.7 ± 7.5	71.3 ± 9.5	9.4**
16	79.7 ± 9.2	77.4 ± 10.5	2.3
19	63.6 ± 7.6	60.1 ± 9.8	3.5
28	73.7 ± 7.1	65.1 ± 12.6	8.6**
56	70.9 ± 10.3	59.9 ± 10.2	11.0**

*$P \leq .05$

**$P \leq .01$

Table VII. - Analyses of variance for blood GSH (mg GSH per 100 ml of erythrocytes)

Source of variation	DF	Ages (days) 1 MS	4 MS	7 MS	10 MS	13 MS	16 MS
Trials (T)	1	19,683**	2,494	1,250	42,186**	2,775	12,546**
Lines (L)	1	9,634*	31,212**	7,179*	1,092	6,143*	784
T X L	1	833	783	7,828*	6,143*	295	1,899
Error	44	1,355	1,251	1,245	1,264	1,496	1,123

Source of variation	DF	Ages (days) 19 MS	28 MS	56 MS
Trials (T)	1	33,655**	54	3,520
Lines (L)	1	3,906*	4,505	4,428
T X L	1	6,143*	462	4,465
Error	44	868	1,204	1,147

*P $\leq$ .05

**P $\leq$ .01

Table VIII. - Means and standard deviations for blood GSH (mg per 100 ml of erythrocytes) by lines and ages

Ages (days)	Lines		Diff
	HWL	LWL	
1	162 ± 38.4^{d}	133 ± 35.1^{d}	29*
4	287 ± 38.2^{b}	235 ± 32.2^{c}	52**
7	317 ± 33.3^{a}	292 ± 37.2^{a}	25*
10	289 ± 40.2^{b}	280 ± 30.2^{ab}	9
13	291 ± 26.4^{b}	269 ± 47.9^{b}	22*
16	288 ± 33.3^{b}	279 ± 33.7^{ab}	9
19	244 ± 27.9^{c}	226 ± 30.9^{bc}	18*
28	265 ± 29.7	246 ± 39.0	19
56	271 ± 36.1	252 ± 31.5	19

Any 2 means in a column having the same superscript are not significantly different

*$P \leq .05$

**$P \leq .01$

Table IX. - Analysis of variance for blood GSH (mg per 100 ml of erythrocytes)

Source of variation	DF	MS
Trials (T)	1	2,475
Ages (A)	6	132,773**
Linear	1	136,468**
Quadratic	1	542,959**
Cubic	1	62,452**
Quartic	1	43,758**
Quintic	1	9,165**
Sextic	1	1,839
T X A	6	18,686**
Lines (L)	1	45,036**
T X L	1	3,146
A X L	6	2,485*
T X A X L	6	3,463**
Error	308	1,125

*$P \leq .05$

**$P \leq .01$

Figure 1. GSH (mg) per 100 ml of erythrocytes, by lines and ages.

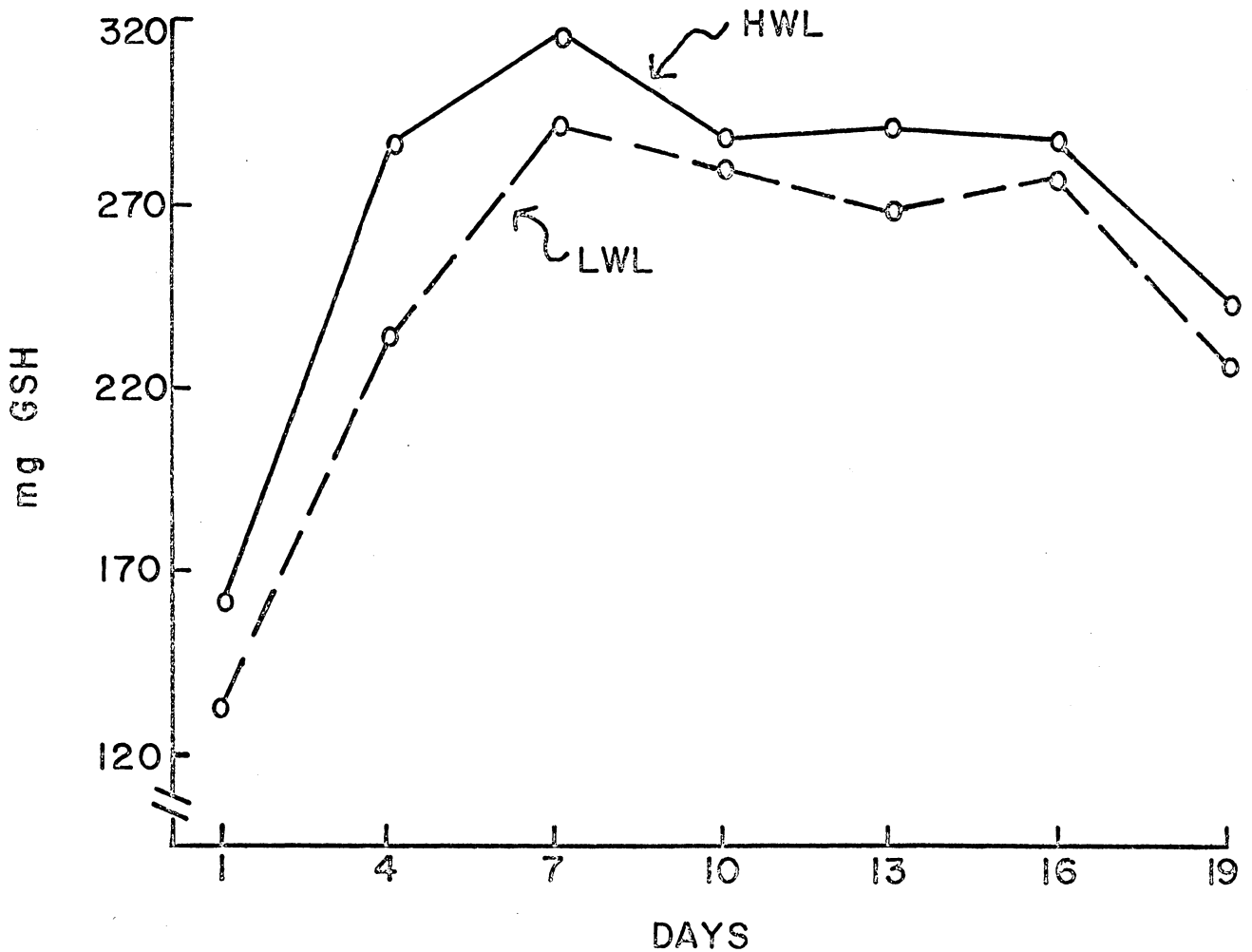

FIGURE 1

result consistent with that of Pflanz and Goodman (1970); and linear and higher order effects through quintic were highly significant. Although the graphic trends appear similar over time for both lines, the line x age interaction was significant, and thus age comparisons are discussed within each line.

During the first 19 days, the greatest concentration of GSH in the HWL was at 7 days of age (Table VIII). This value was different from those at the other ages. Means at 4, 10, 13, and 16 days of age, while not different from each other, were significantly greater than those at 1 and 19 days of age. The lowest concentration of GSH for the period studied was at one day of age a result consistent with that of Gregory et al. (1937). The pattern was similar in the LWL, and specific age comparisons are shown in Table VIII.

These results are in general agreement with those of Charkey et al. (1965). They found differences to 4 weeks of age in whole blood GSH between fast and slow growers in a White Leghorn population maintained on a basal diet. Pooling over 3 sampling periods, they noted an 11% difference in the mean blood GSH of fast and slow growers. The difference in body weight, however, disappeared by the fifth week suggesting that their data did not predict body weight differences at later ages. Pflanz and Goodman (1970) compared blood GSH levels in chickens from a White Leghorn line, a rapid-growth line, and a line selected for dressing percentage and found significant differences in whole blood GSH levels. The differences disappeared, however, when corrections were made for packed cell volumes.

The data summarized in Table VIII show that lines of chickens selected 12 generations for high and low 8-week body weight differ in blood levels of GSH. Chicks in the HWL have higher blood GSH concentrations than those in the LWL. The differences were due to actual differences in GSH per unit volume of erythrocytes and not a result of changes in the volume of erythrocytes. This was because corrections were made for packed cell volumes, thereby removing the erythrocyte number factor.

Divergent selection for body weight has caused a correlated response in blood GSH levels. Lepore et al. (1963) showed more efficient amino acid utilization by HWL embryos than by LWL embryos. Siegel and Wisman (1962) observed that HWL chicks were more efficient in protein and energy utilization than LWL chicks. The blood GSH results obtained in this dissertation suggest a positive correlated intracellular response to selection for body weight with greater blood GSH levels in the HWL than in the LWL. That GSH is the most abundant sulfhydryl compound in cells and since it appears to function in maintaining many enzymes in their active states (White et al., 1968), lines differing in GSH levels may also be expected to differ in enzyme activities. Consequently, the differences in enzyme activities could account, in part, for the HWL chicks being heavier than LWL chicks.

My findings suggest that early ages are best for observing differences in blood GSH levels of chickens differing in body weight. The most lucid differences between lines were during the first week posthatching. Data from this dissertation, plus that of Charkey et al.

(1965) and of Pflanz and Goodman (1970), suggest that age is an important factor in comparing blood GSH levels in fast and slow growing chickens. They are in contrast to those of Stutts et al. (1956) who found that age was not a factor in determining blood GSH levels in chickens. Their results, however, were obtained from mature chickens.

Experiment 2: Metabolic Rate

Procedures

Trial 1: Trial 1 was designed to measure genotype-environment interactions with genotypes being the HWL and the LWL and the environments being constant light and 8 hours of light and 16 hours of darkness per day. The chicks were from the S_{11} generation. Light was provided by a 25 watt incandescent bulb which yielded an intensity of 10.76 luxes when measured directly beneath it at a height of 91 cm above the litter. Both lines and both sexes were grown in each environment and there were replicate pens per line-sex-light environment combination.

Body weights and feed efficiency were measured at 14, 28, 42 and 56 days of age. The data were analyzed as a factorial arrangement of the randomized complete block design. The statistical model with replications considered random and treatment combinations considered fixed was:

$$X_{ijk} = R_i + T_j + RT_{ij} + e_{ijk}$$

where:

$i = 1, 2$ replications

j = 1, 2, 3, 4 treatment combinations

k = 1, 2, ...r individuals per replication per treatment combination.

The treatment combinations were broken down into a line effect, a light environment effect, and a line x light environment interaction.

Trial 2: Procedures for Trial 2 were the same as for Trial 1 with two exceptions. First, the chicks were from the S_{12} generation, and second they were not begun on light treatments immediately. A light intensity of 43.04 luxes was used for the first 48 hours to facilitate early feeding and drinking, and a heat lamp was placed in each pen until day 9 for supplemental heat. The assumption was made that the additional light during this period would not influence the treatments at later ages.

The traits measured were the same as those in Trial 1 except for the addition of measurements of oxygen consumption at 28 and 56 days of age. Oxygen consumptions were measured during the day (8:00 A.M. to 6:00 P.M.) on 8 males/replication/ treatment combination and during the evening (6:00 P.M. to 11:00 P.M.) on a 4 males/ replication/treatment combination. The chicks were fasted 12 hours before measurement.

The apparatus for the measurement of oxygen consumption was based on that designed by Charkey and Thornton (1959). The apparatus consisted of 2 large dessicators, as the animal chambers (A and B), 2 syringes for measuring the oxygen volume and an oxygen supply. The dessicators were painted black since the chicken is a diurnal species.

Each chamber was fitted with a rubber stopper, and each stopper was fitted with a centigrade thermometer, and S-shaped water manometer, oxygen inlets to chamber and syringe and back to chamber and an outlet to the atmosphere. Each chamber contained a wire platform for the chickens to stand on, and beneath the platform was placed a petri dish (9.5 cm in diameter) containing 30 ml of 20% KOH to absorb CO_2. The KOH was changed and droppings were removed after measurements were made for 2 chickens.

When placed in a chamber, the bird was allowed 5 to 10 minutes to become accustomed to the chamber. Saturated oxygen was passed through the system with the outlet to the atmosphere open. After this period, the outlet was closed and oxygen was allowed to collect in the chamber and in the syringe. Then the syringe plunger was drawn past the 100 ml mark and the oxygen was shut off. The chicken was then allowed to use the oxygen until the plunger was pushed to the 100 ml mark and the chamber pressure was at equilibrium with the atmospheric pressure, as noted by the water manometer. Five to ten minutes were required to reach equilibirum. At this point timing was begun, and the bird was given oxygen at its rate of use as recorded by the manometer. The time to use 100 ml was recorded. The temperature inside the chamber was read at the beginning and end of each run and the barometric pressure was recorded in the morning and afternoon of each day to facilitate transformation of oxygen consumption to standard conditions. Oxygen consumption was related to unit body weight and to unit surface area according to Leighton et al., 1966.

Trial 3: Trial 3 was designed to compare oxygen consumption of the HWL and LWL birds from the S_{13} generation. Males from each line were reared in 4 separate pens. Illumination was continuous at an intensity of 43.04 luxes. Heat lamps were in the pens from day 1 to day 14. Other management was as described earlier.

Oxygen consumption was measured during the evening at 28, 42, and 56 days of age. Body weights were obtained for the birds whose oxygen consumption was measured. The statistical model with lines considered fixed was:

$$X_{ij} = \mu + L_i + e_{ij}$$

where:

$i = 1, 2$ lines

$j = 1, 2 \ldots r$ individuals per line.

Results and Discussion

Body Weight

Lines: Differences between lines, with HWL birds being heavier than LWL birds, were highly significant in all comparisons (Tables X, XI, and XII). The difference between lines increased with age (Table XII) and was consistent with that found in Experiment 1. The results obtained were expected because the lines had undergone 11 and 12 generations of selection for juvenile body weight prior to Trials 1 and 2, respectivley.

Light Environments: There was a highly significant difference in body weights between light treatments for males and females of both trials at 14, 28, 42, and 56 days of age (Tables X and XI). In all

Table X. - Analyses of variance for body weight of males by trials

Source of variation	DF	Trial 1 Age (days) 14 MS	28 MS x 10^2	42 MS x 10^3	DF	56 MS x 10^3
Between replications (R)	1	75	4	1	1	<1
Among treatment combinations (TC)	3	19,258**	2,056**	752**	3	2,033**
Within TC						
Lines (L)	1	39,799**	5,209**	2,058**	1	5,905**
Light environments (A)	1	17,126**	955**	187**	1	183**
LA	1	848*	4	9	1	12
R X TC	3	69	3	<1	3	4
Error	100	192	16	6	92	12

Source of variation	DF	Trial 2 Age (days) 14 MS	28 MS x 10^2	42 MS x 10^3	56 MS x 10^3
Between replications (R)	1	3,310	50	10	31
Among treatment combinations (TC)	3	16,751*	1,945**	960**	2,867**
Within TC					
Lines (L)	1	30,767**	4,942**	2,537**	8,317**
Light environments (A)	1	17,159**	752**	282**	242**
LA	1	2,328**	141**	62**	43*
R X TC	3	751**	28*	14**	37**
Error	124	147	9	3	8

*P $\leq$ .05

**P $\leq$ .01

Table XI. - Analyses of variance for body weight of females by trials

Trial 1

Source of variation	DF	Age (days) 14 MS	28 MS x 10^2	42 MS x 10^3	56 MS x 10^3
Between replications (R)	1	28	<1	3	<1
Among treatment combinations (TC)	3	13,747**	1,433**	457**	1,007**
Within TC					
Lines (L)	1	18,782**	3,213**	1,190**	2,846**
Light environments (A)	1	20,996**	1,038**	174**	146**
LA	1	1,463**	49*	5	28
R X TC	3	183	44**	10	3
Error	92	161	12	5	9

Trial 2

Source of variation	DF	Age (days) 14 MS	23 MS x 10^2	DF	42 MS x 10^3	56 MS x 10^3
Between replications (R)	1	4,032	117	1	22	71
Among treatment combinations (TC)	3	14,171*	1,865**	3	2,264**	2,020**
Within TC						
Lines (L)	1	35,467**	5,097**	1	2,2154**	6,023**
Light environments (A)	1	6,507**	452**	1	97**	33**
LA	1	539	45**	1	13**	4
R X TC	3	719**	25**	3	96**	27**
Error	136	139	5	131	2	4

*P $\leq$ .05

**P $\leq$ .01

Table XII. - Mean[1] body weight (g) and standard deviations by trials, sexes, ages, lines, and light environments (hrs/day)

Trials	Sexes	Ages (days)	Lines HWL	Lines LWL	Diff	Light environments (hrs light) 8	Light environments (hrs light) 24	Diff
1	M	14	96 ± 20	56 ± 9	40**	56 ± 13	82 ± 14	-26**
		28	289 ± 57	142 ± 28	147**	162 ± 38	221 ± 41	-59**
		42	575 ± 113	282 ± 52	293**	338 ± 75	421 ± 80	-83**
		56	976 ± 137	480 ± 85	496**	636 ± 99	721 ± 118	-85**
	F	14	87 ± 16	59 ± 10	28**	56 ± 12	85 ± 13	-29**
		28	261 ± 40	145 ± 29	116**	159 ± 37	223 ± 30	-64**
		42	496 ± 80	272 ± 58	224**	320 ± 71	404 ± 64	-84**
		56	801 ± 103	457 ± 88	344**	557 ± 108	633 ± 78	-76**
2	M	14	113 ± 14	80 ± 11	33**	80 ± 12	103 ± 12	-23**
		28	311 ± 37	181 ± 25	130**	200 ± 30	248 ± 29	-48**
		42	638 ± 67	343 ± 50	295**	395 ± 60	488 ± 52	-93**
		56	1085 ± 104	553 ± 80	532**	688 ± 90	773 ± 86	-85**
	F	14	108 ± 15	75 ± 10	33**	79 ± 12	93 ± 12	-14**
		28	287 ± 28	160 ± 19	127**	185 ± 24	220 ± 22	-35**
		42	562 ± 51	292 ± 39	270**	355 ± 43	409 ± 44	-54**
		56	912 ± 85	459 ± 55	453**	594 ± 54	626 ± 76	-32**

[1]Weighted means

*P $\leq$ .05

**P $\leq$ .01

comparisons the chicks that were reared in continuous illumination were heavier than those maintained under 8 hours of light and 16 hours of darkness (Table XII). The primary influence appears to be prior to 42 days of age, since the difference between light environments usually was greatest at this age. Heavier juvenile body weights were also found in meat-type chickens maintained under continuous illumination than under various photoperiods by Moore (1957), Beane, et al. (1962), Krueger, et al. (1962), and Weaver and Siegel (1968). A contrasting response, in which chicks maintained under restricted illumination were heavier than those under continuous illumination was found in White Leghorns (Siegel et al., 1961). The different response of Leghorns and meat-type chickens to continuous light and various photoperiods may be a result of stock x light regime interactions. This will be discussed in the next section of this dissertation.

Weaver and Siegel (1968) showed that chicks reared under continuous light developed a different feeding rhythm from that observed under varying photoperiods. They and Beane et al. (1965) hypothesized that under continuous illumination meat-type chickens did not go for long periods without feeding. Such an environment would facilitate maximization of their growth potential.

Interaction (Line x Light Environment): Line x light environment interactions while significant for males of Trial 1 only at 14 days of age, were highly significant for males at all ages in Trial 2 (Tables X and XI). For females, this interaction was highly significant at 14 days of age and significant at 28 days of age in Trial 1,

and highly significant at 28 and 42 days of age in Trial 2. The interactions presented graphically in Figures 2 and 3 show that although both lines were heavier under 24 hours of light than under 8 hours of light, the increase in weight was greater for the HWL than for the LWL. Since the LWL chickens are comparable in weight to Leghorn chickens, this may explain why Siegel et al. (1961) did not observe heavier weight of Leghorns maintained under continuous illumination.

The consistency of the line x light environment interaction varied with ages. It was present in 3 of 4 comparisons at 14 days and only 1 of 4 comparisons at 56 days of age. This suggests that line x light environment interactions may be of more importance at younger than at older ages. This conclusion is in agreement with Beane et al. (1962 and 1965) and Weaver and Siegel (1968) who found no stock light environment interactions for body weight at 56 days of age.

Feed Efficiency

Lines: Degrees of freedom in the analyses of variance (Tables XIII and XIV) for feed efficiency were small because data were obtained on a pen basis. Feed efficiency of the HWL was equal to or superior to that of the LWL in all 20 comparisons (Table XV). The differences between lines were either significant or highly significant in 14 of these comparisons. Further, for the cumulative 0 to 56 day period the line effect was either significant or highly significant for both males and females in both trials.

Figure 2. Body weight (g) of HWL (_____) and LWL (-----) males maintained under continuous light and 8 hours of light per day, by ages and trials. The notations NS, *, and ** mean non-significant, significant at P $\leq$ .05, and significant at P $\leq$ .01, respectively.

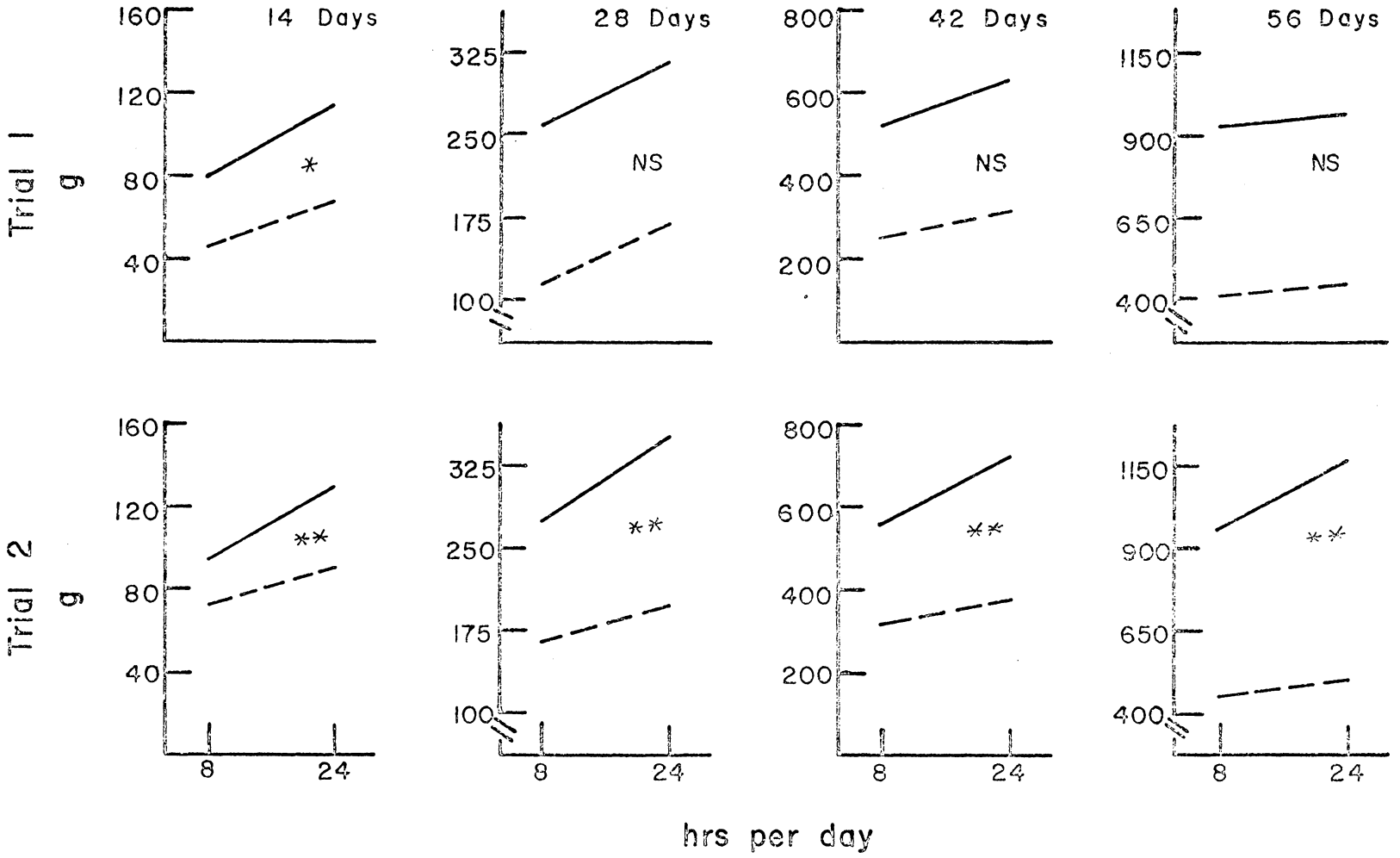

Figure 2

Figure 3. Body weight (g) of HWL (_____) and LWL (-----) females maintained under continuous light and 8 hours of light per day, by ages and trials. The notations, NS, *, and ** mean non-significant, significant at P ≤ .05, and significant at P ≤ .01, respectively.

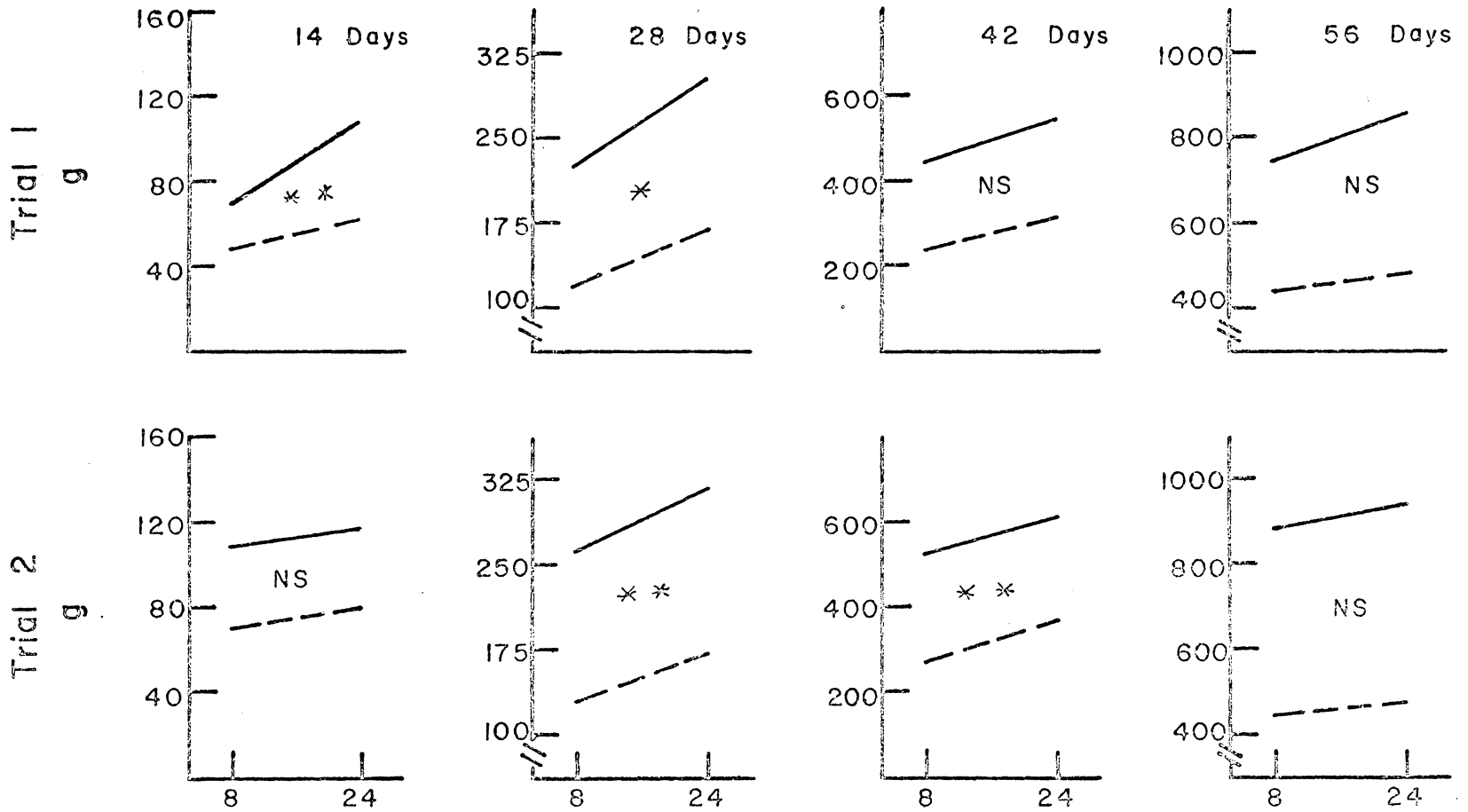

Figure 3

Table XIII. - Analyses of variance[1] for feed efficiency of males by trials

Source of variation	DF	Trial 1 Periods (days) 0-14 MS	14-28 MS	28-42 MS	42-56 MS	0-56 MS
Between replications (R)	1	.2	4.0*	15.3*	1.3	2.8
Lines (L)	1	26.4**	88.2**	10.5	9.8**	30.0**
Light environments (A)	1	28.8**	9.8**	<.1	2.4	4.5*
LA	1	.8	3.2*	.3	11.2**	4.5*
Error	3	2.1	.6	3.2	.9	.9

Source of variation	DF	Trial 2 Periods (days) 0-14 MS	14-28 MS	28-42 MS	42-56 MS	0-56 MS
Between replications (R)	1	18.1*	2.8	5.5	.3	.2
Lines (L)	1	11.3	70.3**	5.5	<.1	14.4*
Light environments (A)	1	5.0	7.8*	2.8	6.6	.2
LA	1	1.2	.2	1.6	7.9	.8
Error	3	2.7	1.5	3.9	8.4	2.4

[1]All MS are 10^{-3}

*$P \leq .05$
**$P \leq .01$

Table XIV. - Analyses of variance[1] for feed efficiency of females by trials

Trial 1

Source of variation	DF	Periods (days) 0-14 MS	14-28 MS	28-42 MS	42-56 MS	0-56 MS
Between replications (R)	1	<.1	2.8	11.2	<.1	1.5
Lines (L)	1	23.1	117.6**	42.0**	17.1*	40.6**
Light environments (A)	1	52.8**	17.1*	22.0*	.6	6.6
LA	1	.1	1.5	<.1	.3	.6
Error	3	5.7	6.4	3.4	3.1	3.5

Trial 2

Source of variation	DF	Periods (days) 0-14 MS	14-28 MS	28-42 MS	42-56 MS	0-56 MS
Between replications	1	2.4	.6	2.1	.1	<.1
Lines (L)	1	20.0	66.6**	17.1**	8.4	20.0**
Light environments (A)	1	18.0	1.5	6.6*	<.1	3.2**
LA	1	.4	4.6	.4	6.1	2.4**
Error	3	2.6	3.7	1.2	4.4	<.1

[1]All MS are 10^{-3}

*P $\leq$ .05

**P $\leq$ .01

Table XV. - Mean feed efficiency (g live weight gained/g feed consumed) by trials, sexes, periods, lines, and light environments (hrs/day)

Trials	Sexes	Periods (days)	Lines			Light environments		
			HWL	LWL	Diff	8	24	Diff
1	M	0-14	.25	.14	.11**	.14	.26	-.12**
		14-28	.41	.20	.21**	.27	.34	-.07**
		28-42	.34	.26	.08	.30	.31	-.01
		42-56	.37	.31	.06**	.32	.36	-.04
		0-56	.36	.24	.12**	.28	.33	-.05*
	F	0-14	.29	.18	.11	.16	.32	-.16**
		14-28	.46	.21	.25**	.28	.38	-.10
		28-42	.38	.23	.15**	.24	.36	-.12*
		42-56	.34	.25	.09*	.30	.28	.02
		0-56	.33	.26	.07**	.26	.32	-.06
2	M	0-14	.37	.30	.07	.30	.36	-.06
		14-28	.42	.24	.18**	.30	.36	-.06*
		28-42	.42	.36	.06	.36	.41	-.05
		42-56	.41	.41	.00	.44	.38	.06
		0-56	.42	.33	.09*	.36	.38	-.02
	F	0-14	.39	.30	.09*	.30	.39	-.09*
		14-28	.43	.27	.16**	.33	.38	-.05
		28-42	.39	.30	.09**	.32	.37	-.05*
		42-56	.39	.32	.07	.35	.36	-.01
		0-56	.40	.30	.10**	.33	.36	-.03**

*P $\leq$ .05

**P $\leq$ .01

These results for feed efficiency, while in agreement with those obtained for S_5 generation HWL and LWL chicks by Siegel and Wisman (1966), go a step further. They had to use a paired feeding design to demonstrate the superior efficiency of feed utilization by HWL chicks in comparison to LWL chicks. This was because the correlated response of appetite resulted in over eating by the HWL chicks when feed was provided ad libitum. This over eating masked feed efficiency differences between lines. Since S_{11} and S_{12} generation chicks were used in this dissertation, apparently the correlated response in feed utilization through these additional generations of selection has caused line differences that are so large that they are no longer masked by the correlated responses in appetite. The data further suggest that the genetic relationship between growth and feed utilization is primarily due to pleiotropy and not the transient effects of linkage.

Light Environments: Feed efficiencies of chicks reared under continuous light were superior to those reared under restricted light in all but 2 comparisons (Table XV). Differences between light environments were either significant or highly significant in 9 of these 20 comparisons, The continuous light may have caused the establishment of a stable feeding rhythm which did not result in over feeding during any part of the day. Contrastingly, the chicks reared under restricted light may have over fed during the light period and had a correspondingly greater digestive feed wastage. These results showing superior feed efficiency under continuous light are not in

agreement with those of other investigators who found that continuous illumination resulted in either poorer or no change in feed efficiency (Moore, 1957, Beane et al., 1962 and 1965, Weaver and Siegel, 1968). No explanation for these discrepancies is offered other than that the degrees of freedom were small in all of these experiments because feed efficiency data were obtained on a pen basis.

Interaction (Line x Light Environment): There was no consistent pattern of line x light environment interactions for feed efficiency (Table XIII and XIV). None was significant for Trial 1 females or for Trial 2 males, whereas 3 were significant for Trial 1 males and 1 was for Trial 2 females. The lack of a general pattern suggests that the feed efficiencies were similar for both lines in the 2 light environments.

Oxygen Consumption

Oxygen consumption was not measured in Trial 1. Analyses of variance and means and standard deviations for oxygen consumption in Trial 2 are presented by ages, light environments, lines, and time of day. Analyses of daytime readings were within chambers since there was a significant chamber effect. This was not necessary for evening readings. Data are presented for oxygen consumption as ml O_2/g/hr and ml O_2/cm^2/hr.

Lines: Oxygen consumption for daytime readings was greater for LWL birds than for HWL birds at 28 and 56 days of age (Table XVII). Differences between lines at 28 days of age were highly significant when oxygen consumption was expressed on a weight basis and significant

Table XVI. - Analyses of variance for oxygen consumption measured between 8:00 A.M. and 6:00 P.M., Trial 2

Per unit body weight					
		Age (days)			
Source of variation	DF	28 MS x 10^{-3}-A	28 MS x 10^{-3}-B	56 MS x 10^{-3}-A	56 MS x 10^{-3}-B
Between replications (R)	1	2832	298	34*	36
Among treatment combinations (TC)	3	1731	7156	126**	119
Within TC					
Lines (L)	1	5009**	9148**	346**	83*
Light environments (A)	1	82	11,993**	10	272**
LA	1	104	326	22	1
R X TC	3	669	1731	1	44
Error	31	311	986	15	17

Per unit surface area					
		Age (days)			
Source of variation	DF	28 MS x 10^{-3}-A	28 MS x 10^{-3}-B	56 MS x 10^{-3}-A	56 MS x 10^{-3}-B
Between replications (R)	1	1328	11	27*	31
Among treatment combinations (TC)	3	453	3468	65**	89
Within TC					
Lines (L)	1	1066*	2714*	167**	2
Light environments (A)	1	242	7605**	5	265**
LA	1	270	84	24	<1
R X TC	3	247	599	2	49
Error	31	191	568	16	18

*$P \leq .05$

**$P \leq .01$

Table XVII. - Means and standard deviations for Trial 2 oxygen consumption[1] by ages, chambers, lines, and light environments (hrs/day)

Units	Ages (days)	Chambers	Lines			Light environments		
			HWL	LWL	Diff	8	24	Diff
ml/g/hr	28	A	1.43 ± .38	2.22 ± .66	-.79**	1.87 ± .52	1.77 ± .56	.10
		B	2.07 ± .74	3.14 ± 1.13	-1.07**	3.22 ± 1.22	1.99 ± .57	1.23**
	56	A	.57 ± .11	.78 ± .13	-.21**	.69 ± .13	.66 ± .11	.03
		B	.70 ± .14	.80 ± .11	-.10*	.84 ± .14	.66 ± .11	.18*
$ml/cm^2/hr$	28	A	1.31 ± .34	1.67 ± .49	-.36*	1.46 ± .37	1.52 ± .46	-.06
		B	1.86 ± .67	2.44 ± .77	-.58*	2.63 ± .88	1.66 ± .53	.97**
	56	A	.62 ± .12	.76 ± .12	-.14**	.70 ± .13	.68 ± .11	.02
		B	.77 ± .15	.78 ± .10	-.01	.88 ± .15	.69 ± .11	.19**

[1]Oxygen consumption measured between 8:00 A.M. and 6:00 P.M.

*$P \leq .05$

**$P \leq .01$

when expressed on a surface area basis (Table XVI and XVII). At 56 days of age the difference between lines for oxygen consumption on a weight basis was highly significant for chamber A and significant for chamber B, while on a surface area basis the difference was highly significant for chamber A and not significant for chamber B.

Analyses of variance and means and standard deviations for oxygen consumption measured between 6:00 P.M. and 11:00 P.M. are presented in Tables XVIII and XIX. As with daytime reading, the LWL chicks had a greater oxygen consumption than HWL chicks. Differences between lines, while highly significant at 56 days of age when related to both body weight and surface area, were not significant at 28 days of age. Evening readings, in comparison with the day readings, were lower, reflecting the diurnal rhythm in oxygen consumption observed by Barott et al. (1938).

These results are not consistent with those of Ross et al. (1954) who observed no differences in metabolic rates ($ml/cm^2/hr$) of fast and slow growing White Rock chicks. They are also not consistent with results of Washburn and Siegel (1963) who, in the S_3 generation found no difference between these lines in oxygen consumption at 68 days of age. It should be remembered that the number of generations of selection between their study and mine has increased four-fold. The data from this experiment show that continuous bi-directional selection for body weight has yielded a concomitant correlated response in metabolic rates as measured by oxygen consumption, because oxygen consumption was greater for LWL than for HWL males both on a surface area and on a body weight basis.

Table XVIII. - Analyses of variance[1] for oxygen consumption measured between 6:00 P.M. and 11:00 P.M., Trial 2

Per unit body weight			
		Age (days)	
Source of variation	DF	28 MS	56 MS
Between replications (R)	1	50.4	2.7
Among treatment combinations (TC)	3	106.3	135.2*
Within TC			
Lines (L)	1	106.9	334.2**
Light environments (A)	1	67.5	44.3
LA	1	144.5	27.0
R X TC	3	53.4	4.8
Error	31	72.3	13.0

Per unit surface area			
		Age (days)	
Source of variation	DF	28 MS	56 MS
Between replications (R)	1	32.5	3.0
Among treatment combinations (TC)	3	18.3	98.7
Within TC			
Lines (L)	1	4.5	209.6**
Light environments (A)	1	37.8	56.9*
LA	1	125.0	29.5
R X TC	3	82.9	4.5
Error	31	62.0	13.1

[1]All MS are 10^{-3}

*$P \leq .05$

**$P \leq .01$

Table XIX. - Means and standard deviations for Trial 2 oxygen consumption[1] by ages, lines, and light environments (hrs/day)

Units	Ages (days)	Lines			Light environments		
		HWL	LWL	Diff	8	24	Diff
ml/g/hr	28	.98 ± .34	1.10 ± .13	-.12	1.09 ± .32	1.00 ± .18	.09
	56	.54 ± .08	.74 ± .13	-.20**	.60 ± .09	.68 ± .12	-.08
$ml/cm^2/hr$	28	.92 ± .32	.94 ± .11	-.02	.96 ± .30	.90 ± .16	.06
	56	.58 ± .09	.74 ± .13	-.16**	.62 ± .09	.70 ± .13	-.08*

[1]Oxygen consumption measured between 6:00 P.M. and 11:00 P.M.

*$P \leq .05$

**$P \leq .01$

Light Environments: Oxygen consumption during daytime readings was greater for birds reared under 8 hours of light than for those maintained under continuous illumination in all comparisons except one (Table XVII). These differences between light environments, on both a body weight and a surface area basis, were highly significant for measurements made in chamber B, but not in chamber A (Table XVI). The consistent light environment pattern for oxygen consumption may reflect the rhythm placed on the chicks reared in the 8-hour light regime. In this regime light was provided during the day. Since oxygen consumption was measured during this period, the chicken's peak activity would also be expected to occur during this time, thereby resulting in a greater metabolic rate. An evaluation of this hypothesis may be obtained from readings that were obtained in the evening.

It can be seen in Tables XVIII and XIX that the pattern of oxygen consumption in the light environments as measured during the evening was not the same as that obtained during the day. This is because for evening readings there were no significant differences in oxygen consumption between light environments with the exception of that measured on a surface area basis at 56 days of age. Here birds under continuous light had a significantly greater oxygen consumption than those under 8 hours of light. If birds in restricted light are more active in the day (when they have light), they might be expected to have lower metabolic rates in the evening.

Interaction (Line x Light Environment): None of the interactions of line x light environment for oxygen consumption were significant (Table XVI and XVIII). This shows that the response of both lines was similar in the two light environments.

Trial 3

This trial was an effort to obtain additional data on the oxygen consumption of male chicks from these lines at 28, 42, and 56 days of age. Chicks from the S_{13} generation and all readings were from a single chamber. Oxygen consumption was greater in the HWL in all comparisons and differences were significant in all but one case (Table XX and XXI). Thus, this trial provides additional evidence of the line effect on oxygen consumption, and is consistent with that found in Trial 2.

It is evident that divergent selection for body weight at 8 weeks of age has caused changes in the metabolism of these lines. This was true for both feed efficiency and oxygen consumption. Individuals in the HWL are more efficient in the utilization of feed than LWL indivduals. These concomitant responses are not the transient effects that might be ascribed to linkage, but rather are from the long term effects of pleiotropy. Subtle changes observed as early as the S_3 generation have become more pronounced with selection. The lines had a parallel response in feed efficiency to the imposed light regimes, with better feed efficiency in continuous light than under a regime of 8 hours of light and 16 hours of darkness.

Table XX. - Analyses of variance[1] for Trial 3 oxygen consumption

Source of variation	DF	ml/g/hr Age (days) 28 MS	42 MS	56 MS	ml/cm^2/hr Age (days) 28 MS	42 MS	56 MS
Between lines	1	1528.0**	308.7**	70.0*	53.5**	77.2*	5.2
Within lines	26	15.7	14.1	10.2	9.7	10.8	10.7

[1]All MS are 10^{-}

*P $\leq$ .05

**P $\leq$ .01

Table XXI. - Means and standard deviations for Trial 3 oxygen consumption[1] by lines and ages

Age (days)	ml/g/hr			ml/cm^2/hr		
	HWL	LWL	Diff	HWL	LWL	Diff
28	.81 ± .10	1.28 ± .14	-.47**	.78 ± .09	1.06 ± .11	-.28**
42	.55 ± .08	.76 ± .15	-.21**	.57 ± .08	.68 ± .12	-.11*
56	.55 ± .10	.65 ± .10	-.10*	.60 ± .11	.63 ± .10	-.03

[1]Oxygen consumption measured between 6:00 P.M. and 11:00 P.M.

*$P \leq .05$

**$P \leq .01$

Metabolic rates were greater in the LWL than in the HWL for day and evening measurements. Selection has been effective in separating the lines to the extent that their metabolic rates diverge as species of smaller size diverge from those of larger size. Chicks maintained in restricted light had greater oxygen consumption when measured during the day. This paralleled the rhythm imposed on them by having the photoperiod during the day. Evening measurements were lower than those obtained during the day, corresponding to the diurnal rhythm of oxygen consumption. Light environments were not important in altering evening metabolic rates.

It was shown in Experiment 1 that HWL chicks had higher concentrations of blood GSH than LWL chicks, and in this experiment HWL chicks had superior feed efficiencies and slower metabolic rates than LWL chicks. These results indicate that there is a measureable (GSH) intracellular difference between the lines and that the end product (feed efficiency) of intracellular metabolism is also different between the lines. These results, combined with the lower rate of oxygen consumption of the HWL chicks as compared to LWL ones, indicate intracellular metabolic differences between these lines selected in opposite directions for growth. The data suggests that intracellular processes are more efficient in the HWL than in the LWL. It may be hypothesized that maintenance for the HWL is less than that for the LWL, thus there are more metabolites released for growth. Support for this hypothesis is that the maintenance or basal metabolism of the LWL was found to be greater than that of the HWL.

SUMMARY AND CONCLUSIONS

This dissertation consisted of two experiments that utilized the high weight line (HWL) and the low weight line (LWL) of chickens developed by Siegel (1962). Experiment 1 was designed to compare blood reduced glutathione (GSH) levels of these lines. Experiment 2 was designed to measure the metabolic rates of the lines and to determine the effect of light environments on their growth and metabolic rates.

Male chicks from the eleventh (S_{11}) generation were utilized in Experiment 1. Two trials were conducted, and chicks were maintained in either floor litter pens or in wire cage brooding batteries. Blood GSH was determined at 1, 4, 7, 10, 13, 16, 19, 28, 56, 112, and 168 days of age. Body weights and percentage packed cell volumes were also measured at each of these ages.

At all ages, the HWL chicks were heavier than LWL chicks. Blood GSH, expressed as mg/100 ml of whole blood and as mg/100 ml of erythrocytes, was consistently greater in the HWL than in the LWL. Differences between lines were greatest at the younger ages. Differences between lines for percentage packed cell volumes were not significant prior to 28 days of age, when the values became greater for the HWL than for the LWL.

Experiment 2 consisted of 3 trials. Chicks, in all trials, were sexed at hatching and reared on litter with food and water provided *ad libitum*. In Trial 1, males and females of each line were reared

in either continuous light or 8 hours of light and 16 hours of darkness per 24 hour cycle. Body weights and feed consumptions were measured at 14, 28, 42, and 56 days of age. Trial 2 was similar to Trial 1 except that oxygen consumption was measured at 28 and 56 days of age from random samples of males from both lines maintained under the 2 light environments.

Body weights were significantly higher and feed efficiencies were significantly superior in the HWL than in the LWL. Metabolic rate, as measured by oxygen consumption, was significantly higher for LWL chicks than for HWL chicks. A diurnal effect for oxygen consumption was observed for day and evening readings, with the former measurements exceeding those obtained during the evening. Chicks maintained in continuous light were heavier and had superior feed efficiencies than those maintained under an 8 hour photoperiod. The growth stimulus to continuous illumination was greater for the HWL than for the LWL. Increased oxygen consumptions for the day measurements were observed for chicks maintained in the 8 hour regime. This corresponded to their photoperiod.

Trial 3 was conducted to obtain additional information on the oxygen consumption of the 2 selected lines. Oxygen consumption was determined for S_{13} generation male chicks from both lines at 28, 42, and 56 days of age. Again, at all ages, values for the LWL were significantly greater than those for the HWL.

The primary conclusions from these experiments are that divergent selection for high and low body weight results in correlated responses

of blood GSH, feed utilization, and metabolic rates. Chicks in the HWL had higher blood GSH, superior feed utilization, and lower metabolic rates than those from the LWL. Further, although different light environments may result in varying responses in feed utilization and metabolic rates, line x light environment interactions were not important for traits other than body weight.

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APPENDIX A

The presentation of data from Experiment 1 by lines, ages, and trials

Table A-I. - Means and standard deviations for body weight (g) by lines and ages

Ages (days)	Trials 1 HWL	Trials 1 LWL	Trials 2 HWL	Trials 2 LWL
1	42 ± 2	32 ± 1	42 ± 2	33 ± 3
4	48 ± 6	42 ± 3	71 ± 9	48 ± 3
7	81 ± 8	53 ± 5	71 ± 8	50 ± 8
10	102 ± 13	65 ± 6	106 ± 6	61 ± 8
13	146 ± 18	83 ± 13	136 ± 17	81 ± 11
16	202 ± 23	118 ± 13	148 ± 15	98 ± 7
19	272 ± 34	129 ± 23	257 ± 15	139 ± 25
28	446 ± 46	167 ± 26	451 ± 33	214 ± 38
56	1259 ± 86	426 ± 77	1182 ± 88	500 ± 81
112	2710 ± 254	1100 ± 244	2879 ± 269	1158 ± 147
168	3726 ± 183	2169 ± 165	3523 ± 295	2120 ± 368

Table A-II. - Means and standard deviations for packed cell volumes (%) by lines and ages

	Trials			
	1		2	
Ages (days)	HWL	LWL	HWL	LWL
1	33.8 ± 3.1	33.9 ± 2.1	33.1 ± 3.8	32.1 ± 2.9
4	31.1 ± 1.3	31.1 ± 2.2	29.5 ± 1.5	30.2 ± 1.9
7	27.1 ± 1.9	28.4 ± 2.2	26.6 ± 1.5	25.5 ± 2.7
10	29.1 ± 2.9	28.5 ± 2.6	26.6 ± 2.6	27.2 ± 3.0
13	29.2 ± 2.0	27.6 ± 2.5	26.2 ± 2.2	25.9 ± 2.0
16	28.0 ± 1.2	27.3 ± 2.0	27.5 ± 2.4	28.1 ± 2.3
19	27.5 ± 2.5	26.2 ± 2.4	25.0 ± 2.8	26.8 ± 2.1
28	27.8 ± 1.4	26.1 ± 2.4	27.9 ± 1.7	26.8 ± 2.8
56	31.1 ± 1.6	29.2 ± 2.3	27.7 ± 1.5	26.9 ± 1.7
112	30.9 ± 3.3	28.1 ± 1.6	31.6 ± 3.2	27.3 ± 3.5
168	39.2 ± 2.9	36.6 ± 4.7	36.9 ± 3.4	31.7 ± 4.2

Table A-III. - Means and standard deviations for blood GSH (mg per 100 ml of whole blood) by lines and ages

	Trials			
	1		2	
Ages (days)	HWL	LWL	HWL	LWL
1	49.4 ± 13.0	37.2 ± 12.6	59.7 ± 16.3	50.1 ± 7.4
4	89.8 ± 7.4	76.7 ± 8.6	83.4 ± 10.7	67.8 ± 11.7
7	84.0 ± 10.2	88.7 ± 16.3	86.1 ± 9.9	70.3 ± 13.7
10	90.2 ± 18.2	91.4 ± 9.9	72.0 ± 10.3	65.2 ± 12.8
13	86.7 ± 8.4	76.1 ± 6.9	74.7 ± 6.4	66.4 ± 11.5
16	83.3 ± 8.9	82.7 ± 12.3	76.2 ± 9.5	72.1 ± 8.3
19	62.7 ± 7.8	49.7 ± 10.0	64.5 ± 7.4	70.5 ± 9.7
28	72.4 ± 5.7	64.7 ± 12.2	74.9 ± 8.2	65.5 ± 13.0
56	83.9 ± 11.9	78.8 ± 7.0	75.3 ± 8.4	62.9 ± 12.6
112	54.5 ± 5.7	64.2 ± 12.6	65.3 ± 14.2	54.5 ± 12.4
168	70.2 ± 13.9	60.8 ± 16.8	57.8 ± 7.9	52.3 ± 8.1

Table A-IV. - Means and standard deviations for blood GSH (mg GSH per 100 ml of erythrocytes) by lines and ages

Ages (days)	Trials 1 HWL	Trials 1 LWL	Trials 2 HWL	Trials 2 LWL
1	146 ± 37	110 ± 36	178 ± 40	158 ± 34
4	290 ± 31	247 ± 26	283 ± 44	224 ± 37
7	309 ± 28	310 ± 39	324 ± 38	274 ± 35
10	308 ± 46	321 ± 27	271 ± 33	239 ± 33
13	296 ± 19	279 ± 42	286 ± 32	259 ± 53
16	298 ± 30	302 ± 36	278 ± 37	257 ± 31
19	229 ± 28	188 ± 25	259 ± 28	264 ± 36
28	261 ± 27	248 ± 37	269 ± 32	244 ± 41
56	270 ± 37	270 ± 18	272 ± 35	234 ± 41
112	177 ± 18	229 ± 47	206 ± 36	197 ± 29
168	179 ± 28	165 ± 33	159 ± 31	155 ± 21

APPENDIX B

The presentation of data from Experiment 2 with the exception of Trial 1 body weight and Trial 3 oxygen consumption, by lines within light environments

Table B-I. - Mean feed efficiency (g live weight gained/g feed consumed) by trials, periods, light environments, and sexes

Trials	Periods (days)	Light environments (hrs/day)	Males		Females	
			HWL	LWL	HWL	LWL
1	0-14	8	.20	.07	.21	.10
		24	.30	.21	.37	.27
	14-28	8	.39	.15	.42	.15
		24	.43	.25	.49	.27
	28-42	8	.33	.27	.32	.17
		24	.35	.26	.43	.28
	42-56	8	.39	.25	.35	.25
		24	.35	.36	.32	.24
	0-56	8	.36	.19	.35	.18
		24	.36	.29	.39	.26
2	0-14	8	.33	.28	.35	.24
		24	.41	.31	.43	.35
	14-28	8	.39	.20	.44	.21
		24	.45	.27	.42	.33
	28-42	8	.38	.35	.37	.26
		24	.45	.37	.41	.33
	45-56	8	.41	.47	.41	.29
		24	.41	.35	.37	.35
	0-56	8	.40	.33	.39	.26
		24	.43	.33	.40	.33

Table B-II. - Means and standard deviations for Trial 2 oxygen consumption[1] by ages, light environments, lines, and chambers

Units	Age (days)	Light environments (hrs/day)	Chamber A		Chamber B	
			HWL	LWL	HWL	LWL
ml/g/hr	28	8	1.53 ± .46	2.21 ± .52	27.1 ± .83	3.85 ± 1.58
		24	1.32 ± .30	2.22 ± .61	1.56 ± .63	2.43 ± .48
	56	8	.61 ± .13	.77 ± .13	.79 ± .17	.90 ± .12
		24	.53 ± .09	.79 ± .11	.62 ± .12	.71 ± .11
$ml/cm^2/hr$	28	8	1.37 ± .41	1.55 ± .32	2.29 ± .72	2.98 ± 1.07
		24	1.25 ± .25	1.79 ± .51	1.42 ± .73	1.90 ± .37
	56	8	.66 ± .14	.75 ± .13	.86 ± .18	.88 ± .12
		24	.58 ± .10	.78 ± .11	.68 ± .12	.69 ± .10

[1]Oxygen consumption measured between 8:00 A.M. and 6:00 P.M.

Table B-III. - Means and standard deviations for Trial 2 oxygen consumption[1] by ages, light environments, and lines

Ages (days)	Light environments (hrs/day)	ml/g/hr		ml/cm^2/hr	
		HWL	LWL	HWL	LWL
28	8	1.10 ± .36	1.08 ± .15	1.01 ± .36	.91 ± .13
	24	.87 ± .23	1.12 ± .11	.82 ± .21	.97 ± .13
56	8	.53 ± .07	.68 ± .10	.57 ± .07	.68 ± .10
	24	.55 ± .09	.81 ± .15	.59 ± .10	.81 ± .15

[1]Oxygen consumption measured between 6:00 P.M. and 11:00 P.M.

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CORRELATED PHYSIOLOGICAL RESPONSES IN A BIDIRECTIONAL SELECTION EXPERIMENT FOR BODY WEIGHT IN CHICKENS

(Charles Allen Owens)

Abstract

The concentration of reduced blood glutathione, feed efficiency, oxygen consumption, and growth were studied in two lines of chickens that had undergone divergent selection for body weight at eight weeks of age. The latter three traits were studied in two light environments, continuous illumination and a ratio of 8 hours light to 16 hours darkness. The dissertation involved two experiments and chickens from the S_{11}, S_{12}, and S_{13} generations of the high and low weight lines.

Blood glutathione, body weight, and percentage packed cell volume were measured in S_{11} generation males at 1, 4, 7, 10, 13, 16, 19, 28, 56, 112, and 168 days of age. Males from the high weight line were heavier at all ages and had a higher packed cell volume at 28 days of age and thereafter than those from the low weight line. Blood glutathione was consistently greater in the high line than in the low line with the largest differences between lines occurring at the younger ages.

The influence of light environments on growth, feed efficiency, and oxygen consumption was studied in two trials utilizing chicks from the S_{11} and S_{12} generations. Body weights and feed efficiencies were measured at 14, 28, 42, and 56 days of age and oxygen consumption at 28 and 56 days of age. Chicks from the high weight line were heavier at all ages and they had consistently superior feed efficiencies

and lower rates of oxygen consumption than those from the low line. Chicks maintained under continuous illumination were heavier and had superior feed efficiencies than those reared in restricted light. Oxygen consumption of chicks reared in restricted light was greater than that for those under continuous light when the measurements were obtained during the day i.e. the time of their photoperiod. No differences were observed between light environments when determinations were made in the evening, showing a diurnal rhythm between the day and evening measurements.

To obtain more information on the metabolism of these lines, oxygen consumption was measured at 28, 42, and 56 days of age on a sample of S_{13} generation males. The results agreed with those obtained in the S_{12} generation in that oxygen consumption was lower for males from the high weight line than for those from the low weight line.

The primary conclusions from these experiments are that divergent selection for high and low body weight results in correlated responses of blood GSH, feed utilization, and metabolic rates. Further, although different light environments may result in varying responses in feed utilization and metabolic rates, line x light environments interactions were not important for traits other than body weight.