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To the Graduate Council:

I am submitting herewith a dissertation written by Shaker Mosleh Al-Mohammadi entitled "Genotype-Environment Interaction in Traits of Egg-Production Poultry Stocks." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy with a major in Animal Science.

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GENOTYPE-ENVIRONMENT INTERACTION IN TRAITS OF EGG-PRODUCTION POULTRY STOCKS

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee, Knoxville

Shaker Mosleh Al-Mohammadi

June 1976

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ABSTRACT

Data used in this study were collected during the Seventeenth and Eighteenth Tennessee Random Sample Laying Tests (1974 and 1975).

Because of their importance to poultrymen many economic egg production traits were studied. Analysis of variance was conducted to determine the existence of the differences among stocks and treatments and of interactions. Stocks were found to differ significantly from each other with respect to most of the traits studied. To illustrate the differences among stocks, a ranking of their means with respect to each traits was prepared.

Treatment effects (varying dietary salt levels and addition of bicarbonate and of methionine and choline) were found to be significant with respect to some tratis studied but not with respect to the others. A low level of salt (0.25%) was found to increase significantly ($P < 0.05$) average egg weight, and the same effect for low level of choline (i.e., no added choline) was found. The low salt level had a significant ($P < 0.001$) influence in increasing percent small blood spots. Supplementary bicarbonate of soda significantly ($P < 0.05$) decreased percent mortality. Choline addition significantly ($P < 0.05$) increased the percentage of medium eggs. Addition of methionine to the layer diet significantly ($P < 0.05$) improved feed efficiency traits, i.e., it significantly ($P < 0.05$) decreased amount of feed per bird housed, pounds of feed per pound of eggs and pounds of feed per dozen eggs. Supplementary methionine significantly ($P < 0.001$) decreased specific gravity.

There were many indications of interaction. First-order inter-

actions, salt-by-bicarbonate-levels interaction was significant ($P < 0.05$ and $P < 0.01$) with respect to average egg weight and percent peewee eggs. Stock-by-salt-level interaction was highly significant ($P < 0.01$) with respect to average egg weight and also significant ($P < 0.05$) with respect to final body weight, percent large eggs and Haugh units. Interaction of stock with bicarbonate was significant ($P < 0.05$) with respect to percent large eggs. Stock-by-choline interaction was significant ($P < 0.05$) with respect to percent large eggs and percent small meat spots. Stock-by-methionine interaction was significant ($P < 0.01$) with respect to percent large eggs and percent large meat spots. Interaction between choline and methionine was significant ($P < 0.01$) with respect to specific gravity. Second-order interaction of stock-by-salt-by-bicarbonate was significant ($P < 0.05$ and $P < 0.01$) with respect to average egg weight and percent large meat spots, respectively. Stock-by-choline-by-methionine interaction was significant ($P < 0.05$) with respect to percent small eggs, large eggs and extra-large eggs.

The second kind of examination of the data was conducting Bartlett's Test of homogenity of variances. The results of that Test declared that variances of stocks to be not homogenous with respect to percent peewee, average egg weight, feed efficiency traits, percent small blood spots, percent meat spots and final body weight in the Seventeenth Test. In the Eighteenth Test the hypothesis of homogenity of stock variances was rejected with respect to percent peewee, small, medium eggs, average egg weight, percent blood and meat spots and percent mortality. Treatments variances were not homogenous with respect to percent peewee eggs, percent small blood spots and percent large meat spots in the

Seventeenth Test. In the Eighteenth Test, with respect to percent pee-wee eggs and percent small eggs, treatment variances were found to be not homogeneous.

The third analysis conducted was the calculation of conventional product - moment coefficients of correlation among all traits studied. Sign and magnitude of the relationships between the traits showed great variation from treatment to treatment and from stock to stock, providing further evidence of differential response of stocks to variations in environment.

Evidence for genotype-environment interaction in this study and in others is sufficient to justify further research specifcally planned to demonstrate and measure such interaction but is not sufficient to formulate any definite and precise recommendations as to testing procedures breeders should use.

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CHAPTER I

INTRODUCTION

The entire makeup of an animal's body is controlled by the genetic material received from his parents. This includes not only physical features that are readily observed, but also metabolic characteristics. Hence, any phenotypic characteristic is determined by the genotype of the individual, the environment ambient of the individual and the genotype-environment interaction.

The quantitative requirements of several nutrients have been shown to vary between breeds or strains of chickens. Some efforts have been made to elucidate differential responses through selection experiments carried out for a period of several generations. In some cases, genetic selection has failed to alter appreciably the requirements of strains. In other cases, many generations of selection on some strains resulted in differences among strains. There are numerous reports of commercial strains differing in requirements of certain amino acids such as methionine, vitamins such as choline and minerals such as salt and sodium bicarbonate.

The level of methionine in the diet is important in relation to the need for choline as a methyl donor, and vice versa. Choline can spare the methionine which is normally used for transmethylation purposes but will not spare the basic methionine requirement for protein synthesis unless the diet contains homocystine. However, the effect of

choline deficiency in laying hens is not clear.

Genotype-environment interaction has been a subject of interest to both eugenists and environmentalists for the last two to three decades because of a rapid decline in the number of strains offered for sale, and performance levels have been approaching a plateau. Hence, there has been increasing interest in dietary requirements as they differ between strains.

Breeders are mainly concerned with those genotype-environment interactions involving changes in phenotypic ranking of genotypes with the shifting of environment. The presence of this type of interaction favors the selection of stocks adapted to particular environments. Characterization of environments likely to prevail in the future, as well as those causing differential responses of genotypes is, of course, critical. A breeding policy aiming at development of stocks having general adaptability may, however, be the alternate choice, if the environmental future of the population or differences between environments causing the genotype-environment interactions are unpredictable.

The poultry industry, in its efforts to improve economic egg production traits, has focused attention not only on improving number of eggs, egg size, feed efficiency and interior and exterior quality of the egg but on sign and magnitude of the relationships among them.

There is often occasion to think that several sample correlations are estimates of a common population value. If this is true, then it is appropriate to combine the sample coefficients of correlation into an estimate more reliable than that afforded by any of the separate coefficients.

Bartlett's Test of homogeneity of variances is a well known test used to determine whether different sample variances of certain traits can be considered to be estimates of the same population variance or not (homogenous or not homogeneous).

CHAPTER II

OBJECTIVES

The objectives of this study were:

1. Evaluate stock, treatment and various genotype-environment interaction effects.

2. Determine the sign and magnitude of the coefficients of correlation between different economic traits.

3. Test homogeneity of variances of stocks and treatments.

CHAPTER III

REVIEW OF LITERATURE

I. STOCK DIFFERENCES

Information on the response of genetically different stocks to different dietary treatments, and subsequent effect on egg production and other egg traits, is abundant.

Many investigators have observed significant ($P< 0.05$ or $P< 0.01$) differences among stocks with respect to most of the economic traits (Tindell et al., 1968; Marks et al., 1969b,c; Perek and Snapir, 1970; Mackin, 1970; Srinivasan, 1972; Ali, 1973; Al-Mohammadi and Shirley, 1974 and Andrews and Marrow, 1975).

Roush and Johnston (1974) observed significant differences between two stocks when they fed diets deficient in choline, methionine or vitamin B_{12}.

McDonald (1958) found specific metabolic difference between breeds of chickens (White Leghorn and Australorps) in conversion of methionine to cystine, while Miller et al. (1960) were unable to show differences between these two breeds in their ability to utilize methionine and cystine added to a diet low in sulfur amino acids.

Egg Production

Considerable research has been conducted to demonstrate strain or stock differences with respect to egg production. Most of the workers reported significant ($P < 0.05$ or $P < 0.01$) differences among stocks in egg production traits such as hen-day egg production and hen-housed egg production (McDonald, 1958; Marks et al., 1969a,c; Hunt and Aitken, 1970; Choudary et al., 1972; Srinivasan, 1972; Aitken et al., 1972, 1973; Al-Mohammadi and Shirley, 1974; Proudfoot and Gowe, 1974; Roush and Johnston, 1974 and Andrews and Marrow, 1975).

However, some researchers observed non-significant differences among stocks in egg production (Wilson et al., 1967; Balnave, 1974 and Bhagwat and Craig, 1975).

Egg Size or Egg Weight

Numerous reports demonstrated a significant ($P < 0.05$ or $P < 0.01$) effect of stock on egg size or egg weight. On the other hand, some investigators found no significant differences among different stocks in respect to egg size or egg weight.

Marks et al. (1969a,c), Hunt and Aitken (1970), Perek and Snaper (1970), Adams and Jackson (1970), Aitken et al. (1972, 1973), Feldkamp and Adams (1973), Christmas et al. (1973, 1974), Al-Mohammadi and Shirley (1974), Proudfoot and Gowe (1974), Potts and Washburn (1974) and Balnave (1974) reported that there were significant ($P < 0.05$ or $P < 0.01$) differences among stocks with respect to egg size or egg weight.

However, some investigators found non-significant differences among stocks (Wilson, et al., 1967; Smith et al., 1970 and Mather and Gleaves, 1970).

Egg Quality Traits

The poultry industry in its efforts to improve egg quality has focused attention not only on interior quality and shell thickness but on shell texture as well.

Egg quality factors include albumin height (Haugh units), shell thickness (specific gravity), shell strength, shell texture, shell roughness, and incidence of blood spots and meat spots have been studied by many research workers (Wilson et al., 1967; Choudary et al., 1972; Al-Rawi and Amer, 1972; Ball et al., 1973; Christmas et al., 1973; Potts and Washburn, 1974 and Andrews and Morrow, 1975).

With respect to Haugh units and albumin height, several reports have indicated that stocks differ significantly (Wilson et al., 1967, $P < 0.005$; Adams and Jackson, 1970, $P < 0.01$; Al-Rawi and Amer, 1972; Aitken et al., 1972, 1973, $P < 0.01$; Feldkamp and Adams, 1973; Christmas et al., 1973, 1974 and Proudfoot and Gowe, 1974). However, some of the workers were unable to show any significant differences among stocks with respect to Haugh units (Tindell et al., 1967; Marks et al., 1969a; Smith et al., 1970; Mather and Gleaves, 1970).

Many experiments have been conducted to determine the effects of stocks on thickness and strength of shell or specific gravity.

Feed Consumption and Body Weight

Considerable research has been done (in broilers and layers) to determine the effect of genotype on body weight, feed intake, feed conversion and body weight gain.

Wilson et al. (1967), Marks et al. (1969b), Aitken et al. (1972, 1973), Christmas et al. (1973, 1974), Gavora et al. (1974), Wilbur and Fuller (1974) and Andrews et al. (1975) reported significant ($P < 0.05$ or $P < 0.01$) influence of genotype on the various traits listed above. However, Wilson et al. (1967) Hunt and Aitken (1970) Feldkamp and Adams (1973) and Bhagwat and Craig (1975) found no significant stock differences.

Mortality

As with all other traits, there is much disagreement among investigators about significance of stocks differences with respect to mortality (i.e., some researchers reported significance of differences among stocks, while others could not find such differences).

Wilson et al. (1967), Marks et al (1969b), Adams and Jackson (1970), Gavora et al. (1974) and Andrews et al. (1975) indicated that stocks were significantly ($P < 0.05$ or $P < 0.01$) different from each other in their ability to survive.

On the contrary, (Hunt and Aitken, 1970; Feldkamp and Adams, 1973 and Balnave, 1974) were unable to demonstrate significant differences among the stocks they studied with respect to mortality.

Perek and Snapir (1970), Ball et al. (1973) Aitken et al. (1972, 1973), Al-Rawi and Amer (1972), Potts and Washburn (1974), Proudfoot and Gowe (1974), Balnave (1974) and Andrews and Marrow (1975) reported significant ($P < 0.05$ or $P < 0.01$) differences among stocks with respect to these traits. However, some others did not find any important differences among stocks (Feldkamp and Adams, 1973).

Blood spot and meat spot incidences have been reported to be affected by stocks (Mackin, 1970, $P< 0.05$ or $P< 0.01$, in some experiments, but not in others; Aitken et al., 1973, $P< 0.01$; Al-Mohammadi, 1973, $P< 0.05$, in candled eggs, but not in broken-out eggs; Proudfoot and Gowe, 1974 and Gavora et al., 1974). Other researchers were not able to find any significant effect of stock on percent of blood or meat spots (Tindell et al., 1967; Mather and Gleaves, 1970; Smith et al., 1970 and Feldkamp and Adams, 1973).

On texture and roughness of shell Ball et al. (1973) reported in detail the description and cause of differences in the trait. They found one line of hens with fifteen times as many rough-shelled eggs as another line. They stated that roughness of shell is not associated with shell thickness.

Sexual Maturity

Age of birds either at first laid or age at 50% of birds laying two or three eggs in sequence is used as a criteria of sexual maturity. Most of the literature available indicates significant differences among different genotypes of chickens with respect to sexual maturity. Feldkamp and Adams (1973) showed highly significant ($P < 0.01$) differences among stock, and Balnave (1974) also reported significant ($P < 0.05$) differences among stocks. These reports agreed with those of Marks et al. (1969a), Adams and Jackson (1970), Choudary et al. (1972), Gavora et al. (1974) and Proudfoot and Gowe (1974).

Income Per Hen

Mackin (1970) found in his study significant ($P < 0.01$) differences among 10 to 16 stocks with respect to this trait. Al-Mohammadi (1973) also reported significant ($P < 0.001$) differences among 14 stocks in his study of income per hen over feed and chick prices.

II. GENOTYPE-ENVIRONMENT INTERACTION

The attention of breeders for the last two or three decades has been directed to genotype-environment interactions. The subject of genotype-environment interaction effects, the productivity of certain genetically different strains or stocks under certain environmental conditions has been discussed in detail by many researchers (Tindell et al., 1967, Marks et al., 1969a,c; Biswas and Craig, 1970; Aitken et al., 1972; Choudary et al., 1972 and Christmas et al., 1973).

Egg Production

The main goal of egg production stock owners is to reach the optimum egg production level with some attention to other important economic traits. Hence, the fact that several factors are involved in reaching that level has increased the importance of genotype-environment in egg production.

Wilson et al. (1967), Marks et al. (1969a), Biswas and Craig (1970), Choudary et al. (1972), Aitken et al. (1973), Feldkamp and Adams (1973), Balnave (1974), Proudfoot and Gowe (1974) and Bhagwat and Craig (1975) reported a significant genotype-environment interaction with respect

to egg production expressed as hen-housed egg production, hen-day egg production and rate of lay.

At the same time there are many reports indicating non-significant genotype-environment interaction involving different environmental aspects (viz., interaction of strain with housing density, with location or with diet) with respect to egg production or at least, if significant, of little practical importance (Tindell et al., 1968; Marks et al., 1969c; Adams and Jackson, 1970; Aitken et al., 1972; Christmas et al., 1973; Christmas et al., 1974 and Al-Mohammadi and Shirley, 1974).

Egg Weight

Several reports have indicated that genotype-environment interaction was significant with respect to egg weight or egg size. Genotype-environment interaction could be stock x diet, stock x density of housing, stock x location or stock x year or period interaction.

Wilson et al. (1967), Marks et al. (1969a,c), Hunt and Aitken (1970), Aitken et al. (1972) and Christmas et al. (1973) stated that genotype-environment interaction was significant ($P < 0.05$ or $P < 0.01$) with respect to egg weight or egg size.

Some other workers found little or no interaction with respect to egg weight or egg size (Adams and Jackson, 1970; Tindell et al., 1968; Al-Mohammadi, 1973 and Christmas et al., 1973, 1974).

Body Weight and Feed Conversion

Most reports on body weight, body weight gain, feed intake or consumption and feed efficiency or feed conversion indicated that those

traits could be significantly ($P < 0.05$ or $P < 0.01$) affected by genotype-environment interaction. Marks et al. (1969a,c) found significant interaction between parent stock and location with respect to 8 and 18- week body weight. Tindell et al. (1967), Airken et al. (1972, 1973), Christmas et al. (1974), Proudfoot and Gowe (1974), Al-Mohammadi and Shirley (1974), reported such interaction with respect to body weight at housing but not at the end of the experiment and interaction of stock by diet but no other interactions and Balnave (1974) reported significant interaction with respect to some of these traits.

However, (Wilson et al., 1967; Tindell et al., 1968, in broilers; Biswas and Craig, 1970; Ali, 1973; Feldkamp and Adams, 1973 and Christmas et al., 1973) were unable to find any significant interaction effect.

Egg Quality

Egg quality characteristics such as Haugh units, specific gravity, shell strength, shell thickness and meat and blood spot incidences and genotype-environment interaction effects upon them have been studied by several workers. Marks et al. (1969a,c) found significant interaction effects on some of these traits but not on others. Tindell et al. (1967) observed significant interaction effects on specific gravity and Haugh units. Aitken et al. (1972) found highly significant ($P < 0.01$) influence of interaction on albumen quality.

The above reports were contrary to reports of Wilson et al. (1967), Tindel et al. (1968), Adams and Jackson (1970), Christmas et al. (1973; 1974), Balnave (1974) and Al-Mohammadi and Shirley (1974).

Mortality

Considerable research has been done to determine if mortality is affected by genotype-environment interaction. Among those reports which indicated significant ($P < 0.05$ or $P < 0.01$) interaction effect were Marks et al. (1969a) and Choudary et al. (1972). However, many reports are available showing non-significant effects of interaction on mortality (Wilson et al., 1967; Tindell et al., 1967, 1968; Marks et al., 1969c; Hunt and Aitken, 1970; Adams and Jackson, 1970; Aitken et al., 1972 and Christmas et al., 1973, 1974).

Sexual Maturity

Some research workers observed significant ($P < 0.05$ or $P < 0.01$) interaction between genotype and different environmental conditions for age of sexual maturity. (Tindell et al., 1967; Marks et al., 1969a; Biswas and Craig, 1970 and Adams and Jackson, 1970.)

In contrast were the results of Marks et al. (1969c), Choudary et al. (1972), Aitken et al. (1972) and Balnave (1974) who found non-significant genotype-environment interaction effect on sexual maturity.

Profit Per Hen

Mackin (1970) and Al-Mohammadi (1973) found a non-significant genotype x diet interaction in a series of Tennessee Random Sample Laying Tests (viz., Eighth, Ninth, Tenth, Eleventh, Twelfth and Fifteenth) for this trait.

In summary, one can say that there is rather general agreement among investigators that there are real stock differences with respect to nearly all traits studied. However, there is much variety of

opinion concerning genotype-environment interactions in poultry. Some investigators, on the basis of their own research, believe that such interaction is real and economically important, others believe it is real but not of sufficient magnitude to be of economic importance and still others believe it does not exist. Thus, further research seems warranted.

III. CORRELATION BETWEEN ECONOMIC TRAITS

The numerous investigations concerning the correlation of production traits have not been in much agreement with respect to either magnitude or sign of the correlations. Hence, the importance of further investigation still exists.

Among those people who have investigated the correlation between economic traits are McCartney (1962), Tung and Staley (1968), Perek and Snapir (1970), Andrews (1972) and Al-Mohammadi (1973).

Egg Production and Egg Weight

Most of the researchers tend to agree that egg production and egg weight are postively correlated (Wayatt, 1954; Hogsett and Nordskog, 1958; McCartney, 1962, $P < 0.05$; USDA, 1969; Srinivasan, 1972, $P < 0.05$ and Al-Mohammadi, 1973, $P < 0.001$). Goher and McGibbon (1974) found differences between breeds in the magnitude of this correlation which agrees with the findings of Nordskog (1960) and Srinivasan (1972) who found stock differences.

However, Lerner (1950) stated that the correlation between egg production and egg size will be positive until certain rates of production are reached, then it will be a negative correlation.

Perek and Snapir (1970) stated that the correlations between rate of production and egg weight were negative but non-significant in both White Leghorns and White Rocks on seasonal and individual-average bases.

Egg Production and Body Weight

Several investigators have observed a negative relationship between these two traits (Hogsett and Nordskog, 1958; Nordskog, 1960, $P < 0.01$, in heavy type; USDA, 1969; Andrews, 1972 and Srinivasan, 1972).

This is contrary to the results of McCartney (1962) ($P < 0.05$) and King (1961) who reported a positive relationship.

Egg Production and Egg Quality

Ideally, improvement in egg production should accompany improvement in egg quality. Therefore, the relationship between egg production and egg quality should be known before starting any breeding program.

Harms and Douglas (1960) found significant negative relationship between egg production and some egg quality traits. However, Johnson and Merritt (1955) found a negative correlation of production with shell thickness in the Barred Rock breed, but a positive correlation in the White Leghorn breed.

Farnsworth and Nordskog (1955) found a positive correlation

between egg production and bloodspot incidence and Goher and McGibbon (1974) found production to be positively correlated with shell thickness.

Srinivasan (1972) and Al-Mohammadi (1973) demonstrated non-significant negative correlations between egg production and Haugh units in each treatment tested when data from all observed stocks were combined.

Most of the USDA (1969) reports show negative relationships of production with some egg quality traits, but at the same time they show positive correlations with the other egg quality characteristics.

Perek and Snapir (1970) reported a non-significant correlation between shell quality and rate of production in White Leghorns, while a significant ($P < 0.05$) positive correlation between the same traits was found only on the basis of individual-bird averages.

Sexual Maturity and Other Traits

USDA (1969) stated that, according to many reports, sexual maturity (age at first egg) had a small negative correlation (-0.01) with mature egg weight but a stronger (-0.23) negative correlation with pullet egg weight and a positive relationship with annual rate of production.

Early maturing pullets had a higher egg production, according to King (1961), Kinney et al. (1968) and Vaccaro and van Vleck (1972), and also larger egg size and a higher albumen score.

Income and Other Traits

Nordskog (1960) found a highly significant ($P < 0.01$) positive correlation of income with egg production in both Leghorn and heavy types, a highly significant ($P < 0.01$) positive correlation of income with egg

size in Leghorn, a non-significant positive value for the same correlation in heavy types and a significant ($P < 0.05$ in Leghorn and $P < 0.01$ in heavy types) positive correlation of income with body weight.

Al-Mohammadi (1973) observed a highly significant ($P < 0.001$) positive correlation of income with egg production, egg weight, feed efficiency, a non-significant positive correlation of income with specific gravity and a non-significant negative correlation of income with Haugh units.

Egg Weight and Egg Quality

Perek and Snapir (1970) found non-significant positive correlation between egg weight and shell quality in White Rocks while the same correlation was significant and negative in White Leghorns. Tung et al. (1968) found a significant positive relationship between egg weight and shell thickness on both pooled-egg and bird-average bases.

Srinivasan (1972) found non-significant negative correlations of egg weight with Haugh units in most of the treatments in a three-year series of Tennessee Random Sample Laying Tests, while Al-Mohammadi (1973) found non-significant positive correlations between the same traits and specific gravity in following year of the same series. Potts and Washburn (1974) reported non-significant correlations of egg weight with various shell measurements (such as shell thickness, specific gravity, breaking strength, etc.).

Egg Weight and Body Weight

Many investigators have agreed that the correlation between these two traits is positive in both meat-and egg-type chickens. The results of Nordskog (1960), Hogsett and Nordskog (1958), McCartney (1962) and King (1961) were in agreement.

However, in another study, Farnsworth and Nordskog (1955) found no relationship between egg weight and body weight.

IV. CHOLINE

Choline is an essential nutrient for many species of animals, but its deficiency in most mature animals such as rats, laying chickens, mice and dogs can be prevented by including methyl donors (methionine and betaine) in the diet (Jukes, 1947; DuVigneaud et al., 1941; Griffith and Wade, 1939; Lucas and DeMaster, 1940 and Ringrose and David, 1946). The rate of choline synthesis in chickens apparently increases with age since it has not been possible to produce a choline deficiency in growing chicks over eight weeks of age and since laying hens seem to have considerable ability to snythesize choline (Ringrose and David, 1946; Nesheim et al., 1971 and Lucas et al., 1946).

Choline Requirements

As stated above, laying hens and pullets do not need supplementary choline in the diet. However, Nesheim et al. (1967) reported that the choline requirement of laying hens can be influenced by the choline level in the diet of the growing pullet. Those hens that had received choline supplements in the growing diets required supplemental

choline in the laying diets for maximum egg production and for maintaining liver fat at a relatively low level.

Choline deficiency readily occurs in chicks fed diets low in choline (Jukes, 1940a,b; Clandinin et al., 1946; Nesheim et al., 1969 and Ewing, 1963). Ketola et al. (1974), Ketola and Young (1973), Nesheim et al. (1971), Jukes (1941) and Ewing (1963) reported that a choline-deficient diet fed to young chicks caused perosis in the chicks. The only animal which can develop perosis is a young chick. Other species and laying hens, which can synthesize choline in their body, will not have the perosis disease.

The National Academy of Sciences - National Research Council (NAS-NRC) (1966), Scott et al. (1969), Kushwaha and Jensen (1974) and Ewing (1963) have indicated that the dietary choline requirement of chicks was 1300 mg. per kg. of the diet for the first few weeks of life. The choline requirement decreases with age and a laying chicken does not need any dietary choline for optimum egg production. Lucas et al. (1946) stated that excellent production and hatch ability have been observed on practical rations containing as little as 0.12% of choline.

The choline required by chicks may be divided into two parts, which may be called essential choline and replaceable choline. Growth of 6% required 0.06% essential choline chloride and 0.14% replaceable choline chloride. Replaceable choline can be replaced by glycine betaine; essential choline cannot (Ewing, 1963). His results indicated that the only function of betaine is to replace replaceable choline.

Choline in the Laying Ration

Considerable research has been done to determine if laying hens need any supplementary choline in the diet for optimum performance. Studies by Lucas et al. (1946) showed that hens fed a diet containing less than 0.03% choline maintained egg production and hatch ability nearly as well as did hens fed the same diet supplemented with additional choline.

Choline requirement in the laying ration could be affected by some of the nutrients of the ration. Methionine, fat, B_{12}, homocystine, folic acid and protein percentages in the diet can influence the requirement of the laying hens for choline supplementation.

Henderson and Henderson (1966) and Welch and Couch (1955) showed that a basal diet low in B_{12} and methionine was improved by the addition of choline. Burns and Ackerman (1955) reported that choline deficiency in the laying hen could be produced in the absence of dietary vitamin B_{12}, and this resulted in hens laying smaller eggs with reduced concentrations of fat and choline. Ketola and Nesheim (1974) reported that dietary protein and methionine had a marked effect on the choline required for maximum growth and for prevention of perosis in growing chicks. They noted that as protein dietary percentage increased, both choline requirement for weight gain and feed/gain increased. These results confirmed those of Homes and Kramer (1965), Griffith et al. (1969), Daghir et al. (1960) and Balloun (1956).

The fatty liver syndrome in laying hens continues to be a serious problem for poultrymen. Many investigators (Griffith et al., 1969; Nesheim et al., 1971, 1969; Tebong, 1974; Best and Huntsman, 1932;

Scott et al., 1969 and Best et al., 1935) have indicated that supplementary choline in the diet reduces the amount of liver fat which has in turn been shown to be associated with a reduction in egg production.

Choline and Egg Production

During recent years considerable attention has been given to the possibility of improving egg production by adding some choline to laying rations. However, an early study concerning the choline requirements of hens (McCollum et al., 1912) has been reported. Supplementation of the laying diet with choline has been reported to increase egg production with varying levels of significance. (Abbott and DeMasters, 1940; Lucas et al., 1946; Daghir et al., 1960; Homes and Kramer, 1965, Griffith et al., 1969; Saloma et al., 1965; Nesheim et al., 1971; Schexnailder and Griffith, 1973; Welch and Couch, 1955; Burns and Ackerman, 1955; Armanious et al., 1973 and Ferguson et al., 1973 in turkey). However, some investigators (Jensen et al., 1974; Griffith and Rodriguez, 1973; Ketola and Nesheim, 1974; Roush and Johnston, 1974; Crawford et al., 1967; Balloun 1956 and Gish et al., 1949) were unable to show any statistically significant differences and even observed no difference at all when choline was added to the laying rations.

Many research reports indicate that most of the hen's requirements of choline is in egg yolk construction. Eggs are considered to be one of the richest sources of choline, and it occurs almost entirely in the yolk. Engel (1943) found 17.13 mg. choline per gm. of fresh egg yolk. Ringrose and Davis (1946) found 10.5 to 15.3 mg. per gm. of egg yolk. However, eggs laid by choline-deficient hens did not have a

reduced content of choline (Ringrose and Davis, 1946; Crawford and Griffith, 1968 and Nesheim et al., 1967, 1971).

Choline and Egg Weight or Egg Size

Most of the research reported indicated that egg weight or egg size was not affected by choline level in the laying diet. Balloun (1956) stated that his experimental results showed that egg size, egg quality and hatch ability of fertile eggs were not affected by adding choline to a low-choline diet in his two experiments. Ketola and Nesheim (1974) conducted an experiment to determine the choline requirements at different levels of dietary protein. They noted that there was not any important difference in egg weight between two levels of choline at two different levels of dietary protein (viz., 16% and 30%). Jensen et al. (1974) and Griffith and Rodriguez (1973) were unable to find any responses in egg weight when choline was added to the diet.

However, some investigators showed important responses in egg size or egg weight when choline was added to a diet which was deficient in choline or had the NRC recommended choline level. Schexnailder and Griffith (1973) reported that supplementing the diet with choline in addition to the diet content resulted in a significant ($P < 0.01$) increase in egg weight. These results confirmed previous results of Welch and Couch, (1955), Burns and Ackerman (1955), Abbott and DeMasters (1940) and Griffith et al. (1969).

Choline, Feed Efficiency and Body Weight

Most of the reports available showed no response in feed consumption or body weight gain when choline was added to the ration. Jensen et al. (1974) indicated that there were no significant body weight changes in two experiments they conducted. Armstrong et al. (1973a,b), in two experiments on chicks, found no significant difference in body growth and feed efficiency in one experiment while the difference was significant ($P < 0.05$) in the other experiment when choline was added to the ration. These results confirm results of Schexnailder and Griffith (1973), Armanious et al. (1973), Griffith and Rodriguez (1973) and Potter and Kelly (1973).

Improvement in feed utilization and weight gain or growth mainly appeared in chicks rather than in pullets or laying hens when an additional amount of choline was added to the diet. Abbott and DeMasters (1940) reported that additions of choline prevented weight loss. Lucas et al. (1946) indicated that the changes in body weight, although small, were greater on the high-choline diet. Jukes (1940a,b) showed that growing chickens and turkey poultry required high levels of dietary choline to support maximum growth and prevent perosis. Ketola and Young (1973) demonstrated that addition of choline to the basal diet fed to quail markedly increased growth rate ($P < 0.01$) and improved feed efficiency. Featherston and Stephenson (1960) and Ketola and Nesheim (1974) stated that choline supplementation significantly ($P < 0.05$ or $P < 0.01$) improved growth rate and feed efficiency. All of these results agreed with those of Jukes et al. (1945), Schaefer et al. (1949), Demers and Bernard (1950), Young et al. (1955) and Vohra et al. (1960).

V. METHIONINE IN LAYING RATIONS

Although methionine is only one of the dozen essential "bricks" that compose the "wall" of protein, and, furthermore, is one of the most recently discovered amino acids (in 1921), it has been the subject of far more research by avian scientists than any of the other amino acids.

Because a combination of corn and soybean meal with minerals and vitamins is the most commonly fed diet in the United States, the amino-acid balance of this mixture is of concern to nutritionists. Both corn and soybean meal are low in sulphur-containing amino acids (methionine and cystine), although corn is somewhat richer in methionine than soybean meal.

Methionine Requirement

Considerable research has been done in an attempt to determine the optimum level of protein in laying rations. Harms and Waldrop (1962) stated that the protein requirement of the laying hen is as high as 17% and as low as 11%, varying from one type of feed to another. This report agrees with those of Moreng et al. (1964), Deaton and Quisenberry (1965), Harms et al. (1966) and Al-Mohammadi and Shirley (1974).

It is generally agreed that the quality of the protein source will effect the total protein requirement. According to calculations based on values of Titus (1955), methionine is indicated to be the first limiting amino acid in a corn-soybean oil meal laying diet. Harms et al. (1962) reported no significant differences between levels of egg production when 0.075% of methionine hydroxy analogue (MHA) was present in the diets. This fact would indicate that either the methionine and/or cystine content

of a 14.7% protein diet containing 0.075% supplemental MHA was adequate to support a maximum rate of egg production. However, evidence has been presented which indicates that the hen will over consume either protein or energy in an attempt to meet her need for the other nutrient.

Methionine requirement of laying hens to obtain optimum egg production, egg weight, feed efficiency and body weight gain is affected by protein level in the diet (Titus, 1955 and Klose and Almquist, 1941. The requirements have been reported to be affected also by the energy content of the diet (Baldini and Rosenbert, 1955). More precisely, it depends on calorie/protein ration which was stated to be 41-47 calories per percent protein for maximum effect from methionine supplementation (Nestler, 1961). Methionine level in the diet has been demonstrated to be affected by the level of cystine in the diet. Nestler (1961) stated that methionine and cystine must be considered jointly since the latter may be syntherized in the chick at the expense of the former, and he showed that the requirement for these sulphur-containing amino acids to be 0.9%, 0.9% methionine alone, or 0.9% of a mixture of methionine and cystine, with a minimum methionine content of 0.5%. The requirements of these sulphur containing amino acids in the laying ration have been reported to be 0.63%, and at least 0.38% of it was methionine (Leong and McGinnis, 1952 and Ingram et al., 1951).

Many reports are available showing the interrelationship between methionine and choline, betaine, homocystine, vitamin B_{12}, certain antibiotics, glycine, lysine, folic acid, cholesterol of the serum, vitamin E (Nestler 1961; Ewing, 1963; Ingram et al., 1951 and Abbott and DeMasters, 1940).

Methionine and protein requirements have been presented in different manners by several authors (Table 1). In some instances, these requirements are minimum requirements, while in others they are recommended allowances. Some of the requirements are based on the composition of eggs, body tissues and feathers, and other requirements are based on the results of production experiments.

Additional Methionine in Layer Rations

The addition of amino acids to supplement the protein in diets of laying hens provides a means of increasing the efficiency with which feed proteins are converted to egg proteins. However, the amino acid composition of the egg is not affected by a methionine efficiency (Ewing, 1963).

There are considerable research results available showing the effect of methionine supplementation on different economic traits.

Methionine and Egg Production

Harms *et al*. (1962) showed a significant improvement in egg production when diets were supplemented with 0.075% methionine hydroxy analogue (MHA). Waldroup *et al*. (1974) stated that total egg mass production was considerably lower on semi-purified diets low in methionine (0.35%) than on positive control corn-soybean diets. Muller and Balloun (1973) reported that egg production was increased when methionine was added to a diet containing 16% protein, but production was reduced when it was added to diets containing 12 or 14% protein. Others (Schexnailder and Griffith, 1973, $P < 0.01$; Reid and Weber, 1973, $P < 0.005$; Anderson *et al*., 1973, $P < 0.05$; Chi and Speers, 1973a, $P < 0.05$; Armanious *et al*.,

Table I

Requirement of Laying Hens for Methionine in the Diet

Researchers	Year	% Protein	% Methionine
N. R. C.	1971	15	0.28
Johnson & Fisher	1958		0.24
Combs	1962		0.26
Shapiro	1968		0.26
Mortan et al.	1967		0.28
Carlson & Guenthner	1969	16	0.26
Arkansas	1965	16	0.31
Scott et al.	1969	16	0.32
Reid & Weber	1973		0.29
Leong & McGinnis	1952		0.38
Ingram et al.	1951		0.38

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1973; Muller and Balloun, 1973 and Nestler, 1961) reported that egg production increased by methionine supplementation even when the diet already had recommended requirements of methionine.

On the other hand, many workers have shown no effect or a negative influence on egg production of methionine supplementation (Muller and Balloun, 1973, with 12 or 14% or protein diet, Carlson and Guenthner, 1969; Roberson and Trujillo, 1975; Reid et al., 1951, Mehring et al., 1954 and Heywang, 1956).

Methionine and Egg Weight

Several researchers observed small but non-significant effect, or no effect at all on egg weight when different levels of methionine were added to the diet (Carlson and Guenthner, 1969; Roberson and Trujillo, 1975 and Nestler, 1961).

However, others stated that methionine supplementation improved egg weight significantly (Armanious et al., 1973, $P < 0.05$ and Schexnailder and Griffith, 1973, $P < 0.01$).

Methionine and Body Weight and Feed Efficiency

Most reported research has shown significant (at different levels of probability) and, in some cases, non-significant improvement in body weight and/or feed efficiency by methionine (Harms et al., 1962, Wilburn and Fuller, 1975, in broilers, $P < 0.05$; Armstrong et al., 1973a,b, $P < 0.05$; Chang and Fuller, 1964; Fuller et al., 1967; Conner et al., 1969; Rayudu et al., 1970; Chi and Speers, 1973a,b, in broiler chicks, $P < 0.05$; Armanious et al., 1973 and Bragg and Akinwande, 1973).

Some investigators (Griminger and Fisher, 1962; Tamimie, 1967 and Boorman and Fisher, 1966) reported that an excess of methionine in the starter ration caused a growth depression in young chicks.

VI. CHOLINE AND METHIONINE INTERRELATIONSHIP

Choline and methionine are sources of methyl groups as is betaine. There is a distinct interrelationship between choline, methionine and betaine. A certain amount of choline is essential in the ration and cannot be replaced by methionine or other methyl donors (Jukes, 1940a,b, 1941; Ringrose and Davis, 1946; Norvell, 1970 and Ketola, 1973). Methionine can furnish methyl groups for converting choline precursors into choline in the natural feedstuffs but not in purified diets.

Jukes (1940a,b) and Jukes et al. (1945) noted that methionine as a source of methyl groups cannot permit synthesis of choline in a chick to prevent perosis. However, Scott et al. (1969) stated that choline deficiency in young chicks is perhaps not due to a total lack of ability to synthesize choline but more likely to lack of ability to synthesize it at a rate sufficient for the needs of the animal.

Ketola and Nesheim (1974) conducted some experiments which showed that the growth of chicks fed a diet containing the lowest level of methionine (0.04%) was improved only by the addition of 300 mg. of choline/kg. of diet, whereas, levels of choline up to 600 mg./kg. of diet improved growth of chicks fed a diet containing 0.4% supplemental methionine. They found also a significant ($P < 0.025$) interaction between choline and methionine in the analysis of variance of growth and perosis variables. These results confirm those of Byington et al. (1972); Tamimie (1967)

and Jukes et al. (1945) who reported that high levels of methionine may increase the need for dietary choline. Baldini and Rosenberg (1955) found a significant ($P < 0.05$) effect of interaction between methionine and choline on growth of the chicks. However, Nesheim et al. (1971) found no interaction. Gerry and Hauge (1948) reported that choline and methionine were interchangeable to a certain extent in supplementing a ration consisting largely of corn and soybean oil meal.

VII. SODIUM BICARBONATE

Some feed manufacturers and also some poultrymen have included sodium bicarbonate in their feeds in small amounts as a standard ingredient, thinking it would aid in digestion and overcome acidity. Recently, there has been an increasing interest in determining if sodium bicarbonate affects egg production and quality.

Egg Production

Research reports have not agreed as to whether or not addition of sodium bicarbonate to the diet will increase egg production.

Howes (1966) declared that egg production was significantly ($P < 0.01$) increased at all levels of sodium bicarbonate (viz., 454, 227, 113 and 57 grams per 45.5 kilograms of feed) as compared to a control diet. Cox and Balloun (1968) added 0.5% sodium bicarbonate to the diet. They found that addition of 0.5% sodium bicarbonate improved significantly ($P < 0.01$) the percent hen-day egg production as compared to a control diet when fed to the pullets; but when different levels of bicarbonate were fed to hens that had been in production for 12 months, successive

additions of bicarbonate resulted in a lower rate of production.

However, Ferguson et al. (1974), Pepper et al. (1968) and Frank and Burger (1965) reported that increasing sodium bicarbonate levels did not significantly alter egg production.

Egg Weight

Most of the reports available on egg weight showed a depression in egg weight when bicarbonate was added or no change in egg weight.

Howes (1966) stated that egg weight was significantly ($P < 0.01$) decreased. Pepper et al. (1968) observed a slight decrease in egg weight. Frank and Burger (1965) and Ferguson et al. (1974) did not find any significant differences in egg weight when sodium bicarbonate was added.

Egg Quality

Frank and Burger (1965) reported that sodium bicarbonate in the drinking water of hens resulted in a 6.6% improvement in egg shell thickness. They concluded that the reported increase in egg shell calcification in birds exposed to high levels of atmospheric carbon dioxide was not a result of changes in blood pH but, rather, a result of respiratory acidosis and its resultant effects upon the availability of bicarbonate ions in the shell gland.

Howes (1966) declared that specific gravity and shell thickness measurements were significantly ($P < 0.01$) improved with all levels of addition of sodium bicarbonate (454, 227, 113 and 57 gm. per 45.5 kg. of feed) as compared to the control diet. He added that improvement in egg shells produced by bicarbonate-fed birds which have been exposed to heat did occur.

Pepper et al. (1968) stated that sodium bicarbonate failed to improve egg shell quality over that of birds on the control diet, using specific gravity, egg shell weight, and shell weight per unit surface area as criteria for measuring a response. They added that Haugh units did not change when bicarbonate was added to the control diet, according to data from last period of the test.

Cox and Balloun (1968) reported that bicarbonate addition resulted in a decrease in shell thickness but did not effect specific gravity when it was fed to pullets. In another experiment with hens which had been in production for 12 months, bicarbonate addition did not significantly alter specific gravity and shell thickness, while it increased the percent of cracked shells.

Hunt (1972) declared that high levels of supplementary sodium bicarbonate (1 to 3%) decreased specific gravity. On the other hand, Charles et al. (1972) observed a significantly harder shell on egg produced by hens which received 0.25% sodium bicarbonate.

Ferguson et al. (1974) showed non-significant differences in specific gravity, average shell weight and average shell thickness due to bicarbonate addition.

Other Traits

Pepper et al. (1968) observed a slight increase in average feed consumed per bird per day when sodium bicarbonate was added to the diet, and weight gain was slightly increased. Difference in mortality was negligible.

Ferguson et al. (1974) found no significant differences in body

weight and mortality when 0.2% of sodium bicarbonate was added to the diet.

VIII. SODIUM CHLORIDE

Sodium chloride is usually referred to as salt in feedstuff terminology. It's requirements for egg production are determined by the contents of sodium and chloride in the egg. One egg contains approximately 73 mg. of sodium and 88 mg. of chloride, amounts that would be provided by 186 mg. of salt (Ewing, 1963).

Egg Production

Dilworth et al. (1972a,b) declared that a level of salt below 0.1% in floor birds or 0.2% in cage birds decreased significantly the rate of egg production.

Hunt (1972) stated that egg production was maximized by supplementary levels of 0.1% sodium chloride or greater.

Monsi and Enos (1973) conducted an experiment using four different levels of salt (viz., 0.0, 0.125, 0.25, 0.5% as a control diet) added to the basal diet which was assumed to be deficient in salt. They observed that egg production significantly declined when the 0.0% salt diet was fed to the birds. Egg production was increased immediately by those hens fed the control diet (0.5% salt). They observed also that 0.125 and 0.25% salt diets decreased egg production.

Nesbeth et al. (1974) reported that a 0.0% salt diet caused egg production to cease in 17 days, while pre-experiment production was 68%. Birds reached 79% production 16 days after returning to the control diet.

Egg Weight

There are several differing reports available on the effect of salt on egg weight or egg size.

Dilworth et al. (1972a) stated that low dietary salt decreased egg size. Dilworth et al. (1972b) found that level of salt below 0.1% in floor or below 0.2% in cage decreased egg size significantly.

Hunt (1972) reported that egg weight was maximized by 0.15% salt or greater.

Monsi and Enos (1973) and Nesbeth et al. (1974) declared that low salt treatments did not have any significant effect on egg weight.

Body Weight and Feed Efficiency

Feed consumption is obviously affected when considerable salt is available in the ration. Increased amounts of salt also increased water intake and raise the moisture content of the droppings.

Hunt (1972) found the feed consumption to be maximized by a supplementary level of 0.1% salt or more.

Dilworth (1972a) stated that feed consumption and body weight were decreased by feeding low dietary salt feed. Significant reduction in body weight and feed consumption were reported also by Monsi and Enos (1973).

Morrison et al. (1975) declared that feed intake and gain in weight in turkeys were unaffected by different levels of salt fed to male turkeys in two experiments.

Hurst et al. (1973) observed that optimum growth rate at both two and four weeks of age was obtained by 0.3% added sodium chloride

which was equivalent to 0.118% added sodium.

Nesbeth et al. (1974) reported an immediate and significant decline in feed consumption and body weight was decreased by 324 gms. (20.1%) in 21 days.

Morrison et al. (1975) found that water intake, feed intake and weight gain were not significantly influenced by different levels of salt (0.7 to 2.7%) fed to turkeys.

Egg Quality and Mortality

Specific gravity was maximized by 0.1% salt (Hunt, 1972). He found also that higher salt levels decreased specific gravity.

Dilworth et al. (1972b) found specific gravity to be unaffected by differences in salt levels.

Monsi and Enos (1973) stated that low salt diets had a non-significant effect on egg shell thickness, shell strength and albumen height.

Nesbeth et al. (1974) stated that specific gravity was significantly decreased after five days of feeding 0.0% salt; but mortality was not affected.

Morrison et al. (1973) observed that mortality occurred in all treatments they used, i.e., on all levels of salt. Seventy percent of this occurred during the first week and was greatest on the highest salt level (2.7%).

Morrison et al. (1975) reported that a high level of salt increased mortality in turkeys.

In summary, one can say that there is sufficient disagreement among researchers with respect to various aspects of dietary supplementation with the substances considered here to warrant further research.

CHAPTER IV

EXPERIMENTAL PROCEDURE

I. MANAGEMENT OF THE EXPERIMENTS

Data collected in the Seventeenth and Eighteenth Tennessee Random Sample Laying Tests were used in this study.

Each of the Tests was started by securing for incubation hatching eggs of each stock (strain). Hatching eggs were supplied by breeder farms, as many as 72 dozen from each stock in each Test. All entries of eggs were set in the same incubator to insure as nearly as possible, the same environment during incubation time. Moverover, uniform management was also applied during the brooding, growing and laying periods. The chicks were removed from the incubator on March 26, 1973 and 1974, for the two tests, respectively. At that time, when the chicks were one day old, they were sexed, dubbed and wing-banded, and vaccinated against Marek's disease. In the Seventeenth Test the chicks received Newcastle and infectious bronchitis vaccine at one day of age and were revaccinated at 20 weeks of age and at that time received fowl pox vaccine also. Chicks in the Eighteenth Test received vaccination at 7, 42 and 138 days of age for Newcastle and infectious bronchitis. For fowl pox, vaccination was made at 42 days of age. Three hundred females of each entry were randomly taken and brooded in two pens in the brooder house where infrared heat lamps served as the source of heat during the first

eight weeks. Chicks were fed 22% protein diet until eight weeks of age (BR_1, Table II). At that time, each entry was divided into four pens in the grower shelter while another diet containing 17.6% protein grower diet (GR6) was fed to fourteen weeks of age. From the fourteenth week to the twentieth week a ration containing 16.2% (GR10) was fed. The pullets were debeaked at 140 days of age in the Seventeenth Test and at seven and 138 days of age in the Eighteenth Test. Pullets were housed at 20 weeks of age, in laying cages, using 240 from each stock. The 240 pullets of each stock were separated into eight lots of 30 pullets each, each lot housed at the rate of two birds per cage. Cage size was 8" x 16". Thus, in each stock there were two lots on each of the four treatments. The four treatments were 0.5% and 0.25% of salt with and without 0.5% bicarbonate of soda in the Seventeenth Test (Table III). In the Eighteenth Test, a laying ration containing 16.7% protein was offered to all pullets from time of housing to 168 days of age. After that a ration containing 13.0% protein but having different levels of choline or methionine constituted the four treatments in that Test (Table IV). The first treatment diet had no added choline or methionine (EL-38). The second treatment diet had added choline (EL-211). The third treatment diet had added methionine (EL-212). The fourth treatment diet had both choline and methionine added (EL-213). Each ration was fed to two lots of each stock. A randomized block design was applied in assigning the treatments in each block and the stocks within each treatment. The Seventeenth Test contained fourteen stocks while the Eighteenth Test had twelve stocks. Each test contained the Kentville-Cornell stock as a control. Water was supplied by continuous-flow troughs. A 14-hour-light day was provided

Table II

Starter and Grower Diets

Feedstuffs	Starter BR1	Grower GR6	Grower GR10
	lbs.	lbs.	lbs.
Yellow corn	638.00	718.75	753.75
Alfalfa meal, 17%	25.00	50.00	50.00
Fish meal	25.00	25.00	25.00
Vitamin mix[a]	6.00	6.00	6.00
Deflourinated Rock Phosphate	15.00	15.00	15.00
Ground Limestone	6.00	10.00	10.00
Salt	4.80	5.00	5.00
Manganese sulfate	0.20	0.25	0.25
Soybean oil meal, 50%	255.00	145.00	135.00
Coccidiostat premix	25.00	25.00	-
	1000.00	1000.00	1000.00
Calculated to contain:			
Crude protein, %	21.95	17.59	16.16
Productive energy, C/lb.	957	966	977
C/P (calorie: protein ratio)	43.60	54.92	60.46
Metabolizable energy C/lb.	1365	1382	1396
Metabolizable energy C/P	62.19	78.57	86.39
Methionine, %	.36	.30	.29
Cystine, %	.32	.26	.25
Lysine, %	1.25	.92	.82
Calcium, %	.89	1.05	1.05
Phosphorus, %	.68	.63	.62
Available phosphorus, %	.43	.42	.42
Manganese, Mg/lb	32.21	37.08	36.42
Vitamin A, I.U./lb.	5349	7966	8022
Vitamin D, I.C.U./lb.	340	340	340
Riboflavin, Mg./lb.	3.05	3.10	3.07
Nacin, Mg./lb.	28.44	28.43	28.41
Pantothenic acid, Mg./lb.	6.71	6.57	6.44
Choline, Mg./lb.	761.02	654.20	617.10

[a]Mineral and vitamin content calculated to equal or exceed NRC requirements, BR1 fed for first 8 weeks, GR6 fed 9th-14th week and GR10 fed 15th to 20th week.

Table III

Layer Diets Used in the Seventeenth Test

Feedstuffs	Hi Salt	Lo Salt	Hi Salt Bicarb	Lo Salt Bicarb
Yellow corn	759.75			
Alfalfa meal, 17%	50.00			
Fish meal	25.00			
Vitamin mix[a]	5.00			
Deflourinated Rock Phosphate	15.00			
Ground limestone	60.00			
Salt	5.00	2.50	5.00	2.50
Manganese sulfate	0.25			
Soybean oil meal, 50%	77.50			
Coccidiostat premix	-	-	-	-
Sand	2.50	5.0	-	2.50
Bicarbonate	-	-	5.00	5.00
	1000.00	1000.00	1000.00	1000.00
Calculated to contain:				
Crude protein, %	13.34			
Productive energy, C/lb.	938.3			
C/P (calorie: protein ratio)	70.34			
Metabolizable energy C/lb.	1339.5			
Metabolizable energy C/P	100.4			
Methionine, %	.25			
Cystine, %	.21			
Lysine, %	.63			
Calcium, %	2.79			
Phosphorus, %	.59			
Available phosphorus, %	.42			
Managanese, Mg/lb.	35.39			
Vitamin A, I.U./lb.	8031			
Vitamin D, I.C.U./lb.	340			
Riboflavin, Mg./lb.	3.0			
Nacin, Mg./lb.	27.92			
Pantothenic acid, Mg./lb.	6.11			
Choline, Mg./lb.	544			

[a]Mineral and vitamin content calculated to equal or exceed NRC requirements.

Table IV

Layer Diet Used in the Eighteenth Test

Feedstuffs	LR-4	EL-38	EL-211	EL-212	EL-213
Yellow corn	673.60	766.10	764.10	764.10	762.10
Alfalfa meal, 17%	50.00				
Fish meal	25.00				
Vitamin mix[a]	5.00				
Deflourinated Rock Phosphate	15.00				
Ground limestone	56.15				
Salt	5.00				
Manganese sulfate	0.25				
Soybean oil meal, 50%	170.00	77.50			
Coccidiostat premix	-	-	-	-	-
Choline, 50%	-	-	2.00	-	2.00
Methionine, 100%	-	-	-	2.00	2.00
	1000.00				
Calculated to contain:					
Crude protein, %	16.70	13.00			
Productive energy, C/lb	950.00	983.00			
C/P (calorie: protein ratio)	56.89	75.62			
Metabolizable energy C/lb.	1301.00	1336.00			
Metabolizable energy C/P	77.90	102.77			
Methionine, %	.30	.25	.25	.45	.45
Cystine, %	.27	.22			
Lysine, %	.86	.59			
Calcium, %	2.9				
Phosphorus, %	.64	.61			
Available phosphorus, %	.43	.42			
Manganese, Mg/lb.	36.96	35.49			
Vitamin A, I.U./lb.	6792.00	6884.00			
Vitamin D, I.C.U./lb.	1342.00				
Riboflavin, Mg./lb.	2.92	2.83			
Nacin, Mg./lb.	21.03				
Pantothenic acid, Mg./lb.	5.81	5.44			
Choline, Mg./lb.	480.62	547.24	1000.00	546.76	1000.00

[a] Mineral and vitamin content calculated to equal or exceed NRC requirements, LR-4 fed 21st to 24th week.

throughout the laying period. The layer diet did not contain a coccidiostat (Table III, page 40 and Table IV, page 41), but it was added to starter and grower diets (BR_1 and GR6, Table II, page 39). Rations were fed ad libitum during all 500 days of each experiment. Termination was on August 8, 1974 and 1975 for the two Tests, respectively.

Variable Names

The Seventeenth Test data included the following independent variables: Block (B), Stock (S), Salt (S1) and bicarbonate of soda (Bi); and the Eighteenth Test data included: Block (B), Stock (S), Choline (C), and Methionine (M).

The dependent variables in both Tests were the same except for shell pebbles score (Shell) which was recorded in the Seventeenth Test but not in the Eighteenth. Variables recorded were: percent hen-housed production (%HHP), percent hen-day production (%HDP), percent peewee (%PWE), percent small (% Small), percent medium (% Medium), percent large (% Large), percent extra large and over (%X-Large), average egg weight (AEW), pounds of feed per bird housed (LBF/BH), pounds of feed per pound of eggs (LBF/LBEG), pounds of feed per dozen eggs (LBF/DZ), percent mortality (%MORT), average specific gravity (SPGR), percent small blood spots (%SBS), percent large meat spots (%LMS), average Haugh units (HAUGH), average body weight at end of experiment (BWT), income over feed and chick costs (PROF), and age in days at 50% production, sexual maturity (SEX).

Data Collection and Calculations

The dependent variables (traits) considered in this study were measured on a lot basis. Daily egg production was recorded for each lot five days a week. A conversion to a seven day week basis was made by multiplying by 1.4. Percent hen-housed production was determined by multiplying by 100 the result of dividing the total number of eggs produced by each lot of hens by the product of number of hens housed and number of days in the laying house. Percent hen-day production was calculated by multiplying by 100 the ratio of average number of eggs produced per hen to the average number of days hens stayed in the laying house.

Egg weight was obtained once during each 28-day period by weighing individually the eggs of that day. These eggs were graded into five weight classes of: peewee, small, medium, large, and extra-large and larger.

Feed consumption was determined each period for each lot. Pounds of feed per hen housed was obtained by dividing the total amount of feed consumed in all periods by number of birds housed at the beginning of the Test in each lot. Pounds of feed per pound of eggs was determined by dividing the amount of feed consumed by each lot of hens by the total weight of eggs in pounds produced in that lot. Pounds of feed per dozen eggs was calculated by dividing the amount of feed consumed in each pen by number of dozen of eggs laid by the hens of that pen.

Percent mortality was calculated by multiplying by 100 the ratio of dead birds to the number of birds housed. Dead birds were collected

daily, and necropsies were performed to determine the cause of death.

The egg quality traits such as Haugh units, calculated from albumen height and egg weight, and the incidence and size of blood and meat spots were recorded on a quarterly basis from eggs laid on one day each quarter in each lot. Shell roughness score as measured by shell pebbles was recorded on one day in each 28-day period. Shells were given scores of 1 (no pebbles) through 5 (very rough shell). Shell thickness of each egg laid on one day of a 28-day period in each lot was measured by the specific gravity method. Ten salt solutions were used for that purpose. Successive concentrations differed by 0.004, starting with 1.068 (score -0) and ended with 1.1 (score -8) specific gravity. The presence of blood and meat spots were determined by breaking out five eggs from each lot. The Haugh units score was determined using both albumen height and egg weight for each of the five eggs of each lot.

Body weight in kilograms was recorded at the termination of the test.

Sexual maturity was measured as the age of the pullets of each lot when they approached 50% production for three consecutive days of lay.

Income from each lot was from the sale of eggs and spent hens at termination of the test. The prices of eggs, feed, chicks and market hens used to determine income and costs were local prices and were assumed to be representative of the local situation at that particular time. The chick prices used were those provided by the breeders based on commercial grades of chicks purchased in lots of 10,000. The market

price per pound at the time the test was terminated was considered in calculating income from the sale of each lot of hens. Feed consumption until 20-weeks of age was calculated by multiplying the live weight of each pullet at that time by six, the estimated amount of feed required to produce one pound of live-weight of egg type pullets at 20-weeks of age. Feed prices were calculated on the basis of current local ingredient costs plus five dollars per ton as a mixing cost. Therefore, the cost of each lot included the chick costs, feed cost during the growing period, and feed cost during the laying period.

The income from eggs produced was calculated by using the prices for different sizes of eggs quoted in the Chicago Market quotations to producers. The net income from eggs was added to income from hens sold to obtain the income for each lot.

Profit per hen in each lot was calculated by substracting the costs of each lot from the income it produced.

II. METHODS OF ANALYSES

Analysis of data from these two Tests involved four general kinds of calculations. The first was analysis of variance based on a factorial arrangement of stocks, salt levels and with and without bicarbonate of soda in the Seventeenth Test. In the Eighteenth Test the arrangement was on the basis of stocks, choline and methionine levels. The following mathematical models are the basis for the analysis of data from each of the respective Tests.

Seventeenth Test

$$Y_{ijklm} = \mu + B_i + S_j + Sl_k + S \times Sl_{jk} + Bi_l + S \times Bi_{jk} + Sl \times Bi_{kl} + S \times Sl \times Bi_{jkl} + e_{ijklm}$$

where:

B_i = effect of i^{th} block, i = 1, 2 blocks

S_j = effect of j^{th} stock, j = 1, 2 ... 14 stocks

Sl_k = effect of k^{th} level of salt, k = 1, 2 levels

$S \times Sl_{jk}$ = effect of jk^{th} stock-by-salt-level interaction

Bi_l = effect of l^{th} level of bicarbonate, l = 1, 2 levels

$S \times Bi_{jl}$ = effect of jl^{th} stock-by-bicarbonate-level interaction

$S \times Sl \times Bi_{jkl}$ = effect of jkl^{th} stock-by-salt-by-bicarbonate-level interaction

m = 1, 2 lots per stock in each salt level in each level of bicarbonate

e_{ijklm} = random error associated with the m^{th} lot fed the l^{th} level of bicarbonate and the k^{th} level of salt from the j^{th} stock in the i^{th} block. The overall mean of the population is symbolized by μ.

Eighteenth Test

$$Y_{ijklm} = \mu + B_i + S_j + C_k + SC_{jk} + M_l + SM_{jl} + CM_{kl} + SCM_{jkl} + e_{ijklm}$$

where:

i = 1, 2 blocks

j = 1, 2, ..., 12 stocks

k = 1, 2 levels of choline

l = 1, 2 levels of methionine

m = 1, 2 lots per stocks fed each level of choline and each level of methionine.

Y_{ijklm} is the observation of the m^{th} lot fed the i^{th} level of methionine and the k^{th} level of choline from the j^{th} stock in the i^{th} block.

M is the overall mean parameter of the population.

e_{ijklm} represents random variation among lots of the same entry.

The second kind of analysis involved calculating coefficients of correlation between economic traits studied with all stocks and treatments combined, for each stock with all treatments combined and for each treatment with all stocks combined to determine the magnitude and the sign of these relationships.

The third kind of analysis consisted of conducting Bartlett's Test of homogeneity of variances among stocks and treatments studied in each Test.

Procedure for Conducting Bartlett's Test

1. The variances of each stock with all treatments combined and each treatment with all stocks combined were calculated.

2. The common logarithm of each variance was obtained. In each stock and treatment subclass the logarithms were summed.

3. In each stock and treatment subclass the mean of the variances was calculated and its logarithm obtained. Then that logarithm was multiplied by number of stocks or of treatments involved.

4. Result of (2) was substracted from result of (3); then the new result was multiplied by the number of degrees of freedom for each

stock or treatment and then the natural logarithm obtained by multiplying the result by the constant (2.3026).

5. Result of (4) was divided by a correction factor calculated by the formula:

$$C = 1 + \frac{N + 1}{3N\ df}$$

where:

N = number of variances

df = number of observation on which each variance is based -1.

The fourth kind of analysis consisted simply of conventional calculation of the mean of each stock in each Test and its standard error. Standard error of a mean ($S_{\bar{x}}$) was calculated in the usual way by dividing the standand deviation by the square root of the number of observation in each stock (number of lots = 8).

CRANFIELD CREST

CHAPTER V

RESULTS AND DISCUSSION

I. ANALYSIS OF VARIANCE

Results of analyses of variances of the various traits are presented in the conventional tabular form.

Block mean square with one degree of freedom in each Test was evaluated to reduce experimental error, block being simply a conventional feature of the design. Significance of block effect is not presented in the tables since block effect, even though large enough to be declared significant, must be due to chance.

Significant interaction mean squares were used as error terms to make appropriate tests of significance of other mean squares according to theoretical composition of mean squares. Pooling of sums of squares and degrees of freedom was done to obtain new appropriate error terms when interactions were non-significant.

Block effect was considered to be a random effect; all others were considered as fixed effects.

Egg Production

Analyses of variance of the two egg production traits are shown in Tables V and VI. Strains were found to differ significantly ($P < 0.001$) from each other in both tests with respect to both egg production traits. These results are in agreement with those obtained by Marks et al. (1969a)

Table V

Analysis of Variance of Egg Production (Seventeenth Test)

Source	Degrees of Freedom	Mean Square	
		% Hen-Housed Egg Production	% Hen-Day Egg Production
Block (B)	1	50.36	126.23
Stock (S)	13	145.05***	117.80***
Treatment (T)	3	3.43	9.61
S x T	39	7.52	5.97
B x S1	1	42.39*	--- [a]
Error	54	7.73	6.73
Total	111	--	--

*$P \leq 0.05$
***$P \leq 0.001$

[a]This interaction was pooled with the error to obtain an appropriate estimate of error based on 55 degrees of freedom.

Table VI

Analysis of Variance of Egg Production (Eighteenth Test)

Source	Degrees of Freedom	Mean Square	
		% Hen-Housed Egg Production	% Hen-Day Egg Production
Block (B)	1	16.92	3.64
Stock (S)	11	174.57***	183.28***
Treatment (T)	3	4.37	4.01
S x T	33	10.75	5.53
Error	47	9.60	7.69
Total	95	--	--

***P< 0.001

Cranes Crest

Hunt and Aitken (1970), Choudary et al. (1972) and Srinvasan (1972). However, they are contradicted by the results of Wilson et al. (1967), Balnave (1974) and Bhagwat and Craig (1975).

Ranks of stocks with respect to various egg production traits are shown in Table VII. In both Tests the first 11 stocks were the same. An interesting result of the ranking is that stocks number 2 in the Seventeenth Test had the highest value for both egg production traits while in the Eighteenth Test it had ranks 6 and 4 for percent hen-housed and percent hen-day egg production, respectively. Several pronounced changes in the ranks of various strains occurred between the Seventeenth and Eighteenth Test. Some of these changes, but probably not all of them, could be simply sampling differences. Though satisfactory between Test comparisons cannot be made to substantiate a statement to the effect that some stocks underwent genetic change between the Tests, it seems likely that some did.

None of the individual treatment effects was significant in either Test nor were their interactions with stocks. Hence, they were combined. These results are confirm those of Tindell et al. (1968), Aitken et al. (1972) and Christmas et al. (1974), while they are in disagreement with the results of Wilson et al. (1967), Marks et al. (1969a) and Choudary et al. (1972).

Average Egg Weight

Stock was a significant ($P < 0.001$) influence on average egg weight in both Tests (Tables VIII and IX). The differences among stocks with respect to this trait for both tests are obvious from observation of

Table VII

Ranks of Stock Means with Respect to Some Economic Traits
(Seventeenth and Eighteenth Test)

Stock	% HHP		% HDP		% PEEWEE		%SMALL		% MEDIUM		% LARGE		% XLARGE		AEW		LBF/BH		LBF/LBEGG		LBF/DZ	
	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th
1	11	8	9	3	9	9.5	6	7	6	4	2	2	9	8	9	8	12	11	10	8	11	10
2	1	6	1	4	4	4	10	4	11	9	11	10	4	4	4	4	5	3	13	6	13	5
3	9	10	12	10	3	1	3	2	5	3	1	4	12	10	12	11	13	12	12	7	14	11
4	7	4	6.5	6	7.5	7	8	9	10	12	10	12	5	1	6	2	6	4	6	11	5	8
5	4	5	3	5	7.5	8	11	8	12	8	12	8	3	5	3	5	7	6	14	9	12	7
6	13	12	13	12	1	2	2	1	2	1	6	5	13	12	14	12	8	10	1	1	2	1
7	12	3	11	7	2	3	1	3	1	2	7	3	14	11	13	10	11	5	3	5	6	9
8	2	1	2	2	12	12	12	12	7.5	10	4	11	6	2	5	1	3	2	11	10	10	6
9	5	2	6.5	1	13	11	13	10	14	5	14	1	1	9	1	9	1	9	4	12	1	12
10	3	9	4	9	6	6	9	5	7.5	6	5	7	7	7	7	7	4	8	7	4	7	4
11	6	11	8	11	14	5	14	6	13	7	13	6	2	6	2	6	2	7	5	2	4	2
12	8	7	5	8	10.5	9.5	7	11	3	11	3	9	11	3	10	3	9	1	9	3	9	3
13	10	-	10	-	10.5	-	4	-	9	-	8	-	8	-	8	-	10	-	8	-	8	-
14	14	-	14	-	5	-	5	-	4	-	9	-	10	-	11	-	14	-	2	-	3	-

Table VIII

Analysis of Variance of Egg Weight, Body Weight, and Percent Mortality (Seventeenth Test)

Source	Degrees of Freedom	Mean Square		
		Average Egg Weight	Final Body Weight	% Mortality
Block (B)	1	0.004	--[a]	277.83
Stock (S)	13	31.79***	0.44***	112.84***
B x S	13	1.10*	--[b]	--[b]
Treatment (T)	3	1.36	0.01	68.63
Salt (S1)	1	1.68*	0.004	31.08
Bicarbonate (Bi)	1	0.21	0.03	174.50*
S1 x Bi	1	2.20*	0.0004	0.30
S x S1	13	1.09**	0.034*	35.99
S x S1 x Bi	13	0.92*[c]	0.01	10.44
Error	42	0.41	0.01	31.86
Total	111	--	--	--

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

[a]This term was ignored because the average of both blocks was used.

[b]This interaction was pooled with error to obtain an appropriate error term based on 55 degrees of freedom for testing %-mortality mean squares.

[c]This interaction was used as an error term for making appropriate tests of other egg-weight mean squares.

Table IX

Analysis of Variance of Egg Weight, Body Weight, and Percent Mortality (Eighteenth Test)

Source	Degrees of Freedom	Mean Square		
		Average Egg Weight	Final Body Weight	% Mortality
Block (B)	1	0.33	0.001	119.04
Stock (S)	11	27.57***	0.37***	156.47***
Treatment (T)	3	2.14	0.03	48.78
Choline (C)	1	5.61*	0.03	37.13
Methionine (M)	1	0.02	0.05	79.39
C x M	1	0.81	0.005	29.82
S x T	33	1.11	0.01	22.01
Error	47	1.06	0.02	28.25
Total	95	--	--	--

*P $\leq$ 0.05
***P $\leq$ 0.001

the ranks in Table VII (page 53). The changes in rank of stocks according to average egg weight suggests some progress of breeder effort to improve this trait. Stock number 8 with the fifth rank in the Seventeenth Test became the highest ranking in the Eighteenth Test. Also, stock number 4 with the sixth rank in the Seventeenth became ranked second in the Eighteenth. Lowering of ranks also occurred. Stock number 9 had the highest average egg weight in the Seventeenth Test but was ninth in the Eighteenth Test. Stock number 11 showed the same loss in rank. These results agree generally with those of Hunt and Aitken (1970), Perek and Snapir (1970), Aitken et al. (1972) and Bànave (1974) but differ from those of Wilson et al. (1970) and Mather and Gleaves (1970).

In the Seventeenth Test salt level was found to have a significant ($P < 0.05$) effect on average egg weight, while the bicarbonate effect was not significant. This is in agreement with results of Hunt (1972), Frank and Burger (1965) and Ferguson et al. (1974) but not with those obtained by Howes (1966), Monsi and Enos (1973) and Nesbeth et al. (1974).

In the Eighteenth Test the only significant ($P < 0.05$) treatment effect was choline (Table IX, page 55).

Stock by salt level interaction had a significant ($P < 0.01$) effect on average egg weight. Strain by salt by bicarbonate and salt by bicarbonate interactions significantly ($P < 0.05$) affected this trait, while no stock by treatment interaction was significant in the Eighteenth Test. These results confirmed the results obtained by Wilson et al (1967), Marks et al. (1969a,c) and Christmas et al. (1973). However, they contradict the results of Adams and Jackson (1970) and Tindell et al. (1968).

Final Body Weight

There were highly significant ($P < 0.001$) stock differences in final body weight in both Tests (Tables VIII and IX, pages 54 and 55).

Table X contains the ranks of the stocks with respect to this trait for both Tests. All of the common stocks (number 1 through number 11) did improve their ranks from one Test to the other except three of them. Two of these three (number 5 and 10) dropped only one rank. Stock number 9 had the largest change in rank, highest in the Seventeenth Test and ninth in the Eighteenth Test.

Treatment did not have any significant effect on final body weight in either Test. These results confirm results of Jensen et al. (1974) and Armanious et al. (1973).

The only significant ($P < 0.05$) interaction was between strain and salt in the Seventeenth Test. Others were non-significant in both Tests. These results agree with those obtained by Ali (1973) and Christmas et al. (1973), but they disagree with those obtained by Tindell et al. (1967), Marks et al. (1969a,b) and Aitken et al. (1972, 1973).

Mortality

Stock differences were significant ($P < 0.001$) with respect to percent mortality during the laying period in both Tests (Tables VIII and IX, pages 54 and 55).

Ranking of the stocks with respect to percent mortality did not show any consistent trend from Test to Test Table X. This may be one of the reasons for the large differences among stocks with respect to this trait. Stock number 6 had the ninth rank in the Seventeenth Test,

Table X

Ranks of the Stocks for Other Economic Traits Means
(Seventeenth and Eighteenth Test)

Stock	% MORT		SPGR		% S Blood		% L Blood		% S Meat		% L Meat		Haugh		Body Wt.		Profit		SEX		SHELL	
	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th	17th	18th
1	4	1	12	12	10.5	2	4	2.5	12	10	10.5	8	5	5	12	10	8	6	2	5	12	-
2	10	3	7	6	13	12	6.5	8.5	7.5	6	4.5	11	12	9	9	8	1	8	11	12	1	-
3	11	7	2.5	1	13	8.5	12	6.5	3	3	10.5	11	7	11	14	12	4	7	3.5	11	7	-
4	5	10	2.5	5	6	5.5	8.5	10.5	7.5	4	4.5	6	14	4	11	7	7	3	3.5	4	3	-
5	1	5	8	8	3	10.5	6.5	12	4	10	10.5	5	13	12	4	5	3	5	9	7	11	-
6	9	2	6	7	4	3.5	2	4.5	5	10	4.5	3.5	9	10	3	3	13	12	1	1	4	-
7	6	11.5	5	4	5	5.5	8.5	6.5	7.5	6	4.5	11	4	1	13	11	12	4	10	8	6	-
8	12	8	4	2	13	7	12	10.5	12	6	10.5	8	3	3	7	4	2	2	8	10	2	-
9	14	6	13	3	1	8.5	1	8.5	2	10	2	8	6	8	1	9	10	1	5	6	14	-
10	7	4	11	9	8	10.5	4	4.5	7.5	10	10.5	3.5	2	6	5	6	5	9	7	9	8	-
11	13	11.5	14	11	2	1	4	1	1	2	1	2	8	2	2	1	11	11	12	2	13	-
12	3	8	1	10	9	3.5	12	2.5	12	1	10.5	1	1	7	8	2	6	10	14	3	5	-
13	8	-	10	-	7	-	12	-	12	-	10.5	-	10	-	10	-	9	-	13	-	10	-
14	2	-	9	-	10.5	-	12	-	12	-	10.5	-	11	-	6	-	14	-	6	-	9	-

while it had the second highest percent mortality in the Eighteenth Test. Similarly, stock number 2 had the tenth rank in the Seventeenth Test then ranked the third in the Eighteenth Test. Rank of stock number 9 changed from fourteenth to sixth.

Bicarbonate effect on percent mortality was significant ($P < 0.05$) while other treatment effects were not significant in either Test. These results are in agreement with those obtained by Ferguson et al. (1974) but in disagreement with those of Pepper et al. (1968).

Stock by individual treatment interactions were not significant in either Test. These results confirm those obtained by Tindell et al. (1967, 1968), Marks et al. (1969a), Hunt and Aitken (1970) and Christmas et al. (1973, 1974), while they contradict those of Marks et al. (1969b) and Choudary et al. (1972).

Egg Size Distribution

Differences among stocks were found to be significant with respect to egg size distribution ($P < 0.05$ for % PWE, $P < 0.001$ for % Small, % Medium, % Large and % X-Large in both Tests, Tables XI, XII and XIII).

Comparison of stock means Table VII (page 53), shows that some stocks produced eggs consistently distributed such as stocks number 6 and 7, while others did not. Stock number 9, the fourteenth ranking one in the Seventeenth Test in producing medium and large eggs, improved its rank considerably. Of X-Large eggs, it had produced the highest percentage in the Seventeenth Test but was ninth in the Eighteenth Test. Stock number 8 was fourth in producing large eggs then dropped to eleventh. Stock number 2 was tenth in the Seventeenth Test then rose to fourth in the Eighteenth Test in producing small eggs.

Table XI

Analysis of Variance of Some Egg Size Percentages
(Seventeenth Test)

Source	Degree of Freedom	Mean Square	
		% PeeWee	% Small
Block (B)	1	0.02	7.72
Stock (S)	13	1.15*	102.10***
B x S	13	0.43*	--[a]
Treatment	3	0.44	0.76
Salt (Sl)	1	0.02	1.65
Bicarbonate (Bi)	1	0.08	0.32
Sl x Bi	1	1.22**	0.30
B x Bi	1	--[b]	30.87**
Stock x Treatment	39	0.11	2.88
Error	41	0.13	3.67
Total	111	--	--

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

[a]This term was pooled with error to obtain an appropriate error term based on 54 degrees of freedom for testing %-small mean squares.

[b]This term was pooled with error term to get an appropriate error term based on 42 degrees of freedom for testing %-peewee mean squares.

Table XII

Analysis of Variance of Other Egg Size Percentages
(Seventeenth Test)

Source	Degrees of Freedom	Mean Square		
		% Medium	% Large	% Extra-large & over
Block (B)	1	91.62	45.26	0.07
Stock (S)	13	227.59***	2208.24***	1205.51***
Treatment (T)	3	7.59	29.24	21.56
S x S1	13	14.28	12.04	17.25*
S x Bi	13	12.24	19.77*	14.45
S x S1 x Bi	13	14.32	4.65	23.71
Error	55	9.32	16.35	17.15
Total	111	--	--	--

*P $\leq$ 0.05
**P $\leq$ 0.01
***O $\leq$ 0.001

Table XIII

Analysis of Variance of Egg Size Distribution
(Eighteenth Test)

Source	Degrees of Freedom	Mean Square of % Egg Size Characteristics				
		%PeeWee	% Small	% Medium	% Large	% X-Large
Block (B)	1	0.10	3.05	16.17	3.30	0.01
Stock (S)	11	0.59*	16.99***	275.36***	182.01***	1000.94***
Treatment (T)	3	0.003	2.70	22.61	0.71	30.17
Choline (C)	1	0.003	7.43	57.04*	1.5	82.51
Methionine (M)	1	0.01	0.41	0.77	0.63	1.17
C x M	1	0.001	0.27	10.01	0.0004	6.83
S x C	11	0.16	2.19	25.45	31.95*	31.96
S x M	11	0.18	.02	15.53	9.45**	30.11
Error	47	0.23	1.95	14.03	14.57	26.40
Total	95	--	--	--	--	--

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

None of the treatments significantly affected egg size distribution in either Test with the exception of the effect of choline on percent of medium eggs ($P < 0.05$). These results agree with most of the results obtained by many investigators such as Balloun (1956), Ketola and Nasheim (1974), and Nestler (1961).

Egg size distribution was affected by many interaction effects. In the Seventeenth Test, salt by bicarbonate interaction was significant ($P < 0.01$) for percent peewee. Stock by salt interaction was significant ($P < 0.05$) for percent extra-large. Stock by bicarbonate was significant ($P < 0.05$) for percent large eggs. Other interactions were not significant. In the Eighteenth Test, percent large egg size was affected significantly ($P < 0.05$) by stock by choline interaction, by stock by methionine interaction ($P < 0.01$), and by stock by choline and methionine interaction ($P < 0.05$). Stock by choline by methionine had a significant ($P < 0.05$) effect also on percent small eggs. Other interactions were declared non-significant. These different evidences of interaction support the findings of some investigators while they contradicted those of others.

Feed Efficiency

Analyses of variances of measures of feed efficiency are presented in Tables XIV and XV.

Stocks were observed to differ significantly ($P < 0.001$) with regard to feed efficiency traits except pounds of feed per dozen of eggs in the Eighteenth Test. These results are in agreement with those of Marks *et al*. (1969b), Aitken *et al*. (1972, 1973) and Christmas *et al*. (1973, 1974) but in disagreement with those obtained by Wilson *et al*. (1967)

Table XIV

Analysis of Variance of Feed Consumption and Efficiency
(Seventeenth Test)

Source	Degrees of Freedom	Mean Square		
		Lb Feed/ Hen Housed	Lb Feed/ Lb Eggs	Lb Feed/ Dozen Eggs
Block (B)	1	3.43	0.08	0.18
Stock (S)	13	238.12***	0.25***	0.46***
Treatment (T)	3	5.17	0.01	0.01
S x T	39	6.34	0.01	0.03
B x S1	1	35.21*	-- [a]	-- [a]
Error	54	5.96	0.02	0.04
Total	111			

*P≤ 0.05
***P≤ 0.001

[a]This term was pooled with error to obtain an appropriate error term based on 55 degrees of freedom each for testing lb. feed/ lb. eggs and lb. feed/dozen eggs.

Table XV

Analysis of Variance of Feed Consumption and Efficiency
(Eighteenth Test)

Source	Degrees of Freedom	Mean Square of Lb. Feed Per		
		Bird Housed	Lb. Eggs	Doz Eggs
Block (B)	1	52.36	0.003	0.003
Stock (S)	11	195.44***	0.39***	0.69
Treatment (T)	3	20.65	0.03	0.07
Choline (C)	1	1.79	0.002	0.02
Methionine (M)	1	48.88*	0.08*	0.19*
C x M	1	11.28	0.001	0.0003
B x M	1	45.24*	--[a]	--[a]
S x T	33	8.63	0.01	0.02
Error	46	10.26	0.02	0.03
Total	95	--	--	--

*P $\leq$ 0.05
***P $\leq$ 0.001

[a]This term was pooled with error to obtain an appropriate error term for lb. feed/lb. eggs and lb. feed/dozen eggs.

and Hunt and Aitken (1970).

Table VII (page 53), presents the rank of stocks with respect to feed efficiency traits. Some stocks had a similar rank from Test to Test, such as sock number 6 had the highest amount of feed consumed per pound of eggs in both Tests while others changed rank considerable from one Test to the other. Stock number 7 ranked eleventh in the Seventeenth Test, but was fifth in the Eighteenth Test, stock number 9 changed from the highest rank in the Seventeenth Test to ninth in theEighteenth Test and stock number 11 was second in the Seventeenth Test and seventh in the Eighteenth Test with respect to pounds of feed per bird housed. With respect to pounds of feed per dozen eggs, stock number 2 had ranked next to lowest in the Seventeenth Test but was fifth in the Eighteenth Test. Stock number 9 had the highest amount of feed per dozen eggs in the Seventeenth Test while it had the lowest amount in the Eighteenth Test.

In the Seventeenth Test, differences among treatments in the three of feed efficiency traits were found to be non-significant. These results agree with those of Morrison (1975) but contradict those obtained by Morrison et al. (1973). In the Eighteenth Test methionine level significantly ($P < 0.05$) effected feed efficiency while the choline effect was not significant. These results agree with those obtained by Harms et al. (1962), Wilbur and Fuller (1975) and Jensen et al. (1974) but differ from those obtained by Ketola and Young (1973), Jukes et al. (1945) and Armanious et al. (1973).

Stock by individual treatment interactions were found to have non-significant effects on feed efficiency in both Tests. These results are in agreement with those obtained by Wilson (1967) and Tindell et al.

(1968) but differ from those obtained by Tindell et al. (1967), Aitken et al. (1972, 1973), Al-Mohammadi and Shirley (1974) and Christmas et al. (1974).

Egg Quality

Stocks were observed to differ significantly ($P < 0.001$) from each other with respect to all egg quality traits in the two Tests (Tables XVI and XVII). These results confirm the findings of Wilson et al. (1967), Adams and Jackson (1970), Al-Rawi and Amer (1972) and Aitken et al. (1972, 1973). However they do not agree with the findings of Tindell et al. (1967) and Mather and Gleaves (1970).

Table X (page 58) shows the stock ranks in the two Tests. Stocks involved in both Tests had mostly consistent ranks from Test to Test. Stock number 1 had the twelfth and fifth ranks in the two Tests for specific gravity and Haugh units traits, respectively. Stock number 5 behaved similarly, having the eighth rank in the two Tests for specific gravity and next to lowest Haugh unit score in the Seventeenth Test and the lowest in the Eighteenth Test. Stock number 8 had the third highest Haugh unit score in the two Tests and had the fourth and the second highest specific gravity in the two Tests, respectively. At the same time, some stocks showed inconsistent ranks from Test to Test in specific gravity and Haugh units. Stock number 4 had the lowest Haugh unit score in the Seventeenth Test while it had the fourth highest score in the Eighteenth Test. Stock number 9 had the second lowest value for specific gravity in the Seventeenth Test, while it had the third highest value in the Eighteenth Test.

Shell roughness was studied in the Seventeenth Test only.

Table XVI

Analysis of Variance of Specific Gravity, Haugh Units and Shell Roughness (Seventeenth Test)

Source	Degrees of Freedom	Mean Square		
		Specific Gravity	Haugh Units	Shell Roughness
Block (B)	1	0.97	0.86	1.75
Stock (S)	13	1.45***	61.52***	26.94***
Treatments (T)	3	0.04	14.92	1.60
B x S1	1	-- [a]	37.49**	-- [a]
B x Bi	1	0.41*	87.51***	-- [b]
S x S1	13	0.02	7.91*	1.01
S x Bi	13	0.03	3.56	1.18
S x S1 x Bi	13	0.02	3.96	1.35
Error	53	0.04	3.34	1.79
Total	111			

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

[a] This term was pooled with error to obtain an appropriate error term based on 54 degrees of freedom for testing specific gravity.

[b] This term was pooled with error to obtain an appropriate error term based on 55 degrees of freedom for testing shell roughness.

Table XVII

Analysis of Variance of Specific Gravity, Haugh Units, Profit Per Hen and Age at Sexual Maturity (Eighteenth Test)

Source	Degree of Freedom	Mean Square			
		Specific Gravity	Haugh Units	Profit Per Hen	Sexual Maturity
Block (B)	1	1.67	29.70	0.05	26.04
Stock (S)	11	0.95***	75.93***	4.54***	290.42***
Treatment (T)	3	0.45*	4.18	0.02	2.81
Choline (C)	1	0.08	3.60	0.0002	0.00
Methionine (M)	1	0.87***	4.51	0.003	3.38
C x M	1	0.403**	4.42	0.04	5.04
S x T	33	0.06	5.61	0.21	10.90
Error	47	0.06	5.79	0.18	11.00
Total	95	--	--	--	--

**P $\leq$ 0.01
***P $\leq$ 0.001

Differences among stocks in shell roughness scores are obvious from the rank of the stocks. Stock number 2 had the highest score, while stock number 9 had the lowest score for this trait (Table XVI).

The only significant ($P < 0.001$) effect of treatment was that of methionine on specific gravity in the Eighteenth Test. Other treatments had no significant effects on any of the egg quality traits in the two Tests.

Magnitude of the stock by individual treatment interaction was not sufficient to show a significant effect on egg quality traits except for the stock by salt interaction ($P < 0.05$) on Haugh units. Choline by methionine interaction also had a significant ($P < 0.01$) effect on specific gravity. Other first and second order interactions were not significant.

Profit Per Hen

Stock showed a significant ($P < 0.001$) effect on the performance index, income over chick and feed cost or profit per hen (Table XVII and Table XVIII). These results confirm the findings of Mackin (1970) and Al-Mohammadi and Shirley (1974).

Comparison of the profit-per-hen means of all stocks involved in both Tests is presented in Table X (page 58) as a stock ranking. This comparison shows some interesting points such as: Stock number 11 had the eleventh rank in both Tests, stock number 2 had the second highest profit per hen in the two Tests and stock number 6 had the second lowest profit and the lowest profit per hen in the two Tests, respectively. stock number 2 had the highest profit per hen in the Seventeenth Test

Table XVIII

Analysis of Variance of Profit Per Hen and Age at Sexual Maturity (Seventeenth Test)

Source	Degrees of Freedom	Mean Square	
		Profit per hen	Sexual Maturity
Block (B)	1	1.88	339.51
Stock (S)	13	2.76***	108.62***
Treatment (T)	3	0.04	5.96
S x T	39	0.16	7.74
Error	55	0.21	14.36
Total	111	--	--

***P< 0.001

then ranked eighth in the Eighteenth Test. Stock number 7 was twelveth in the Seventeenth Test and fourth in the Eighteenth Test. Stock number 9 was tenth in the Seventeenth Test but had the highest profit per hen in the Eighteenth Test.

No treatment main effects on interactions of treatment with stock were significant in either Test. This unexpected lack of significance may be due to the small sample size. It may be possible in further study with larger samples to show a significant genotype-environment interaction effect on this important trait.

Sexual Maturity

There were significant ($P < 0.001$) differences among stocks with respect to sexual maturity (Tables XVII and XVIII, pages 70 and 71). These results are in agreement with those obtained by Feldkamp and Adams (1973), Balnave (1974) and Gavora et al. (1974).

Table X (page 58) shows the ranks of stocks involved in both Tests. Stock number 6 was the slowest stock to reach maturity in both Tests. Stocks number 7 and 8 were ranked alternatively in the two Tests, viz., stock number 7 had the tenth and the eighth ranks, while stock number 8 had the eighth and the tenth position, respectively. Some inconsistency of stock rankings were observed with respect to this trait. Stocks number 3 and 4 had the same rank in both Tests but changed from third and fourth ranking eleventh and fourth latest, respectively. Stock number 11 was third in maturation rate in the Seventeenth Test but was second in the Eighteenth Test.

None of the treatment effects on sexual maturity were significant,

nor were any first and second-order interaction of stock with treatment. These results agree those obtained by Marks et al. (1969c), Choudary et al. (1972), Aitken et al. (1972) and Balnave (1974) but disagree with the findings of Tindell et al. (1967), Marks et al. (1969a), Biswas and Craig (1970) and Adams and Jackson (1970).

Blood and Meat Spots

Stocks were found to differ significantly ($P < 0.01$ or $P < 0.001$) with respect to all egg quality traits in both Tests except for percent large blood spots with respect to which stocks were found to differ but nonsignificantly (Tables XIX, XX and XXI).

Stock ranking is presented in Table X (page 58) with respect to these traits in both Tests. Some stocks had a similar rank in the two Tests. Stocks number 1, 8, 12, 13 and 14 had practically equal means with ranks of 10 through 14 with a mean rank of 12 with respect to percent small meat spots in the Seventeenth Test. In the same Test four other stocks show the same mean value with a mean rank of 7.5. With respect to the same trait in the Eighteenth Test five stocks show the lowest mean, making 10 the mean of their ranks. With respect to percent large meat spots in the Seventeenth Test eight stocks had the lowest value with a mean rank of 10.5, and the other four stocks had the same mean value with a mean rank of 4.5.

Some stocks show consistent percentages of blood or meat spots from Test to Test. Stock eleven had the highest percentage or next to the highest with respect to all these traits in the two Tests except in the Seventeenth Test with respect to percent large blood spots. Contrary to

Table XIX

Analysis of Variance of Percent Blood Spots
(Seventeenth Test)

Source	Degrees of Freedom	Mean Square	
		% Small Blood Spots	% Large Blood Spots
Block (B)	1	4.32	0.84
Stock (S)	13	80.11***	6.64
Treatment (T)	3	65.81	0.88
Salt (S1)	1	175.50***	0.84
Bicarbonate (BI)	1	21.09	0.95
S1 x Bi	1	0.82	0.84
S x T	39	18.22	3.31
Error	55	16.95	5.01
Total	111	--	--

***P $\leq$ 0.001

Table XX

Analysis of Variance of Percent Meat Spots
(Seventeenth Test)

Source	Degrees of Freedom	Mean Square	
		% Small Meat Spots	% Large Meat Spots
Block (B)	1	0.84	5.58
Stock (S)	13	299.31***	35.39***
B x S	13	34.13**	-- [a]
Treatment (T)	3	10.68	3.79
B x S1	1	-- [b]	10.94*
B x Bi	1	-- [c]	10.94*
S x S1	13	9.01	2.15
B x S x S1	13	-- [d]	15.75***
S x Bi	13	6.04	3.11
B x S x Bi	13	-- e	9.01**
S x S1 x Bi	13	5.14	9.98**
Error	27	4.93	3.27
Total	111		

**P $\leq$ 0.01
***P $\leq$ 0.001

[a] This term was pooled with error to obtain an appropriate error term for testing % large meat spots based on 27 degrees of freedom.

[b,c,d,e] These terms were pooled with error to obtain an appropriate error term for testing % small meat spots based on 42 degrees of freedom.

Table XXI

Analysis of Variance of Percent Blood and Meat Spots (Eighteenth Test)

Source	Degrees of Freedom	Mean Square of Percent of Spots			
		Small Blood	Large Blood	Small Meat	Large Meat
Block (B)	1	4.17	3.23	1.04	31.51
Stock (S)	11	45.36**	16.74	121.21***	80.37***
Treatment (T)	3	30.90	7.20	9.03	12.76
S x C	11	26.89	19.96	18.09*	9.35
S x M	11	18.18	10.49	12.12	32.08**
S x C x M	11	7.86	12.76	8.24	13.90
Error	47	16.40	10.85	8.49	9.17
Total	95	--	--	--	--

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

this, stock number 9 had the highest percentage in the Seventeenth Test with respect to percent small and large blood spots, while it had a mean rank of 8.5 in the Eighteenth Test with respect to percent small and large meat spots. It had the next to highest percentage in the Seventeenth Test, while it had the tenth and eighth ranks with respect to these percentages, respectively in the Eighteenth Test.

There were no significant differences among treatments in the two Tests with respect to all spot traits except between the levels of salt where the effect was highly significant ($P < 0.001$) (Table XIX, page 74) with respect to percent small blood spots.

Many stock by individual treatment interactions had a significant effect on these traits. Stock-by-salt-by-bicarbonate interaction had a highly significant ($P < 0.001$) effect on percent large meat spots. Stock-by-methionine interaction had a highly significant ($P < 0.01$) effect on percent large meat spots. Stock with choline interaction had a significant ($P < 0.05$) effect on percent small meat spots. Other interactions did not show any significant effect with respect to all percentages of spots in the two Tests.

Genotype-environment interactions may be important with respect to some economic traits, but because of their small magnitude, they are often not demonstrated by experimental procedure to have significant effects, especially on traits of low heritability.

II. HOMOGENEITY OF VARIANCES

Homogeneity of Strain Variances

Chi-square values calculated by Bartlett's Test with respect to variances of stocks are presented in Table XXII for the two Tests, with corresponding degrees of freedom. The degrees of freedom differed from one trait to another depending on the number of variances available in each trait, i.e. some stocks had no variances among the eight lots of the stock. Hence, some stocks were not counted in the degrees of freedom with respect to the trait considered, even though the usual degrees of freedom in these two Tests were thirteen and eleven because the numbers of stocks were fourteen and twelve, respectively.

Bartlett's Test is a test of the hypothesis that variances were drawn from a common population.

Chi-square resulting from Bartlett's Test was found to be highly significant ($P < 0.001$) in the two Tests with respect to percent peewee egg size with twelve and eleven degrees of freedom, respectively. This means that variances of stocks with respect to this trait were heterogenous or they are not estimates of a common population variance.

Stock differences with respect to percent small and medium egg sizes were found to be significant ($P < 0.05$) in the Eighteenth Test but not in the Seventeenth.

There were highly significant ($P < 0.001$) differences among stock variances of average egg weight in both Tests.

For feed efficiency traits the results of the Bartlett's Test were significant ($P < 0.01$ and $P < 0.001$) in the Seventeenth Test but not

Table XXII

Bartlett's Test of Homogeneity of Stock Variances

Traits	Seventeenth Test Chi-Square	d.f.	Eighteenth Test Chi-Square	d.f.
% HHP	11.042	13	10.563	11
% HDP	16.793	13	6.437	11
% PWE	49.028***	12	39.449***	11
% SMALL	21.461	13	24.477*	11
% MEDIUM	10.899	13	23.744*	11
% LARGE	11.081	13	8.100	11
% X-LARGE	19.918	13	13.820	11
AEW	33.424***	13	35.692***	11
LBF/BH	28.044**	13	15.106	11
LBF/LBEG	30.043***	13	9.191	11
LBF/DZ	24.757*	13	10.167	11
% SBS	31.787***	13	26.267**	11
% LBS	4.796	8	18.693*	10
% SMS	37.848***	8	27.931***	6
% LMS	32.209***	5	31.202***	8
% MORT	16.308	13	22.975*	11
SPGR	8.892	13	8.022	11
HAUGH	15.871	13	13.432	11
BWT	41.165***	13	16.389	11
PROF	9.697	13	9.601	11
SEX	12.941	13	15.729	11
SHELL	12.185	13	--- [a]	

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

[a]This trait was not studied in Eighteenth Test

in the Eighteenth with respect to pounds of feed per bird housed and per pound of eggs respectively. With respect to pounds of feed per dozen of eggs the chi-square obtained also was significant ($P < 0.05$).

Chi-square was significant ($P < 0.001$ and $P < 0.01$) in the two Tests, respectively, with respect to percent small blood spots, significant ($P < 0.05$) in the Eighteenth Test only with respect to percent large blood spots and significant ($P < 0.001$) in the two Tests with respect to percent small and large meat spots.

Stock variances of percent mortality were observed to be significantly ($P < 0.05$) heterogeneous in the Eighteenth Test.

Test of homogeneity stock variances showed highly significant ($P < 0.001$) differences among variances (i.e. variances were heterogenous) with respect to final body weight in the Seventeenth Test, while the test indicated homogeneity of the variances in the Eighteenth Test with respect to the same trait.

Other variances of the stocks with respect to all traits studied are not mentioned here since variances in the two Tests were homogeneous or if they were pooled together, they would give an estimate of the same population variance.

Homogeneity of Treatment Variances

Table XXIII contains the chi-square values resulting from Bartlett's Test on variances of treatments with respect to all traits studied. Degrees of freedom were three because the number of treatments in each Test was four treatments.

Percent peewee egg size showed significant ($P < 0.001$ and < 0.05)

Table XXIII

Bartlett's Test of Homogeneity of Variances Among Treatments[a]

Traits	Chi-Square	
	Seventeenth Test	Eighteenth Test
% HHP	2.232	1.428
% HDP	0.940	1.994
% PWE	13.341***	9.197*
% SMALL	0.584	8.682*
% MEDIUM	1.236	0.638
% LARGE	0.256	0.193
% X-LARGE	0.215	0.246
AEW	0.671	3.020
LBF/BH	0.531	0.312
LBF/LBEG	2.304	0.282
LBF/DZ	0.408	2.463
% SBS	30.430***	5.445
% LBS	1.654	1.903
% SMS	5.903	3.620
% LMS	26.311***	6.466
% MORT	1.347	1.556
SPGR	0.072	0.871
HAUGH	0.542	1.413
BWT	1.455	1.061
PROF	1.204	2.277
SEX	2.613	3.716
SHELL	1.385	--[b]

*P $\leq$ 0.05
***P $\leq$ 0.005

[a]Degrees of freedom are 3 in both Tests.

[b]This trait was not studied in the Eighteenth Test.

differences among variances of treatments in the two Tests, respectively. The differences were large enough to reject the hypothesis of homogeneity of variances, and, alternatively, to accept the assumption of heterogeneity of the treatment variances.

Percent small egg size showed significant differences among variances of treatments in the Eighteenth Test, but not in the Seventeenth Test.

There were significant ($P < 0.001$) differences among variances of treatments with respect to percent small blood spots and percent large meat spots in the Seventeenth Test, but not in the Eighteenth Test.

Other chi-square values not mentioned here were not large enough to reject the hypothesis of homogeneity of variances and one can believe that pooling those variances would give valid estimates of a single population variance.

III. COEFFICIENTS OF CORRELATION

Phenotypic correlations, the combined effect of genetic and environmental correlations, between different traits are discussed here.

Egg Production and Feed Efficiency

Stocks were found to differ from each other with respect to coefficient of correlation between percent hen-housed egg production and pounds of feed per bird housed in the Seventeenth and Eighteenth Test (Tables XXIV and XXV). Most of the stocks in the two Tests show positive relationships between these two traits (except three stocks in the Seventeenth Test and two stocks in the Eighteenth Test showed non-significant negative relationships). Some stocks show significant positive

Table XXIV

Comparison of Stock Coefficients of Correlation Among Some Economic Traits
(Seventeenth Test)

Traits	Level of Significance of Correlations				
	Significant (P < 0.001)	Significant (P < 0.01)	Significant (0.01 < P < 0.05)	Positive (P > 0.05)	Negative (P > 0.05)
%HHP & LBF/BH	5,13	6	1,2	8,9,10,11,12,14	3,4,7
%HHP & AEW			14	1,2,3,5,7,8,11	4,6,9,10,12,13
%HHP & SEX		9(-)	2(-),10(-)	5,6	1,3,4,7,8,11,12,13,14
%HHP & HAUGH		4		2,7,9,11,14	1,3,5,6,8,10,12,13
%HHP & PROFIT	1,4,5,6,7,8,10,13,14	2,3,9,11,12			
%HHP & SPGR				4,5,6,11,14	1,2,3,7,8,9,10,12,13
AEW & LBF/BH			4	1,2,3,5,7,8,9,11,12,14	6,10,13
AEW & HAUGH			5,11	2,4,7,8,10,13,14	1,3,6,9,12
AEW & PROFIT				1,2,3,5,7,11,13,14	4,6,8,9,10,12
AEW & SPGR				2,5,7,8,9,10,11,12,14	1,3,4,6,13
AEW & SEX			5	4,8,9,10,12	1,2,3,6,7,11,13,14

Table XXV

Comparison of Stock Coefficients of Correlation among some Economic Traits (Eighteenth Test)

Traits Correlated	Level of Significant of Correlations				
	Significant (P < 0.001)	Significant (P < 0.01)	Significant (0.01<P<0.05)	Positive (P > 0.05)	Negative (P > 0.05)
% HHP & LBF/BH	6	1,11	4,5,9	2,3,10,12	7,8
% HHP & AEW		4(-)	2(-),9,12(-)	3,7,10,11	1,4,5,6,8
% HHP & SEX			6(-),12(-)	5	1,2,3,7,8,9,10,11
% HHP & HAUGH			8(-)	5,9,10	1,2,3,4,6,7,11,12
% HHP & PROFIT	6,7,8,9,10	1,2,4,5,11,12	3		
% HHP & SPGR				5,6,10	1,2,3,4,7,8,9,11,12
AEW & LBF/BH			9	3,7,8,10,11,12	1,2,4,5,6
AEW & HAUGH				2,6,7,10,11	1,3,4,5,8,9
AEW & PROFIT				1,3,7,9,10,11	2,4,5,6,8,12
AEW & SPGR				1,6,7,10,12	2,3,4,5,8,9,11
AEW & SEX				2,4,6,8,10,11,12	1,3,5,7,9

coefficients of correlation. However, in both Tests, all negative relationships were non-significant.

Some stocks gave interesting, but confusing results. For example, stocks number 3, 4 and 9 showed positive relationship between these traits in one Test and negative relationship in the other, while the other stocks were consistent in sign of coefficients of correlation.

Coefficients of correlation between these two traits by treatments with all stocks combined are shown in Tables XXVI and XXVII. These relationships were significantly positive in all treatments in the two Tests.

Tables XXVIII and XXIX contain the general coefficients of correlation among all the traits studied with all treatments and stocks combined together in the Seventeenth and Eighteenth Tests. The relationships between egg production traits and feed efficiency traits were significant ($P < 0.001$). As expected, these relationships were positive with pounds of feed per bird housed and negative with pounds of feed per pound of eggs and per dozen eggs.

Egg Production and Egg Weight

Coefficients of correlation between percent hen-housed egg production and average egg weight differs from stock to stock in sign and magnitude. Tables XXIV and XXV (pages 83 and 84) shows a classification, according to sign and magnitude of correlation of the stocks in the Seventeenth Test and the Eighteenth Test. Most of the stocks showed non-significant coefficients of correlation except one stock in the Seventeenth Test and three stocks in the Eighteenth Test in which the correlations were significant ($P < 0.05$).

Table XXVI

Comparison of Treatment Coefficients of Correlation among Economic Traits with all Stocks Combined (Seventeenth Test)

Traits	% Hen-Housed Egg Production				Average Egg Weight			
	0.5% Salt	0.25% Salt	0.5% Salt 0.5% Bicarb	0.25% Salt 0.5% Bicarb	0.5% Salt	0.25% Salt	0.5% Salt 0.5% Bicarb	0.25% Salt 0.5% Bicarb
Average Egg Weight	0.42*	0.55**	0.51**	0.35				
Pound of feed/ bird housed	0.72***	0.76***	0.68***	0.56**	0.78***	0.66***	0.76***	0.44*
Specific Gravity	0.08	0.03	-0.06	0.01	-0.58**	-0.48**	-0.43*	-0.52**
Haugh Unit	0.04	0.20	0.09	0.10	-0.05	-0.15	0.10	-0.21
Profit	0.94***	0.92***	0.86***	0.87***	0.24	0.47*	0.29	0.24
Sexual Maturity	-0.50**	-0.52**	0.11	-0.38*	-0.40*	-0.40*	-0.23	-0.13

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

Table XXVII

Comparison of Treatment Coefficients of Correlation among Economic Traits with all Stocks Combined (Eighteenth Test)

Traits	% Hen Housed Egg Production				Average Egg Weight			
	Control	+ Choline	+ Methionine	+Choline +Methionine	Control	+ Choline	+Methionine	+Choline +Methionine
Average Egg Weight	0.34	0.65***	0.30	0.54**				
Pound of feed/ bird housed	0.51*	0.69***	0.58**	0.60**	0.63**	-.61**	0.53**	0.60**
Specific Gravity	0.44*	0.22	0.06	0.17	-0.12	-0.04	0.22	-0.10
Haugh Units	0.24	0.13	0.17	-0.05	0.22	0.24	0.06	-0.16
Profit	0.88***	0.84***	0.91***	0.87***	0.09	0.44*	0.14	0.36
Sexual Maturity	-0.54**	-0.34*	-0.62**	-0.74***	-0.23	-0.29	-0.18	-0.34

*P $\leq$ 0.05
**P $\leq$ 0.01
***P $\leq$ 0.001

Table XXVIII

Coefficients of Correlation Among Economic Traits (Seventeenth Test)

Variables	% HEP	% PWE	% SMALL	% MEDIUM	% LARGE	% X-LARGE	AEW	LBF/BH	LBF/BLBG	LBF/DZ	% MORT	SPCR	SBS	LBS	SWS	LWS	HAUGH	BWT	PROF	SEX	SHELL
% HEP	0.93***	-0.18	-0.43***	-0.39***	-0.11	0.38***	0.46***	0.69***	-0.75***	-0.56***	-0.35***	0.01	0.01	0.08	0.11	0.10	0.06	0.11	0.90***	-0.35***	0.18
ZHDP		-0.20*	-0.42***	-0.32***	-0.07	0.33***	0.39***	0.56***	-0.75***	-0.60***	-0.06	0.02	-0.04	0.10	0.02	0.01	0.12	0.03	0.88***	-0.44***	0.22*
% PWE			0.44***	0.35***	0.06	-0.38***	-0.46***	-0.11	0.36***	0.12	0.06	0.16	-0.11	0.05	-0.20*	-0.13	-0.08	-0.03	-0.26**	0.39***	0.18
% SMALL				0.69***	0.29**	-0.80***	-0.83***	-0.53***	0.40***	-0.03	0.10	0.38***	-0.16*	-0.06	-0.44***	-0.27**	-0.04	-0.38***	-0.36***	0.29**	0.22*
% MEDIUM					0.29**	-0.85***	-0.84***	-0.53***	0.38***	-0.06	0.26**	0.37***	-0.23*	-0.13	-0.42***	-0.34***	0.15	-0.41***	-0.28**	0.12	0.27**
% LARGE						-0.69***	-0.57***	-0.31***	-0.10	-0.42***	0.12	0.44***	-0.55***	-0.24*	-0.57***	-0.42***	0.19*	-0.62***	0.11	0.15	0.30**
% X-LARGE							0.95***	0.66***	-0.28**	0.22*	-0.22*	-0.52***	0.42***	-0.19*	0.61***	0.45***	-0.14	0.61***	0.21*	-0.23*	-0.36***
AEW								0.66***	-0.40***	0.13	-0.26**	-0.49***	0.36***	-0.18*	0.60***	0.45***	-0.06	0.55***	0.31**	-0.28**	-0.34***
LBF/BH									-0.14	0.22*	-0.44***	-0.25**	0.35***	0.29**	0.49***	0.37***	-0.02	0.64***	0.33***	-0.20*	-0.04
LBF/LBBG										-0.86***	0.12	-0.02	0.17	0.11	0.05	0.02	-0.06	0.26**	-0.92***	0.36***	-0.05
LBF/DZ											-0.02	-0.29**	0.39***	0.22*	0.39***	0.27**	-0.10	0.58***	-0.82***	0.23*	-0.25**
% MORT												0.05	-0.10	-0.05	-0.29**	-0.27**	0.01	-0.26**	-0.18	-0.08	0.14
SPCR													-0.31**	-0.18*	-0.50***	-0.32***	0.15	-0.51***	0.11	0.07	0.58***
SBS														0.20*	0.41***	0.23*	-0.05	0.43***	-0.14	-0.04	0.26**
LBS															0.25**	0.18*	-0.08	0.29**	-0.05	0.04	-0.12
SWS																0.56***	-0.07	0.62***	-0.09	-0.15	-0.40***
LWS																	-0.01	0.48***	-0.07	-0.06	-0.23*
HAUGH																		-0.03	0.06	-0.07	-0.08
BWT																			-0.20*	-0.02	-0.35***
PROF																				-0.41***	0.21*
SEX																					-0.002
SHELL																					

*P< 0.05.
**P< 0.01.
***P< 0.001.

Table XXIX

Coefficients of Correlation Among Economic Traits (Eighteenth Test)

Variables	% HDP	% FWE	% SMALL	% MEDIUM	% LARGE	% X-LARGE	AEW	LBF/BH	LBF/LBEG	LBF/DZ	% MORT	SPRG	SBS	LBS	SMS	LMS	HAUGH	BWT	PROF	SEX
% HDP	0.99***	-0.23*	-0.45***	-0.38***	-0.17	0.38***	0.45***	0.59***	-0.76***	-0.63***	-0.40***	0.19	-0.30**	-0.16	-0.12	-0.14	0.13	-0.24*	0.88***	-0.57***
% HDP		-0.27**	-0.42***	-0.33***	-0.10	0.32**	0.38***	0.38***	-0.80***	-0.71***	-0.01	0.12	-0.29**	-0.20	-0.26**	-0.23*	0.05	-0.31**	0.87***	-0.58***
% FWE			0.45***	0.37***	0.07	-0.36***	-0.41***	-0.23*	0.22*	0.05	0.04	0.16	0.06	0.16	-0.14	0.04	-0.10	-0.14	-0.17	-0.02
% SMALL				0.63***	0.12	-0.60***	-0.63***	-0.48***	0.34***	0.08	0.16	0.05	-0.01	0.09	-0.14	-0.05	-0.13	-0.16	-0.31**	0.14
% MEDIUM					0.35***	-0.87***	-0.84***	-0.46***	0.38***	0.03	0.20*	-0.01	0.02	0.08	-0.19	-0.23*	-0.03	-0.26*	-0.24*	0.29**
% LARGE						-0.75***	-0.61***	-0.38***	0.11	-0.14	0.16	-0.07	-0.07	0.12	-0.13*	-0.06	-0.04	-0.26**	0.01	0.07
% X-LARGE							0.92***	0.55***	-0.34**	0.05	-0.22*	0.03	0.03	-0.13	0.21*	0.17	0.06	0.31**	0.19	-0.22*
AEW								0.58***	-0.43***	0.01	-0.27**	-0.02	0.04	-0.16	0.20	0.18	0.10	0.26**	0.25*	-0.25*
LBF/BH									-0.82	0.25*	-0.53***	0.01	-0.04	0.01	0.25*	0.28**	0.23*	0.41***	0.15	-0.09
LBF/LBEG										0.90***	0.10	-0.18	0.26**	0.24*	0.23*	0.29**	0.01	0.50***	-0.92***	0.68***
LBF/DZ											-0.82	-0.22*	0.32**	0.18	0.36***	0.42***	0.07	0.68***	-0.90***	0.63***
% MORT												-0.24*	0.03	0.02	-0.27**	-0.10	-0.27**	-0.09	-0.19	0.12
SPGR													-0.34***	-0.12	-0.16	-0.26**	-0.02	-0.39***	0.28**	-0.23*
SBS														0.09	0.15	0.23*	0.33**	0.34***	-0.37***	0.31**
LBS															0.08	0.27**	0.15	0.14	-0.20*	0.04
SMS																0.37***	0.06	0.43***	-0.34**	0.20*
LMS																	0.08	0.48***	-0.34***	0.21*
HAUGH																		0.11	0.02	0.02
BWT																			-0.55***	0.40***
PROF																				-0.66***

* $p \leq 0.05$.
** $p \leq 0.01$.
*** $p \leq 0.001$.

Stock number 3, 7 and 11 showed consistent positive relationships between these two traits in both Tests and while stocks number 4 and 6 showed consistent negative relationships in both Tests. However, stocks number 1, 2, 5, 8, 9 and 10 showed inconsistency in sign of the relationships from Test to Test.

Coefficients of correlation by treatments with all stocks combined with respect to these traits are shown in Tables XXVI and XXVII (pages 86 and 87). These relationships observed as positive with different magnitude, i.e., some of them were significant in some treatments, while the others were non-significant in other treatments in both Tests.

When both stocks and treatments were combined, coefficients of correlation were significant ($P < 0.001$) and positive in the two Tests (Tables XXVIII and XXIX, pages 88 and 89). These results generally agree with those of Hogsett and Nordskog (1958), USDA (1969), Srinivasan (1972), Al-Mohammadi (1973) and Goher and McGibbon (1974). However, they are in disagreement with those of Perek and Snapir (1970).

Egg Production and Sexual Maturity

Generally, there were stock differences with respect to the relationship between percent hen-housed egg production and age of pullets at sexual maturity. Although most of the stocks in both Tests show a negative relationship (two of them) stock number 5 in both Tests and stock number 6 in the Seventeenth Test, showed positive relationships (Tables XXIV and XXV, pages 83 and 84).

Three stocks in each Test showed a significant negative relationship between these two traits. One of the interesting relationships was

that shown by stock number 6, viz. a non-significant positive coefficient of correlation in the Seventeenth Test but significant ($P < 0.05$) negative coefficient of correlation in the Eighteenth Test.

Tables XXVI and XXVII (pages 86 and 87) show significant ($0.05 > P < 0.001$) negative relationships between these two traits on every treatment when all stocks were combined in each Test except for one treatment in the Seventeenth Test.

Both egg production traits (Tables XXVIII and XXIX, pages 88 and 89) had highly significant ($P < 0.001$) negative coefficients of correlation with age at sexual maturity in the two Tests when all stocks and treatments were combined. These results confirm those obtained by King (1961), Kinney et al. (1968) but differ from those of USDA (1969).

Egg Production and Haugh Units

Some stocks showed positive coefficients of correlation between percent hen-housed egg production and Haugh unit scores while others showed negative coefficients of correlation in both Tests (Tables XXIV and XXV, pages 83 and 84). The only two stocks showing significant relationships were stock number 4 ($P < 0.01$) with a positive relationship and stock number 8 ($P < 0.05$) with a negative relationship between the two traits.

Some stocks showed consistent negative relationships viz., stocks number 1, 3, 6 and 8, while only one stock, number 9, had consistent positive relationships. Other stocks showed inconsistency in the sign of the relationship.

All coefficients of correlation between these two traits were non-significant but positive in the two Tests on each treatment when all stocks

were combined, except for one treatment in the Eighteenth Test in which there was a non-significant negative relationship (Table XXVI and XXVII, pages 86 and 87).

The relationship between these two traits also was non-significant but positive when all stocks and treatments were combined (Tables XXVIII and XXIX, pages 88 and 89). These results do not agree with previous results obtained by Srinivason (1972) and Al-Mohammadi (1973).

Egg Production and Specific Gravity

Coefficients of correlation between percent hen-housed egg production and specific gravity differ from stock to stock with respect to sign of the relationship. All of them showed non-significant relationships in both Tests (Tables XXIV and XXV, pages 83 and 84).

In Tables XXVI and XXVII (pages 86 and 87) it can be seen that this relationship was non-significant but positive on each treatment, except one treatment in the Eighteenth Test in which it was significant ($P < 0.05$) and positive (all stocks combined).

When all treatments and stocks were combined in each Test, the relationships also were non-significant but positive in both Tests (Tables XXVIII and XXIX, pages 88 and 89). These results confirm those of the previous study by Al-Mohammadi (1973).

Egg Production and Profit Per Hen

All stocks, as expected, showed highly significant ($P < 0.01$ or $P < 0.001$) positive relationships between percent hen-housed egg production and profit per hen (Tables XXIV and XXV, pages 83 and 84) in both Tests.

The same trends in sign and magnitude prevailed across treatments when all stocks were combined and when all treatments and stocks were combined (Tables XXVI, XXVII, XXVIII and XXIX, pages 83, 84, 88 and 89). These results agree with those of Nordskog (1960) and Srinivasan (1972).

Egg Weight and Feed Efficiency

Stock classification with respect to coefficients of correlation between average egg weight and pounds of feed per bird housed is presented in Tables XXIV and XXV (pages 83 and 84) for both Tests. Some stocks showed positive relationships while others showed negative ones. The only two significant ($P < 0.05$) relationships were in stocks number 4 and 9 in both Tests. Others were non-significant.

Coefficients of correlation which showed significant ($P < 0.01$ or $P < 0.001$) positive correlations between these two traits when all treatments and stocks were combined were inconsistent in sign and magnitude (Tables XXVIII and XXIX, pages 88 and 89) in both Tests, i.e., the coefficient of correlation between average egg weight and pounds of feed per bird housed was significant ($P< 0.001$) and positive with pounds of feed per pound of eggs was significant ($P< 0.001$) and negative and with pounds of feed per dozen of eggs was non-significant and positive.

Egg Weight and Haugh Units

Most of the stocks in both Tests showed a non-significant relationship between these two traits. The only two stocks in the two Tests which showed significant ($P < 0.05$) relationships were stocks number 5 and 11 in the Seventeenth Test only (Tables XXIV and XXV, pages 83 and 84).

In Tables XXVI and XXVII (pages 86 and 87) are shown inconsistent relationships between these two traits in each treatment when all stocks were combined, i.e., the Seventeenth Test showed non-significant negative relationships on each treatment except one of them on which it was non-significant negative. In the Eighteenth Test the relationships were non-significant positive except for one treatment in which the relationship was non-significant negative.

When all treatments and stocks were combined (Tables XXVIII and XXIX, pages 88 and 89) the relationships were non-significant and negative in the Seventeenth Test while they were non-significant and positive in the Eighteenth Test.

Egg Weight and Specific Gravity

All stocks in both Tests showed non-significant positive or negative coefficients of correlation (Tables XXIV and XXV, pages 83 and 84) between average egg weight and specific gravity.

In the Seventeenth Test significant ($P < 0.05$ or $P < 0.01$) negative relationships were shown with respect of each treatment when all stocks were combined, while in the Eighteenth Test non-significant negative relationships were shown except on one treatment on which the relationship was non-significant and positive (Tables XXVI and XXVII, pages 86 and 87).

When all stocks and treatments were combined, the relationships were negative in sign in both Tests, highly significant ($P < 0.001$) in the Seventeenth Test and non-significant in the Eighteenth Test.

Egg Weight and Profit

Some stocks showed unexpected negative relationships between egg weight and profit per hen (Tables XXIV and XXV, pages 83 and 84). However, no stock showed significant relationships.

When all stocks were combined, coefficients of correlation by treatment were non-significant and positive except one significant ($P < 0.05$) relationship in each Test (Tables XXVI and XXVII, pages 86 and 87).

However, the relationship was significant ($P < 0.01$ or $P < 0.05$) and positive in the two Tests separately (Table XXVIII and XXIX, pages 88 and 89).

Egg Weight and Sexual Maturity

The only significant ($P < 0.05$) positive coefficient of correlation between average egg weight and age at sexual maturity in the stocks. classification was shown by stock number 5 in the Seventeenth Test. Other stocks showed either negative or positive non-significant relationships between these two traits (Tables XXIV and XXV, pages 83 and 84).

When all stock were combined, relationships between these two traits on the various treatments were non-significant and negative in both Tests except for two treatments in the Seventeenth Test in which the relationships were significant ($P < 0.05$) and negative (Tables XXVI and XXVII, pages 86 and 87).

Generally, the relationship between these two traits shown in Tables XXVIII and XXIX (pages 88 and 89) is significant ($P<0.01$ or $P<0.05$) and negative in both Tests when all stocks and treatments were combined.

Means of Traits

As a matter of interest, stock means, overall means and standard errors of all traits studied are presented by stocks in the appendix tables. No mean-separation tests were conducted. However, analysis of variance tables reflect the existence of differences among the means when significant F values were obtained.

IV. CONCLUSION

Genotype-environment interaction is a much discussed subject among many interested investigators. There is no consistent, clear cut, evidence either in this study or in previous ones, of the existence of predictable genotype-environment interaction. Although, some workers have reported that while interactions in egg production stocks may be statistically significant for some traits, they appear to be of minor importance (Tindell et al., 1967 and Marks et al., 1969a,b).

The results of this study show some significant genotype-environment interaction with respect to some traits in both Tests, such as interactions of stock-by-salt and stock-by-bicarbonate in average egg weight in the Seventeenth Test and some other interactions. It is possible that some of the non-significant interaction effects might have been shown to be significant if the sample size had been larger and other experimental procedures added which would permit detection of small differences. Therefore, genotype-environment interaction may be important with respect to some economic traits, but it is not easy or simple to demonstrate it, expecially in traits of low heritability. Those who work with poultry

must be alert to the possibility of genotype-environment interaction and plan accordingly.

The strong indication of interaction in this and other studies make it worthwhile for further study to be conducted with larger samples and planned specifically to demonstrate and measure interactions suggested by some studies.

Results of Bartlett's Test of homogeneity of stock variances which showed lack of homogeneity among stocks variances of some traits and the extreme variation from treatment to treatment within stock of various correlations provide further evidence of genotype-environment interaction or variable response of stocks to variations in environment.

In general, it can be concluded that genotype-environment interaction in egg-production poultry stocks should be given continued research attention but that, at present, there is no basis for any definite and precise recommendations as to testing procedures which breeders should use.

CHAPTER VI

SUMMARY

Data used in this study were collected during the Seventeenth and Eighteenth Tennessee Random Sample Laying Tests (1974 and 1975).

Because of their importance to poultrymen many economic egg production traits were studied. Analysis of variance was conducted to determine the existence of the differences among stocks and treatments and of interactions. Stocks were found to differ significantly from each other with respect to most of the traits studied. To illustrate the differences among stocks, a ranking of their means with respect to each traits was prepared.

Treatment effects (varying dietary salt levels and addition of bicarbonate and of methionine and choline) were found to be significant with respect to some traits studied but not with respect to the others. A low level of salt (0.25%) was found to increase significantly ($P < 0.05$) average egg weight, and the same effect for low level of choline (i.e., no added choline) was found. The low salt level had a significant ($P< 0.001$) influence in increasing percent small blood spots. Supplementary bicarbonate of soda significantly ($P < 0.05$) decreased percent mortality. Choline addition significantly ($P < 0.05$) increased the percentage of medium eggs. Addition of methionine to the layer diet significantly ($P < 0.05$) improved feed efficiency traits, i.e., it significantly ($P < 0.05$) decreased amount of feed per bird housed, pounds of feed per pound of eggs and pounds of

feed per dozen eggs. Supplementary methionine significantly ($P < 0.001$) decreased specific gravity.

There were many indications of interaction. First-order interactions, salt-by-bicarbonate-levels interaction was significant ($P < 0.05$ and $P < 0.01$) with respect to average egg weight and percent peewee eggs. Stock-by-salt-level interaction was highly significant ($P < 0.01$) with respect to average egg weight and also significant ($P < 0.05$) with respect to final body weight, percent large eggs and Haugh units. Interaction of stock with bicarbonate was significant ($P < 0.05$) with respect to percent large eggs. Stock-by-choline interaction was significant ($P < 0.05$) with respect to percent large eggs and percent small meat spots. Stock-by-methionine interaction was significant ($P < 0.01$) with respect to percent large eggs and percent large meat spots. Interaction between choline and methionine was significant ($P < 0.01$) with respect to specific gravity. Second-order interaction of stock-by-salt-by-bicarbonate was significant ($P < 0.05$ and $P < 0.01$) with respect to average egg weight and percent large meat spots, respectively. Stock-by-choline-by-methionine interaction was significant ($P < 0.05$) with respect to percent small eggs, large eggs and extra-large eggs.

The second kind of examination of the data was conducting Bartlett's Test of homogeneity of variances. The results of that Test declared that variances of stocks to be not homogeneous with respect to percent peewee, average egg weight, feed efficiency traits, percent small blood spots, percent meat spots and final body weight in the Seventeenth Test. In the Eighteenth Test the hypothesis of homogeity of stock variances was rejected with respect to percent peewee, small, medium eggs,

average egg weight, percent blood and meat spots and percent mortality. Treatments variances were not homogeneous with respect to percent peewee eggs, percent small blood spots and percent large meat spots in the Seventeenth Test. In the Eighteenth Test, with respect to percent peewee eggs and percent small eggs, treatment variances were found to be not homogeneous.

The third analysis conducted was the calculation of conventional product - moment coefficients of correlation among all traits studied. Sign and magnitude of the relationships between the traits showed great variation from treatment to treatment and from stock to stock, providing further evidence of differential response of stocks to variations in environment.

Evidence for genotype-environment interaction in this study and in others is sufficient to justify further research specifically planned to demonstrate and measure such interaction but is not sufficient to formulate any definite and precise recommendations as to testing procedures breeders should use.

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APPENDIX

Table XXX

Stock Means and Standard Errors of Some Economic Traits (Seventeenth Test)

S	% HHP	% HDP	% PWE	% SMALL	% MEDIUM	% LARGE	% X-LARGE	AEW	LBF/BH	LBF/LBEG	LBF/DZ
1	56.3±1.2	60.1±1.6	0.2±0.1	7.5±0.7	22.9±0.9	42.1±1.6	28.3±1.0	57.6±0.5	72.2±1.1	2.8±0.1	4.3±0.1
2	63.5±0.7	65.9±1.0	0.3±0.1	6.0±0.6	20.0±1.3	37.2±1.2	36.5±1.6	58.5±0.2	80.5±1.0	2.7±0.0	4.2±0.0
3	57.3±0.8	59.1±0.6	0.4±0.2	9.7±0.8	23.9±1.2	42.5±0.9	23.5±0.8	56.7±0.1	70.3±0.3	2.7±0.1	4.1±0.1
4	59.9±0.8	61.6±0.7	0.2±0.1	6.8±0.9	20.3±1.2	37.4±2.1	35.1±2.9	58.3±0.4	80.0±0.2	2.9±0.0	4.5±0.1
5	60.8±1.0	64.3±0.4	0.2±0.1	4.6±0.4	19.3±1.1	35.4±1.1	40.5±1.0	59.2±0.2	77.9±1.0	2.7±0.0	4.3±0.0
6	58.9±0.9	63.1±1.2	0.2±0.1	7.0±0.5	26.2±1.3	41.6±0.9	25.1±1.5	57.0±0.2	76.1±0.8	2.9±0.0	4.3±0.1
7	53.3±1.4	55.9±0.9	1.6±0.4	14.2±1.1	30.7±1.4	38.4±1.8	15.2±1.2	54.4±0.2	76.5±1.2	3.3±0.1	4.8±0.1
8	55.9±1.2	59.5±1.0	0.4±0.1	14.7±0.8	34.4±1.3	38.3±1.3	12.3±1.1	55.0±0.8	73.9±0.9	3.1±0.1	4.4±0.1
9	63.2±0.7	64.8±1.0	0.1±0.0	4.6±0.4	21.5±1.1	39.7±1.4	34.1±1.4	58.5±0.2	81.2±0.7	2.8±0.7	4.3±0.1
10	60.3±0.7	61.6±1.0	0.1±0.1	3.4±0.5	14.6±0.8	25.9±1.4	56.6±1.1	61.5±0.2	87.2±0.7	3.0±0.0	4.8±0.1
11	61.0±1.1	63.7±0.9	0.3±0.1	6.5±0.9	21.5±1.4	39.0±1.0	32.7±1.8	58.2±0.3	80.6±0.7	2.9±0.0	4.4±0.1
12	59.9±0.8	61.1±0.8	0.0±0.0	2.6±0.4	15.5±0.8	29.4±1.4	52.6±1.4	61.3±0.3	84.7±1.0	2.9±0.0	4.7±0.1
13	56.8±1.5	59.8±1.2	0.2±0.1	9.0±0.5	21.5±0.9	38.0±1.2	31.4±1.5	57.6±0.1	74.4±1.2	2.9±0.0	4.4±0.1
14	47.1±1.1	51.2±1.1	0.3±0.1	8.6±0.5	25.7±1.9	38.0±1.6	27.5±1.3	56.9±0.2	67.6±0.9	3.2±0.1	4.8±0.1

Table XXX (continued)

S	% MORT	SPGR	%SBS	%LBS	%SMS	%LMS	HAUGH	BWT	PROFIT	SEX	SHELL
1	13.8±1.8	3.2±0.1	1.3±0.8	1.9±0.9	0.0±0.0	0.0±0.0	80.2±0.6	1.7±0.0	4.1±0.2	173.0±2.1	14.5±0.5
2	10.5±1.9	4.0±0.1	1.3±0.8	1.3±1.3	0.6±0.6	0.6±0.6	76.0±0.8	1.8±0.1	4.8±0.1	164.8±1.2	19.6±0.6
3	9.6±2.2	4.2±0.1	1.3±0.8	0.0±0.0	1.9±1.3	0.0±0.0	78.4±0.8	1.5±0.0	4.4±0.2	168.0±1.0	16.6±0.5
4	13.4±1.8	4.2±0.1	3.8±1.3	0.6±0.6	0.6±0.6	0.6±0.6	74.6±1.1	1.8±0.0	4.2±0.1	168.0±0.7	18.3±0.6
5	16.7±3.4	3.7±0.1	4.4±1.5	1.3±0.8	1.3±0.8	0.0±0.0	75.7±1.1	1.9±0.0	4.6±0.1	165.1±1.3	14.9±0.2
6	14.6±2.0	4.4±0.1	2.5±1.3	0.0±0.0	0.0±0.0	0.0±0.0	85.0±1.1	1.9±0.0	4.2±0.1	162.9±1.4	16.9±0.4
7	11.2±2.3	4.0±0.1	4.4±1.5	1.9±0.9	1.3±1.3	0.6±0.6	77.2±1.0	2.0±0.1	3.0±0.1	176.1±1.2	17.5±0.4
8	12.4±1.9	4.1±0.1	4.4±1.5	0.6±0.6	0.6±0.6	0.6±0.6	80.4±0.9	1.7±0.1	3.8±0.2	164.9±1.3	16.8±0.3
9	5.9±1.2	4.2±0.1	1.3±0.8	0.0±0.0	0.0±0.0	0.0±0.0	80.7±0.6	1.9±0.0	4.7±0.1	165.5±1.8	18.6±0.4
10	5.0±1.1	3.1±0.1	12.5±3.0	2.5±0.9	11.9±3.0	5.6±1.5	78.6±1.0	2.5±0.0	3.9±0.1	166.5±1.3	13.5±0.4
11	12.1±2.4	3.6±0.1	3.1±1.3	1.9±0.9	0.6±0.6	0.0±0.0	81.3±0.4	1.9±0.0	4.3±0.2	166.0±1.2	15.8±0.3
12	5.9±1.5	3.1±0.0	8.1±2.3	1.9±0.9	21.3±1.5	6.3±2.8	78.1±0.5	2.2±0.0	3.9±0.2	163.9±1.2	13.8±0.4
13	11.7±1.7	3.6±0.1	3.2±1.9	0.0±0.0	0.0±0.0	0.0±0.0	76.8±0.6	1.8±0.0	4.1±0.2	163.5±1.6	15.3±0.5
14	16.7±1.1	3.6±0.1	1.3±0.8	0.0±0.0	0.0±0.0	0.0±0.0	76.5±0.8	1.9±0.0	2.8±0.2	166.3±0.9	15.6±0.5

Table XXXI

Stock Means and Standard Errors of Some Economic Traits (Eighteenth Test)

S	% HHP	%HDP	%PWE	% SMALL	% MEDIUM	% LARGE	% X-LARGE	AEW	LBF/BH	LBF/LBEG	LBF/DZ
1	62.7±1.1	68.6±0.9	0.2±0.1	3.4±0.4	21.3±1.1	45.1±1.6	30.1±1.7	58.3±0.1	76.8±1.1	2.7±0.0	4.1±0.1
2	65.0±0.7	68.4±0.8	0.4±0.3	3.6±0.3	14.8±0.6	36.0±1.8	45.2±1.9	60.1±0.2	83.5±0.7	2.7±0.0	4.3±0.1
3	58.8±0.8	60.8±0.8	0.9±0.2	6.3±0.8	23.9±2.0	44.3±1.8	24.6±1.9	56.9±0.2	76.7±1.4	2.7±0.0	4.0±0.1
4	66.2±1.0	67.3±0.7	0.3±0.1	2.9±0.3	12.2±0.7	32.4±0.9	52.3±1.6	61.1±0.2	83.2±1.1	2.6±0.0	4.2±0.0
5	65.2±1.2	67.9±0.7	0.2±0.1	3.0±0.7	15.1±1.4	39.0±2.3	42.7±2.7	60.1±0.4	82.1±1.6	2.6±0.0	4.2±0.0
6	53.7±1.6	56.8±1.0	0.8±0.3	6.8±0.9	29.9±1.2	42.4±1.3	20.1±1.1	55.6±0.7	78.8±1.2	3.3±0.1	4.9±0.1
7	66.3±1.0	67.1±1.0	0.7±0.3	4.7±0.5	27.2±1.3	44.4±1.2	23.1±0.9	57.0±0.2	82.4±0.5	2.8±0.0	4.2±0.1
8	69.5±0.9	71.0±0.9	0.1±0.1	2.4±0.4	12.9±1.2	34.1±1.8	50.5±2.5	61.6±0.4	88.5±1.0	2.6±0.0	4.3±0.1
9	68.1±1.1	71.1±0.7	0.2±0.1	2.7±0.3	20.4±2.3	48.1±1.7	28.7±2.2	58.0±0.6	80.7±1.4	2.6±0.0	4.0±0.0
10	62.4±1.7	65.2±1.4	0.3±0.1	3.6±0.4	20.1±0.9	40.1±1.5	35.3±1.5	58.9±0.3	80.9±1.6	2.8±0.1	4.3±0.1
11	57.1±0.9	57.5±0.8	0.3±0.1	3.5±0.6	16.9±0.8	41.1±1.3	38.2±2.1	59.3±0.3	81.1±1.0	3.0±0.0	4.7±0.0
12	64.9±0.9	65.6±1.0	0.2±0.1	2.4±0.3	12.6±1.9	37.4±1.9	47.5±2.5	60.9±0.4	89.5±1.0	2.9±0.0	4.6±0.1

Table XXXI (continued)

S	% MORT	SPGR	%SBS	%LBS	%SMS	%LMS	HAUGH	BWT	PROFIT	SEX
1	16.7±2.7	2.7±0.1	5.0±2.1	3.8±1.8	0.0±0.0	0.6±0.6	76.7±0.6	1.8±0.1	4.0±0.1	167.1±0.8
2	10.8±1.6	3.5±0.1	0.6±0.7	1.3±0.8	0.6±0.6	0.0±0.0	72.8±0.7	1.8±0.0	3.8±0.1	160.0±1.2
3	7.9±1.2	3.7±0.1	1.9±0.9	2.5±1.3	1.8±1.9	0.0±0.0	72.0±0.6	1.5±0.0	3.9±0.1	161.0±1.3
4	3.3±1.3	3.5±0.1	3.1±1.6	0.6±0.6	1.3±0.8	1.3±0.8	77.0±1.0	1.9±0.0	4.2±0.1	168.8±1.2
5	9.2±2.2	3.2±0.1	1.3±0.8	0.0±0.0	0.0±0.0	1.9±1.3	68.1±1.0	1.9±0.0	4.1±0.2	163.9±1.0
6	12.9±2.4	3.2±0.1	4.4±1.5	3.1±1.3	0.0±0.0	2.5±1.9	72.2±0.5	2.1±0.0	2.1±0.2	182.0±1.9
7	2.9±1.0	3.5±0.1	3.1±1.3	2.5±1.9	0.6±0.6	0.0±0.0	79.3±1.0	1.7±0.0	4.1±0.2	163.8±0.7
8	4.2±1.1	3.7±0.1	2.5±1.3	0.6±0.6	0.6±0.6	0.6±0.6	77.2±0.9	1.9±0.1	4.4±0.2	161.4±0.5
9	8.3±2.5	3.6±0.1	1.9±0.9	1.3±0.8	0.0±0.0	0.6±0.6	74.6±0.5	1.8±0.0	4.7±0.1	166.1±1.3
10	10.0±2.7	3.1±0.1	1.3±0.8	3.1±1.3	0.0±0.0	2.5±1.3	75.0±0.9	1.9±0.0	3.7±0.2	162.1±0.9
11	2.9±1.0	2.8±0.1	9.4±2.6	4.4±1.1	7.5±2.3	6.3±1.8	77.4±1.1	2.3±0.1	2.5±0.1	170.1±1.3
12	4.2±1.2	3.0±1.0	4.4±1.8	3.8±1.6	6.0±2.1	10.6±2.7	74.8±1.3	2.2±0.1	3.2±0.1	168.9±1.2

VITA

Shaker Mosleh Al-Mohammadi was born in Fallujah, Iraq, on May 15, 1939. He was educated in the elementary and secondary schools of that city and was graduated from Al-Fallujah High School in June 1957. The following September, he entered the College of Agriculture, University of Baghdad, receiving a Bachelor's degree in Agriculture with a major in Animal Science in June 1961. The following October, he was employed as a teacher by the Iraqi Ministry of Education in the Al-Ramadi Vocational Agricultural High School, at the Al-Fallujah Intermediate School and then in the Mecca High School in Saudi Arabia as part of the Educational Assistance Program between Iraq and Saudi Arabia Governments. In 1972, he was awarded a scholarship from the Iraqi Ministry of High Education and Scientific Research to study toward a Master of Science and the Ph.D. degree in Animal Science. He entered the University of Tennessee Graduate School, on September 21, 1972. In December 1973, he was granted a Master of Science degree and in June 1976 was granted a Ph.D. degree with a major in Animal Science. He is a member of Gamma Sigma Delta.

He was married in October 1967. He is the father of three children, two boys, Saad and Mohammad and one girl, Afraa.